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AIM AND SCOPE

Journal of Aviation (JAV) established in 2017. It is a peer–reviewed international journal to be of interest and use to all those concerned with research in various fields of, or closely related to, Aviation science. Journal of Aviation (JAV) aims to provide a highly readable and valuable addition to the literature which will serve as an indispensable reference tool for years to come. The coverage of the journal includes all new theoretical and experimental findings in the fields of Aviation Science or any closely related fields. The journal also encourages the submission of critical review articles covering advances in recent research of such fields as well as technical notes.

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Investigation of The Fatigue Behavior of Gyrocopter Propellers Produced From 6061 T6 Aluminium Alloy

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RESEARCH ARTICLE

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Abstract

In the aviation sector, the production of propeller-driven aircraft is being accelerated due to the increase in passenger numbers, the possibility of transportation for shorter distances, and the reduction in costs in aircraft designs. Gyrocopter vehicles, which have recently begun to be used in aviation, have significant potential in the near future. The demand for these air vehicles in the aviation sector is growing due to their ability to operate in relatively short ranges, their low operational and maintenance costs. Generally, the systems that most significantly reduce costs in these aircraft are propellers. The technological advancements in material science have facilitated innovative solutions in the design and manufacturing of propellers from a wide range of materials. The combination of nanotechnology and materials science has been achieved alongside ongoing innovations in these two evolving technologies. In this study, samples of propellers produced from 6061 T6 Aluminium Alloy, were produced with a special extrusion model and were then subjected to fatigue, tensile, and hardness tests. The mechanical standards of the produced propellers were examined to determine whether the desired flight configurations could be achieved.

1. Introduction

Fatigue behavior in aviation materials is a critical concern, as aircraft components are subject to cyclic stresses during operation, leading to progressive structural degradation over time. In recent studies, researchers have emphasized the importance of understanding fatigue mechanisms in materials such as aluminum alloys, composites, and titanium alloys, which are commonly used in the aerospace industry. These materials are tested under repeated loading conditions to simulate real-world scenarios, enabling the prediction of their lifespan and the optimization of maintenance schedules. Findings show that fatigue behavior is influenced by factors such as microstructure, crack initiation, and propagation, as well as the presence of stress concentrators, all of which can significantly reduce the performance and safety of aircraft components. Thus, advancements in fatigue analysis contribute to the development of more resilient materials and improved safety measures in aviation (Kansoy & Tekin, 2023; Gürbüz & Taşkın, 2023; Uzun et al., 2024;).

6061 aluminum alloy is widely used in aerospace, automotive, and structural applications due to its favorable combination of strength, corrosion resistance, and ease of fabrication. Its fatigue behavior, however, is a critical factor in determining its reliability in cyclic loading conditions. Fatigue occurs when materials are subjected to repeated stresses below their ultimate tensile strength, leading to crack initiation and propagation over time. For 6061 aluminum alloy, the fatigue life is influenced by its microstructure, surface finish, and environmental factors, including corrosion and temperature. The material's response to cyclic loading is also affected by heat treatments such as T6, which enhance its mechanical properties. Numerous studies have investigated the fatigue characteristics of 6061 aluminum under various conditions, focusing on crack growth rates, fatigue strength, and the role of defects and surface imperfections. These investigations are crucial for optimizing the use of 6061 aluminum in safety-critical components, ensuring both longevity and performance under fatigue-inducing conditions (Chen et al., 2018; Johnson & Miller, 2020).

Gyrocopter propellers are essential components that contribute significantly to the efficient operation and flight stability of gyrocopters. These air vehicles feature an unpowered rotor for lift and a powered propeller for thrust, with the propeller playing a crucial role in generating the forward propulsive force. The performance of the gyrocopter propellers directly impacts the aircraft's stability maneuverability and performance in various mission legs during the flight (Czyż et al., 2021). Recent numerical computational studies have focused on the aerodynamics of gyrocopters, particularly examining the the autorotating rotors under various conditions. These studies have shed light on the intricate interactions between the fuselage, empennage and propellers in gyrocopters, highlighting the importance of understanding the dynamics and aerodynamic characteristics of the gyrocopter propellers. This understanding is vital for optimizing the propeller design and for enhancing the overall performance of the gyrocopters in diverse flight scenarios.

6061-T6 aluminum alloy, part of the 6xxx series, is widely utilized in engineering fields such as automotive, aircraft and shipbuilding due to its advantageous properties (Abioye et al., 2021). This alloy is commonly used in the production of structural components like wings, fuselages in aircraft, wheel spacers, rims in automobiles, and ship frames (Abioye et al., 2021). Its popularity is attributed to its high strength, corrosion resistance, cost-effectiveness, formability, and weldability (Lee & Liu, 2014). The 6061-T6 alloy is favored for its mechanical strength, low density, and corrosion resistance (Irizalp & Saklakoğlu, 2018). Studies have investigated the mechanical properties of 6061-T6 aluminum alloy, including its laser welded joints, showcasing its versatility and significance in engineering applications (Nie et al., 2020). The unique properties of the AA 6061-T6 aluminum alloy make it a preferred material for a wide range of structural and engineering applications.

In this study, propellers were manufactured from 6000 series aluminum using the extrusion method, and their mechanical properties were investigated. The mechanical standards of the produced propellers were examined to determine whether the desired flight configurations could be achieved.

2. Materials and Methods

In this study, aluminium propellers were produced using the hot extrusion method, with Aluminum 6061 alloy chosen for its numerous benefits. The production process consisted of five main steps: Billet Preparation and Heating, Extrusion Pressing, Cooling, Cutting, and Heat Treatment. The cutting process was applied to propeller blades for the gyrocopter, set at a diameter of 9 inches (22.86 cm). Billets underwent heating to facilitate the passage of aluminum material through the die, with temperatures ranging from 350 °C - 500 °C. Initially, billets were heated to around 250°C using recycled exhaust gases before reaching approximately 450°C in the main heating section. Temperature accuracy was ensured through thermocouple measurements directly contacting the billet surface. Maintaining billet temperatures within the optimal range of 350 °C - 500 °C was crucial for enhancing product quality.

The 3D design of the rotor blade was created using AutoCAD software, with its lateral area calculated as 39.60 cm² (0.00396 m²). The length of the aluminum billet, post-cutting, was determined to be 5 meters with a radius of 11.43 cm, resulting in a lateral area of 410.43 cm² and 0.04 m². Employing the extrusion ratio formula yielded a ratio of 10:1. The extrusion process operated at a ram speed of 0.4 meters per second, exerting a force of 950 MPa on the aluminum billet. Upon completion of the extrusion process, the aluminum billet formed the foundational structure of the propeller.

At the end of the extrusion the aerophyll structure reached a temperature of approximately 310 °C. In order to maintain the desired quality, temperatures during the process were kept below 50 °C. High-quality surface finish and proper hardening of the aerophyll structure according to the specified shape were ensured through rapid heating and controlled cooling.

After cooling with water to below 50 °C, the aerophyll structure underwent finalization of propeller shaping through a cutting operation. To enhance corrosion resistance against anticipated high humidity and environmental conditions during gyrocopter usage, the propeller underwent an anodizing process. Surface sanding was conducted using sandpaper to eliminate imperfections prior to anodizing. Anodizing of the propeller blades was carried out using sulfuric acid at 18 °C, with voltage set at 15 volts and current at 1200 Amperes. To economize on anodizing costs for the aluminum propeller blades, preference was given to a horizontal anodizing bath. Following 30 minutes of anodizing, the blades underwent inspection in a detection bath and were subsequently immersed in pure water at 90 °C for 45 minutes. This process resulted in the formation of a 5-micron thick anodized coating on the blades. A 4.1-meter cutting operation was conducted on the extrusion-produced propeller, reinforced with a steel shaft, to prevent breakage and enhance rigidity against flight forces, ensuring minimal deflection during flight.

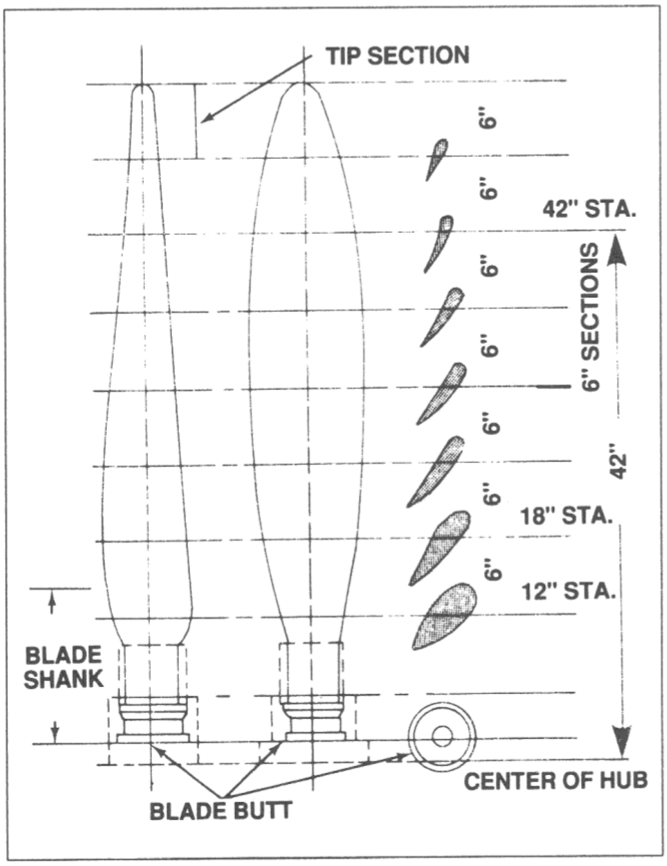

Figure 1. Representation of the nine station areas from which samples were taken for testing. (De Remer, D., 2017).

Samples, extracted from extrusion-manufactured propeller, were produced using the Lasermark 4000 laser cutting machine at GÜRBÜZ TREYLER A.Ş facility. Laser cutting was employed to ensure flawless and error-free sample production, with the process completed successfully using 4 kW voltage in 15 minutes. Utilization of the laser-cutting also facilitated a production free of any post-porcessing, such as chip removal or sanding. Following the completion of the cutting process, the samples were removed after 1 hour, given the high power and temperature during cutting. The samples were horizontally cut from the propeller blade to ensure homogeneous distribution, with sample specimens extracted from different segments (root, mid and tip) of the propeller blade.

In order to demonstrate homogeneity in propeller production, nine samples were obtained, as depicted in Figure 1, based on propeller stations. This process was conducted progressively from the hub to the tip of the blade.

The NACA 8H/12 airfoil structure was selected due to its high efficiency in lightweight constructions, despite its inadequacy for achieving high lift ratios, which are essential for helicopters and civilian aircraft.

Nine samples derived from the propeller blades underwent fatigue tests at the Margem Laboratory of Karabük University. The fatigue tests were conducted using the MTS Landmark dynamic test machine in accordance with TS EN ISO 13674-1 standards, at a temperature of 26°C and 35% humidity. Initially, the required loads for the samples were determined within a range of minimum 0.55 kN to maximum 2.5 kN. Subsequently, load values were set at 0.55 kN, 1 kN, 1.35 kN, 1.5 kN, 2 kN, and 2.5 kN. Fatigue tests were performed under a total of six different dynamic loads, comprising seven main and two spare tests. The total duration of the tests for these samples was 170 hours.

In order to achieve the desired accuracy in the tensile test results, three test specimens were extracted, and the tensile tests of these prepared specimens were conducted using the Zwick Roell Z250 model tensile testing machine at the laboratory of BERDAN CIVATA company. All tensile tests were conducted at 23°C and 39% humidity with a test speed of 0.33 mm/s. The testing process was carried out in accordance with TS EN ISO 6892-1 METHOD B standards.

The hardness measurements of the samples produced from the propeller blades were performed using the Galileo digital hardness measurement device in the quality laboratory of BERDAN CIVATA company. To ensure high accuracy in hardness measurement results, three measurements were taken at equal intervals along a line passing through the center of each sample, dividing the sample into two equal parts.

3. Result and Discussion

The raw data obtained from the experiments conducted on nine samples within the load range of 0.55 kN to 2.50 kN are presented in Table 1 and Figure 2.

Table 1. Fatigue test data

Dynamic Load	Cycle
± 0.55 kN	10 x 10^6
± 1.0 kN	10 x 10^6
± 1.35 kN	1132865
± 1.5 kN	393122
± 2.0 kN	103487
± 2.50 kN	13905

Sample dimensions were logged into AUTOCAD for drawing and for calculation of the sample areas. Through this computational process, the sample area was determined to be 30,510 mm². Utilizing this calculation, the stress/strain curve was derived using the unitary transformation MPa = Newton/mm². Figure 3 illustrates the stress/strain curve.

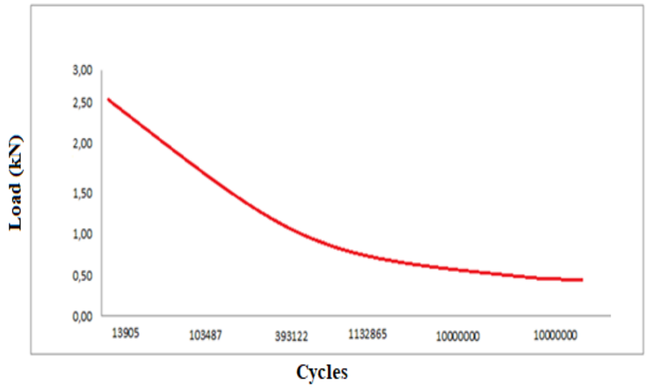

Figure 2. Load/Cycles graphic.

As depicted in Figure 3, experiments conducted under dynamic loading from 2.5 kN to 0.55 kN demonstrate a logarithmic increase in cycle count. This increase remains constant beyond 10x10^6 cycles, indicating the onset of infinite fatigue life.

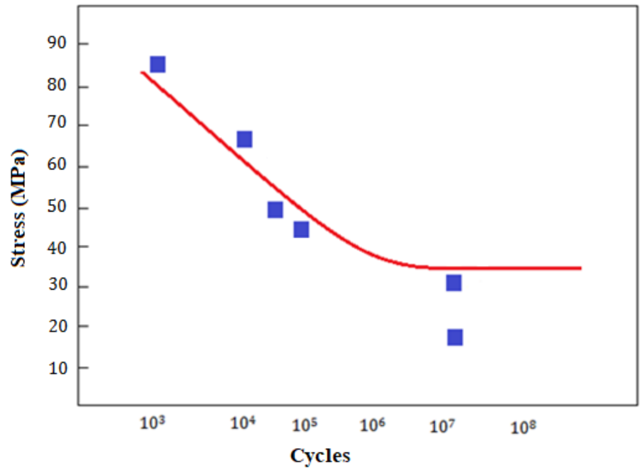

Figure 3. Stress/ Cycle Graph.

The fatigue graph shown in Figure 4 reveals two significant regions known as the ultimate strength and fatigue limit which shown by X signs. Tensile strength is defined as the stress level required to cause damage in a single cycle. In Zone I and Zone III region, our material is subjected to high stresses.

The graph in Figure 4 illustrates the maximum strength level of the propeller blades to be approximately 81 MPa. Stress levels at and above this threshold result in significant damage to the material. Therefore, the maximum stress level that can be tolerated by the propeller blades is determined to be 81 MPa.

Figure 4 illustrates the fatigue strength of the propeller blades. The limit shown on 10^6 cycles signifies that the material can endure an infinite number of cycles without experiencing damage. The approximate value of stress is 30 MPa, indicating that the propeller blades will operate for an extended duration under stress levels below this threshold. This value indicates nearly infinite fatigue life, regardless of other factors. In the fatigue limit region, shown as Zone I in Figure 5, the samples undergo a high number of cycles. Therefore, he fatigues limit region is also named as the high-cycle fatigue value.

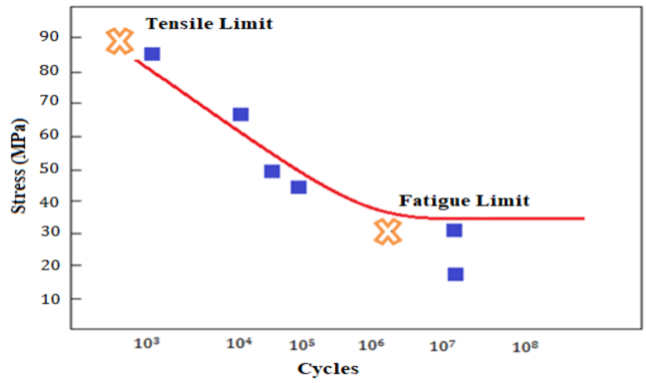

Figure 4. The representation of the tensile limit and fatigue limit on the fatigue graph.

Figure 5 illustrates the initiation of damage starting at a maximum of 81 MPa. Zone I exhibits rapid damage formation, ultimately resulting in propeller fracture. Zone I, also known as the rapid damage occurrence range, spans from 81 MPa to 65 MPa in the graphical representation. Prolonged operation of the propeller within this range is deemed abnormal due to potential adverse consequences.

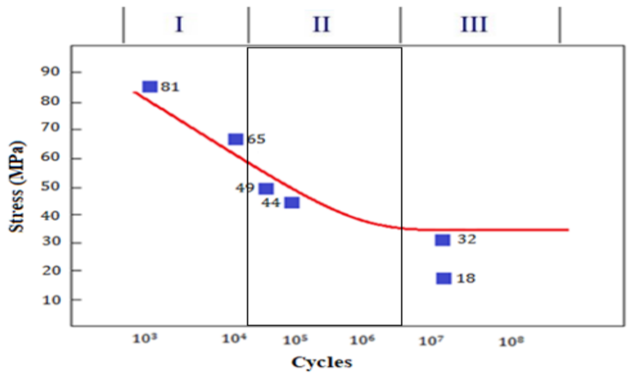

Figure 5. Representation of high and low-cycle fatigue limits.

High-cycle fatigue, prolongs propeller usage due to reduced pressure exertion and ranging from 65 Mpa to 32 Mpa. Within this range, damage formation slows down, which enables longer term use however the damage is not prevented entirely. Eventually, despite increased propeller usage, damage-related issues will impede further operation.

The stress value required for the propeller to achieve extended fatigue life is evident in Figures 3 and 4. Zone III, representing infinite fatigue life for the sample, ranges below 32 MPa. At this stress level or lower, it is established that the fatigue life is infinite regardless of external factors. Therefore in this fatigue range, the propeller's fatigue life can also be assumed to be infinite. Although, in time, some damage may still occur, however, without it leading to any fractures or cracks.

The fatigue test graphs depict the propeller's fatigue life under various pressure levels experienced during operation, expressed in MPa. These graphs establish the maximum and minimum pressure thresholds that the propeller should endure throughout its operational life.

These pressure ranges offer valuable insights into the operational configurations of the propellers, revealing the requisite pressure levels for prolonged usage without experiencing fatigue damage.

The analysis of aluminum's tensile and yield strength results from Material's study indicates no issues with the propeller's usability (Material, 2020). It can withstand flight-induced tensile forces such as fatigue strength, without any concerns.

Figure 6 presents the tensile test graph of the propeller sample specimens. Prepared samples were attached to the test device, where tests were conducted at a constant ambient temperature of 23°C and a pulling speed of 15 mm/min. The samples, with dimensions of 50 mm in length and a cross-sectional area of 30,510 mm² before testing, exhibited a length change of 56.763 mm post-test.

Subsequently, the test data (recorded in the form of, the modulus of elasticity, percentage elongation, maximum tensile strength, yield strength, and ultimate tensile strength of the material) were analyzed by using an ORIGIN software.

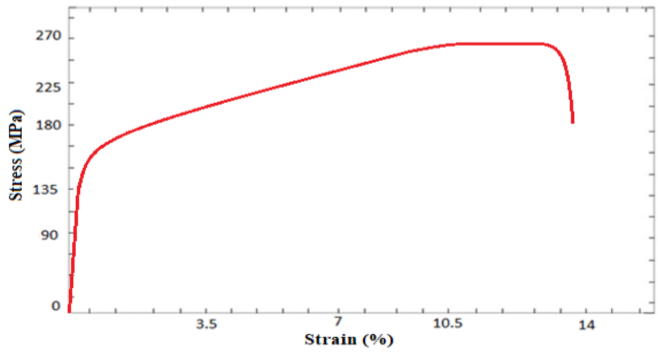

Figure 6. Stress-strain graphic.

Upon examining the stress-strain graph presented in Figure 6, it is observed that the stress increases logarithmically, reaching maximum tensile strength with a slight increase in pressure, followed by fracture of the samples.

All samples have reached the same tensile strength and fracture limit. The yield and ultimate tensile strengths are separately shown in Table 2 (Robert, 2018).

Table 2. Tensile strength results.

Sample Code	Yield Strength 0.02% (MPa)	Yield Strength 0.05% (MPa)	Tensile Strength (MPa)
A.1	250	253	264
6061-T4	110-140	130-160	180-230
6061-T6	215-290	240 -275	260 -310

Figure 6 displays the permanent yield values at 0.2% and 0.5% elongation of the samples. In the tensile test study utilizing the 6061-T6 aluminium alloy, the absence of a distinct yield point necessitated defining the stress value corresponding to plastic elongation of 0.2% and 0.5% as the yield strength.

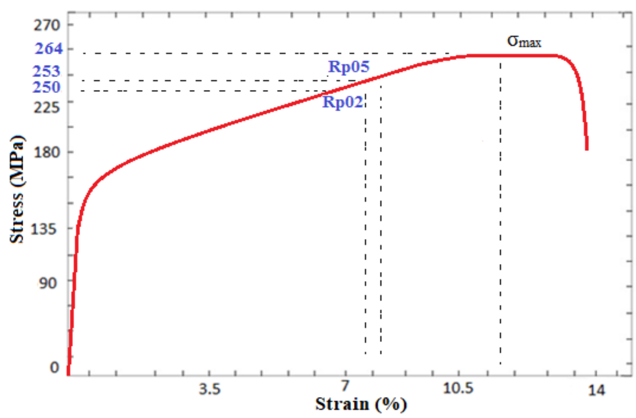

Figure 7. Representation of yield and tensile strength on the graph.

Table 2 illustrates that the yield strengths at 0.2% and 0.5% elongation of the produced samples fall within the previously determined limits of the 6061-T6 aluminum alloy. Additionally, the tensile strength of the sample, measured at 264 MPa, lies within the boundaries of the aluminum 6061-T6 temper. Both mechanical property values exceed those of the T4 temper.

In Figure 7, illustrates the σ_{max} value which is the maximum tensile strength attainable by the sample. The terms Rp02 and Rp05 signify the yield strength at 0.2% and 0.5% elongation, respectively.

When comparing the tensile test data presented in Table 3 with the data for aluminum 6061-T6, it can be seen that the sample with a 13% elongation falls within the standard limits. The elasticity modulus of 85 GPa for the sample is notably higher than the standard values, indicating minimal deformation under the stress applied. This property is desirable for propeller systems and will positively impact their utilization.

Table 3. The results of tensile strength.

Sample Code	Elongation (%)	Elastic Modulus (GPa)	Strength (kN)
A.1	13%	85	9.105
6061-T6	12-25%	68.3	-

All the data obtained from the tensile tests conducted on the samples are provided in Tables 2 and 3. Examination of the data in these tables reveals that the tensile strength is 264 MPa, the elasticity modulus is 85 GPa, and the maximum force strength is 9.105 kN.

Propellers made from 6061-T6 material have similar tensile and fatigue strength to T6 and T4 specimens (Sunström, 2018). Compared to 6063-T5 alloy, our samples exhibit higher fatigue and tensile strength. The propeller shows no damage under dynamic loads, indicating infinite fatigue life. Successful production of propeller blades with infinite fatigue life is evident. Tensile test analysis confirms that the propeller's strengths fall within established ranges in similar studies.

Comparing the stress-strain characteristics of 6061-T6 and 6063-T5 aluminum, the stress value of the produced propeller is very close to that of previously obtained 6061-T6 aluminum stress values. These findings indicate that the gyrocopter propeller provides the necessary tensile strength for flight. The tensile and yield values of the propeller do not pose any obstacles in terms of flight configurations (Chawla, 2013).

These three mechanical properties play a critical role in the flight configurations of the propeller. Their measurements are within the required standard range for aluminum, ensuring compliance with aviation safety standards. Deviation from these standard ranges could lead to dislocations during use, posing risks to aviation safety. The inclusion of these values within the desired range demonstrates that the manufactured propeller meets all required flight standards. Thus, propeller blades flying within the specified value range will not exhibit any dislocations, damage, or deterioration. Longer service life is offered by propellers that do not manifest damage or defects during use. Therefore, it has been demonstrated that manufactured propellers can have a high service life when used within the desired strength range.

Table 4. Hardness test results.

Sample Code	Rockwell (HRB)	Brinell (HB)	Vickers (HV)
1	51	90	95
2	52	90	95
3	52	90	95

The average hardness value of the samples following the hardness test is 90 HB, which closely aligns with the standard measurements of aluminum 6061-T6. Through the conducted heat treatments, the hardness value has been maintained at the indicated level. This preservation is due to the undesirability of excessive hardness in the flight configuration of the propeller. Consequently, the hardness value of the produced propeller resembles that of previously manufactured aluminum 6061-T6 in terms of hardness. This value signifies a moderate-soft hardness conducive to flight safety. Given that propeller blades must execute various movements during flight, excessive hardness is undesirable. Hence, the resultant moderate-soft value is deemed suitable for flight safety.

4. Conclusion

In conclusion, it has been demonstrated that the 6061-T6 aluminum alloy propeller blades possess mechanical properties that align with and exceed the rigorous standards required for aviation applications. The fatigue life was confirmed to endure significant cyclic loading, with the potential for infinite fatigue life under certain stress conditions, ensuring long-term durability in flight operations. The tensile strength was validated to meet industry standards, indicating that the material can withstand operational stresses without compromising structural integrity. Additionally, the hardness measurements were found to strike an optimal balance between strength and ductility, contributing to the propeller's resilience and safety. These findings affirm that the 6061-T6 aluminum alloy is suitable for the manufacture of propeller blades, ensuring compliance with aviation safety standards and offering the potential for an extended service life under the specified operational conditions.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Design and Implementation of A Low-Cost Parachute Landing System for Fixed-Wing Mini Unmanned Aerial Vehicles

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Abstract

Fixed-wing mini-UAVs (Unmanned Aerial Vehicles) face difficulties due to the need for runways during take-off and landing. While fixed-wing UAVs are capable of using catapults during take-off, various landing systems are required for landing. Therefore, in this study, a parachute system design and production were carried out for the safe landing of fixed-wing mini-UAVs. The produced parachute utilized ultra-lightweight ripstop nylon fabric and suspension lines, while a carbon fiber tube was chosen for the launching system for its lightweight and strength. The parachute deployment system was triggered by a servo motor with low power consumption and high torque. During tests, the parachute was activated at a height of 47 meters during flight. The parachute deployment was completed in 1.42 seconds, and the descent with the parachute lasted 11 seconds. The vertical descent speed of the parachute during landing was measured at 4.27 m/s. The produced parachute landing system was manufactured at 71% lower cost compared to existing parachute landing systems in the literature and on the market. Additionally, the ultra-light ripstop parachute weighed 56 grams, making it 12% lighter than similar systems. Considering the advantages in terms of cost and weight, it is anticipated that parachute landing systems will be increasingly used for fixed-wing UAVs in the future.

1. Introduction

Unmanned **A**erial **V**ehicles (UAVs) have seen a significant expansion in their utilization in recent years due to advancements in technology. While UAVs are classified into fixed-wing, rotary-wing, and hybrid types, they can also be categorized based on their size, mission system, and weight. UAVs weighing less than 20 kg are referred to as mini-UAVs. Controlling and ensuring the flight stability of mini-UAVs, which have smaller dimensions and lower weight, pose greater challenges. Various measures have been initiated to ensure flight safety (Austin, 2010).

It is well known that UAVs have higher accident rates compared to manned aircraft. Many UAV accidents related to human factors occur during take-off and landing. Landing is one of the most challenging tasks for pilots. Proper guidance towards the landing area and maintaining an appropriate approach angle are essential for aircraft. Statistics provided by Boeing indicate that 53% of fatal accidents occur during landing or take-off phases. Efforts are underway to reduce these accident rates in UAVs, with particular emphasis on ensuring safe landings (Kim et al., 2013; Oktay et al., 2016; Williams, 2004).

Bellis investigated the design and production steps of parachute landing systems for fixed-wing UAVs. The research revealed that the rescue system should be safe, reliable, and predictable (Bellis, 2019; Wilson, 2024). Furthermore, some techniques have been developed to allow continuous use of parachute rescue systems. Determining the types of parachutes is crucial due to their variable drag coefficient values. Among these types, the most commonly used ones are the dome, cruciform and parafoil structures. It is anticipated that dome and cruciform structures will be more suitable for current UAVs, while parafoil systems are considered to be open to development and expected to be used more in the future (Wyllie, 2001).

In literature another study was related with a parachute landing system to rescue and assist in the landing of fixed-wing mini-UAVs (Zakaria, 2013). He anticipated the use of three different parachute canopies for the parachute landing system. He calculated that using a parachute canopy with a parafoil structure would not be efficient, as this type of parachute would drag the UAV. He stated that the cruciform parachute canopy is the simplest design and could be easily manufactured, but it has a low drag coefficient and is not suitable for flight safety. Therefore, due to its high drag coefficient, reliability, and non-steerable parachute type, he used the round parachute canopy in his study.

(Gleason and Fahlstrom, 2016) discussed seven different UAV recovery systems. The first one is conventional landing, where a landing gear and wheels are added to the UAV for runway landing. They mentioned that a net system could be used for this purpose, but it could potentially damage the UAV during recovery. In this study in the parachute recovery system, it was emphasized that a parachute with a parafoil structure should be preferred due to its high stability and low landing speed in this study. VTOL (Vertical Take-off and Landing) UAVs were considered to have vertical take-off and landing capabilities, making this feature valuable as a landing system. Regarding air recovery systems, it was suggested that while the UAV is airborne with a parachute deployed, it could be hooked up by another aircraft for mid-air recovery. Ship recovery systems were also discussed, highlighting the need to design the recovery system considering certain ship-related issues (Gleason and Fahlstrom, 2016).

In the study conducted by (Abinaya and Arravind, 2017), the low-cost design of UAV recovery and landing systems was investigated. Traditional wheeled landing, skid landing, net recovery, parachute recovery, and mid-altitude recovery methods were examined in this study, discussing their advantages and disadvantages. Additionally, each recovery method was compared with others in terms of parameters such as cost, safety, operator requirements, complexity, and success rate in recovery (Abinaya and Arravind, 2017).

In UAV parachute recovery systems, externally produced and subsequently added payloads are available. Companies such as Fruity Chutes, Tulpar Space Aviation and Defense Co., Mars Parachutes, Butler Company, and My Research Company commercially manufacture and sell parachute systems (Ultimate Drone Parachute System for All Multicopters, Fixed Wing, UAS, 2024). Fruity Chutes indicated that for rotary-wing UAVs, a spring system and CO_2-based ballistic launchers could be utilized. For fixed-wing UAVs, the use of a pilot chute was recommended to allow the parachute to meet free air. Additionally, they offer various parachute options to ensure the selection of the most suitable parachute for the UAV.

2. Parachute Landing System Design for Fixed-Wing Mini UAVs

With the increasing utilization of fixed-wing mini-UAVs for observation and reconnaissance purposes in civilian areas, the need for these UAVs to be capable of taking off and landing near residential areas has arisen (Blom, 2010). However, while UAVs can utilize a catapult for take-off, they still require a runway for landing. To eliminate the need for a runway, this study focuses on the design and production of a parachute landing system for mini-UAVs. Parachutes are devices that utilize basic physics and aerodynamic equations to slow down the descent speed of objects and provide stability by harnessing frictional forces. With a rich history, parachutes have diverse applications, and are commonly used in aviation practices today. Parachute systems are widely used for UAVs as emergency recovery systems and for landings in confined spaces. The design of a parachute and launch mechanism for the safe landing of fixed-wing mini-UAVs has been developed in this study. In this design, the total weight of the UAV was first calculated, and accordingly, calculations for the required parachute area and parachute diameter were made. The first step in parachute system design is to determine the type of parachute. Parachute types vary depending on parameters such as drag coefficient, opening force, and average swing angle (Knacke, 1991). Parachute types can be categorized into three main types: round, cruciform, and parafoil (ram-air). Among these, round parachutes have the highest drag coefficient, but their high swing angle may cause damage when used with UAVs (Historical Review, 2024). Cruciform parachute types have a low swing angle but are not preferred due to their lower drag coefficient compared to round parachutes (Different parachute types: Styles of canopy for skydiving, 2024). Parafoil parachutes have a very high drag coefficient, but their high glide ratio makes them very difficult to use in residential areas (Szafran and Kramarski, 2019). However, advancements in round parachutes have led to the emergence of annular, or pull-down apex, and conical parachutes. The purpose of these developments in round parachutes is to reduce the average swing angle and increase stability. Therefore, an annular type parachute is used in our parachute system. (Kekeç et al., 2020; Parachute, 2024).

Alongside the parachute type, one of the paramount considerations is the selection of parachute system components. These encompass the parachute fabric, parachute cord, and connecting elements. Optimal choices for the parachute canopy entail durable, elastic, and tear-resistant nylon fabrics. Known as ripstop, tear-resistant nylon fabric is woven using a specialized technique during fabrication. In ripstop fabrics, a grid pattern is formed by weaving threads in perpendicular directions, thereby fostering a robust fabric structure. This methodology aims to impede thread displacement and enhance fabric resilience, preventing the propagation of minor tears. Hence, our parachute design incorporates ultra-lightweight ripstop nylon fabric for both the canopy and suspension cord (Federal Aviation Administration, 2015; Poynter, 1991).

In parachute design, the initial step involves calculating the total mass and determining the desired drag coefficient to be produced by the parachute. Such variables as parachute configuration and surface area can be readily computed based on the specified drag coefficient. The linkage between the total weight exerted on the parachute and the resultant drag force generated by the parachute is delineated by Equation (1).

$$F_D = mg \quad (1)$$

Equation (1) represents F_D as the drag force, m as the mass, and g as the gravitational acceleration. Equation (2) depicts the drag force.

$$F_D = \frac{1}{2}\rho V_p^2 C_D S_p \quad (2)$$

C_D represents the drag coefficient, S_p is the projected area of the parachute, V_P is the parachute velocity, and ρ is the air density. Equation (3) is derived from Equations (1) and (2).

$$\frac{1}{2}\rho V_p^2 C_D S_p = mg \quad (3)$$

Once parameters such as mass, parachute descent speed, and drag coefficient are determined, the required surface area for the parachute can be calculated as shown in Equation (4).

$$S_p = \frac{2mg}{\rho V_p^2 C_D} \quad (4)$$

Based on the parachute area calculated in Equation (4), the parachute diameter R_p can be calculated according to Equation (5).

$$R_p = 2\sqrt{\frac{S_p}{\pi}} \quad (5)$$

One of the important aspects in the mathematical modelling of the parachute is determining the measurements of the suspension lines. Here, Equation (6) can be derived based on Equation (5).

$$L_p = 1{,}1 * (R_p + S_l) \tag{6}$$

According to Equation (6), L_p represents the measurement of the suspension lines, while S_l indicates the seam or cut allowance. The block diagram of the system's production based on the equations is illustrated in Figure 1.

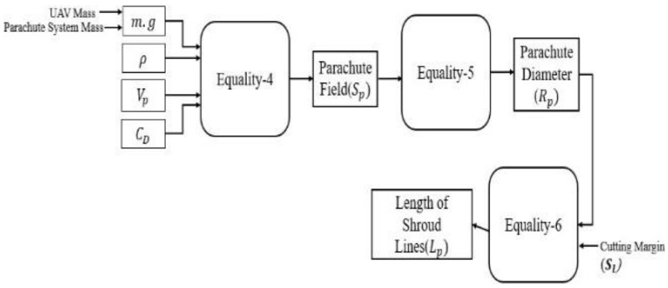


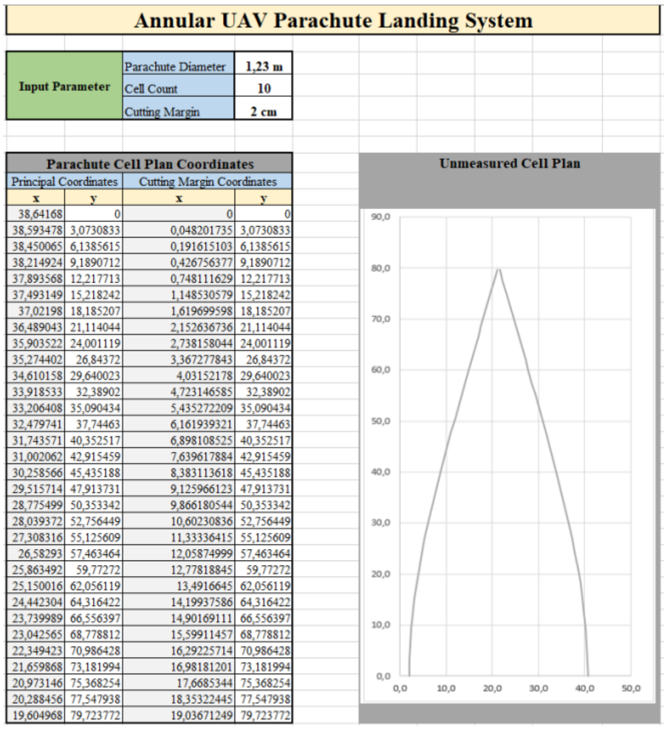
Figure 1. Block Diagram of Parachute Design Entry and Exit.

One of the first parameters to be determined when designing parachute systems is the vertical speed of the specified mass. Vertical speed can vary depending on the type of object to be landed. In the case of the UAV system used here, this value is designed to minimize impact energy. By keeping descent speeds high, the parachute diameter and area can be reduced, thereby reducing the total mass of the parachute system. Although parachute designs and types may vary depending on various applications, particular attention should be paid to determining or maintaining vertical speed within certain limits.

It has been observed in the literature that parachute systems can be designed considering different speed values for the landings of UAV systems. One of the fundamental principles here is that designs have been developed according to the UAV payload density. While the landing speed of the parachute system for UAVs varies between 4.5 m/s and 5.5 m/s in the literature (Al-Madani et al., 2018), the parachute system designed in this study is planned to land at a speed of 4.5 m/s.

After determining the parachute diameter, the number of cells and the design of the cells were carried out. Three-dimensional modelling software, or numerical designs, can be used for cell design. In this study, a two-dimensional design process prepared in Excel format was carried out numerically for cell design. The interface and input parameters prepared are shown in Figure 2. The number of cells was determined based on similar studies conducted in the literature and the most preferred systems on the market at a similar scale. In this study, a ten-cell parachute structure was chosen to facilitate production and increase stability.

The Excel file created in Figure 2 provides a practical solution with a simple interface for designing parachute cell layouts that can be produced in different dimensions later on. Here, users can determine the coordinates of the cells to be produced by entering the parachute area and diameter calculated using Equations (4 and 5).



Annular UAV Parachute Landing System

Input Parameter	Parachute Diameter	1,23 m
	Cell Count	10
	Cutting Margin	2 cm

Parachute Cell Plan Coordinates			
Principal Coordinates		Cutting Margin Coordinates	
x	y	x	y
38,64168	0	0	0
38,593478	3,0730833	0,048201735	3,0730833
38,450065	6,1385615	0,191615103	6,1385615
38,214924	9,1890712	0,426756377	9,1890712
37,893568	12,217713	0,748111629	12,217713
37,493149	15,218242	1,148530579	15,218242
37,02198	18,185207	1,619699598	18,185207
36,489043	21,114044	2,152636736	21,114044
35,903522	24,001119	2,738158044	24,001119
35,274402	26,84372	3,367277843	26,84372
34,610158	29,640023	4,03152178	29,640023
33,918533	32,38902	4,723146585	32,38902
33,206408	35,090434	5,435272209	35,090434
32,479741	37,74463	6,161939321	37,74463
31,743571	40,352517	6,898108525	40,352517
31,002062	42,915459	7,639617884	42,915459
30,258566	45,435188	8,383113618	45,435188
29,515714	47,913731	9,125966123	47,913731
28,775499	50,353342	9,866180544	50,353342
28,039372	52,756449	10,60230836	52,756449
27,308316	55,125609	11,33336415	55,125609
26,58293	57,463464	12,05874999	57,463464
25,863492	59,77272	12,77818845	59,77272
25,150016	62,056119	13,4916645	62,056119
24,442304	64,316422	14,19937586	64,316422
23,739989	66,556397	14,90169111	66,556397
23,042565	68,778812	15,59911457	68,778812
22,349423	70,986428	16,29225714	70,986428
21,659868	73,181994	16,98181201	73,181994
20,973146	75,368254	17,6685344	75,368254
20,288456	77,547938	18,35322445	77,547938
19,604968	79,723772	19,03671249	79,723772

Figure 2. 2-Dimensional Parameters of the Produced Parachute.

According to Figure 2, the coordinates on the left side of the table are provided in two different x and y planes. The x and y coordinates on the left side indicate the shape the parachute cell will take after sewing, while the coordinates on the right side indicate the area to be cut from the fabric, including seam allowances. The visual provided on the right shows a preview of the two-dimensional shape created by the coordinates and is not to scale. Figure 3, on the other hand, demonstrates the previously generated cell information from the Excel file scaled and showing their actual dimensions.

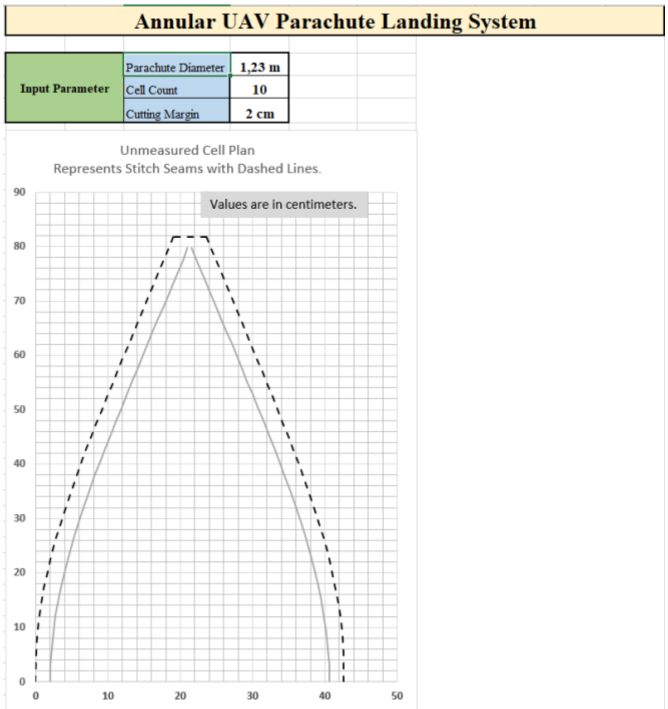


Figure 3. Scaled Parachute Cell Plan.

After placing the cell plans on the fabric and marking them with fabric pens, they were cut. Following the equal and smooth cutting of the ten cells, stitching operations were initiated for their assembly. The quality, frequency, and type of stitching thread are crucial to prevent damage to the cells during their assembly and parachute deployment shock. In this study, TEX 70 model threads were used for stitching, which can withstand high tensile strength values. In this study, utilizing ultra-lightweight fabric technology, TEX 70 threads provide superior durability to eliminate the possibility of abrasion in the stitches. The breaking strength of this thread is specified by the manufacturer as 40 N with a diameter of 0.33 mm. For the assembly of cells, a brother ZE-856/858 industrial sewing machine was used, which allows adjustment of various stitching types and frequencies. Zigzag stitches were specifically used to join the threads with the canopy and apex, enabling the distribution of load on the fabric and threads, especially during instantaneous shock loads. After completing the stitches of the cells, binding was made to prevent fraying and structural disruption of the weft and warp threads in the fabric. Figure 4 illustrates how the folds and seam allowances of the cells are aligned, while Figure 5 demonstrates the joining of two cells, their alignment with zigzag stitches, and the junctions with the load ribbon.

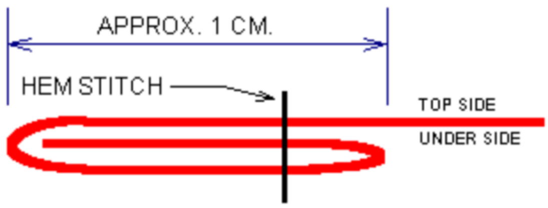


Figure 4. Folding and Seam Allowances of Parachute Cells (Nakka, 2020).

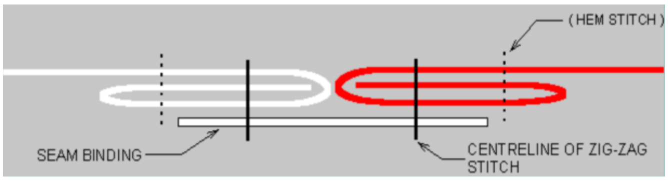


Figure 5. Assembly of Parachute Cells and Zigzag Stitching (Nakka, 2020).

One of the critical components of parachute systems is the suspension lines. Proper determination of line dimensions is essential for the safe operation of parachute designs and maintaining consistent drag coefficients. In this study, when calculating line dimensions for the designed and manufactured parachutes, Equation (6) was utilized. The parachute diameter and seam allowance calculated from Equation (5) were applied to Equation (6) to determine the length of line to be used for each cell. For this study, a 2-centimeter seam allowance was set for a 1.23-meters parachute diameter, resulting in line lengths of 1.38 meters. Here, in addition to the parachute line length, an approximately 10-centimeter allowance was left by considering connections to the canopy, seam allowances, and all lines' connection to the UAV for cutting the lines. The suspension lines used for the parachute are characterized by their ripstop and 100% nylon structure, providing natural durability and flexibility. Additionally, it has been noted that the suspension lines exhibit high tensile strength over 100 kg and minimal elongation or shortening during prolonged use. Furthermore, compared to suspension lines used in many parachute landing systems designed for UAVs, these lines have a lower weight.

The release mechanism for parachute systems is crucial for both protecting the parachute and enabling it to open when needed. Therefore, release mechanisms are designed to allow for different designs and release systems, as well as triggering the parachute using servo motors or ballistic systems. Release mechanism body parts are typically made of composite materials, as well as plastics or aluminium alloys. In this study, carbon fiber and PLA parts were used for the release mechanism, chosen for their cost-effectiveness and lightness. The release mechanism, designed using 3D solid modelling software like SolidWorks, consists of 4 different PLA parts and was produced using a 3D printer.

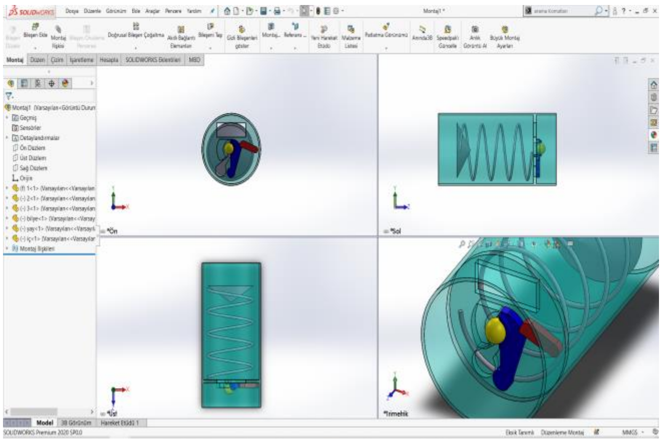


Figure 6. Solidworks designs of the parachute deployment mechanism.

During the production stage, parts designed using SolidWorks software were saved in STL format and transferred to CURA software for conversion to Gcode format. In CURA, the density of the parts was set to 50%, and they were adjusted for printing from an Ender3 model printer. The produced parts are shown in Figure 7.

Figure 7. Representation of CURA software and produced PLA parts.

The launch mechanism is used to release the parachute upon command from the pilot. For this purpose, the system utilizes the force exerted by a spring to rapidly deploy the parachute without being attached to the aircraft or its subsystems during flight. Prior to flight, the launch mechanism is set up to lock the tension of the spring using a servo motor to prevent its release. Thus, unless commanded by the pilot, the servo motor will store the energy of the spring, preventing the parachute from being launched. Figure 8 illustrates the response of the launch mechanism in its closed and open positions.

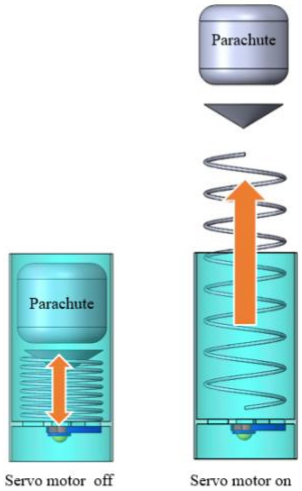


Figure 8. Illustration of the open and closed positions of the parachute launch mechanism.

The use of PLA parts and carbon fiber tubes in the launch mechanism has significantly minimized costs. Furthermore, the avoidance of heavy metals commonly found in similar products has resulted in less impact on the UAV take-off weight. This has demonstrated the potential to alleviate problems encountered by users with flight durations in similar systems. Additionally, the stable operation of the launch mechanisms, along with the systematic folding of parachutes and cords within them, is crucial for the system. Hence, the ability for the annular configuration parachute produced to be easily and quickly folded will provide a significant advantage to users.

Ground tests of the parachute launch mechanism have enabled the observation of the system's stability and its response in potential emergency scenarios. Following ground tests, the integration of the UAV and parachute system was performed. The total mass of the parachute landing system was estimated to be 500g during the design phase, but it was measured at 465 g after production. To ensure that the parachute system does not compromise the structural integrity of the UAV, epoxy resin and plywood supports were added to the areas where the launch mechanism was installed.

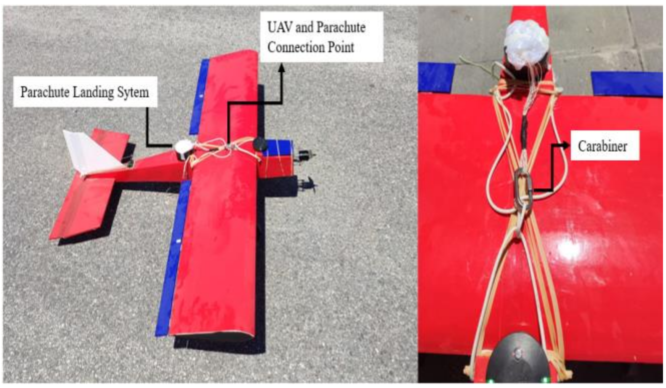


Figure 9. Presentation of the Parachute Landing System on the UAV.

After the parachute is deployed, it is essential to establish a connection between the parachute and the UAV for the safe landing of the UAV. This connection point also creates a shock force based on the weight and acceleration of the UAV. To prevent damage to the system and ensure that the parachute does not detach, the UAV parachute connection was made using a 3mm aluminium carabiner. The positioning of the connection near the center of gravity or in close proximity to it is crucial for the safe landing of the UAV. Therefore, in this study, the parachute and UAV connection were positioned very close to the center of gravity. Figure 9 depicts the connection point on the wing where the UAV will be carried by the parachute after deployment.

3. Result and Discussion

After the successful completion of ground tests for the UAV electronics and launch mechanism, real flight tests were conducted. For the test flights, the Talas Municipality Model Aircraft Runway located in the Kayseri Talas district, away from residential areas, was chosen. Initially, to ensure flight safety, the calibration of the flight controller and telemetry communication distance were tested in the flight area. After rechecking the UAV's center of gravity, battery levels, and structural components, thrust testing of the brushless motor and trim adjustments of the servo motors were performed. Following the verification of the SW-A switch connection used for parachute triggering, the GPS satellite count and signal quality were also checked. After a short flight of 2 minutes and 36 seconds, the parachute landing system was activated, and a safe landing of the UAV was observed.

Post-flight checks revealed no damage to the UAV's structural components, electronics, or parachute landing system. During the brief flight, the UAV took off under pilot control in stabilize mode and was brought to a balanced flight position with minor trim adjustments after reaching a certain altitude post-take-off. Subsequently, the parachute was deployed using the SW-A switch over a suitable area by the pilot. Upon issuing the triggering command, the parachute fully deployed in 1.42 seconds. Pre-flight, flight, and landing with the parachute are illustrated in Figure 10.

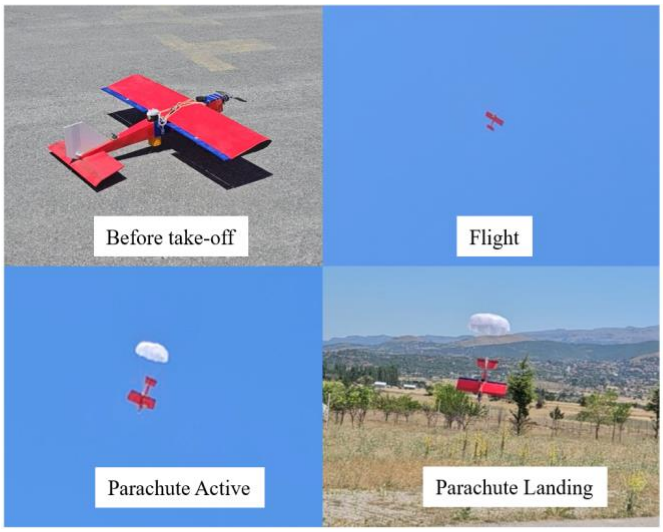


Figure 10. Phases of UAV Flight.

During the flight, a total distance of 2.68 km was covered, reaching a maximum altitude of 134 meters. The parachute was activated at an altitude of approximately 47 meters, and the descent with the parachute took a total of 11 seconds. After the parachute deployment, the UAV descended at a vertical speed of 4.27 m/s, or 14 FPS. The trajectory followed during the flight and the representation of the flight area are depicted in Figure 11. The blue lines represent the UAV flight path.

The altitude-time graph depicting changes in altitude during the UAV flight is presented in Figure 12. The variability in altitude is primarily due to the flight being conducted in stabilized mode with pilot control. Although autonomous testing could be conducted with GPS support, it was deemed appropriate in this study to conduct flights under pilot control to better control and intervene in UAV responses. In Figure 12, the altitude values obtained from the internal barometric pressure sensor are shown in green, while the altitude change data recorded by the GPS receiver is shown in red. Additionally, the estimated altitude value, derived from the composite of data from GPS and the barometric pressure sensor, is shown in blue. The shaded area in Figure 12 indicates the change in altitude from the activation of the parachute until landing.

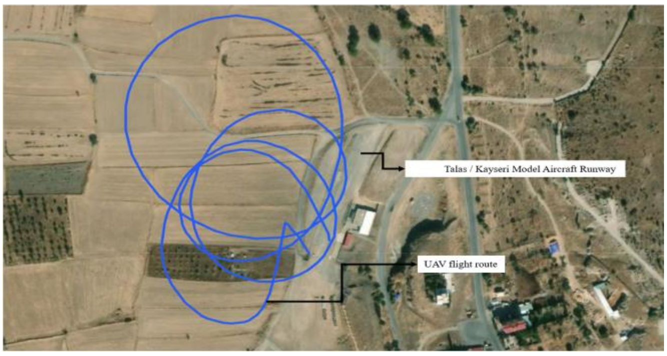


Figure 11. UAV Flight Path.

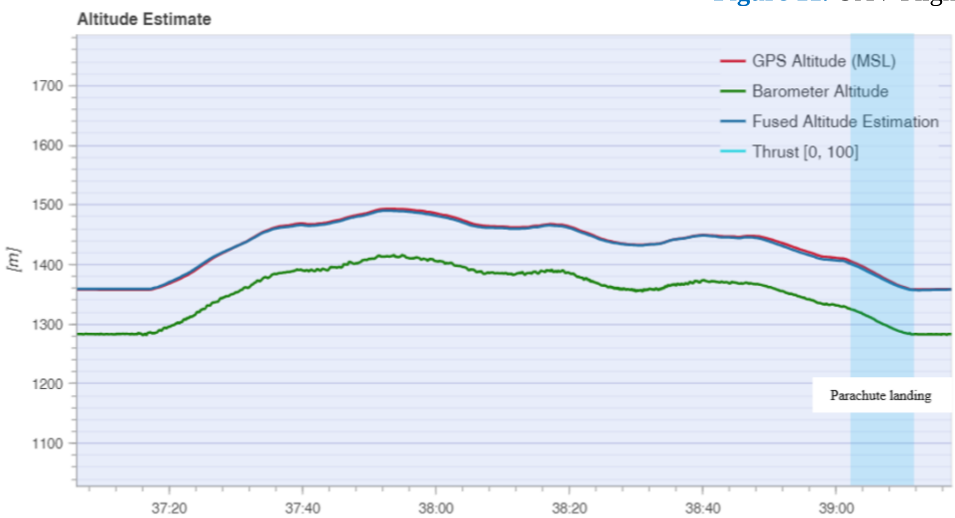


Figure 12. UAV Altitude-Time Graph.

Acceleration values over time in the X, Y, and Z axes during the UAV flight are depicted in Figure 13. The blue area in Figure 13 indicates the speed of the UAV after the parachute is deployed. The Z-axis is represented by the blue line, representing the vertical speed of the UAV. The average vertical speed of 4.27 m/s is clearly indicated by the black line.

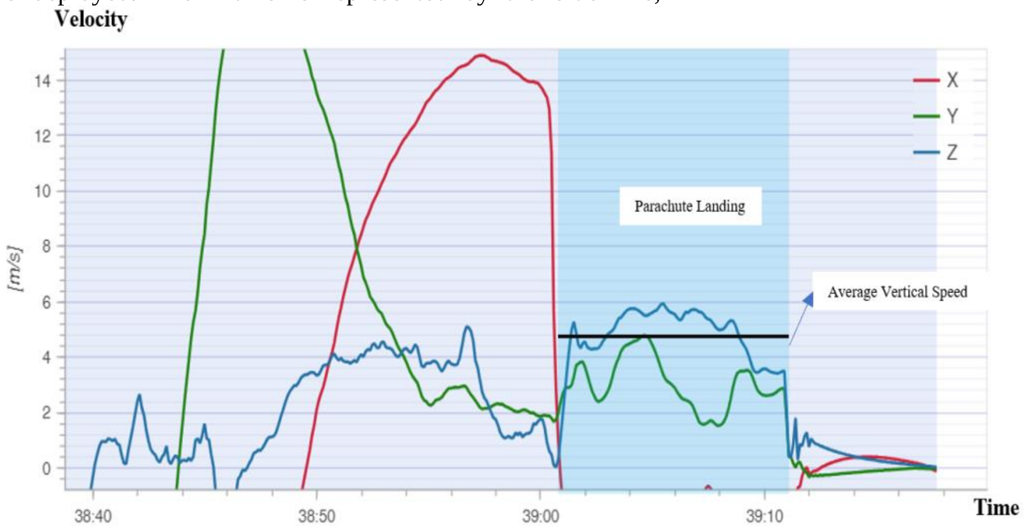


Figure 13. UAV Speed-Time Graph.

When examining parachute systems used worldwide, it is observed that only a few companies manufacture landing and recovery parachutes specifically for UAVs. The reasons for this are both the cost of UAV landing system parachutes and the difficulty of integrating them into UAV systems. Additionally, parachutes designed for mini-UAVs need to occupy minimal volume and have a light mass for the landing system. Consequently, parachute manufacturers tend to avoid producing parachutes with high drag coefficients and low oscillation.

The costs of UAV parachute landing and recovery systems produced by some companies are provided in Table 1. In this study, a low-cost parachute landing system was designed for mini fixed-wing UAVs. The costs of the produced parachute landing system are listed in Table 2. The pricing in Table 2 is calculated based on the quantities of materials used for a parachute system, not on the quantities purchased.

Rescue systems used in unmanned aerial vehicles (UAVs) have shown highly successful results in line with their designated missions. These landing systems are especially critical for UAVs carrying valuable payloads or operating over populated areas. Similarly, rescue systems for manned aircraft have been a subject of research for many years and are considered a significant safety solution in this regard. For instance, ballistic rescue systems used in popular ultralight aircraft, such as the Cirrus Aircraft SR20 and SR22, have effectively prevented accidents and damage, thereby saving human lives. However, the applicability of similar systems for large passenger aircraft has been limited due to cost and technical challenges. One of the primary factors complicating the integration of these systems is the weight of passenger aircraft. For example, the maximum takeoff weight of one of the most popular aircraft models, the Airbus A320, is 77,000 kg. To safely land an aircraft of this size at a vertical speed of 6-7 m/s, an extremely large parachute would be required, and with current technologies, the production of such a parachute is not feasible. Additionally, considering the critical importance of minimizing weight in commercial aviation, the use of such a large parachute system would present significant cost challenges (Copper, 2024; Airbus, 2024).

Table 1. Costs of Various Parachute Landing and Recovery Systems

Parachute Systems	System Weight	Maximum Usable Weight	Price
Fruity chutes Fixed Wing (1,8 kg)	221 grams	1.8 kg	312$
Fruity chutes Fixed Wing (3,2 kg)	270 grams	3.2 kg	350$
Fruity chutes skycat	272 grams	5 kg (2.5 kg optimum weight)	755,5$
Fruity chutes harrier	154 grams	5 kg (2.5 kg optimum weight)	416.24$
Mars Parachutes (Mars 58)	277.5 grams	4.5 kg	450$
Manufactured Parachute	465 grams	2.1 kg	87$

4. Conclusion

This study, tested on a UAV with traditional control surfaces, demonstrates that this system can be actively used in many fixed-wing UAVs. The use of ultra-lightweight ripstop fabric and suspension lines in the parachute landing system, along with modern sewing techniques, highlights the original aspects of the study. Additionally, significant cost improvements have been made compared to other parachute systems available in the literature and on the market, thanks to the consumables and production techniques used in the study. Furthermore, the design of the launch system has been conceived considering the opening of the parachute and its integration into different aircraft concepts compared to existing systems. The servo motor used to trigger the launch mechanism, with its low power consumption and high torque, has opened the way for its use in many aircraft. An optimal thrust spring has been used in the launch mechanism to easily activate parachute descent even at low altitudes.

The UAV used in flight tests was controlled by the pilot using the stabilize mode, thanks to the flight control card. After a short take-off and flight phase, the launch mechanism was triggered via a switch previously assigned to the ground control station, and the parachute was released. After 1.42 seconds, the parachute fully opened, and the UAV made a safe landing in the designated area as planned. This descent took 11 seconds, and the vertical speed during descent was recorded as 4.27 m/s (14 FPS), as planned during the design phase. It was determined that the parachute deployment time and the vertical speed of the UAV during descent with the parachute complied with the limits set by aviation authorities and recommended in the literature. It is anticipated that the study will contribute significantly to the widespread use of fixed-wing and civilian UAV systems in the future.

The produced parachute landing system in the study has been proven to be 71% more cost-effective compared to similar systems found in the literature and on the market. Additionally, the parachute weight was determined to be 56 grams without including the launch mechanism. Thus, it has demonstrated a 12% lighter parachute design compared to other systems with similar features. Further studies are aimed at achieving a much lighter design for the launch mechanism in the future. With the advantages achieved in terms of cost and weight in this study, significant contributions are anticipated for the development of landing system designs for fixed-wing UAV systems. This study is expected to contribute to future scientific studies focusing on UAV landing systems.

Common examples of aircraft in which rescue systems are widely used include paragliders, hang gliders, microlights, ultralights, and paramotors. One of the main reasons rescue systems are not utilized in manned aircraft, particularly large passenger planes, is the weight of the mechanisms required to deploy such systems. Even in UAVs, parachute rescue systems require ballistic deployment mechanisms when they exceed certain weight limits. Furthermore, during a free fall, a passenger aircraft, which weighs several tons, would impose significant stress on the parachute lines and fabric, potentially causing damage to the system and leading to failure. For these reasons, while parachute rescue systems offer a viable solution for sport aircraft and ultralight single-engine planes, such systems have yet to be developed for large passenger aircraft.

Table 2. Cost of Produced Parachute System

Material	Model (Type)	Price
Fabric	0,66 Oz membrane ripstop	19$
Length of Shroud Lines	Ripstop nylon lines	4$
Servo	JX Servo PS-1171MG Metal gear	10$
Carbon Fibre Tubes	70mm diameter carbon fibre tube with a wall thickness of 1mm	12$
Mini Carabiner	Aluminium 5 kN	5$
Spring	Stainless steel	5$
Other Expenses	PLA etc. materials	2$
Parachute Manufacture	Labour	30$
Total Price		87$

Conflicts of Interest

There is no conflict of interest regarding the publication of this paper.

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Maximization of Flight Performance of Eight-Rotor Multirotor with Differentiated Hub Angle

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Abstract

The aim of this article is to design a rotary wing aircraft autopilot system that improves flight performance by changing the body shape during flight. The method is to obtain values that stabilize the longitudinal and lateral flight of the aircraft, where the amount of metamorphosis and Proportional-Integral-Derivative (PID) coefficients are determined using the simultaneous perturbation stochastic approximation (SPSA) optimization algorithm. The rotary wing aircraft has a deformable structure with eight rotors. Shape-changing rotary-wing aircraft are aircraft that can fly with the lift generated by propellers. Aerial platform; It consists of arms and trunk. The angle between mechanism A and the arm to which the rotors are connected can be changed with the horizontal plane and different configurations are obtained. When the angle between the arms is 45°, the octo configuration turns into a stable structure, while when the angle between the arms is 0°, the X8 configuration provides high maneuverability and increased controllability. Metamorphosis, its effect on longitudinal and lateral flight stability and improvement studies were carried out in a simulation environment and the results are presented in this study. As a result of the shape change, longitudinal and lateral narrowing occurred by 26.8° percent. Simulation tests were modeled in a closed environment, free from atmospheric effects. The obtained flight performance values are presented in Tables.

1. Introduction

Unmanned aerial vehicle (UAV) is an unmanned or remote-controlled aircraft (Bao et al., 2022). UAVs are generally used in various fields such as reconnaissance, surveillance, mapping, security, and agriculture (Husain et al., 2022). UAVs can be produced in different sizes and shapes. Small-sized UAVs are hand-held devices with cameras and various sensors (Chen et al., 2022). Larger-sized UAVs can generally have fixed wings and can travel longer distances (Çoba et al., 2020). Rotary-wing unmanned aerial vehicle is a type of UAV that can hover and stay in the air via its rotating wings (Falanga et al. 2018). Such UAVs operate similarly to helicopters and can take off and land vertically in the air (Alanezi et al., 2022). Rotary-wing UAVs can be used in many different areas such as reconnaissance and surveillance, rescue, agriculture, firefighting, mining, construction, film production and military purposes. They are usually produced in small sizes and are portable. Some models may have different features such as cameras, thermal imagers, laser meters and other sensors. Thanks to these features, rotary-wing UAVs can perform various tasks. Rotary wing aircraft are named according to the number of rotors they have. In this study, the aircraft type with eight rotors is named in the literature as X8 and octo. Conventional quad-rotor aircraft are designed for indoor or outdoor use. While smaller volume aircraft are preferred for indoor use, the octocopter structure, which is more resistant to atmospheric disturbances, is preferred (Zhang et al., 2022). The design and optimization of an eight-rotor aircraft controller that can change shape and has a structure suitable for both situations is the subject of this study.

Optimization of morphing aircraft requires considering factors such as its design, material selection and control system to improve the performance of the aircraft and increase its energy efficiency.

The optimization process usually includes these steps:

1. Problem definition: Identifying problems such as objectives, requirements and constraints for designing the aircraft.

2. Design variations: Identifying different design options, e.g. evaluating different options such as continuous deformation technologies or modular designs.

3. Analysis and testing: Comparison of selected designs with computer simulations or real tests.

4. Optimization: Determination of the best design or combination is evaluated according to the necessary criteria to ensure the most appropriate choice in terms of performance and cost.

5. Redesign: Improving the qualities of the selected designs and redesigning them when necessary.

6. Application: Production and flight testing of the optimized morphing aircraft.

The choice of materials used in the design of the shape-shifting aircraft is also important. By using light and durable materials, energy efficiency can be increased and flight costs can be reduced. Finally, control systems must also be optimized and be able to optimize the aircraft's flight stabilizations and performance.

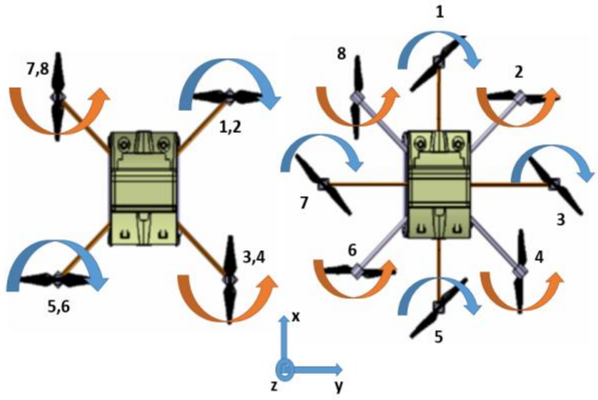
In this study, the simultaneous X8-octo autopilot system is considered both longitudinally and laterally. For the first time, methods of changing the arm intersection angles of an eight-rotor aircraft were combined and applied as morphing in the simulation. In order to implement the transformation, a multirotor mathematical model was created using the Newton-Euler method. Mathematical model of multirotor dynamics is developed using Newton-Euler method. Both linear and nonlinear equations are derived in mathematical model. However, linear equations are used in state space model approach. Modeling was done with a state space model approach using linear equations of motion (Debines et al.,2017). To make it more stable against longitudinal and lateral flight parameter changes, the PID control algorithm was used, and the SPSA optimization method was used to best estimate the PID coefficients and determine the transition parameters (Köse et al, 2021). Again, SPSA and this type of morphing were applied for the first time. Simulations were carried out with the calculated parameters and the longitudinal and lateral flight of the aircraft was controlled in the active transition state. With the results obtained, important data for quadrotor transformation has been obtained and it has been demonstrated that combining different transformation situations and optimization algorithms plays an important role in determining the transformation rate, and it is aimed to eliminate the gap in this regard.

2. Materials and Methods

2.1. Theoretical Background and Experimental Method

Unmanned aerial vehicles (UAVs) are aircraft that possess autonomous flight capabilities. These capabilities are predominantly dependent on an autopilot system, which comprises a combination of software and hardware components. The autopilot system allows UAVs to execute operations in accordance with a pre-established flight plan.

Autopilot systems enable UAVs to control various flight parameters, including altitude, speed, heading, orientation, and other critical factors. These systems process data received from the UAV's sensors and make the necessary adjustments to stabilize the flight and ensure adherence to a predefined flight plan. The autopilot system comprises numerous components, including sensors such as inertial measurement units (IMUs), GPS, airspeed sensors, barometers, and magnetometers. Additionally, hardware components like motors, propellers, and control surfaces are utilized to manage the UAV's movement. The X8-Octo model, depicted in Fig. 1, features eight propellers and corresponding rotors. The rotation directions of the rotors are provided for both configurations.



a) b)

Figure 1. a) X8 Configuration, b) Octo Configuration

The development of unmanned aerial vehicles (UAVs) has seen a significant rise, particularly in applications that require stability, precision, and versatility. An octocopter, a UAV with eight rotors, provides enhanced lift, stability, and redundancy compared to quadcopters and hexacopters. This article details the mathematical modeling of an octocopter, covering its kinematics, dynamics, rotor forces, and control systems.

Coordinate System and Notation

Inertial Frame (Earth Frame)

The inertial frame, or Earth frame, is fixed and serves as a reference:

Axes: $\{X_E, \quad Y_E, \quad Z_E\}$

Position Vector: $r_E = [x_E, \quad y_E, \quad z_E,]^T$

Body Frame (UAV Frame)

The body frame is fixed to the UAV's center of mass:

Axes: $\{X_B, \quad Y_B, \quad Z_B\}$

Position Vector: $r_B = [x_B, \quad y_B, \quad z_B,]^T$

Transformation Matrix

To transform vectors between frames, the rotation matrix R_B^E is used:

$$R_B^E = \begin{bmatrix} c\psi c\theta & c\psi s\theta s\phi - s\psi c\phi & c\psi s\theta s\phi + s\psi s\phi \\ s\psi c\theta & s\psi s\theta s\phi + c\psi c\phi & s\psi s\theta c\phi - c\psi s\phi \\ -s\theta & c\theta s\phi & s\theta s\phi \end{bmatrix} \quad (1)$$

Where ϕ, θ, and ψ represent roll, pitch, and yaw, respectively.

Kinematics

Position and Velocity

The position and velocity vectors in the inertial frame are given by:

Position Vector: $r_E = [x, \quad y, \quad z]^T$

Velocity Vector: $v_E = [\dot{x}, \quad \dot{y}, \quad \dot{z}]^T$

Orientation

Orientation can be represented using Euler angles or quaternions.

Euler Angles

- Roll (ϕ), Pitch (θ), Yaw (ψ)

The angular velocity in the body frame:

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & 0 & -s\theta \\ 0 & c\phi & s\phi c\theta \\ 0 & -s\phi & c\phi c\theta \end{bmatrix} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} \quad (2)$$

Dynamics

Translational Dynamics

The translational motion is described by Newton's second law:

$$m\ddot{r} = F_E + mg \quad (3)$$

Where:

F_E is the net external force in the inertial frame.

$g = [0, \quad 0, \quad -mg]^T$ represent gravitational force.

The thrust force F_B in the body frame is transformed to the inertial frame:

$$F_E = R_B^E F_B \quad (4)$$

Where:

$$F_B = \left[0, \quad 0, \quad \sum_{i=1}^{8} T_i\right]^T \quad (5)$$

Rotational Dynamics

The rotational dynamics are given by the Euler equations for rigid body rotation:

$$I\omega + \dot{\omega} x(I\omega) = \tau \quad (6)$$

Where:

I is the inertia matrix, $\omega = [p, \quad q, \quad r]^T$, τ is the torque vector.

Forces and Torques from Rotors

Thrust and Torque of Individual Rotors

For each rotor i:

Thrust Force:

$$T_i = k_T \omega_i^2 \quad (7)$$

Where ωi is the angular speed and kt is the thrust coefficient.

Torque:

$$\tau_i = k_\tau \omega_i^2 \quad (8)$$

Where $k\tau$ is the torque coefficient.

Total Thrust and Torques

Sum the contributions from all eight rotors.

$$F_B = \begin{bmatrix} 0 \\ 0 \\ \sum_{i=1}^{8} T_i \end{bmatrix}$$
$$T = \sum_{i=1}^{8} \begin{bmatrix} y_i T_i - z_i \tau_i \\ z_i T_i - x\tau_i \\ k_\tau \omega_i^2 \end{bmatrix} \quad (9)$$

Where x_i, y_i, z_i are the rotor coordinates.

Control Allocation

Distributing the desired thrust and torques among the rotors involves mapping control inputs to rotor speeds.

Control Inputs

Control inputs u_1, u_2, u_3, u_4 correspond to:

$$u_1 = k_T(\omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2 + \omega_5^2 + \omega_6^2 + \omega_7^2 + \omega_8^2)$$

$$u_2 = k_T l \begin{pmatrix} \omega_5^2 \frac{\sqrt{2}}{2} \cos\alpha + \omega_6^2 \frac{\sqrt{2}}{2} + \omega_7^2 \frac{\sqrt{2}}{2} \cos\alpha + \omega_8^2 \frac{\sqrt{2}}{2} \\ -\omega_1^2 \frac{\sqrt{2}}{2} \cos\alpha - \omega_2^2 \frac{\sqrt{2}}{2} - \omega_3^2 \frac{\sqrt{2}}{2} \cos\alpha - \omega_4^2 \frac{\sqrt{2}}{2} \end{pmatrix} \quad (10)$$

$$u_3 = k_T l \begin{pmatrix} \omega_1^2 \frac{\sqrt{2}}{2} \sin\alpha + \omega_2^2 \frac{\sqrt{2}}{2} + \omega_7^2 \frac{\sqrt{2}}{2} \sin\alpha + \omega_8^2 \frac{\sqrt{2}}{2} \\ -\omega_5^2 \frac{\sqrt{2}}{2} \sin\alpha - \omega_6^2 \frac{\sqrt{2}}{2} - \omega_3^2 \frac{\sqrt{2}}{2} \sin\alpha - \omega_4^2 \frac{\sqrt{2}}{2} \end{pmatrix}$$

$$u_4 = k_\tau(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2 + \omega_5^2 - \omega_6^2 + \omega_7^2 - \omega_8^2)$$

Considering the body structure of the shuttle rotor aircraft and the locations of the rotor, the control inputs are defined as follows.

The changes in the structure geometry after the resulting shape change are given in Table 1.

Table 1. Dimensions of Multirotor

Aircraft Configuration	Width (mm)	Length (mm)
Octo	1100	1100
X8	777	777

2.2. Control System

2.2.1. Hierarchical Autopilot System

The X8-Octo UAV calculates linear and angular movements using the angular and linear acceleration data obtained from its sensors. The control signal u_1 is used to control altitude, while u_2, u_3, and u_4 are employed to manage roll (ϕ), pitch (θ), and yaw (ψ) movements, respectively. Although there are four control signals, the system governs six states, rendering it underactuated (Köse et al., 2019). The four control inputs available—pitch, roll, yaw, and altitude—are used to manage these motions. To enable linear forward and lateral movements, the flight control software installed on the flight controller generates two additional commands, thereby ensuring full control of the aircraft. The flight control software integrates commands received from the guidance and navigation systems into its subsystems—angular and linear—and then transmits the corresponding output signals to the actuators. The system's schematic is presented in Fig. 2.

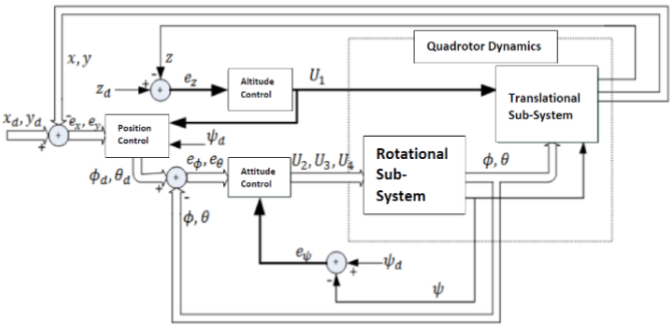


Figure 2. Hierarchical Autopilot System Structure

PID controllers manage the UAV's position and orientation. Position control for x, y, z:

$$u_x = K_{p_x}(x_{ref} - x) + K_{d_x}(\dot{x_{ref}} - \dot{x}) + K_{i_x}\int (x_{ref} - x)dt$$
$$u_y = K_{p_y}(y_{ref} - y) + K_{d_y}(\dot{y_{ref}} - \dot{y}) + K_{i_y}\int (y_{ref} - y)dt \quad (11)$$
$$u_z = K_{p_z}(z_{ref} - z) + K_{d_z}(\dot{z_{ref}} - \dot{z}) + K_{i_z}\int (z_{ref} - z)dt$$

Attitude control for roll (ϕ), pitch (θ), yaw (ψ):

$$u_\phi = K_{p_\phi}(\phi_{ref} - \phi) + K_{d_\phi}(\dot{\phi_{ref}} - \dot{\phi}) + K_{i_\phi}\int (\phi_{ref} - \phi)dt$$
$$u_\theta = K_{p_\theta}(\theta_{ref} - \theta) + K_{d_\theta}(\dot{\theta_{ref}} - \dot{\theta}) + K_{i_\theta}\int (\theta_{ref} - \theta)dt \quad (12)$$
$$u_\psi = K_{p_\psi}(\psi_{ref} - \psi) + K_{d_\psi}(\dot{\psi_{ref}} - \dot{\psi}) + K_{i_\psi}\int (\psi_{ref} - \psi)dt$$

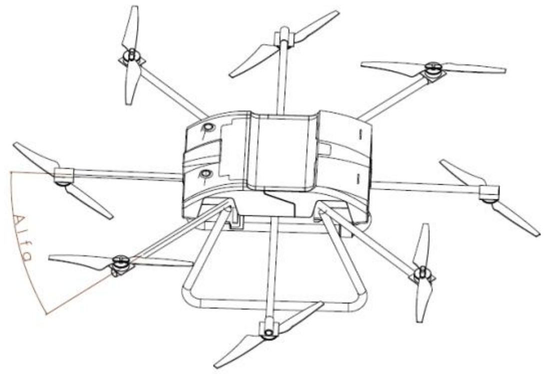
This detailed mathematical model forms the basis for designing and simulating the control systems of an eight-rotor UAV. By understanding and applying these principles, we have developed more efficient, stable and robust UAV systems.

2.3. Problem Definition

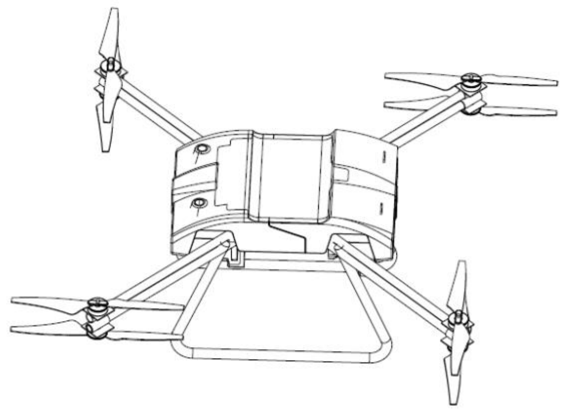
Today, UAVs are employed for a wide array of purposes, ranging from applications in the entertainment industry to military operations on battlefields. The specific missions and performance requirements for UAVs vary depending on the intended use. UAVs achieve the necessary mission objectives through modifications in their geometry, a process referred to as morphing (Uzun et al., 2021). In multirotor UAVs, this morphing typically involves extending or shortening the arm length (Köse et al., 2021). However, in this study, an alternative approach is explored by altering the arm intersection angle. The geometric changes made by the X8-Octo during flight result in shifts in its dynamic properties. The key parameter affected by this morphing is the moment of inertia, as detailed in Table 2. The moment of inertia values are calculated using Eq. 13.

$$I = \frac{1}{3}ml^2 \quad (13)$$

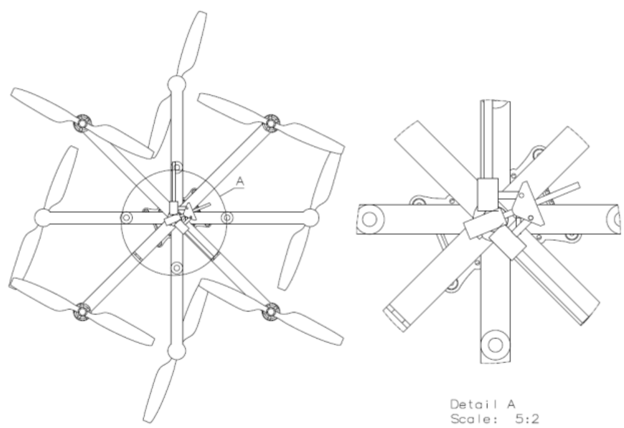
Here l is the arm length, m is the total mass, α is the hub angle (arm intersection angle) (Fig. 3). It has two body structures of type X and + that can move independently or together. Morphing (Sal et al., 2016) is performed by changing the angle α [0°, 45°] thanks to mechanism A (Fig. 3c). The weight of each arm was considered to be one eighth of the total weight and 1 kg.



a)



b)



c)

Figure 3. a) Arm Intersection Angle (alpha=45°) b)Arm Intersection Angle (alpha=0°) c) Mechanism A

Moment during deflection; It is calculated by multiplying the moment of inertia (I_z) with respect to the z axis and the angular acceleration. Here I_z is given in Eq.14.

$$I_z = \frac{8}{3}ml^2 \quad (14)$$

The moment of inertia of the aircraft around the z-axis was calculated according to Eq.14. from Eq.3 , the moment occurring during pitching motion is calculated as I_y times the angular acceleration. Here I_y, it is obtained from Eq. 15.

$$I_{x,y} = \frac{2}{3}m(lcos\alpha)^2 + \frac{2}{3}m(lsin\alpha)^2 + \frac{4}{3}m\left(\frac{l\sqrt{2}}{2}\right)^2 \quad (15)$$

The moment during the rolling motion is calculated as I_x times the angular acceleration. Here I_x is obtained from Eq.15.

When the angle between the arms is increased, the dynamics of the aircraft changes. According to 11 and 12, the calculation of the moments of inertia in configurations 1 and 2 is given in Eq. 14 and 15. The moment of inertia results obtained as a result of the change in shape and geometric dimensions are given in Table 2.

Table 2. Moment of Inertia Values of Eight Rotor Air Vehicles in Different Configurations

Aircraft Configuration	I_x (kgm^2)	I_y (kgm^2)	I_z (kgm^2)
Configuration 1	0.408	0.408	0.813
Configuration 2	0.408	0.408	0.813

2.3.1. SPSA Optimization Algorithm

The eight-rotor UAV in question can dynamically switch between a cross and plus configuration, providing versatility in maneuverability and stability. The transition between configurations is controlled by a hub angle, and the system's performance can be optimized by tuning 7 variable parameters, including PID coefficients for both longitudinal and lateral control. This article defines the Simultaneous Perturbation Stochastic Approximation (SPSA) optimization algorithm to optimize these parameters.

UAV Configuration

Variable Configurations

Cross Configuration (Plus Configuration): Two intersecting frames at a 45-degree angle.

X8 Quadcopter Configuration: Frames aligned at 0 degrees.

Variable Parameters

Hub Angle (α): Angle between the cross and plus configurations.

Longitudinal PID Coefficients: Kplong, Kilong, Kdlong.

Lateral PID Coefficients: Kplat, Kilat, Kdlat.

Simultaneous Perturbation Stochastic Approximation (SPSA) is an efficient method for optimizing systems with multiple parameters. It is particularly useful for systems where the objective function is noisy and the cost of evaluating the gradient is high.

SPSA Steps:
1. Initialization:
Set initial parameter values:

$$\theta_0 = [\alpha,\ K_{p_{long}},\ K_{i_{long}},\ K_{d_{long}},\ K_{p_{lat}},\ K_{i_{lat}},\ K_{d_{lat}}]$$

Choose SPSA coefficients: a, c, A, α, γ.

Set the initial iteration count $k = 0$

2. Iteration:
For each iteration k:
Generate perturbation vector:

$$\Delta_k = [\delta_\alpha,\ \delta_{p_{long}},\ \delta_{i_{long}},\ \delta_{d_{long}},\ \delta_{p_{lat}},\ \delta_{i_{lat}},\ \delta_{d_{lat}}]$$

Where δ_i are randomly selected from a symmetric Bernoulli distribution (±1).

Parameter perturbation:

$$\theta_k^+ = \theta_k + c_k\Delta_k$$
$$\theta_k^- = \theta_k - c_k\Delta_k$$

Objective function evaluation:

Evaluate the objective function L (e.g., cost function, error) at θ_k^+ and θ_k^- :

$$L^+ = L(\theta_k^+)$$

$$L^- = L(\theta_k^-)$$

Gradient approximation:

$$\hat{g}_k = \frac{L^+ - L^-}{2c_k\Delta_k}$$

Parameter update:

$$\theta_{k+1} = \theta_k - a_k\hat{g}_k$$

Update coefficients:

$$a_k = \frac{a}{(k+1+A)^\alpha}$$

$$c_k = \frac{c}{(k+1)^\gamma}$$

Increment the iteration count k.

3. Convergence Check:
Repeat the iteration until convergence criteria are met (e.g., maximum iterations, tolerance threshold).

Implementation
Initialization

Choose initial values for θ_0 based on domain knowledge or preliminary experiments. Set the SPSA coefficients appropriately. Typical values are α=0.602, γ=0.101 and A=10 (tuning may be required).

Objective Function

Define the objective function (θ) L(θ) based on UAV performance metrics such as stability, control error, energy efficiency, etc.

Autonomous performance cost, longitudinal cost, weighted lateral cost, total cost and endurance coefficients are the weight values during the application of SPSA algorithm and are selected by considering all design parameters (autonomous performance cost vs. longitudinal cost vs. lateral cost). The weight values are determined according to the ratios of the design performance criteria in each iteration.

The SPSA algorithm offers an efficient and robust method for optimizing the control parameters of an eight-rotor UAV with a variable configuration. By adjusting the hub angle and PID coefficients, the UAV can achieve optimal performance across different operational scenarios. This approach ensures that the UAV maintains stability and control while transitioning between configurations, leveraging the flexibility provided by the unique design.

3. Result and Discussion

Hub angle and arm elevation angle changes were examined together for lateral and longitudinal flight. Flight simulation and calculations for longitudinal and lateral flight are set to 1 (degree). The cost index includes the terms longitudinal and lateral flight. To minimize the cost index, a combined approach combining longitudinal and lateral flight cost index was used instead of traditional methods. With the combined approach, the optimum values of the transformation parameters are designed simultaneously for both the longitudinal and lateral flight control system. As a result, both PID coefficients and migration rates for longitudinal and lateral flight were determined separately for each iteration. SPSA is an iteration-based optimization algorithm. For this reason, the number of SPSA iterations was chosen as the optimum value of 10.

In order to obtain improvement in the autonomous performance of the multirotor and to keep the PID coefficients at better levels with lateral and longitudinal movements, multirotor control was performed with SPSA using transformation. In order to obtain at least 10-15% improvement in the multirotor autonomous performance index, the cost function given in equation 16 related to both lateral and longitudinal movements was created.

$$\%J_{tot_i} = J_{long_i} + \frac{J_{long_0}}{J_{long_0}} + J_{lat_i} \qquad (16)$$

In the case where the lateral and longitudinal flight control system is handled with SPSA using transformation, $\frac{\pi}{2}$ for lateral flight and 1 degree for longitudinal flight are applied. SPSA determines seven parameters in the flight parameter determination phase. 1 of these is the transformation parameter, 3 of them are lateral flight PID coefficients and 3 of them are longitudinal flight parameters.

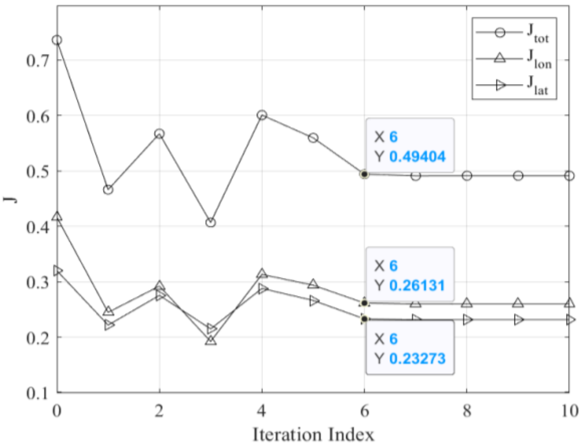


Figure 4. Cost Optimization; Total, Longitudinal, Lateral

In this study, PID coefficients in all simulations except optimization were given by using similar studies in the literature and past experiences. The PID coefficients used for longitudinal and lateral motion control are; 50,5,50.

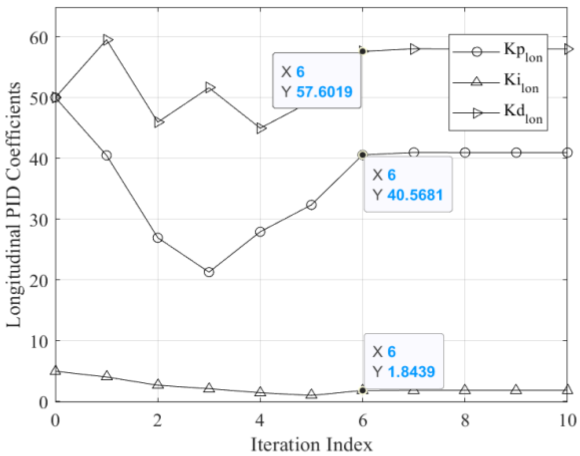


Figure 5. Longitudinal PID Coefficients

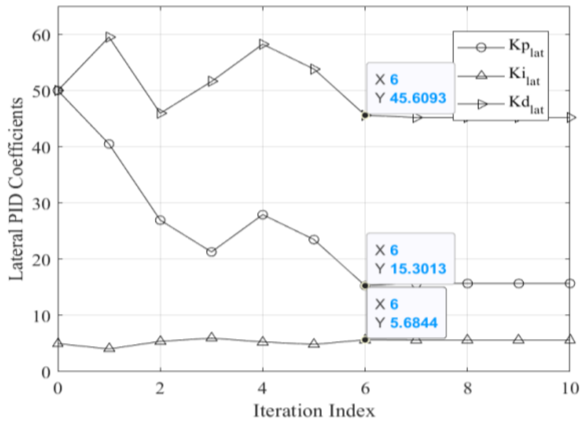


Figure 6. Lateral PID Coefficients

Design performance criteria were examined separately to achieve improvements in aircraft longitudinal and lateral flight autonomous performance. Design performance criteria provide precise information about the stability of a system (Oktay et al., 2017). In Figs. 10 and 11 the design performance criteria are presented for longitudinal and lateral flight. Longitudinal flight closed loop rise time, settling time and overshoot values are given in the graph below. SPSA has achieved improvement in system parameters in the 6th iteration compared to the initial values. Satisfactory results were obtained in other simulations. For this reason, it was limited to the 10th iteration and thus unnecessary calculations were not made and the workload of the system was reduced.

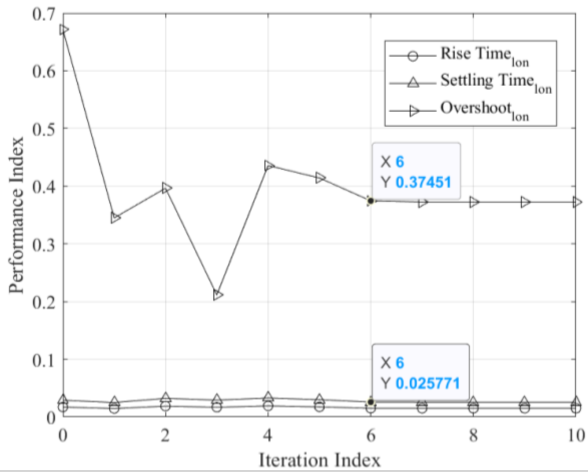


Figure 7. Longitudinal Performance Index

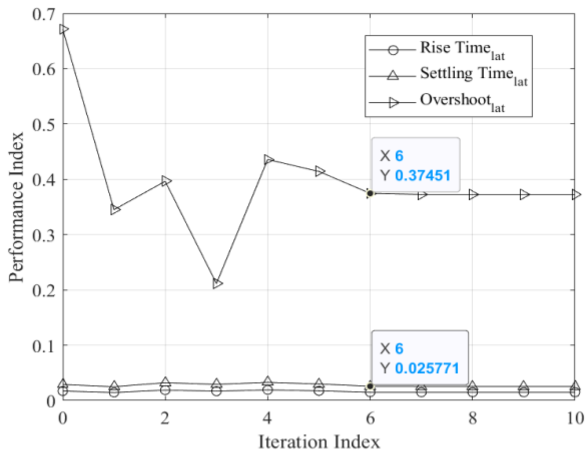


Figure 8. Lateral Performance Index

In the initial state, the hub angle (α) between the arms is 22.5 degrees, and as it increases to 45 degrees, the shape change narrows laterally and longitudinally.

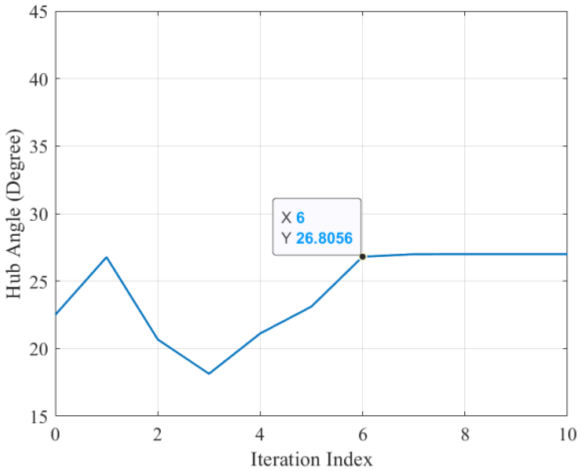


Figure 9. Hub Angle Values in Each Iteration

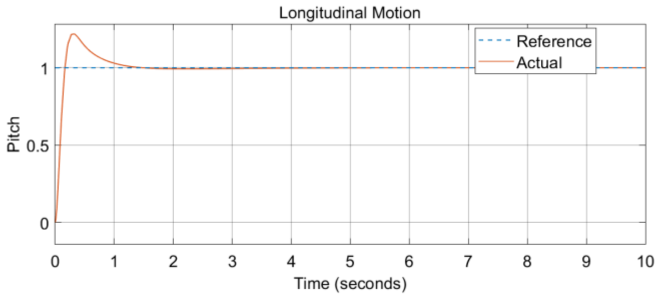


Figure 10. Pitch Angle Signal (Responses to Longitudinal Motion)

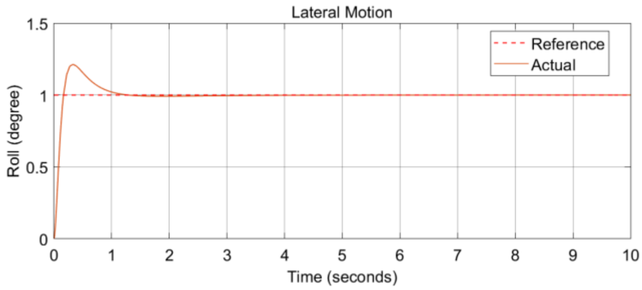


Figure 11. Roll Angle Signal (Responses to Lateral Movement)

Simulation results were compared with the initial values and are given in Table 3.

Table 3. Initial and Final Values of Variables in SPSA Optimization

Variable	Unit	Initial Value	Last Value
α	degree	22.5	26.8
$K_{Plongitudinal}$	-	50	40
$K_{Ilongitudinal}$	-	5	1.8
$K_{Dlongitudinal}$	-	50	57
$K_{Plateral}$	-	50	15
$K_{Ilateral}$	-	5	5.6
$K_{Dlateral}$	-	50	45
I_x	kgm^2	0.408	0.813
I_y	kgm^2	0.408	0.813
I_z	kgm^2	0.808	0.813

Performance criteria; Previous studies were examined and flight performance parameters (Trt, Tst, OS) were found to be satisfactory (Şahin et al. 2022).

Compared to similar studies (Köse, 2023) with the proposed combined approach, SPSA not only made optimum predictions without reaching the PID parameters at limit values, but also achieved the desired morphing rate quickly (Fabris et al., 2021)

4. Conclusion

This paper addresses the development of a control system model for both longitudinal and lateral flight under varying arm intersection angles. The Simultaneous Perturbation Stochastic Approximation (SPSA) optimization method was employed to determine optimal transformation parameters and to calculate the PID gains for longitudinal and lateral flight. The overall cost index demonstrated effective performance for both flight modes. Initially, the PID coefficients for both longitudinal and lateral flight were set at (50, 5, 50). After applying the SPSA method, the optimized PID coefficients for longitudinal flight were calculated as (40, 1.8, 57), and for lateral flight, as (15, 5.6, 45). These results indicate that the optimization method is effective, as it identifies optimal coefficients without reaching boundary values. As shown in Figures 5 through 9, the SPSA algorithm achieved optimal results by the 6th iteration.

The change in the arm intersection angle of the aircraft affects its dynamic model. The moment of inertia values obtained from analytical calculations and the aircraft model designed in the CATIA V5 software are presented in Table 2, showing consistency between the two methods. This consistency was achieved by integrating the analytical method into the SPSA optimization algorithm's framework. The equations and algorithm derived for the aircraft's controller design were simulated using the MATLAB/Simulink software with a state-space model. The hub angle was set at 26.8 degrees, with the best optimization result occurring in the 6th iteration, aligning with the expected performance of the SPSA algorithm.

Future studies will focus on developing a navigation system for indoor environments using image processing and artificial intelligence algorithms (Uzun et al., 2021). This system, combined with the proposed guidance algorithm, aims to achieve optimal autonomous flight in confined spaces.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Statistical Analysis of Airfoil Usage in Aircraft

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Abstract

The study aims to answer how frequently airfoils are used in fixed and rotary wing aerial vehicles produced both individually and based on airfoil families. Frequency distribution analysis of airfoil utilization in fixed-wing and rotary-wing aircraft helps in understanding design preferences and performance needs and constraints. The literature study provides the history of airfoils, the subjects mostly studied regarding airfoils and mentions the current state of the field. The study investigates the airfoil families to which the wing profiles of approximately 6,000 fixed-wing and approximately 450 rotary-wing aircraft belong through frequency distribution. The results indicate that in fixed-wing aircraft, NACA airfoils are used in 52.2%, Clark-Y airfoils in 8.2%, Goettingen airfoils in 5.9%, Wortman airfoils in 4.8%, and TsAGI airfoils in 3.1%. When considered as singular airfoil use rather than airfoil families, Clark-Y is the most widely used airfoil, followed by the NACA 23XXX series. In rotary-wing aircraft, NACA 0012 and NACA 0015 airfoils, both symmetrical profiles developed by NACA, are the most widely used. The study is valuable as it provides statistical data on the use of both airfoil families and singular airfoil design in fixed and rotary-wing aircraft. However, it is important to note that the airfoil data is incomplete, and the study aims to provide a general impression of the findings.

1. Introduction

Airfoils are wing profiles used in fixed-wing aircraft, helicopter rotor blades, wind turbines, fans, propeller blades, and more. The most well-known types of airfoils include symmetrical airfoils, axisymmetric airfoils with positive camber, reflexed airfoils, flat bottom airfoils, supercritical airfoils, and supersonic airfoils (biconvex, double wedge). Common airfoil families include the National Advisory Committee for Aeronautics (NACA) airfoils, Goettingen (GOE) airfoils, Wortmann FX airfoils designed by Hermann Wortmann, TsAGI airfoils from the Russian Central Aerodynamics and Hydrodynamics Institute, Eppler airfoils designed by Richard Eppler, Selig airfoils designed by Michael Selig, the Royal Aircraft Factory (RAF) airfoils designed in the United Kingdom, and the United States Air Force (USAF) airfoils. These are commonly used airfoil families (Anderson, 2011). Most used airfoils often represent optimal choices for performance in terms of lift, drag, aerodynamic efficiency and stability. Fixed-wing aircraft require airfoils that provide efficient lift-to-drag ratios, good stall characteristics, and stability across various flight regimes. Helicopter rotor blades require airfoils that provide good lift-to-drag ratios, minimize retreating blade stall, and maintain performance at varying angles of attack while reducing vibration and noise (Russel,1996).

Airfoils used in the period before the first flight were non-optimized; they were very thin and highly cambered. In 1884, H.F. Phillips patented some airfoil shapes. Subsequently, Octave Chanute, Otto Lilienthal, and the Wright brothers conducted pioneering studies on thin and highly cambered airfoils (Greydanus, 2020). In 1910, Joukowsky created a complex plane airfoil from a circle using conformal mapping. One of the challenges associated with the Joukowsky airfoil is its cusped trailing edge. To address this issue, the Kármán–Trefftz transform was developed, allowing for a non-zero angle at the trailing edge (Burington, 1940; Milne, 1973). In the late 1920s, NACA developed four-digit airfoils representing a series of extensively tested geometric features such as maximum thickness, maximum camber, and the location of maximum camber on the chord (Allen, 2017).

Laminar flow airfoils are specifically engineered to maintain extended periods of advantageous pressure gradients. Typically, laminar airfoils exhibit favorable pressure gradients that typically extend from around 30% to 75% of the chord length (Dwyer, 2013). The Clark Y airfoil, designed in 1922 by Virginius E. Clark, is often used in light aircraft and model airplanes. It is a well-known and widely used airfoil with a flat bottom and a curved upper surface (Anderson, 2011). During World War II, German aerodynamic experts initially proposed the concept of the supercritical airfoil. Supercritical airfoils have a flat upper surface, blunted trailing edge, reduced camber, and rearward-moved maximum thickness. These airfoils are designed to enhance aircraft performance in the transonic speed ranges, where the primary goals are managing shock waves and reducing drag (Harris, 1990). The journey of the airfoil design process is illustrated in Fig. 1 (Greydanus, 2020).

Figure 1. Historical Evolution of Airfoil Designs (Greydanus, 2020)

In natural laminar flow (NLF), the air flows smoothly and parallel to the object's surface, with minimal disruption and turbulence. Key characteristics of NLF include smooth flow, low drag, and delayed boundary layer separation. NLF airfoils notably enhance an aircraft's overall aerodynamic efficiency and fuel economy (Somers, 1981). Slotted airfoils are incorporated to enhance an aircraft's lift properties, focusing primarily on improving performance during takeoff and landing, as well as contributing to the prevention of stalling. In modern Boeing aircraft, triple-slotted flaps, when not actively engaged, align flush with the wing. When fully deployed, they maintain attached airflow to the flap's surface, preventing flow separation (Parlett, 1971; Gudmundsson, 2013).

A laminar separation bubble is an aerodynamic occurrence on an airfoil's surface, marked by the transition of the boundary layer flow from a smooth, laminar state to a turbulent state. This transition leads to the separation of the airflow from the airfoil's surface before reattaching downstream. Therefore, controlling and managing laminar separation bubbles is a critical aspect of minimizing drag and maximizing lift (Gaster, 1967). Low Reynolds number airfoils are specially designed airfoil shapes optimized for Micro Aerial Vehicles (MAVs), mini–Unmanned Aerial Vehicles (UAVs), gliders, and smaller wind turbines. Low Reynolds number airfoils have higher camber and a thicker profile compared to other airfoils (Selig et al., 1989).

The inverse design of airfoils aims to create airfoil shapes with specific performance characteristics or desired properties, starting with a known airfoil shape. Inverse design begins with a set of desired performance criteria and works backward to create an airfoil shape that meets those criteria (Volpe, 1983). Methods such as the PARSEC (PARametric SECtion) method, Bezier curves, NACA airfoil parameters, or other mathematical functions are used for parametric representation (Sun et al., 2018). The design parameters for camber and thickness distribution are then established. It is common to utilize artificial neural networks, genetic algorithms, gradient-based techniques, or other optimization algorithms. This process is typically iterative, with ongoing adjustments made until the desired performance criteria are achieved (Quagliarella & Vicini, 2001; Secanell et al., 2006; Jahangirian & Ebrahimi, 2017).

Recent research in airfoil design focuses on optimizing boundary-layer parameters to enhance aerodynamic performance. Collazo and Ansell (2023) proposed a framework that generates pressure distributions to achieve desired boundary-layer characteristics, resulting in significant drag reductions for optimized airfoils. Their method, validated through experimental campaigns, proved effective in improving aerodynamic performance. Krishna et al. (2021) emphasized the importance of airfoil design in determining lift and thrust requirements, utilizing computational fluid dynamics (CFD) for analysis. Asan et al. (2023) numerically investigated NACA 0018 airfoil with slot at various angles of attack. Glaws et al. (2022) studied invertible neural networks enable rapid inverse design of airfoil shapes for wind turbines. Xu and Wu (2023) worked on numerical optimization of airfoil design, including the effects of angle of attack, thickness, and additional tips, as well as using machine learning to predict lift and drag. Patel et al. (2023) examined the design of two new airfoils optimized for low Reynolds number rotary wing applications.

After providing a comprehensive historical overview of airfoil development and discussing the current challenges faced in the field, the main objective of this study is to bring out the utilization of airfoil frequency distribution. Specifically, we aim to analyze the prevalence and distribution patterns of airfoils used in both fixed-wing and rotary-wing aircraft. This investigation will be carried out by employing frequency distribution techniques, allowing us to gain insights into the frequency at which different types of airfoils are utilized across various aircraft types.

2. Materials and Methods

In 2010, Dave Lednicer made a significant contribution to the field with his comprehensive work titled "The Incomplete Guide to Airfoil Usage." Lednicer's exhaustive study serves as a valuable resource, offering detailed airfoil data for a wide spectrum of aircraft and rotorcraft. This seminal work, available to the public through the University of Illinois Urbana-Champaign (UIUC) airfoil data website, consolidates information on airfoil usage across various aviation applications. Within Lednicer's compilation lie detailed records encompassing airfoil data for approximately 6,000 fixed-wing aircraft types and nearly 450 rotary-wing aircraft. This vast repository provides researchers and aviation enthusiasts alike with invaluable insights into the aerodynamic profiles utilized in aviation engineering.

For the purposes of the current study, our analysis focuses specifically on the airfoils employed in the inboard sections of aircraft wings. This strategic decision acknowledges the potential variability in airfoil selection across different segments of an aircraft's wing structure. By concentrating our investigation on the inboard sections, we aim to ensure a more precise examination of airfoil utilization trends and patterns.

Throughout the data analysis phase, we employed a rigorous approach, utilizing frequency distribution as a fundamental statistical tool. Airfoil profiles exhibiting frequencies falling below a predefined threshold were systematically categorized as "others." This strategic categorization served to streamline the presentation of our study's findings, ensuring clarity and coherence in the results. A frequency distribution, a cornerstone of statistical analysis, provides a graphical or tabular representation illustrating the frequency of occurrence for various values or categories within a dataset. By systematically tallying the occurrences of each specific value or category, frequency distributions offer a structured and condensed overview of the dataset.

For a 4 digit NACA airfoil (NACA 00XX), the equation for the airfoil's thickness distribution is given in Eq. 1.

$$y_t = \frac{t_{max}}{0.2}\left[0.2969\sqrt{\frac{x}{c}} - 0.1260\frac{x}{c} - 0.3516\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 - 0.1015\left(\frac{x}{c}\right)^4\right] \quad (1)$$

where y_t=half-thickness at any point along the chord, t_{max}=maximum thickness as a fraction of the chord length, x=distance along the chord, and c=chord length of the airfoil.

The camber line equation varies depending on whether you are in the region before or after the location of maximum camber equation for the airfoil's camber line height is given in Eq. 2 and Eq. 3.

For x≤p·c

$$y_c = \frac{m}{(p)^2}\left(2p\frac{x}{c} - \left(\frac{x}{c}\right)^2\right) \quad (2)$$

For x>p·c

$$y_c = \frac{m}{(1-p)^2}\left((1-2p) + 2p\frac{x}{c} - \left(\frac{x}{c}\right)^2\right) \quad (3)$$

where y_c=camber line height at a given, m = maximum camber (as a fraction of the chord), and p = position of maximum camber along the chord.

Beyond mere tabulation, frequency distributions serve as powerful analytical instruments, enabling researchers to extract valuable insights regarding data distribution. They facilitate the identification of underlying patterns, trends, and measures of central tendency within the dataset, thereby enhancing our understanding of the phenomena under investigation.

3. Result and Discussion

In the results section of our study, we meticulously present the outcomes derived from our analysis. This presentation encompasses findings pertaining to both airfoil families and individual airfoil designs, offering a comprehensive overview of the distribution patterns observed within the dataset. In Fig. 2, wing profiles commonly utilized in aircraft are categorized by airfoil families. NACA has the highest value, with 3112, far surpassing all others. This suggests NACA's dominance in the domain being measured, possibly airfoil design or use. Clark Y and Goettingen also have significant contributions with 487 and 349, respectively. Wortmann and TsAGI show moderate contributions with values of 284 and 187. USAF, NASA, and RAF have notable entries, suggesting their active roles in this field, with the USAF having 117 and NASA at 97. Smaller contributions are observed from researchers or organizations like Eppler, Curtiss, and Aeromarine. Other holds the second highest value (787), which likely represents a collection of entities or airfoils not specifically listed.

The NACA airfoil family demonstrates significant prevalence, with 52.2 out of every 100 airfoils belonging to this category. Nearly half of all fixed-wing aircraft employ airfoils from the NACA family. Following NACA, the next most frequently used airfoil is the Clark-Y, along with its modified versions, comprising 8.2 out of every 100 airfoils. A notable portion of aircraft wings also utilize airfoils from the German Schools, with 5.9 out of every 100 airfoils belonging to the Goettingen family, and 4.8 to the Wortmann family. Subsequent airfoil families include TsAGI, RAF, USAF, NASA, Boeing, and Eppler. Of these, 3.1 out of every 100 airfoils belong to the TsAGI family, 2.8 to RAF, 2.0 to USAF, 1.6 to NASA, 1.5 to Boeing, and 1.0 to Eppler. Additionally, 13.2% of the airfoils were categorized as 'other' due to their association with less common airfoil families. Notable individual airfoil designers include Curtis Robin, Mark Drela, Gustave Eiffel, Robert Liebeck, John Roncz, and Michael Selig. Moreover, various institutions have contributed to airfoil design, including the Aeromarine Plane and Motor Company, the German Research and Development Establishment for Air and Space Travel (DFVLR), IAW airfoils of the Polish Air Force, and Delft University airfoils.

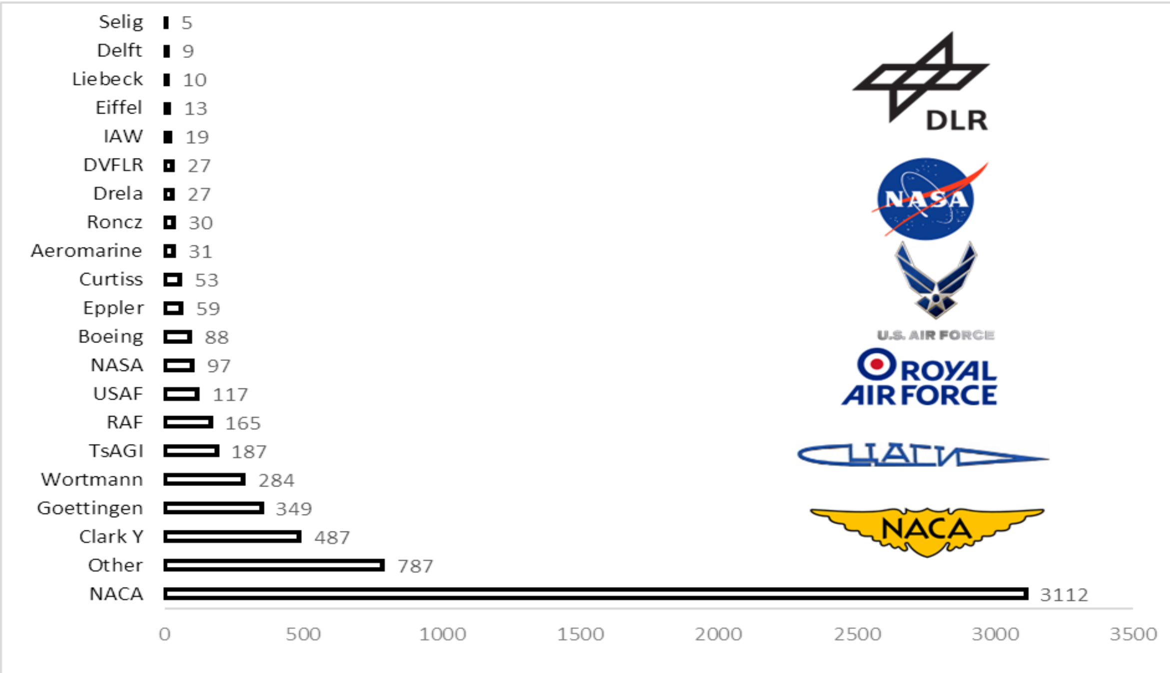

Figure 2. Frequency distribution of airfoil family usage in approximately 6,000 fixed-wing aircraft.

When assessed on an individual design basis rather than by airfoil family, the Clark-Y airfoils, along with their modified versions, emerge as the most prevalent. Their widespread use underscores their effectiveness in diverse aircraft applications. Following closely behind are the NACA 5-digit series airfoils, exemplified by profiles such as NACA 23012, 23015, and 23018, renowned for their versatility and performance across various flight regimes. Additionally, the NACA 4-digit series airfoils, including variants like NACA 2215, 4412, and 2412, hold considerable significance in aircraft design due to their favorable aerodynamic characteristics. In Fig. 3, the frequency distribution of individual airfoil usage in fixed-wing aircraft has been meticulously sorted from the most to the least prevalent. Clark Y airfoil has the highest number of occurrences or usage with a value of 487. It is a widely recognized airfoil that has been extensively used historically, especially in aviation. NACA 23012 follows with a value of 205, showing significant usage but not as much as the Clark Y airfoil. Other NACA airfoils (like NACA 23015, NACA 23018, NACA 2215, NACA 4412, NACA 2412) have progressively smaller values, ranging from 149 down to 105, indicating less frequent usage but still notable representation in the dataset. This graphical representation offers a clear visualization of the prevalence of each airfoil type within the dataset, providing valuable insights into industry trends and design preferences. Furthermore, it is noteworthy that both the Clark-Y and NACA 4412 airfoils exhibit geometric similarities, as illustrated in Fig. 3. This resemblance underscores the importance of recognizing common design features and their impact on aircraft performance and aerodynamic behavior.

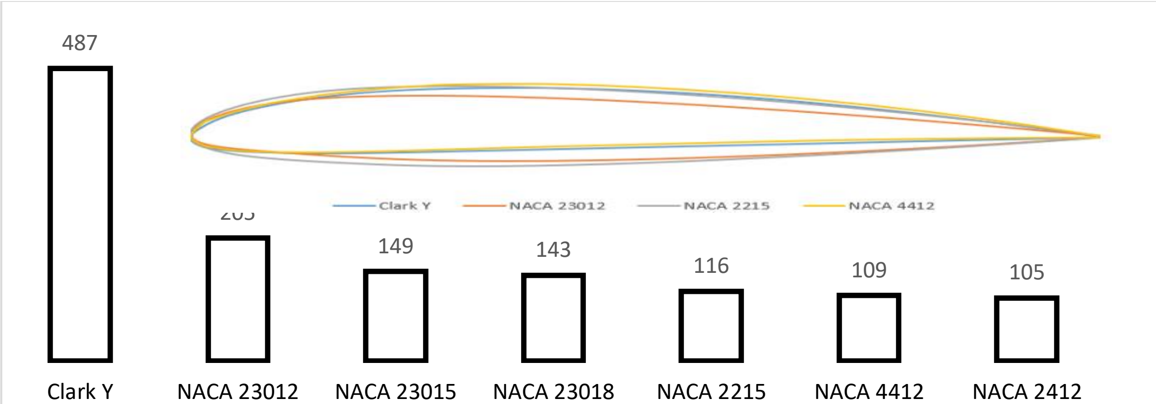

Figure 3. Frequency distribution of airfoil usage in approximately 6,000 fixed-wing aircraft.

Frequency distribution of use of NACA airfoils in 3,112 fixed wing aircraft is shown in Fig.4. NACA 23012, NACA 23015, and NACA 2412 stand out among the individual airfoils, with values of 205, 149, and 105 respectively. These profiles are prominently used, as depicted by their larger representations in the chart. A range of other NACA airfoils is listed, with values between 20 and 83. These include more specialized airfoils like NACA 4415 (74), NACA 2213 (42), and NACA 64A215 (37). The NACA airfoil family boasts widespread adoption of both its 5-digit and 4-digit series across fixed-wing aircraft. Among these, the NACA 5-digit series, represented by profiles such as NACA 23XXX and 63XXX, stands out for its versatility and performance across a range of flight conditions. Similarly, the NACA 4-digit series, characterized by airfoils like NACA XX12 and XX15, enjoys extensive usage owing to its favorable aerodynamic properties and well-established performance characteristics. In addition to these commonly utilized series, certain airfoil designs within the NACA family have gained prominence in fixed-wing aircraft applications. Notably, the 6-digit series features airfoils such as the 64A215 and 64A212, which have found widespread acceptance due to their favorable lift and drag characteristics. Furthermore, the NACA M-6 and NACA M-12 airfoils, both conceived by the renowned aerodynamicist Max Michael Munk, occupy a significant position among the repertoire of commonly used wing profiles in fixed-wing aircraft. These airfoils, crafted with precision to meet specific aerodynamic requirements, have garnered recognition for their exceptional performance and suitability across a range of aircraft designs and missions.

Frequency distribution of Wortmann FX, Goettingen (GOE), and TsAGI airfoil usage in fixed wing aircraft is shown in Fig.5. The counts range from 4 to 97, with most Wortmann FX models having relatively low frequencies (under 20) and a few having higher frequencies. The mode among the specific Wortmann FX models is 4, occurring three times for models 81-K-130/17, 67-K-170 mod, and 66-H-159. Aside from "OTHER", the most common Wortmann FX models are: 61-184 and 67-K-170 and 61-163.

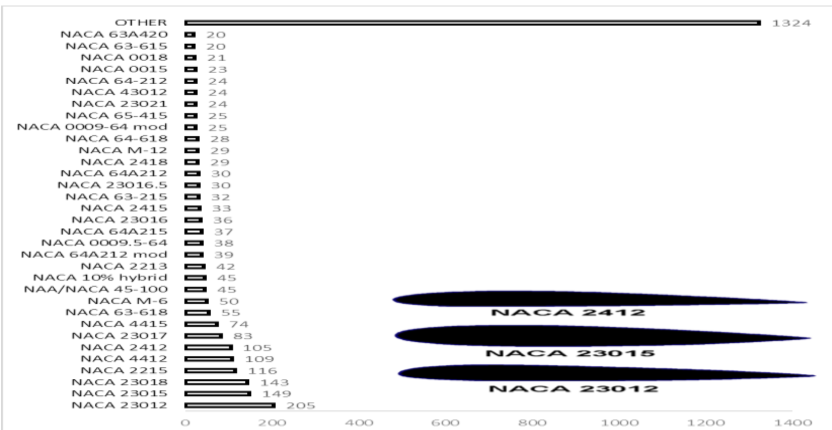

Figure 4. Frequency distribution of use of NACA airfoils in 3,112 fixed wing aircraft.

The Wortmann FX airfoil family encompasses several widely utilized wing profiles, with standout examples including the FX 61-184, FX 61-163, and FX 67-K-170. Renowned for their aerodynamic efficiency and versatility, these airfoils have become staples in the design of various fixed-wing aircraft, offering superior performance across a range of flight conditions. Similarly, within the Goettingen airfoil family, several wing profiles have emerged as favorites among aircraft designers. Notable examples include the GOE 549, GOE 387, GOE 535, and GOE 398 airfoils, recognized for their favorable lift-to-drag ratios and stable aerodynamic characteristics. These profiles are widely employed in the construction of both experimental and production aircraft, contributing to enhanced performance and stability. In contrast to other wing profile families, the TsAGI series boasts a diverse array of wing profiles tailored to suit different aircraft types and mission requirements. Among the most prevalent TsAGI wing profiles are the TsAGI R-II and TsAGI SR-5S, each accounting for a significant portion of usage within their respective aircraft categories. Both fixed-wing and rotary-wing aircraft prioritize airfoils that enhance lift and minimize drag. The primary difference lies in the operational requirements-fixed-wing airfoils are optimized for sustained high-speed flight, while rotary-wing airfoils are designed for variable speeds and dynamic conditions. It's worth noting that rotary-wing aerial vehicles commonly employ symmetrical airfoils due to their unique aerodynamic requirements and operational characteristics. Frequency distribution of airfoil usage in a sample of 450 rotary-wing aircraft is given in Fig. 6. The counts range from 5 to 153, with most models having relatively low frequencies (under 20) and a few having very high frequencies. The distribution is highly right-skewed (positively skewed), with many low-frequency models and only a few high-frequency ones. Among these, the NACA 0012 and NACA 0015 symmetrical airfoils stand out as the most prevalent choices in rotary-wing aircraft design. The NACA 0012 airfoil, characterized by a symmetrical shape with a thickness of 12%, holds a dominant position in rotary-wing applications, constituting 27.1 out of every 100 airfoils analyzed. Similarly, the NACA 0015 airfoil, with a symmetrical profile and a thickness of 15%, emerges as another commonly used option, representing 9.5 out of every 100 airfoils.

Additionally, our analysis revealed the utilization of other notable airfoils in rotary-wing aircraft design. For instance, the NACA 23012 airfoil, a modified version of the NACA 0012 with enhanced aerodynamic performance, accounts for 4.4 out of every 100 airfoils. Moreover, the Boeing VR-7, NACA-8-H-12, and ONERA OA211 airfoils also make notable appearances, representing 4.2, 2.2, and 1.8 out of every 100 airfoils, respectively. These findings underscore the prevalence of specific airfoil profiles in rotary-wing aircraft design, highlighting the importance of selecting airfoils tailored to meet the unique aerodynamic demands of helicopter rotor blades and other rotary-wing applications.

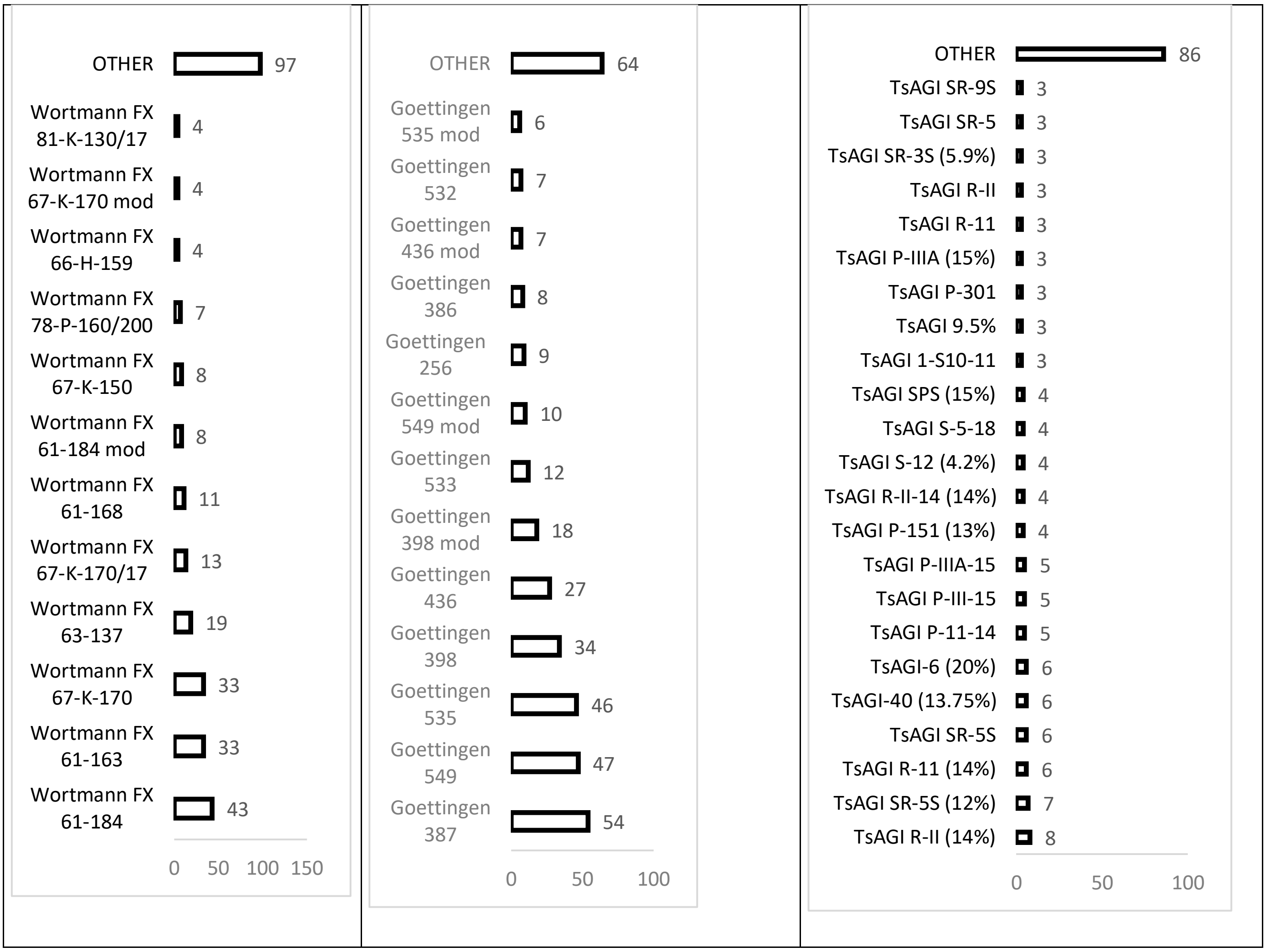

Figure 5. Frequency distribution of Wortmann FX, Goettingen (GOE), and TsAGI airfoil usage in fixed-wing aircraft: analysis of 284, 349, and 187 profiles, respectively

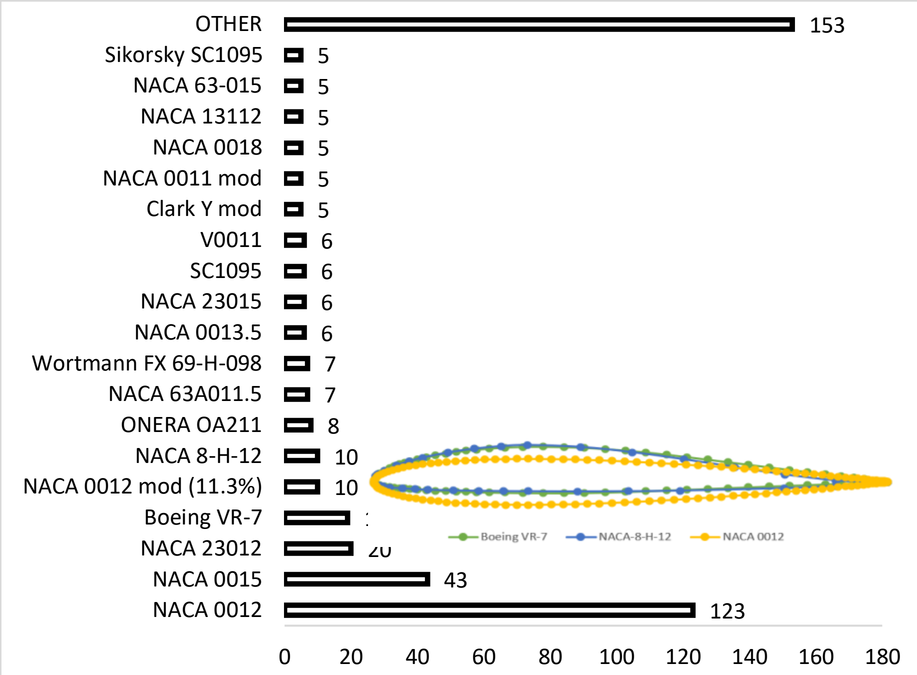

Figure 6. Frequency distribution of airfoil usage in a sample of 450 rotary-wing aircraft

The preference for different wing profiles could be the subject of another study. In this study, the reasons why the Clark Y airfoil, one of the most used wing profiles, is widely employed are discussed. The Clark Y airfoil is widely used in aircraft design due to its versatile and favorable characteristics across various flight conditions. The Clark Y features a flat bottom surface, which simplifies construction and makes it easier to manufacture. This flat undersurface also provides stability when the airfoil is placed on a flat surface, making it useful for wind tunnel testing and theoretical analysis. Relatively high lift-to-drag ratio, good lift characteristics at low angles of attack, making it suitable for a wide range of aircraft. The airfoil's design also allows for a gentle stall characteristic, which is crucial for safety in low-speed flight conditions. Additionally, the Clark Y exhibits predictable behavior across different Reynolds numbers, making it adaptable to various aircraft sizes and speeds.

4. Conclusion

This study focuses on examining the utilization of airfoil designs in both fixed-wing and rotary-wing aircraft. To achieve this, the study conducts a frequency distribution analysis of various airfoil families associated with approximately 6,000 fixed-wing and roughly 450 rotary-wing aircraft. The introductory section provides a historical overview of airfoils and categorizes the current research conducted in this field. The findings reveal that in fixed-wing aircraft, NACA airfoils are employed in 52.2% of cases, followed by Clark-Y airfoils at 8.2%, Goettingen airfoils at 5.9%, Wortman airfoils at 4.8%, and TsAGI airfoils at 3.1%. When considering singular airfoil design types rather than families, Clark-Y emerges as the most frequently used airfoil, closely followed by the NACA 23XXX series. In rotary-wing aircraft, symmetrical profiles like NACA 0012 and NACA 0015 are the predominant airfoil choices. It's important to note that while this study provides insights into the prevalence of airfoil usage in aircraft, the presence of incomplete data means that its aim is to offer a general impression on this subject rather than definitive conclusions. Future studies can improve upon these findings by updating frequency distributions and expanding the scope of the study with more comprehensive data.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Acquisition of Flight Data from Mini Unmanned Aerial Systems

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Abstract

Swift progress in unmanned aerial vehicle (UAV) system technology mandates effective real-time monitoring and accurate flight data capture for building an optimum target-based cutting-edge UAVs. In the current epoch of modern-UAV era, small size and mission-oriented UAV prototypes are increasingly pervasive. This study highlights the design of a data acquisition target-based mini-UAV and introduces a novel telemetry software solution to safe and reliable communication between mini-UAV and ground control station (GCS). The primary aim is to demystify the proposed wireless communication software solution on mini-UAV capability in obtaining and managing comprehensive flight data. While creating the appropriate target-based mini-UAV prototype architecture, the features that we aim to realize for the UAV components are addressed with a system approach and the component selection is presented in detail. The integration point of the selected components is conveyed in general terms. Thus, a guiding resource for future UAV studies will be presented. Then, the processes of obtaining the flight data of mini-UAVs will be addressed. At this point, the design logic of the required commands and background software will be conveyed. Obtaining the flight data of mini-UAVs will provide important scientific contributions to the literature in terms of aviation research and safety analysis. Obtaining the flight data of mini-UAVs will meet the data set needs for flight safety improvements and air traffic management optimization studies. A general analysis of the flight parameters obtained as a result of obtaining the flight data will be performed, the predictability of the parameters will be evaluated, and the analysis of the flight phases will be performed by presenting the relationships of the parameters according to the flight scenarios and the sections taken from the parameter set in the study. This study can be considered as a concrete example of situational monitoring of UAVs.

1. Introduction

The first crewed powered takeoff had been occurred in 1903 as a milestone for aeronautics. Since that fateful day, innovators are zeroing in on their pursuits of ensuring the continuous airworthiness in the sky. Indeed, seven years before, in 1896, Aerodrome No 5's flight have been a triumphant symbol of first powered uncrewed aviation (Schwing, 2007).

Above the centenary of elevation to prototypes, nowadays UAVS have stepped in to modern UAV age for their proficiency in addressing instantaneous and pinpoint flight data access (Wyatt, 2013). Revolution of unmanned aircraft system technology has been determined by miscellaneous significant advancements in diverse areas. Advancements in radio control systems, in conjunction with the introduction of electric motors and progress in micro-mechanical systems, micro-electronic components, and sensors, facilitated the feasibility of employing small unmanned aerial vehicles in the 1990s (Mueller,2009). These technological breakthroughs made it possible to develop more reliable and versatile UAVs.

Increasingly widespread, mini-UAVs serve as crucial tools for instant online intelligence and are projected to be central in future missions (Abershitz et al.,2005). Considered as the principal goal of UAVs are intelligence, surveillance and reconnaissance (ISR) mission. Today's world state-of art mini-UAVs come to the forefront of the wide-range capabilities in demanding operational conditions, ISR mission, low-risk and low-cost operation compared with traditional manned flights (Butler,2001). Real time monitoring, operational area situational awareness and UAV parameter monitoring concept have a great importance for gaining superiority and handling situations.

In this point, acquiring flight data from cutting-edge mini-UAVs is one of the primary research priorities. This involves not only analyzing the performance of numerous sensors and system components but also integrating this data to accurately assess flight parameters. Effective data integration ensures that UAVs can operate safely and efficiently in diverse conditions.

A-number-of parameters have been triggered in UAV construction processes. These parameters include factors such as aerodynamic design, power efficiency, and communication capabilities (Konar, 2009; Konar,2018; Konar,2020; Erşen et. al.,2021). In this context, parameter optimization through mission-specific UAV design is of critical importance. Tailoring UAV design to meet specific mission requirements enhances performance and ensures the successful completion of tasks (Bagis 2018).

Though literature has a diverse range of methods that is appropriate for acquiring data from UAVs, especially small ones (Dantsker et al.,2019; Ho et al., 2015; Dankster et al., 2014; Tsouros et al., 2019; Brusov et al.,2011; Yang et al., 2018; Hao et al.,2022; Taha et al.,2011; Tahar et al., 2012; Luo et al.,2017; Jia et al.,2019; Popescu et al.,2019; Say et al.,2017; Schwarzbach et al.,2009)

Dankster studies on Sensor Data Acquisition System and integration of avionics UAV components (Dankster et al..,2019) Ho et al. suggested a wide-range wireless sensor network (WSN) for acquiring UAV data and evaluate the performance in the aspects of algorithms (Ho et al.,2015). Dankster et al. focuses their studies on high-frequency SDAC and evaluate the overall performance by using ground and flight tests (Dankster et al.,2014). Trosouros et al. states the UAV data acquisition methods with the axis of sensing systems and their complement the Internet of Things (IoT)-based techniques (Tsouros et al.,2019). Brusov introduces a flight data acquisition system for Small Unmanned Aerial Vehicles (SUAVs) With suggested automatic data acquisition model mini and micro-UAV flight dynamics have been monitored and understanding the characteristics of SUAV and flight data analyses have been enabled (Brusov et al.,2011). Yang et al. used sensing data acquisition technique by utilizing wide wireless UAV sensor data networks (Yang et al., 2018). Hao et al., addressed in UAV-based IoT real-time flight fata acquisition technique which aims to expand lifetime of IoT and consumed energy minimization (Hao et al., 2022). Taha et al., proposed a flight data collection technique and cumulate their efforts on utilizing flight tests for identifying the mathematical model of small- scale UAV helicopters. (Taha et al.,2011). Tahar et al., creates a 3Dmodel by using UAV images and evaluate the model usage as the source of geographical information systems data (Tahar et al.,2012). Luo et al., demonstrated cloud-based model for UAV data acquisition and processing (Luo et al.,2017). Jia et al., observe the flight modes and developed data collection strategies with the concept of age of information and observe the mathematical model for UAV data acquisition (Jia et al.,2019). Popescu et al., (Popescu et al.,2019). Say et al, put forward a collaborate partnership and data forwarding manner for UAV studied data framework chosen (Say et al.,2017). Schwarzbach et al., chose an open-source autonomous pilot assistance system for UAV mission monitoring (Schwarzbach et al.,2009).

Weighed the examinations in the literature, it is clearly observed that obtaining flight parameters from UAV integrated hardware or software have presented an imp reliable way. When the literature is examined in general terms, it is observed that wireless and sensor technologies are widely used for communication system solutions. In this study, a mini-UAV is designed for acquiring flight data. UAV components are selected to optimize target-based UAV feature monitoring, chiefly interference prevention and noise reduction. After the target-based mini-UAV construction has been built, UAV prepare for implementations of hardware and software requirements. This paper presents a novel approach in a reliable flight data acquisition process with using telemetry protocol. Along with software, the hardware structure of mini-UAV has been discussed elaborately. Ensuring the software and hardware compatibility, mini-UAV data acquisition flights are conducted. Acquired flight data from successful mini-UAV flights enables flight parameters. Flight parameters are discussed thoroughly, and the results and analyses of the mini-UAV flights represented with graphs and maps overall.

2. Methods

This section is to clarify the selection of flight data acquisition target-based mini-UAV onboard components. İn line with chosen criteria. After the special purpose mini-UAV prototype has been built, novel suggested approach for reliable data communication has been applied.

2.1. Mini-UAV Target-Based Component Selection

Mini-UAV platform configuration suggest a compromise between the prerequisites (Benito et al.,2014). Prerequisites are classified into three main criteria in general. Mini category UAV construction requirements such as size, mass, payload capability, endurance and other linked parameters comes first (Papa et al.,2014). All the on-board materials must be assessed over the size criteria.

Secondly, criteria assign for data acquisition purpose mini-UAV flight requirements. Mini-UAV should be purified from the noise and interference of signal. For this purpose, numerous enhancements have been effectuated. Vibration dampener carbon-fiber frame structure has chosen (Khan et al.,2011). The preference has been given to brushless motor due to its advantage of eliminating the surface wear and brush arching problems (van Niekerk,2009). Mini-UAV Electronic Speed Control (ESC) and motor units are regulated in compatibility to keep mini-UAV in a safety performance are (Chaput,2018). Mini-UAV propeller material has been appointed plastic ones cause of the impact of the propeller payload on energy consumption and motor performance (Rutkay et al.,2016).

Thirdly, mini-UAV systems are equipped with the effective and capable sensors to secure reliable flight parameters. In this context, predilections for superior units are being discerned.

Figure 1. UAV

2.2. Telemetry Software

This section unveils a methodical framework on robust data acquisition and handling from on-board avionics software, centering on the integration of telemetry hardware, communication systems, data logging mechanisms, and error handling protocols. The suggested framework, endeavors to augment mini-UAV operation's reliability, accessibility and maintainability factor, underpinning the mission capabilities and welfare.

2.2.1. Initialization of Communication Systems

The mini-UAV telemetry data acquisition system commences with the setting-up two critical communication links to guarantee accurate data transfer between the flight control system and ground control station. The beginning phase structures facilitating the requisite connections through the utilization of the MAVLink (Micro Air Vehicle Link) protocol. MAVLink protocol offers solutions to users in the process of creating target-oriented mini-UAVs by incorporating the requirements of wide range tracking and mapping, reliability and lightweight (Chalkiadaki, A. et al.,2021). MAVLink connection is configured by a local network address (e.g., udpin:localhost:14550), which facilitates seamless data transmission by ensuring that both endpoints are correctly addressed and synchronized.

Simultaneously, a serial communication link is established with the telemetry module. The telemetry module acts as an intermediary, transmitting data between the flight control system and the ground station. The serial interface is configured to operate at a specified baud rate, which ensures that data is transmitted at a speed suitable for real-time telemetry updates. The specific baud rate is selected based on the data throughput requirements and the capabilities of the communication hardware. This configuration is crucial for maintaining the integrity and continuity of the data stream, especially during high-speed or complex flight maneuvers.

2.2.2. Handshake Protocols

Data transmission has handshake protocols which is used before the communication agreement constructed inter-party (Peeters,2005). After communication links established between flight control card and telemetry, heartbeat messages from the flight control unit are waited for system. Heartbeat mechanism is one of the most widespread techniques among the remote nodes by sending periodic messages to inform other nodes that they are alive. If there is no heartbeat received for a certain period, the node is pronounced defunct (Johnson, 2005). Heartbeat plays an important role in the aspects of enhancing system safety. In this study, heartbeat indicator provides information about telemetry system readiness condition for data transmission. This message covers the system and component identifiers. System health monitoring is pivotal for reliable and continuous data acquisition of mini-UAV, supplied by heartbeat messages.

2.2.3. Continuous State Monitoring and Data Acquisition

After the handshaking protocols, telemetry system is ready to acquire data and write messages coming from MAVLink connection. Telemetry system continuously monitoring the messages through an infinite loop. There are two conditions. If the receiver catches a message from MAVLink, message will give us information about the operational conditions. If there is no message occurs, infinite loop will continue. Thereby, real-time flight data acquisition is put into effect.

2.2.4. Creating a Dictionary for Defining Mini-UAV Flight Parameters

Operational messages are adjusted by infinite loop. Messages are related to UAV operational parameters. Writing codes for catching messages but the telemetry system has no clear information about 'what is the message', 'which packet of input data send', 'what is the unit of this data'. To mitigate information overload and rectify informational deficiencies, data address methodology is harnessed. To evidently addressed, a dictionary has been constituted via flight data received from each sensor and unit is labeled with related scientific unit. each sensor and unit have equivalent to different types of messages. By the way, the dictionary provides their users to revise dictionary for scientific unit conversation and related types of applications.

2.2.5. Converting Data into Message

Data converted into a string from any preaddressed dictionary. Then, adding timestamp to data and hashing. One of the advantages of hashing is that it does not require index storage space. With hashing, the records are distributed to places that normally require an index (Singh, 2009).

2.2.6. Conditional File Management Based on Armed Status

A key feature of the telemetry system is its ability to conditionally log data based on the UAV's armed status. When the UAV transitions to an armed state, a new log file is created. This file is uniquely named based on the current timestamp, ensuring chronological organization of flight data. This naming convention facilitates easy retrieval and analysis of the data, allowing for detailed post-flight analysis and performance assessment.

Conversely, when the UAV disarms, the open log file is promptly closed. This practice ensures that all data is properly saved and prevents potential data corruption that could occur if the file remained open. The systematic management of log files based on the armed status is critical for maintaining data integrity and reliability. Additionally, the use of time-based file naming allows for automated data processing and integration with other flight data management systems.

2.2.7. Processing and Logging of Telemetry Data

The proposed communication system is operated by laying down the relevant units and evaluating the data coming from the sensors. In addition, the processed data is recorded and the flight data set is obtained. In the mini-UAV prototype, the sensors that will provide data on flight changes are positioned on the battery and GPS modules.

2.2.7.1 GPS Data Handling

GPS data contains the latitude, longitude and altitude information of the mini-UAV. Using this information, it is possible to obtain ground speed information. The file is opened by checking the power status. Messages from the sensors are displayed as different message types. In the MAVLink protocol architecture, GPS messages are assigned as the GPS_RAW_INT message type. Data is processed and sent via ports. After sending, the messages are written to the file and given meaning.The system extracts essential parameters such as latitude, longitude, altitude, and velocity from the GPS messages. The altitude value, for instance, is converted from millimeters to meters for standardization. This conversion is necessary to align with commonly used units in flight data analysis.

2.2.7.2 Battery Status Monitoring

UAV battery sensors play a critical role in monitoring and managing battery performance. Battery sensors carry information such as voltage and current monitoring and remaining battery percentage. The battery message type assigned for the MAVLink data communication protocol is BATTERY_STATUS. This message type acts as a BMS in a sense and provides safety critical data such as the SoC. When the mini-UAV is powered up, the file is opened and the message that the battery wants to transmit is received by determining the BATTERY_STATUS message type. It is determined which flight parameter related to the battery provided by the sensor data is included in the received message and the message is written to the file.

2.2.8. Error Handling Mechanisms and System Resilience

To ensure robustness, the telemetry acquisition system incorporates comprehensive error handling mechanisms. Exceptions are caught and logged, allowing the system to continue operation despite encountering errors via try-except blocks (Alvarez et al.,2024). This resilience is crucial for maintaining continuous data acquisition during the UAV's operation. The error handling routines are designed to minimize downtime and ensure that the system can recover gracefully from unexpected issues. This includes handling communication timeouts, data corruption, and unexpected disconnections, all of which are critical for maintaining system reliability.

2.2.9. Autonomous Boot-up Procedures for mini-UAV Telemetry Systems

The proposed communication system model includes an operating system (OS) design within itself. OS executes the command in the string at the OS level. With the OS command, MAVProxy, which is the MAVLink Proxy service, is automatically started. This automatic start facilitates the data flow between the UAV and the UAV. Another advantage of the proxy system is that the data is cached and accessed faster (Zeng et al., 2004). This automatic procedure receives the mini-UAV flight data via the MAVProxy software and transmits this data to the UAV via the UDP port. The use of a mini-UAV communication system with autonomous start-up procedures ensures that the system is commissioned quickly and consistently even under difficult operating conditions.

3. Mini-UAV On-Board Avionics Integration

In this section, the interface units of mini-UAV which is used for data acquisition process are detailed. Figure 3 shows that the schematic architecture of system components.

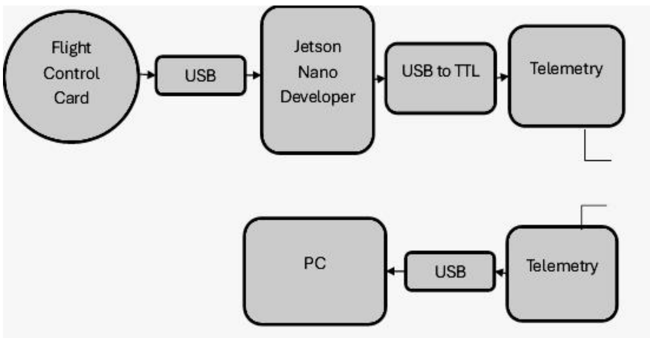

Figure 2. System Architecture

The flight control unit integrated into the UAV is a crucial component engineered for the acquisition and transmission of flight data. The data generated by this unit is conveyed to the Jetson Nano Development Kit through a USB connection. The Jetson Nano Development Kit is a high-performance artificial intelligence unit renowned for its substantial computational power and AI processing capabilities. Once the USB connection is established, the raw data obtained from the flight control unit is transmitted to the Jetson Nano Development Kit, where it undergoes processing.

Subsequent to the data processing, the processed data is transmitted to the ground station. This data transmission is facilitated by a USB-to-TTL converter, which allows the data to be sent using the UART protocol. The telemetry device then transmits the data to the ground telemetry device via a wireless connection, ensuring reliable data transfer within a wireless environment. The data format utilized in this process is JSON.

The ground control station serves as a software interface for the processing and analysis of the received data. When the telemetry device is connected to the computer via USB, it streams data to the ground control station interface. This configuration enables users to monitor and analyze flight data in real-time. Ensuring the accuracy of data transmission is essential for the effective operation of the ground control station. Figure 4 illustrates a visual representation of the data acquisition process from the ground control station.

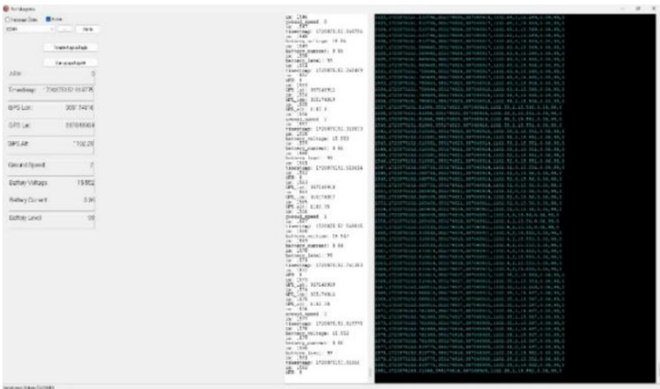

Figure 3. Ground Control Station

Figure 4 demonstrates the mini-UAV system components for flight data acquisition.

Figure 4. Mini-UAV

4. Results

This section elucidates the results of mini-UAV flights conducted specifically for the purpose of acquiring detailed flight data. This section elucidates the outcomes from mini-UAV flights, based on the data acquisition purpose flights.

Following the completion of hardware and software integration, mini-UAV flights were conducted to achieve flight data acquisition, and the flight data was successfully captured. Figure 6 illustrates the waypoints assigned for the mini-UAV flight conducted.

Figure 5. Mini-UAV Path Planning

The flight is structured into the phases of takeoff, navigation, and landing. In this context, the flight dataset was analyzed and found to encompass 12,572 data rows corresponding to a flight duration of 3 minutes and 35 seconds. The navigation phase selected for examination includes instantaneous flight data spanning from row 6,421 to row 11,740, representing a 3-minute segment of the flight. The dataset comprises 5,321 observation units and 9 variables across its columns.

To data analysis, the navigation phase selected extends from waypoint 2 to waypoint 26. Graphs depicting the parameter data pertinent to the navigation phase of the flight have been constructed. Figures 6 through 16 present these graphs.

During the analysis, there is an arm feature indicating the engage/disengage status of the UAV. The UAV's operational status has been monitored through this parameter. Each electronic device is equipped with an internal counter. The number of incoming data packets and the information from the electronic device's counter have been assigned as separate features within the dataset. This allows for the analysis of the sampling rate of incoming data packets and the associated transmission delays within the dataset. Figure 9 presents a graph related to this analysis.

The process of acquiring flight data enables users to perform real-time monitoring and gain access to comprehensive flight details. It facilitates the monitoring of real-time data during the flight and allows for a detailed analysis of flight performance. The data obtained is a critical resource for evaluating the UAV's performance, verifying the reliability of the system, and optimizing flight operations. Moreover, this data collection process provides a valuable reference for future research and can contribute to the development of strategies aimed at enhancing data accuracy and system efficiency in forthcoming applications.

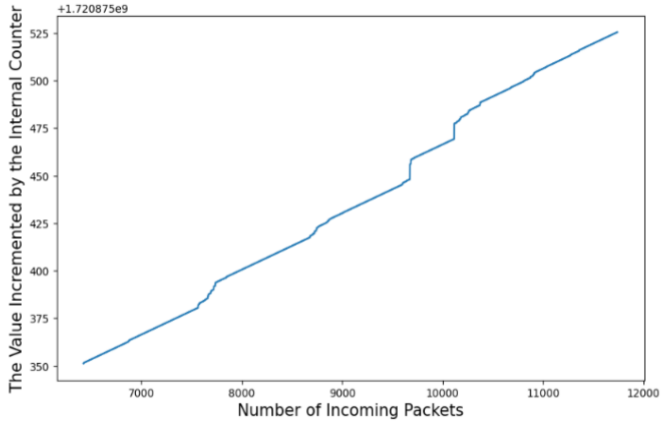

Figure 6. Relations Between Timestamp vs Internal Counter Value

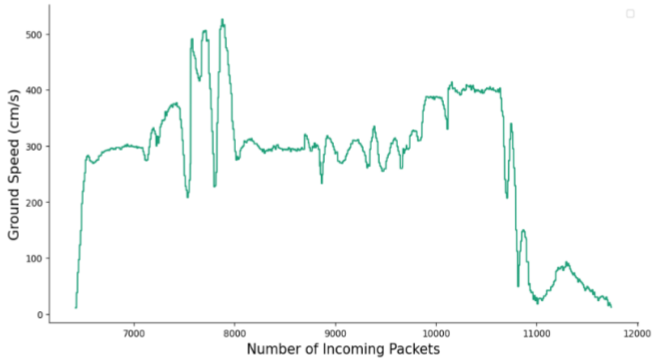

Figure 7. Ground Speed Change Over Time

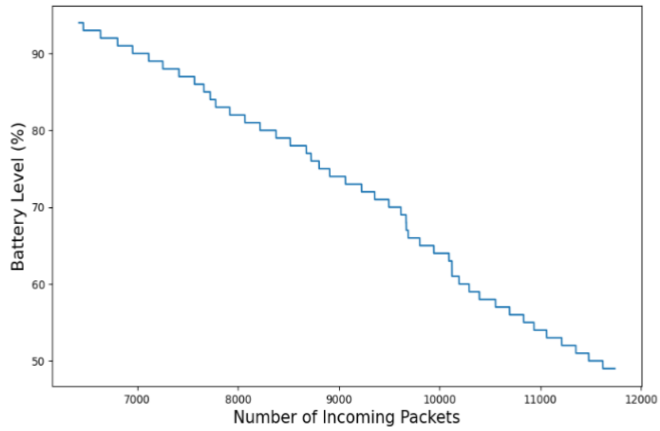

Figure 8. Battery Level Change Over Time

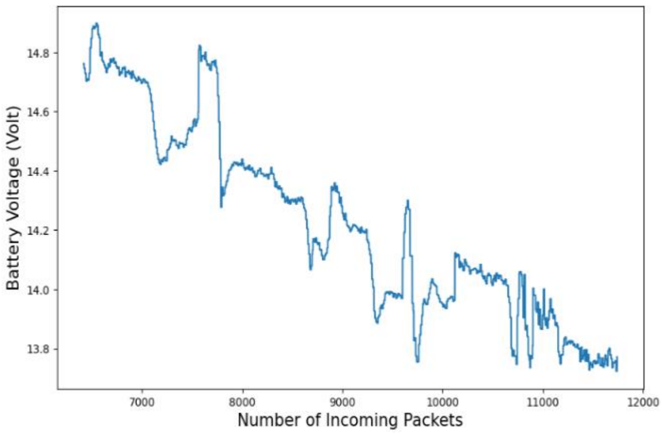

Figure 9. Battery Voltage Change Over Time

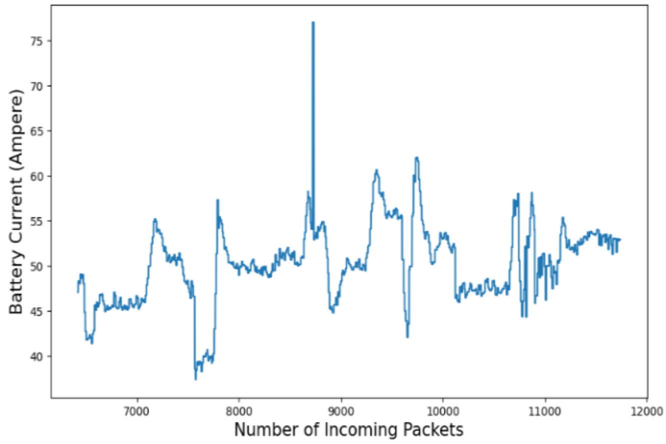

Figure 10. Battery Current Change Over Time

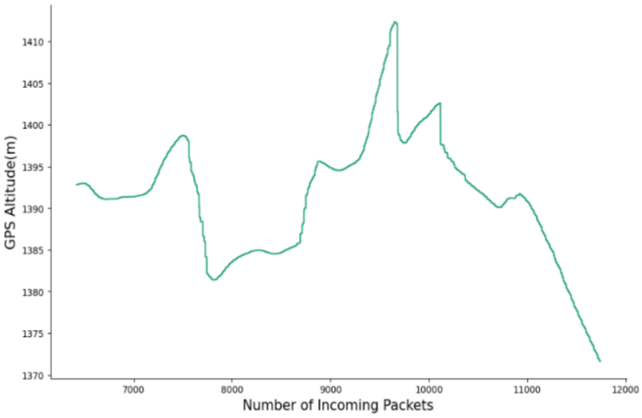

Figure 11. GPS Altitude Change Over Time

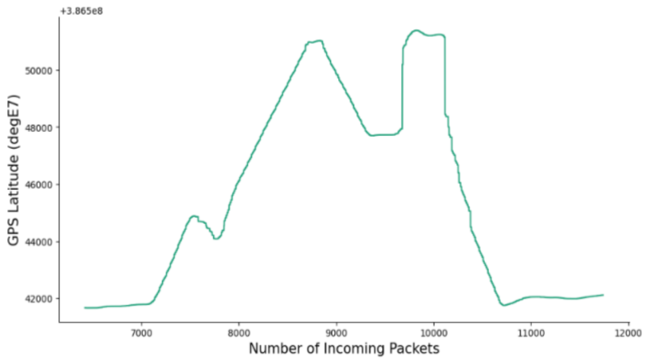

Figure 12. GPS Latitude Change Over Time

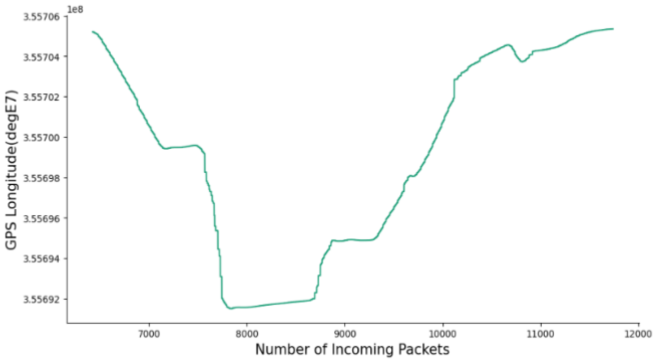

Figure 13. GPS Longitude Change Over Time

For the analyzing between the flight parameters correlation heat map is used. The term of correlation signifies to define quantitively in the aspect of degree of interdependence between two or more than two variables (Roggers,1959). Map designed for represent relations in the range of -1 to 1. -1 and 1 are the maximum relation parameters respectively negatively relation and positively relation. Heat map colors indicate the flight parameters relations with warm and cool colors. Figure 14 indicates the flight parameters' relations. Correlation heat map in accordance with flight data set's flight parameters empowered users to make informed decisions.

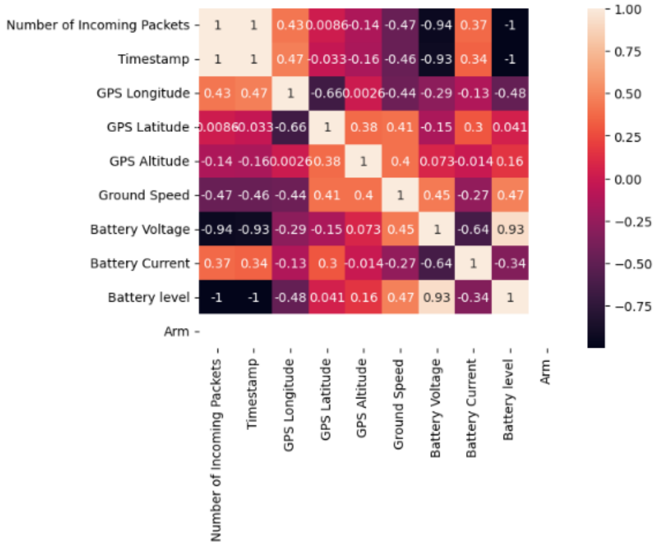

Figure 14. Flight Parameters Correlation Heat Map

Three-Dimensional flight pattern graphs present users to evaluate flight in the aspect of phase mode maneuver etc. Figure 15 and 16 shows flight pattern graphs. To review the map in detailed, we determine the non-colored right upper area to compare with Figure5 flight pattern, understand that mini-UAV is maybe in the hover mode. On the other hand, non-colored area can represent unscaled space. Although this situation is not definitive, it demonstrates the effectiveness of the data set in estimating the flight phase and maneuver.

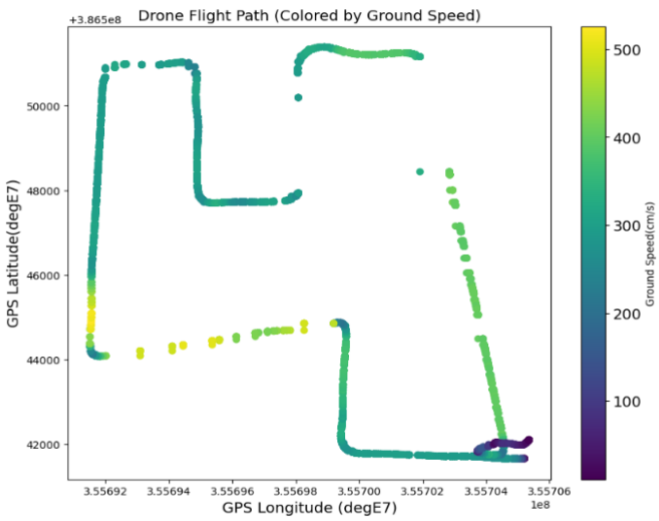

Figure 15. Flight Pattern Colored by Ground Speed

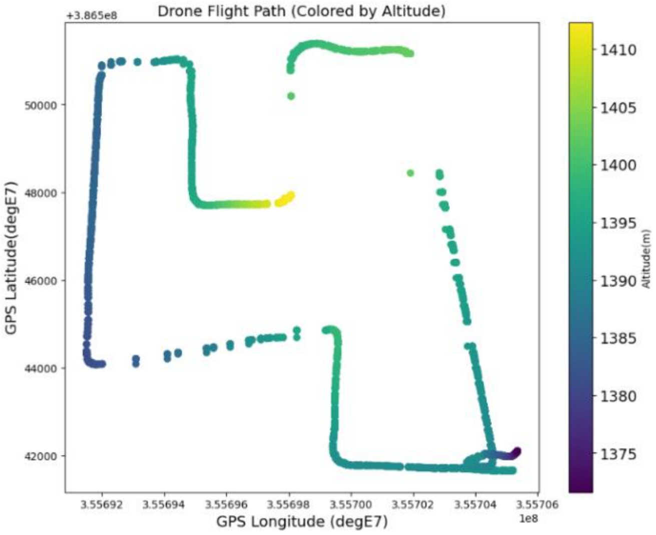

Figure 16. Three-Dimensional Flight Pattern Colored

5. Conclusion

In this study, a mini-UAV prototype was meticulously designed to facilitate the acquisition of flight data through conducted UAV flights. The prototype has been optimized to effectively capture flight data from UAV components. Throughout this process, custom-developed software for telemetry communication was employed to ensure the secure and accurate transmission of data. The data retrieved from the ground control station was successfully processed, enabling both real-time monitoring and comprehensive analysis.

In conclusion, this study offers an innovative and effective approach to data collection and processing for mini-UAVs. The implemented system has significantly improved the accuracy and efficiency of flight data, while also ensuring the reliability of data transmission. The software and telemetry communication strategies utilized may serve as valuable references for other UAV projects. Future research could focus on areas such as predictive analysis of flight data, monitoring system performance and parameters according to varying flight scenarios, enhancing UAV performance through AI-supported decision-making processes, and refining system design for diverse operation scenarios.

This study will be a resource for the integration of route-based parameter analyses into the autopilot in future studies and the pre-flight analysis of the effects of the obtained flight parameters on the UAV configuration; and for determining how the UAV parameters will be observed before, after and during the flight. In future studies, it is envisaged to improve the prototype configuration, make parameter-based improvements and design the parameters given as input according to the desired output parameters. By examining the flight phases in detail, estimating the relevant flight parameters in the flight phase of UAVs and determining how a maneuver will affect the UAV parameters will be made possible by obtaining and evaluating flight data sets from mini-UAVs.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Effect of Laser Surface Texturing Process on Dry Sliding Wear Behavior of NiTi Shape Memory Alloy Used in Airplane

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RESEARCH ARTICLE

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Abstract

In this study, the effect of laser surface texturing (LST) applied to NiTi Shape Memory Alloy (SMA) on the dry sliding wear behavior of the material was investigated. After polishing and cleaning the material surface, a pitted surface texturing process was performed using a femtosecond laser under atmospheric conditions. After the surface texturing process, dry sliding wear tests were performed at room temperature. When the wear behavior of the laser-applied and non-laser-applied test samples was evaluated comparatively, it was determined that the coefficient of friction (COF) of the laser-applied samples under 1N load was approximately 17% lower. It was determined that the decrease in the COF value decreased with increasing load. However, the wear amount of the LSD-applied NiTi SMA was higher than the untreated sample. It was evaluated that this situation was due to thermal softening that occurred depending on the ablation geometry and dimensions.

1. Introduction

Shape memory alloys (SMAs), in their most general expression, are materials that have the property of returning to their original shape or size when heated after deformation in the cold state. It belongs to the class of shape memory materials (SMAs) that have the property of returning to their previous form or shape as a result of mechanical, magnetic, or thermomechanical effects (Jani, Leary, Subic, & Gibson, 2014). One of the reasons for the high ductility of NiTi SMAs is the low elastic anisotropy (Otsuka & Ren, 2005). The shape memory property of these alloys occurs as a result of the shape change or thermoelastic martensite transformation taking place by the twinning mechanism instead of the sliding mechanism. SMAs can exist in two possible phases with three different crystal structures (twinned martensitic, untwinned martensitic, and austenite) and six different transformations (Sun & Huang, 2009). While the austenitic structure is stable at high temperatures, the martensitic structure is stable at low temperatures.

The first use of NiTi SMAs began in 1963, and from 1973 onwards, they were used in biomedical applications such as braces, stents, and implants. After 1980, they became one of the preferred materials in the automotive, space, and aviation fields. In recent years, significant advancements have been made in shape memory alloys, which can change their properties in response to environmental conditions and convert one form of energy into another. The use of smart materials is rapidly increasing in industries such as biomedical, textile, aerospace, and automotive (Fig.1). The literature summary provides a concise and effective overview of key studies focused on improving the tribological properties of materials used in aerospace applications. When the studies are examined, Abedini et al. studied the wear behavior of a Ti-50.3 at% Ni alloy against bearing steel under different loads and sliding distances. It was found that increasing the load from 40 N to 60 N reduced the wear rate due to the formation of iron-rich oxide layers. Similarly, longer sliding distances at higher loads (60 N and 80 N) also decreased wear, attributed to more stable oxide layers forming on the alloy's surface (Abedini, Ghasemi, & Ahmadabadi, 2012). DellaCorte et al. evaluated 60NiTi spherical bearings for aerospace and industrial use, focusing on their tribological performance. The bearings, tested under 4.54 kN loads and exposed to hydraulic and deicing fluids, performed comparably to stainless steel bearings. The results showed 60NiTi as a corrosion-resistant, viable material for these applications (DellaCorte & Jefferson, 2015). Wang et al., the study focuses on enhancing the tribological properties of titanium alloys using laser surface alloying and cladding. In-situ composite coatings like Cr7C3/NiCr, Ti5Si3/Ti, and Ti5Si3/NiTi2 were created on titanium substrates. The research evaluates the coatings' tribological performance at room and elevated temperatures, analyzing how microstructural features and laser processing conditions affect wear mechanisms. It also discusses the potential applications of these modified titanium alloys in the aerospace industry (Wang, Jiang, & Liu, 2002). A study investigated the unlubricated friction and wear of NiTiHf alloy treated with gas and plasma nitriding. Pin-on-disk tests revealed friction coefficients from 0.7 to 1.6 for nitrided disks and wear factors of about 10^{-6} for NiTiHf and plasma-nitrided disks, compared to 10^{-4} for gas-nitrided disks. Plasma nitriding offered better wear resistance, while gas nitriding resulted in more pin wear. The results are relevant for designing aerospace components like gears and fasteners (Stanford, 2019). Overall, the reviewed studies collectively underscore the importance of material treatment and alloy selection in enhancing the performance and durability of components in the aerospace sector, suggesting a trend toward using advanced materials like NiTi for critical applications.

Figure 1. SMA application on Boeing's variable geometry chevron (Costanza & Tata, 2020).

Lasers were first used in scientific studies in 1960. Today, continuous or pulsed lasers with high or very low power density are available in wavelengths ranging from infrared to ultraviolet radiation. Laser use has spread to many areas, such as communication, medicine, chemistry, and the defense industry. Among laser material processing, welding, cutting, drilling, surface treatment, alloying, shocking, and ablation are the first applications that come to mind. Material processing with laser is carried out in three ways: with melting (welding, surface melting, etc.), without melting (shocking, bending, etc.), or by evaporation (ablation, cutting, drilling, etc.) (Bahar, 2024).

Friction and wear are inevitable in various engineering applications where surface interactions occur. Various studies have been conducted to investigate the effect of intentionally created surface textures on the tribological performance of the material in contact with the surfaces moving against each other (Holmberg & Mathews, 1994; Priest & Taylor, 2000; Zhang, Deng, Ding, Guo, & Sun, 2017). Laser surface texturing (LST) is used as an effective and widespread method to modify the interaction between surfaces to provide better lubrication and wear resistance to engineering materials (Gachot, Rosenkranz, Hsu, & Costa, 2017; He et al., 2018; Menezes & Kailas, 2006; Vilhena et al., 2009).

The first successful application of LST dates back to the 1940s when an "interrupted surface finish" was developed at the diesel engine piston ring-liner interface to prevent seizure under hot operating conditions (Martz, 1949). In the 1960s, Anno et al. (Anno, Walowit, & Allen, 1968) proposed their theory on micro-asperity lubrication by adding protrusions to improve tribological performance. In the late 1990s, Etsion et al. (Etsion, 2004; Etsion & Burstein, 1996; Faces, 1994) proposed that micro-dimples on the surface of mechanical seals could reduce friction and improve wear resistance. Recently, Rosenkranz et al. (Rosenkranz, Grützmacher, Gachot, & Costa, 2019) and Grützmacher et al. (Grützmacher, Profito, & Rosenkranz, 2019) have summarized the state of the art of LST applied to mechanical components.

Over the years, various surface texturing techniques have been developed, including LST (Ryk & Etsion, 2006), ion beam etching/milling (Marchetto et al., 2008), lithography (Pettersson & Jacobson, 2004), hot embossing (Li, Xu, Liu, Wang, & Liu, 2016), micro-milling (Chen, Liu, & Shen, 2018), electrochemical machining (Walker, Kamps, Lam, Mitchell-Smith, & Clare, 2017), and mechanical texturing (Greco, Raphaelson, Ehmann, Wang, & Lin, 2009). Among these methods, LST has attracted significant attention due to its unique advantages, such as fast speed, high efficiency, good controllability, environmentally friendly structure, and the ability to produce surface texture with high complexity and accuracy (Earl, Castrejón-Pita, Hilton, & O'Neill, 2016; Kennedy, Byrne, & Collins, 2004; Kurella & Dahotre, 2005; Singh & Harimkar, 2012). Due to these advantages, LST has been widely used in various applications to improve the tribological performance of engineering components with contact surfaces, such as mechanical seals (Etsion, 2000), thrust bearings (Brizmer, Kligerman, & Etsion, 2003), piston rings (Ryk, Kligerman, Etsion, & Shinkarenko, 2005), and magnetic storage devices (Baumgart, Krajnovich, Nguyen, & Tam, 1995). Moreover, it has been used to improve the tribological performance of various materials, from metals (Tripathi, Gyawali, Joshi, Amanov, & Wohn, 2017; Xu et al., 2017) to ceramics (Meng, Deng, Liu, Duan, & Zhang, 2018; Xing, Deng, Gao, Gao, & Wu, 2018) and polymers (Maruo & Fourkas, 2008; Mitov & Kumacheva, 1998).

In this study, circular dimple-shaped patterns were created on the NiTi SMA samples' surfaces using the LST method. The effects of the surface texture on the COF value and wear rate were investigated.

2. Materials and Methods

In this study, materials obtained by purchasing from cylindrical NiTi alloy (51% Ni-49% Ti) shape memory alloy were used, and the test sample dimensions were prepared as 25x5 mm. The prepared test sample surfaces were polished by sanding and cleaned with alcohol. The LST process was performed with a femtosecond laser with a beam size of 15 µm, a wavelength of 250 fs, a frequency of 400 kHz, an average power of 1.25 W, a scanning speed of 10 mm/s, as surface ablation. The laser process was performed under normal atmospheric conditions, and no protective environment was applied. Some preliminary wear tests were performed to determine the appropriate experimental parameters, and the wear test parameters given in Table 1 were determined. Wear tests were performed in a ball-on-disc device (Turkyus, Turkey) in reciprocating motion mode, in a dry environment, and at room temperature. Then, the wear volume loss and specific wear rate values were calculated using the wear track profiles obtained from the 3D profilometer images. In addition, the values of friction coefficient for the laser-treated and untreated samples were compared. The SEM images were examined to evaluate the wear mechanisms.

Table 1. Wear test parameters

Abrasive ball	Load (N)	Sliding speed (mm/s)	Test duration (min)
∅6 mm WC ball Hardness 19 GPa	1	8	30
	3		

3. Result and Discussion

3.1. Abrasion of untreated surfaces

When the worn surface images and EDS analysis of the untreated NiTi SMA sample are examined (Fig. 2), it is seen that the width of the indentation formed at the end of the dry sliding wear test performed for 30 min under 1N load is approximately 800 µm (Fig. 2a). The place where the contact pressure is the highest and therefore, the plastic deformation occurs most severely is the middle region of the indentation (Küçük, 2020, 2021). There is delamination formation and wear waste transfer due to severe plastic deformation in the specified area (Fig. 2b). Transferred and smeared wear waste is observed in Fig. 2c. Still, it is seen that no microcracks are formed. The main reason for this situation is that NiTi SMA (Ni51Ti49) is in the stable austenite phase (B2 phase) at room temperature, in addition to the low load effect. Because the temperature increase caused by friction in the contact region supports the completion of the austenite phase transformation, the microstructure is in the austenite phase. Thus, it is evaluated that the contact area gains high elastic recovery ability, residual elongation is suppressed (Strnadel, Ohashi, Ohtsuka, Ishihara, & Miyazaki, 1995), and fatigue crack formation is prevented. In the examination made after the experiments carried out using the same test parameters under 3N load, it was seen that the wear scar width increased and reached 900 µm. Severe plastic deformation, abrasion, and delamination traces were observed on the worn surface.

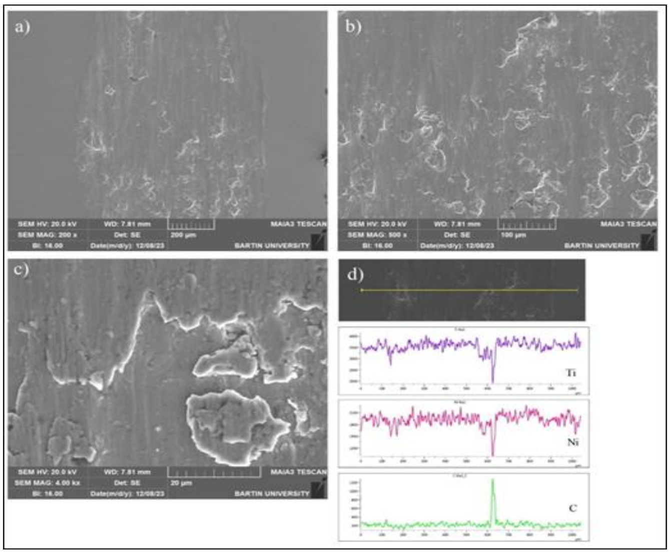

Figure 2. SEM and EDS line analysis images of the worn surface after the wear test of the NiTi SMA sample without LST application (load: 1N) a) 200x b) 500x c) 4kx d) EDS line analysis of the wear trace.

The 3D profilometer images of the worn surface of the samples under 1N and 3N loads are given in Fig. 3. As seen in Fig. 3a, the depth and width of the scar are approximately 7 µm and 600 µm, respectively, and abrasive wear is the dominant mechanism on the scar surface. In the worn surface image under 3N load (Fig.3b), it is understood that the depth and width of the scar are approximately 22 µm and 850 µm, respectively. The worn scar surface formed under 3N has a smoother contour, and rough abrasive wear marks are on the surface.

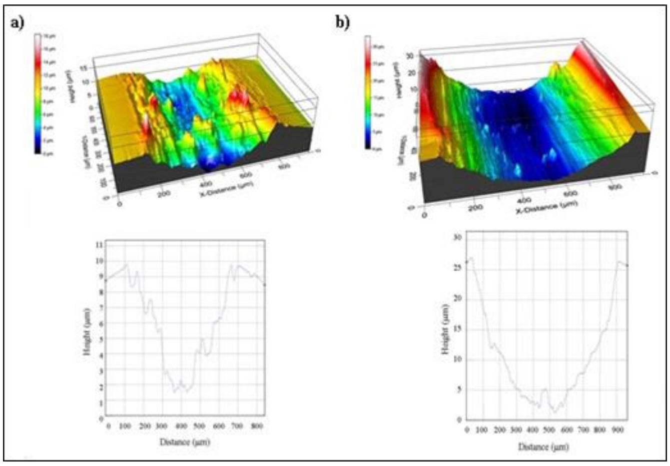

Figure 3. 3D profile images of the worn surface of the NiTi SMA sample without LST application a) 1N, b) 3N.

3.2. Wear of laser-applied surfaces

The optical microscope (OM) image taken after surface texturing is given in Fig. 4. The areal laser pattern density of the ablation region is 34%.

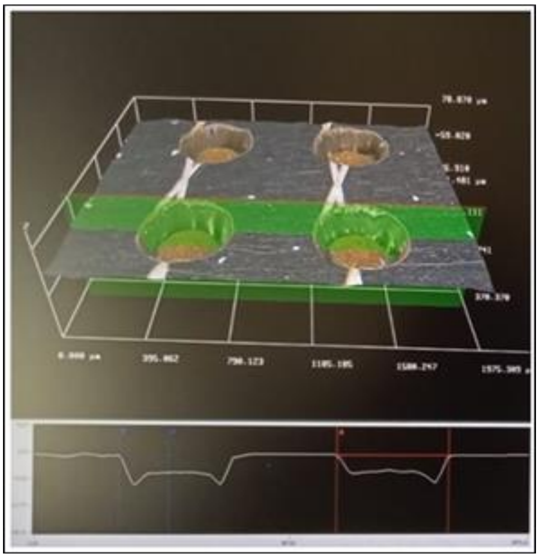

Figure 4. OM surface image of NiTi SMA after LST process.

When Fig. 4 is examined, it is seen that the ablation on the surface after the laser process is circular and 440 µm in diameter. The circular pit pattern has a conical structure that narrows inward and is approximately 42 µm deep. Fig. 5 shows the SEM images of the worn surface of the laser-ablated surface under 1N load.

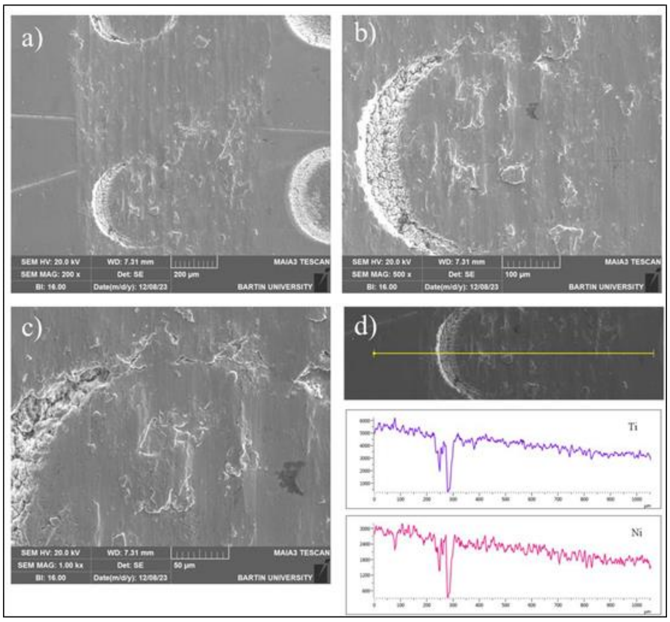

Figure 5. SEM and EDS line analysis images of the worn surface of the LST-applied NiTi SMA sample (load: 1N) a) 200x b) 500x c) 1kx d) EDS line analysis.

In addition to the plowing marks on the worn surface due to abrasion (Fig. 5b), delamination was also observed. In addition, the worn surface around the laser mark was smooth and even, and no microcracks or oxide layers were formed.

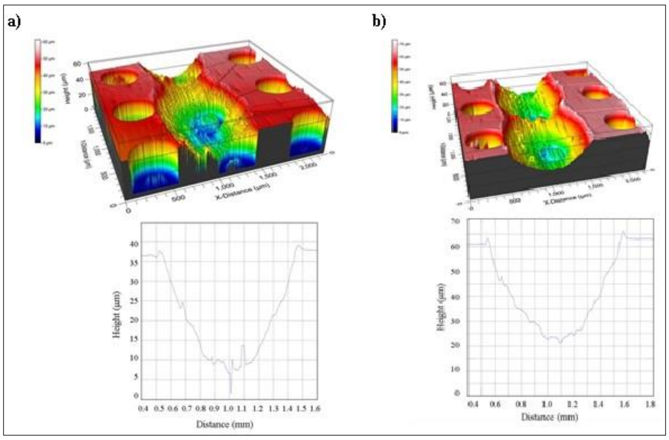

Figure 6. 3D profile images of the worn surface of the LST-applied NiTi SMA sample a) 1N, b) 3N.

Fig. 6 shows the worn surface images of the NiTi sample to which LST was applied under 1N and 3N loads. The depth of the scar formed under 1N load is 27 µm, while its width is 1000 µm (Fig. 6a). It is noteworthy that the laser pit trace on the surface was not erased after the wear test, and a scar formed around the laser trace in a widened and narrowed form. This situation is thought to occur due to fatigue crack formation and separation due to repeated loading at the trace edge. Fig. 6b shows the worn surface profile formed as a result of the wear of the surface after LST under 3N load. It is seen that the scar depth increased to approximately 40 µm under a 3N load, and its width remained almost the same as under a 1N load. It is understood from this that the amount of wear increased with increasing load.

Fig. 7 shows the worn surface SEM micrograph images of the sample to which the LST process was applied. It was observed that plastic deformation and abrasion wear occurred in the inner region and surroundings of the laser ablation scar. Wear particles were carried from the center of the scar to the edge and adhered to the surface (Fig. 7b). A smooth and even surface was formed due to plastic deformation around the laser ablation scar, and no microcracks were observed.

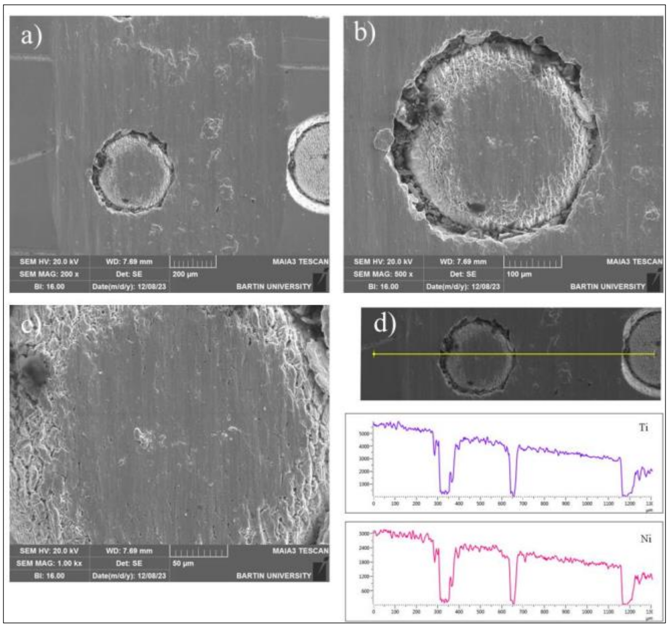

Figure 7. SEM and EDS images of the worn surface of the LST-applied NiTi SMA sample (load: 3N) a) 200x b) 500x c) 1kx d) EDS line analysis.

3.3. Changes in wear volume and friction coefficient before and after LST

The calculated wear volume loss, specific wear rate values, and friction coefficient graphs before and after LST are given in Fig. 8. As seen in Fig. 8a, the volume loss values in laser-applied samples are higher than those of untreated ones. It is thought that this situation is because the evacuation of the ablation area, which is quite broad compared to the width of the laser beam single pass, causes a long-term heat input and thus causes thermal softening in the heat-affected zone (HAZ) near the laser application region. This situation may be why microcracks do not form in LST samples. Thus, the tangential shear stress created by thermal softening and repeated friction causes more wear in the LST-applied sample. However, it is seen that the volume loss values increase with increasing load in all samples. According to Fig. 8b, the specific wear rate values decrease with increasing load in untreated and laser-ablation-applied samples; in other words, no directly proportional increase occurs. When the COF values recorded during wear are examined, it is seen that the COF values of the LST-applied samples decrease (Fig 8c). Similarly, it is understood that the COF values decrease with increasing load. The tangential friction force during sliding is decisive in determining the friction coefficient. The number of contacting surface roughnesses affects the tangential friction force. Since the number of contacts roughnesses decreases with laser ablation, the tangential friction force decreases, and the COF value decreases.

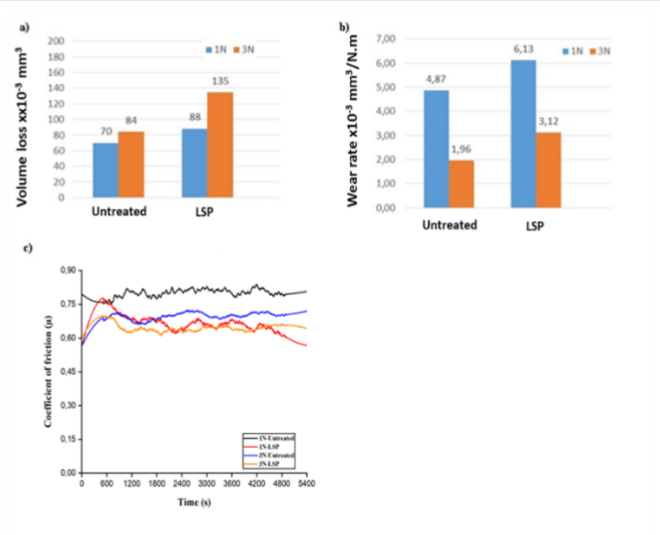

Figure 8. Graphical representation of NiTi samples before and after LST.

4. Conclusion

In this study, surface patterns in circular dimples with a diameter of 440 µm and a depth of approximately 40 µm were obtained by surface texturing (ablation) of NiTi SMA with a fiber laser. The results can be summarized as follows:

The pattern area density determined in surface texturing with the applied laser ablation process was 34%. Under 1N load, it caused a decrease of approximately 17% compared to the friction coefficient values of the samples without laser treatment. The reduction in the COF value under 3N load was calculated as approximately 14%.

When the wear volume loss values were examined, the volume loss values of the laser-applied samples were higher. The main reason for this is the thermal softening effect due to multiple laser passes due to the high ablation volume. It is estimated that the impact of LST on the wear behavior will also change with the reduction of the ablation surface area.

From the worn surface examinations, at low load (1N), a rough surface formed by wear track channels (grooving) and the plowing effect was formed on the untreated sample surface, while a smoother contoured wear track profile due to plastic deformation was obtained on the laser ablated sample surface.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Climb Performance Prediction in High Drag Configuration Middle-Class Transportation Aircraft: An Ensemble Learning Approach

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Abstract

This study addresses the application of machine learning and artificial neural network models for predicting the climb speed of the C-130H military transport aircraft. Random Forest, Neural Network, and Ensemble models were developed to overcome limitations of traditional chart reading and interpolation methods. Models were trained on flight manual data, considering factors such as gross weight, pressure altitude, drag index, temperature deviation, and engine efficiency. Comparative analysis revealed the Ensemble approach, combining Random Forest and Neural Network techniques, provided the highest accuracy ($R^2 \approx 0.4532$), followed by Random Forest ($R^2 \approx 0.4303$) and Neural Network ($R^2 \approx 0.3765$) models. All significantly outperformed the traditional Young Method ($R^2 = -1.2673$). Feature importance analysis identified pressure altitude, gross weight, and engine efficiency as critical factors influencing climb speed. The ensemble approach demonstrated more reliable and accurate results in predicting C-130H climb rates, reducing risks associated with single-model reliance. This research highlights the potential of machine learning in aircraft performance prediction, offering possibilities for improving pre-flight preparation, reducing workload, and enhancing flight safety. Implications for the aviation industry and future research directions are discussed, emphasizing the role of advanced predictive models in shaping future flight operations and aircraft performance management.

1. Introduction

Due to the fact that aircrafts fly in a wide range of mission areas for cargo, passenger, tactical and military purposes, manufacturers conduct a number of test flights to determine the aerodynamic characteristics, design requirements and flight performance limits of the aircraft (Baklacıoğlu, 2010). During the test flights, all the forced physical and environmental conditions of the aircraft are tested and finally performance charts are obtained. The manufacturer has developed many different versions of the aircrafts, which have different mission versatility and airspaces. Each version is designed to fly in different environmental conditions (Oktay et al., 2022).

Because of changing environmental conditions of the flight missions, it is extremely important to analyze the performance characteristics of the aircraft in order to ensure both fuel economy and flight safety. For this purpose, manufacturers determine the flight envelope by testing different flight scenarios in all flight phases. In other words, flight performance parameters are investigations that reveal the aerodynamic characteristics of the aircraft and determine the limits of use. (Filippone, 2008).

In order to determine aircraft limits, aircraft performance calculations involve the calculation of numerous parameters; including take-off, cruise, climb and landing speeds, torque, cruising altitudes, and maximum aircraft weight. These parameters are obtained by manual use of a variety of charts (Erdmański et al., 2010). The use of these charts presents several challenges, including time-consuming calculations, low accuracy of the results obtained from the calculations, and the necessity of performing these calculations separately for each phase of the flight. This is due to the fact that many charts must be used simultaneously to reach the correct result. Additionally, the lack of chart-specific equations and the fact that the curves do not exhibit the same characteristics at every point depending on the changing parameters also contribute to an excessive workload and time loss (Güleç, 2002).

When the studies on aircraft performance parameters in the literature are examined, it is observed that artificial neural networks are intensively preferred due to obtaining the closest results to the real values and being more easily adaptable in practice. Among these studies, (Altuntaş, 2007) created a fuel consumption model for Boeing 737-800 aircraft. (Türkmen et al. 2017) developed an alternative airspeed calculation method for Boeing 737-400 aircraft. (Yildirim et al. 2017) created a prediction model for low-pressure turbine vibration in Boeing 737-500 aircraft. (Türkmen et al. 2022) used neural networks to predict angle of attack and Mach number for Boeing 757 aircraft. (Fenar et al. 2014) developed a model to predict aircraft icing risk. (Yildirim Dalkiran et al. 2021) created a prediction model for engine thrust calculation in Airbus A319 aircraft. (Baklacıoğlu, 2010) created an aircraft performance model using genetic algorithms for trajectory prediction. (İlbaş et al. 2012) developed an exhaust gas temperature prediction model for CFM56-7B turbofan engines.

Flight performance parameters can be examined in many flight phases such as taxi, take-off, climb, level flight, descent and landing. When we consider the climb phase in order to examine the performance parameters, the climb speed during the flight period required for an aircraft to climb to the desired altitude after take-off is of great importance (Konar et al. 2020; Altuntaş, 2007). The climb speed, which directly affects fuel consumption, varies depending on variables such as gross weight of the aircraft, altitude change, temperature deviations, engine efficiency, drag coefficient. By analyzing the climb speed, fuel optimization can be achieved and flight performance can be improved (Türkmen et al., 2022; PHAC, 2023).

In this study, the climb performance of middle-class transportation C-130H aircraft with high drag coefficient, turboprop Allison T56-A-15 four-engine is investigated. When examining the performance limits of the C-130H aircraft, since the service ceiling is 30,000 feet and the maximum gross weight is 175,000 pounds, the data sets were limited to these values when developing the climb speed prediction model. As a result of this study, it is aimed to create a prediction model by using artificial neural networks and machine learning methods instead of the classical method. In the classical method, climb speeds are obtained manually from the climb performance charts in the flight manual for the prediction of the climb speed on the Take-Off and Landing card called TOLD card, which must be prepared by the ground crew before take-off. The study yielded faster and more reliable forecasting results through the application of machine learning and artificial neural networks. As a practical benefit, it is aimed to reduce workload and time loss and to ensure flight safety at a high level.

2. Methods

In this study, data sets were obtained by utilizing the charts in the high drag C-130H aircraft flight manual climb performance section (USAF, 2002). Gross weight, pressure altitude, drag index, temperature deviation, engine efficiency, uncorrected indicated air speed was used as inputs from the obtained data sets and an alternative prediction model to the classical calculation method was created by estimating the climb speed as output. Figure 1 shows the block diagram of the proposed models.

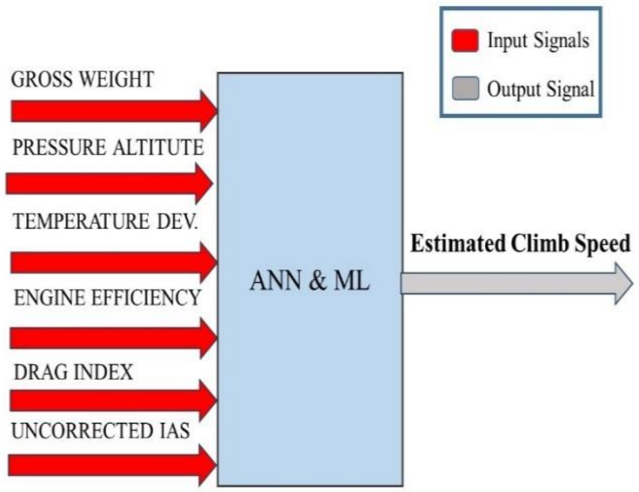

Figure 1. Block Representation of Trained ANN&ML Model

Each variable used in the input set has different effects on the climbing speed and hence climbing performance obtained in the model output. In order to determine the verified climbing speed, it is necessary to use each effect as a correction factor.

Gross Weight: It is expressed as the sum of the aircraft's payloads such as oil, fuel, cargo and the weight of the basic configuration elements, which we call basic aircraft weight. With the increase in the weight of the aircraft, the aircraft will need to fly with a higher angle of attack in order to maintain the altitude and speed at which it flies. This will lead to increase the parasitic drag on the aircraft and the induced drag on the wings. In order to overcome the drag effect, thrust must be increased (Erdmański et al., 2010). Therefore, aircraft manufacturers prefer to low weight aircraft designs in order to increase aircraft performance due to drag effects (Boztepe et al., 2001).

Pressure Altitude: 29.92 inches or 1013.2 millibars is the altitude indicated by an altimeter set to standard sea level atmospheric pressure. Increasing the altitude at which aircraft fly means that an aircraft flying at level flight climbs to a higher altitude. This will lead to increase the required power while decreasing the available power in the engines. Thus, the climb performance of the aircraft will decrease as the engine performance is affected by the increase in altitude (Pooley Dorothy et al., 2010).

Temperature Deviation: In international standard atmospheric conditions, air temperature is accepted as 15 ºC. When the aircraft is in the climb phase, the outside temperature decreases by 2 ºC for every 1000 feet (Batchelor, 1967). In this case, the climb performance is affected by the decrease in the temperature of the air entering the engines (AFH, 2011).

Engine Efficiency: Even though engine efficiency is theoretically accepted as 100%, in practice, engines are usually operated at 95% efficiency for longer engine life. Again, this has a direct impact on climb performance (USAF, 2002).

Drag Index: As a result of the increase in drag coefficients in aircraft, it is necessary to increase the required power by setting the engines to a thrust value higher than the set thrust value in order to realize the climb process. Again, as a result of this situation, the increase in the drag coefficient of the aircraft has a negative effect on the climb performance (Boztepe et al., 2001; Eken, 2009).

Data were collected from the high drag C-130H aircraft flight manual (USAF 2002). Preprocessing steps included normalizing continuous variables and encoding categorical variables to ensure the data were suitable for machine learning algorithms. Any missing or inconsistent data were handled appropriately. Specifically, outliers were removed using the Z-score method, and the data were split into training (70%), validation (15%), and test (15%) sets. Feature engineering and robust normalization were applied to enhance model performance. Two data sets were used:

- Primary Data Set: This data set was used for training, validation, and testing the models. It includes features such as gross weight, pressure altitude, drag index, temperature deviation, engine efficiency, and uncorrected indicated airspeed. The data were preprocessed to remove outliers, normalize features, and split into training (70%), validation (15%), and test (15%) sets.
- Comparison Data Set: This data set was used to compare the model predictions with the actual climb speed and the Young Method. It includes similar features as the primary data set but is used solely for evaluating the final model performance.

Two rows of examples from each data set are given in Tables 1 and 2.

Table 1. Two-row transposed sample of the primary data set (1312 rows in all)

	Row 1	Row 2	Row …
1. Input	-1000	-1000	…
2. Input	130000	131000	…
3. Input	173.7519	174.0019	…
4. Input	179.2465	179.4942	…
5. Input	177.3369	177.5845	…
6. Input	176.78	177.03	…
Real Climb Speed	157.8431	157.1172	…

Table 2. Two-row transposed example of the comparison dataset (634 rows in all)

	Row 1	Row 2	Row …
1. Input	-1000	-1000	…
2. Input	80000	85000	…
3. Input	160	160.9996	…
4. Input	164.9996	165.9492	…
5. Input	160.4671	161.4941	…
6. Input	154.4904	155.5688	…
Young Method Prediction	145.5159	146.7486	…
Real Climb Speed	154.4904	155.5688	…

In this study, four different models were used: Random Forest, Neural Network, Ensemble, and Young Method. The performance of these models was evaluated using mean squared error (MSE), root mean square error (RMSE), and the R^2 coefficient of determination.

2.1. Random Forest Model

The Random Forest model employs multiple decision trees to make predictions, which are then averaged to improve accuracy and robustness against overfitting. Each decision tree is trained on a random subset of the dataset and branches by selecting a certain number of attributes. This approach increases the generalizability of the model and reduces overfitting (Cutler et al. 2012). Figure 2 shows the block diagram of the Random Forest Model.

Parameters used:

- Number of trees: 200
- Minimum leaf size: 5
- Number of predictors to sample: All

The Random Forest model can be described as follows:

$$\hat{f}(x) = \frac{1}{B}\sum_{b=1}^{B} T_b(x) \quad (1)$$

where B is the number of trees, and $T_b(x)$ is the prediction from the b-th tree.

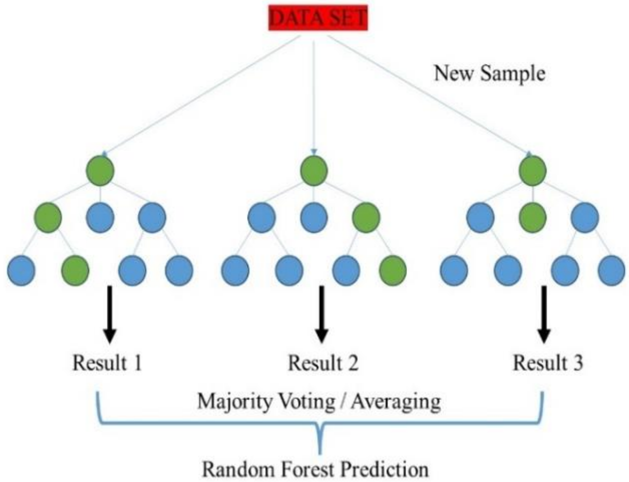

Figure 2. Random Forest Machine Learning Model

2.2. Neural Network Model

The Neural Network model used in this study was trained using the Levenberg-Marquardt algorithm, an optimization technique that combines the speed of the Gauss-Newton method with the robustness of the gradient descent method. The Levenberg-Marquardt method is a least squares computation method based on the idea of maximum neighborhood. This algorithm combines the best features of the Gauss-Newton and Steepest-Descent algorithms. The LM algorithm avoids the limitations of the two aforementioned methods and is not affected by slow convergence problems (Sağıroğlu et al., 2003). Figure 3 shows the block diagram of the Levenberg-Marquardt ANN Learning Model.

The architecture of the neural network included:

- Input layer with normalized features
- Multiple hidden layers with poslin activation functions (a variant of ReLU that allows small positive values to pass through unchanged)
- Output layer with a linear activation function

Poslin (Positive Linear) is closely related to ReLU (Rectified Linear Unit). While ReLU sets all negative values to zero, poslin allows small positive values to pass through unchanged, providing a slight smoothing effect. This choice maintains the benefits of ReLU in addressing the vanishing gradient problem while potentially offering improved model stability.

Optimization was performed using Bayesian optimization to determine the best hyperparameters:

- Hidden layer size: 5 to 30
- Learning rate: 10^{-4} to 10^{-2}
- Regularization parameter: 10^{-4} to 10^{-1}

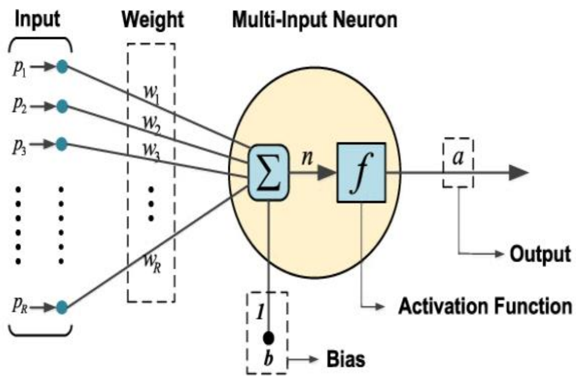

Figure 3. Levenberg-Marquardt ANN Learning Model

In equation $E(w)$ is an objective error function. $e_i^2(w)$ for m error terms is given in equation 2. The explicit form of $e_i^2(w)$ in this equation is shown in equation 3.

$$E(w) = \sum_{i=1}^{m} e_i^2(w) = \|f(w)\|^2 \tag{2}$$

$$e_i^2(w) = (y_{di} - y_i)^2 \tag{3}$$

In this context, the objective function $f(.)$ and its Jacobian J are assumed to be known at some point in time. The LM method is employed to identify the parameter vector w when $E(w)$ is at a minimum. Using the LM, one tries to calculate w_{k+1} from w_k shown in equation 4.

$$w_{k+1} = w_k + \delta w_k \tag{4}$$

Here δx_k is given by the following.

$$(J_k^T J_k + \lambda I)\delta w_k = -J_k^T f(w_k) \tag{5}$$

where J_k is Jacobian substituted for w_k in f, λ is Marquardt parameter, I is Unit matrix.

2.3. Ensemble Model

The ensemble learning model aims to achieve more reliable and accurate predictions by combining the strengths of different machine learning models. This model is effective in reducing high variance and improving performance. In traditional classification methods, different classification algorithms are used to build a model on a pre-labeled dataset. Since each algorithm has certain weaknesses, the ensemble learning model aims to provide better classification by combining the strengths of different algorithms (Dong et al., 2020; Matloob et al., 2021; Güzel et al., 2019). The ensemble model in this study is an approach that combines predictions from two different machine learning techniques - Artificial Neural Networks (ANN) and Random Forest. Ensemble learning aims to obtain more reliable and accurate predictions by combining the strengths of different models. In this model, ANN contributes with its ability to learn complex non-linear relationships. Random Forest contributes with its strength in reducing overfitting and determining feature importance. The predictions of these two models are combined using optimal weights. The weights are determined to minimize the ensemble error. The ensemble model is:

$$\hat{f}_{ensemble}(x) = w_1 \hat{f}_1(x) + w_2 \hat{f}_2(x) \tag{6}$$

where $\hat{f}_1(x)$ and $\hat{f}_2(x)$ are the predictions from the Neural Network and Random Forest models, respectively, and $w_1$and w_2 are the weights optimized to minimize the ensemble error using a constrained optimization approach.

2.4. Young Method

The Young Method is a traditional interpolation method applied to performance charts to estimate climb speeds (Young, 2019). This method serves as a benchmark for demonstrating the enhancement provided by machine learning techniques. Especially when it is difficult to obtain some performance parameters from charts, this method is used to obtain unknown values by curve fitting based on known values. However, in this method, deviations from the actual values should be carefully monitored and it should be ensured that the performance data obtained are within the safe range (within the tolerance given in the technical order).

This method uses interpolation to determine unknown values based on known data points from performance charts. It is used to calculate climb speed by taking into account factors such as gross weight, pressure altitude, and temperature deviation. Using the pressure altitude and gross weight, determine the base climb speed from the charts:

$$V_{ucs} = \Big[((52 * 10^{-10}) * \textstyle\sum(w)) - \big((1329558 * 10^{-9}) * \Delta P\big)\big) + ((25 * 10^{-5}) * \textstyle\sum(w)) + 140\Big] \tag{7}$$

In the formula here, Gross Weight is symbolized by $\sum(w)$ and Pressure Altitude is symbolized by ΔP. Also ΔT denotes temperature deviation.

By interpolating the charts for all factors such as gross weight, altitude change, temperature deviation, drag index and engine efficiency affecting the climb speed, a validated climb speed formula was obtained (Young, 2019).

$$V_{ccs} = [1.0071 * ((9995 * 10^{-4}) * ((9 * 10^{-10}) * \Delta T^4 + (85 * 10^{-9}) * \Delta T^3 - (151444 * 10^{-10}) * \Delta T^2 + (4865344 * 10^{-10}) * \Delta T + 1.0023015873) * \big((52 * 10^{-10}) * \textstyle\sum(w) - (1329558 * 10^{-9}) * \Delta P + 25 * 10^{-5} * \textstyle\sum(w) + 140.42169 - 0.5\big) + (-(58858 * 10^{-10}) * \Delta T^3 + (10638236 * 10^{-10}) * \Delta T^2 - (2924101117 * 10^{-10}) * \Delta T - (1798236332 * 10^{-10}) - 1.82) - 19.429] \tag{8}$$

2.5. Performance Evaluation

In this study, mean square error (MSE), root mean square error (RMSE) and the R^2 value, which is called the determination coefficient were chosen as the performance functions. MSE represents a general error value for all neurons in the output layer and is defined as:

$$MSE = E(w) = \frac{1}{n}\sum_{i=1}^{n} {e_i}^2(w) \tag{9}$$

The root mean square error (RMSE) determines the error ratio between the actual value and the estimated value. The increase in the predictive ability of the ANN model is understood to be the approach of the RMSE value to zero. The number of data sets used, the estimated value obtained from the neural network, the real value of RMSE is calculated by the following equation:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - y_{d_i})^2} \tag{10}$$

The R^2 value, which is called the determination coefficient, indicates the degree of conformity for the ANN model. The fact that the value of R^2 is close to 1 indicates that the predicted values are very close to the real values and that the predicted values are very far from the true values. The R^2 value is expressed as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - y_{d_i})^2}{\sum_{i=1}^{n}(y_{d_i} - y_m)^2} \tag{11}$$

3. Result and Discussion

The application of machine learning and artificial neural network models to predict the climb speed of the C-130H military transport aircraft yielded significant findings.

Our analysis encompassed Random Forest, Neural Network, and Ensemble models, each providing unique insights into the factors affecting climb speed prediction. Figure 4 illustrates the feature importance in the Random Forest model, offering a clear visualization of the most influential factors in our prediction task.

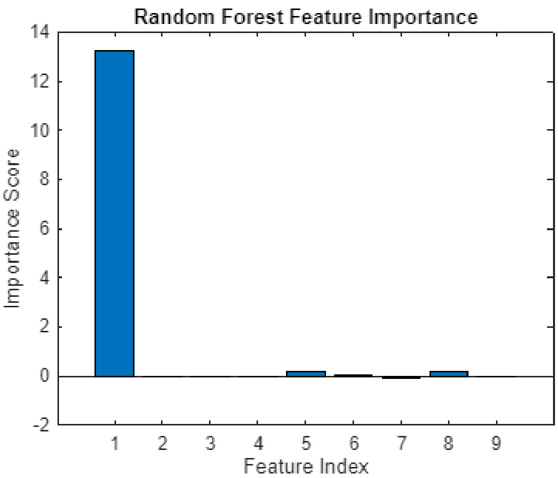

Figure 4. Feature Importance in Random Forest Model

The feature importance analysis of the Random Forest model revealed that pressure altitude (Feature 1) is the most critical factor in predicting climb speed, which can be attributed to its direct impact on air density and aircraft performance. Gross weight (Feature 2) and engine efficiency (Feature 5) also emerged as significant factors, albeit with considerably less influence compared to pressure altitude. Three derived features (Features 7, 8, and 9) were created to capture complex relationships between the original inputs. While these derived features show low importance individually, they may contribute to the model's overall performance. The relatively low importance of other original inputs (drag index, temperature deviation, and uncorrected indicated air speed) suggests they may have less direct impact on the C-130H aircraft's climb speed. However, removing these factors from the model is not recommended as they may still be significant under specific flight conditions.

The Neural Network model's performance was evaluated using various activation functions and hyperparameter configurations. Table 3 presents the performance comparison of different activation functions.

Table 3. Performance Comparison of Activation Functions

Activation Function	MSE	RMSE	R^2
poslin	0.00001	0.0060	0.9946
tansig	0.00003	0.0024	0.9991
logsig	0.0001	0.0116	0.9798
purelin	0.00003	0.0019	0.9995

As seen in Table 3, the logsig function clearly demonstrated the lowest performance among all tested activation functions, with notably higher MSE and RMSE values and a lower R^2 score. The other three functions (poslin, tansig, and purelin) showed very close performance, with purelin slightly outperforming the others in terms of RMSE and R^2. However, considering the overall stability, generalization ability of the model, and the need to capture potential non-linear relationships in the data, the 'poslin' (positive linear) activation function was chosen for our final model. This choice aims to strike a balance between the model's ability to represent complex patterns and its resistance to overfitting, especially given the close performance of poslin to the best-performing purelin function.

The architecture of the neural network included multiple hidden layers, with the number of neurons in these layers being a crucial hyperparameter. The optimization process explored various configurations, ranging from 5 to 30 neurons in the hidden layers. This exploration aimed to find the right balance between model complexity and generalization ability.

The hyperparameter optimization process and its results are illustrated in Figure 5. This figure shows the minimum objective value versus the number of function evaluations during the optimization process.

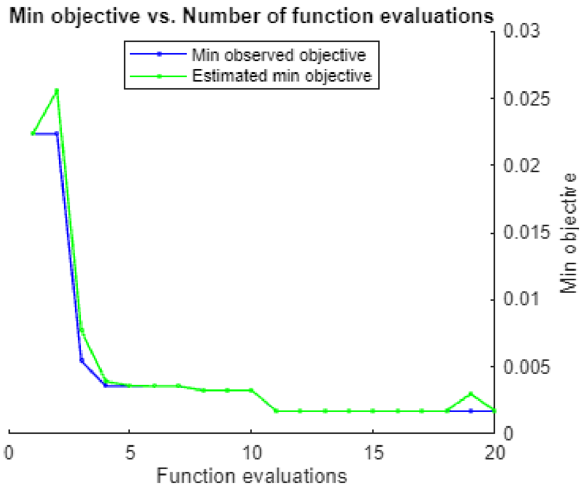

Figure 5. Minimum Objective vs. Number of Function Evaluations

As seen in Figure 5, there is a rapid convergence of both observed and estimated minimum objective values after approximately 10 evaluations. This indicates the efficiency of the Bayesian optimization approach in exploring the hyperparameter space. The best configuration achieved an objective function value of 0.0017079, with 30 neurons in the hidden layer, a learning rate of 0.00090854, and a regularization parameter of 0.00040608.

This optimal configuration suggests that the model benefits from a relatively complex architecture with 30 neurons in the hidden layer to capture the intricacies of the C-130H climb speed prediction task. The low learning rate (0.00090854) indicates a careful, gradual approach to updating the model's weights during training, which can help in finding a more precise minimum and avoiding overshooting. The small regularization parameter (0.00040608) suggests that the model did not require strong regularization to prevent overfitting, indicating a good balance between fitting the training data and maintaining generalization ability.

The Ensemble Model's performance, which combines the strengths of both Random Forest and Neural Network approaches, is illustrated in Figures 6 and 7.

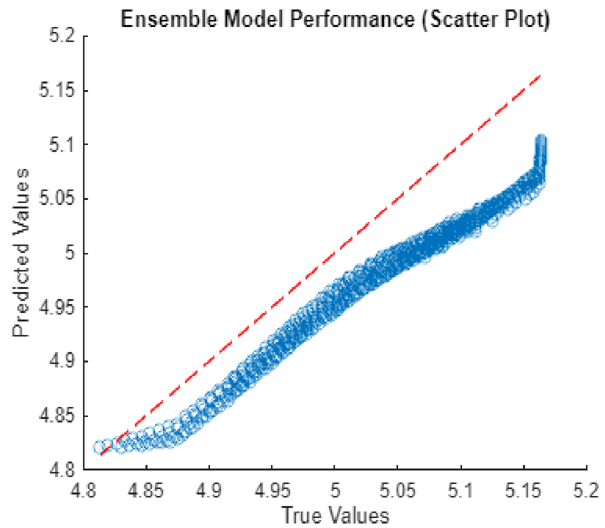

Figure 6. Ensemble Model Performance (Scatter Plot)

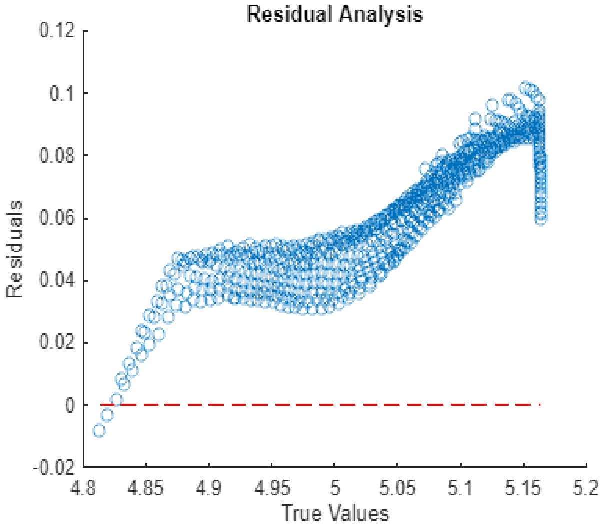

Figure 7. Residual Analysis Graph

Figure 6 demonstrates the Ensemble Model's predictive accuracy through a scatter plot of predicted versus true values. The clustering of points around the ideal line (red dashed line) indicates high overall predictive accuracy. The model shows particularly strong performance in the mid-range of climb speeds, with a slight tendency to underestimate at higher speeds.

The residual analysis in Figure 7 provides further insights into the model's performance. The distribution of residuals shows a generally consistent pattern, with a slight widening at higher true values. This suggests that the model maintains good predictive power across most of the range, with a minor decrease in precision for very high climb speeds.

Overall, these figures demonstrate the Ensemble Model's robust performance in predicting the C-130H aircraft's climb speed. The model effectively captures the complex relationships between input variables and climb speed, showcasing the advantages of combining multiple machine learning techniques. While there's always room for refinement, especially in extreme value predictions, the Ensemble Model proves to be a reliable tool for climb speed estimation in various flight conditions.

The overall performance of our models is illustrated in Figures 8 and 9, providing a comprehensive comparison of the different approaches used in this study.

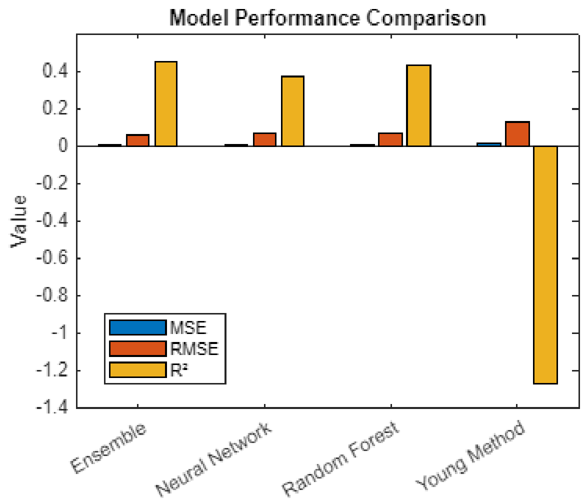

Figure 8. Model Performance Comparision (Bar Plot)

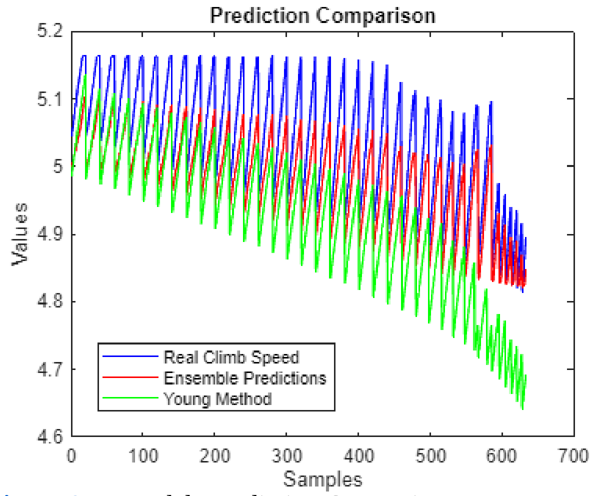

Figure 9. Models Prediction Comparison

Figure 8 presents a bar plot comparing the performance metrics (MSE, RMSE, and R^2) for each model. The Ensemble model demonstrates the best overall performance, with the highest R^2 value (approximately 0.45) and the lowest MSE and RMSE. The Random Forest model follows closely, while the Neural Network shows slightly lower performance. Notably, the Young Method exhibits significantly poorer performance, with a negative R^2 value.

The negative R^2 value for the Young Method indicates that this traditional approach performs worse than a horizontal line (the mean of the observed data) in predicting climb speeds. This underscores the limitations of conventional methods and highlights the advantages of machine learning approaches in capturing complex relationships within the data.

Figure 9 provides a visual comparison of the predictions made by the Ensemble model and the Young Method against the real climb speed values. The graph clearly shows that the Ensemble model's predictions (red line) closely follow the pattern of real climb speeds (blue line), while the Young Method's predictions (green line) deviate significantly, often underestimating the climb speed.

These results demonstrate the superior performance of the Ensemble model in predicting C-130H aircraft climb speeds. By combining the strengths of Random Forest and Neural Network approaches, the Ensemble model achieves more accurate and reliable predictions compared to both individual machine learning models and traditional methods. The significant improvement over the Young Method, as evidenced by the negative R^2 value, underscores the potential of machine learning techniques in enhancing aircraft performance predictions and flight planning processes.

4. Conclusion

In this study, a comprehensive analysis of machine learning and artificial neural network models for predicting the climb speed of the C-130H military transport aircraft has been presented. The research was aimed at overcoming the limitations of traditional graph reading and interpolation methods through the development and comparison of Random Forest, Neural Network, and Ensemble models.

It has been demonstrated that the Ensemble model exhibited superior performance ($R^2 \approx 0.4532$) compared to the individual Random Forest ($R^2 \approx 0.4303$) and Neural Network ($R^2 \approx 0.3765$) models, and significantly outperformed the traditional Young Method ($R^2 = -1.2673$). This superiority can be attributed to the Ensemble model's ability to capture complex, non-linear relationships in the data and its robustness against overfitting. The Ensemble approach, which combines the strengths of both Random Forest and Neural Network models, has proven to be particularly effective, providing more reliable and accurate results while mitigating the risks associated with relying on a single model.

The feature importance analysis revealed that pressure altitude, gross weight, and engine efficiency are the most critical factors in predicting the climb speed of the C-130H aircraft. This insight provides valuable guidance for future model development and optimization efforts.

In the Neural Network model, we tested various activation functions and found that while purelin showed slightly better performance, the poslin function was chosen for its balance between performance and ability to capture non-linear relationships. The hyperparameter optimization process led to a model with 30 neurons in the hidden layer, demonstrating the complexity required to accurately predict climb speeds.

The practical implications of this research for the aviation industry are significant. It is anticipated that the improved pre-flight preparation can be achieved through these models, potentially reducing the time and effort required for calculating climb speeds and allowing for more efficient pre-flight planning. Enhanced flight safety can be expected as more accurate climb speed predictions contribute to safer flight operations, especially in challenging conditions or when operating near performance limits. Furthermore, better climb speed predictions can lead to more efficient flight profiles, potentially reducing fuel consumption and environmental impact. The automation of climb speed calculations can significantly reduce the workload on ground crews and pilots, allowing them to focus on other critical tasks.

While the potential of machine learning in aircraft performance prediction has been demonstrated in this study, some limitations have been identified. The models were trained and tested on data specific to the C-130H aircraft, and their generalizability to other aircraft types needs further investigation. Additionally, the unexpectedly low performance of the Neural Network model suggests that further optimization of its architecture and hyperparameters might be beneficial.

Several directions for future research have been identified. The approach could be extended to other aircraft types and performance parameters. The incorporation of real-time flight data could be explored to improve model accuracy and adaptability. The integration of these models into existing flight management systems could be investigated. Furthermore, the use of deep learning techniques for even more accurate predictions could be explored.

In conclusion, the significant potential of machine learning techniques in aircraft performance prediction has been highlighted by this research. By providing more accurate and reliable climb speed predictions, these models offer possibilities for improving pre-flight preparation processes, reducing workload, enhancing flight safety, and optimizing fuel consumption. As the aviation industry continues to evolve, it is anticipated that the integration of such advanced predictive models could play a crucial role in shaping the future of flight operations and aircraft performance management.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Use of UAVs in Earthquakes and UAV Base Location Selection for a Possible Marmara Earthquake

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Abstract

UAV's are widely used in many fields today, and one of the most important of these fields is disaster management. The most significant disaster that comes to mind when mentioning disasters is undoubtedly earthquakes. UAV's are used to support search and rescue operations before and especially after an earthquake. As Türkiye is located in an earthquake zone, earthquakes have affected and will continue to affect us from past to present. The Marmara earthquake, which is predicted to occur in the coming years, will cause great destruction considering the population density of the region. In this study, the use of UAV's in earthquakes and the selection of the most suitable UAV base location for quick intervention without being affected by a potential Marmara earthquake was conducted using the TOPSIS method, which is one of the multi-criteria decision-making methods with criteria weights. As for the UAV class, MALE class UAV's, which are produced by Türkiye and classified by NATO, were preferred due to their mission duration and payload capacity. While determining the alternatives, seven airports close to the Marmara region but not on the fault line were selected. The criteria and their weights were determined based on the opinions of five UAV pilots, and a total of six criteria were chosen. As a result of applying the TOPSIS method, Sivrihisar Aviation Center was determined to be the most suitable UAV base for intervention in a potential Marmara earthquake, being the closest to the ideal solution among the selected alternatives.

1. Introduction

With the advancement of technology, Unmanned Aerial Vehicles (UAVs) have become widespread and are actively used in many areas, ranging from reconnaissance and surveillance to disaster management, air security, traffic control, and agricultural applications. As one of the few countries capable of producing UAVs in this field, Türkiye manufactures and exports tactical and operational-level UAVs.

Disaster management is one of the most common areas where UAVs are used, and their role in supporting search and rescue operations, especially after disasters, is significant. In Türkiye, the payloads on tactical and operational-level UAVs, which are primarily used in military applications, are also utilized in post-earthquake search and rescue operations to provide aerial support to personnel and to offer mobile base station support in areas where communication disruptions occur.

Due to the fact that Türkiye is located in an earthquake-prone region, many earthquakes have occurred from the past to the present, impacting Türkiye socially and economically. Considering the population density, a potential future Marmara earthquake could have devastating effects.

In this study, the use of UAVs in earthquakes has been briefly examined, and the selection of the most suitable location for establishing a UAV base that can rapidly respond to a possible Marmara earthquake has been made using the TOPSIS method, one of the multi-criteria decision-making processes.

This study also aims to raise awareness about the importance of using UAVs during earthquakes, highlight the significance of the anticipated Marmara earthquake, and provide insights for other researchers on possible locations for UAV operations in response to this earthquake. Additionally, the study seeks to demonstrate once again that multi criteria decision making methods can be effectively utilized in base selection problems.

2. Literature Review

In the literature, some studies have been conducted on the use of UAVs in earthquakes. In their study, Halat, M., and Özkan, Ö. (2020) determined the flight path that a UAV, launched within 24 hours after a possible Istanbul earthquake, should take to observe damage assessment activities.

In her study, Gülüm, P. (2021) utilized multi-criteria decision-making methods to accurately identify and analyze fires that may occur after an earthquake, and investigated how these fires could be intervened with unmanned aerial vehicles.

In his study, Sarıyıldız, H.İ. (2021) attempted to detect damaged structures after an earthquake using unmanned aerial vehicles and satellite images in combination with deep learning algorithms, achieving an accuracy rate exceeding 95%.

In his study, Canözü, Ö. (2022) used a photogrammetric point cloud in conjunction with the cadastral map of the area to automatically detect damaged or collapsed buildings from UAV images after an earthquake.

In their study, Maraş, E.E., and Sarıyıldız H.İ. (2023) tried to detect damaged structures after an earthquake using unmanned aerial vehicle images and deep learning algorithms, achieving an accuracy rate exceeding 95%.

In their study, Milev, N. et al. (2023) attempted to analyze and detect landslides that may occur after an earthquake using unmanned aerial vehicle images.

In his study, Chen Z. (2024) utilized UAVs equipped with sensors that perform temperature and image analysis for the early detection and monitoring of earthquake, flood, and landslide disasters.

3. Earthquake Disasters

Earthquakes are defined as the phenomenon of vibrations suddenly arising from sudden fractures within the Earth's crust, spreading in wave form through the environment and shaking the Earth's surface. In essence, an earthquake is a natural event that demonstrates the Earth's dynamic nature, which is an indispensable aspect of life, and that can potentially cause loss of life for humans (AFAD, 2024).

Earthquakes occur due to the influence of many factors and can lead to various negative consequences. Earthquakes have affected Türkiye at different times from psychological, economic, demographic, social, and environmental perspectives. Being in an earthquake-prone region necessitates the evaluation of the severity and negative impacts of these effects (Aktan and Arık, 2024).

Türkiye is located in the Alp-Himalayan belt, one of the world's significant earthquake zones. Due to its complex geological structure and geodynamic position, Türkiye has many active fault lines (MTA, 2023). Due to these active and living faults, both small and large-scale earthquakes occur from time to time. In the post-Republic period, 15 different earthquakes with magnitudes of M≥7.0 can be mentioned. These earthquakes include: 26.06.1926 Datça Offshore (MS 7.7), 26.12.1939 Erzincan (MS 7.9), 20.12.1942 Erbaa-Tokat (MS 7.0), 26.11.1943 Ilgaz-Çankırı (MS 7.2), 01.02.1944 Gerede-Bolu (MS 7.3), 18.03.1953 Çanakkale (MS 7.2), 26.05.1957 Düzce-Bolu (MS 7.1), 06.10.1964 Karacabey-Bursa (MS 7.0), 28.03.1970 Kütahya (MS 7.2), 24.11.1976 Çaldıran-Van (Mw 7.0), 17.08.1999 Gölcük-Kocaeli (Mw 7.6), 12.11.1999 Düzce-Bolu (Mw 7.1), 23.10.2011 Van (Mw 7.1), 06.02.2023 Pazarcık-Kahramanmaraş (Mw 7.7), 06.02.2023 Elbistan-Kahramanmaraş (Mw 7.6) (AFAD, 2024).

Along with all these earthquakes, examining the earthquake-prone areas map shows that 92% of Türkiye is within an earthquake zone (İşçi, 2008). As can be seen from the earthquake zone map in Figure 1, there are three fault lines affecting Türkiye. These fault lines are named the North Anatolian Fault Line, the East Anatolian Fault Line, and the West Anatolian Fault Line. Fault lines refer to the points where the Earth's crust has been fractured or cracked. Since these fault lines cover many regions of Türkiye, there is a risk of earthquakes of varying magnitudes at any moment in every region of Türkiye (Canözü, 2022).

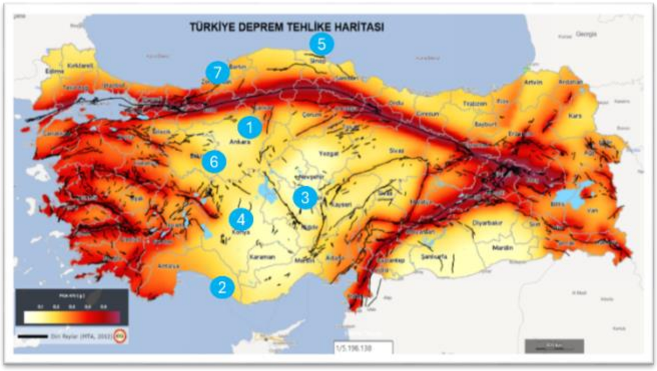

Figure 1. Earthquake Danger Map (AFAD, 2024) and Alternatives Used in TOPSIS Method

4. Unmanned Aerial Vehicles

Any vehicle capable of flying unmanned, remotely controlled, or autonomously operated through a program, carrying lethal or non-lethal payloads, is referred to as an Unmanned Aerial Vehicle (UAV) (Eisenbeiss, 2004). Additionally, terms such as "Drone," "Pilotless Aircraft," and "Remotely Piloted Aircraft" are also used to describe UAVs (Akyürek et al., 2012). Furthermore, the International Civil Aviation Organization (ICAO) classifies UAVs into three types: Remotely Piloted Aircraft (RPAs), Autonomous Aircraft, and Model Aircraft (ICAO-RPAS, 2015).

Moreover, there are Ground Control Stations, Ground Data Terminals, and other equipment that enable the flight and operation of UAVs. Systems formed by including these types of equipment are called Unmanned Aerial Systems (UAS) (Akyürek et al., 2012). Unmanned Aerial Systems are mostly used for military purposes, particularly for air vehicles with high payload capacity and takeoff weight.

UAVs were initially developed to meet military needs and became widespread through applications in military fields such as reconnaissance and surveillance, intelligence, and unmanned research. Nowadays, especially with the integration of digital cameras into lightweight UAVs, their use has become widespread in fields such as photography and AI-supported image processing (Ruzgiene et al., 2015).

4.1. Classification of UAVs

UAV systems are classified in various ways according to many different criteria. These classifications are fundamentally based on qualitative and quantitative approaches. Classifications made according to characteristics such as the duration of UAV operations, the weight of the payload carried, or the takeoff weight can be considered qualitative approaches. The classification where the total flight time and operational altitude are decisive factors is a quantitative approach. In the quantitative approach, the priority is the operational altitude. In quantitative classification, UAVs are commonly divided into four main groups: mini, tactical, operational, and strategic (Haser, 2010).

In Türkiye, the civil aviation authority, which is the authority on civil aviation, the Directorate General of Civil Aviation (DGCA), classifies UAVs according to their weight. Accordingly, UAVs are categorized into four groups based on their maximum takeoff weight (SHGM, SHT-UAV, 2016).

Table 1. Classification of UAVs (DGCA)

Class	Mass
UAV0	500 gr to 4 kg
UAV1	4 kg to 25 kg
UAV2	25 kg to 150 kg
UAV3	More than 150 kg

UAVs used for military purposes are classified by the NATO Joint Air Power Competence Centre (JAPCC) based on their takeoff weight, operational altitude, and mission radius (Haser, 2010).

Table 2. Classification of UAVs (NATO)

CLASS	CATEGORY	Employment	Mission Altitude	Mission Radius
Class I (Lesss than 150 kg)	Small (more than 20 kg)	Tactical Unit	Up to 5000 ft AGL	50 km (LOS)
	Mini (2 kg to 20 kg)	Tactical Sub-unit	Up to 3000 ft AGL	25 km (LOS)
	Micro (Less than 20 kg)	Tactical, Individual	Up to 200 ft AGL	5 km (LOS)
Class II (150kg to 600 kg)	Tactical	Tactical Formation	Up to 10.000 ft AGL	200 km (LOS)
Class III (More than 600 kg)	Strike/Combat	Strategic /National	Up to 65.000 ft AGL	Unlimited (BLOS)
	HALE (High Altitude Long Endurance)	Strategic /National	Up to 65.000 ft AGL	Unlimited (BLOS)
	MALE (Medium Altitude Long Endurance)	Operational	Up to 45.000 ft AGL	Unlimited (BLOS)

4.2. Use of UAVs in Earthquake

UAVs are widely used in all natural or natural disasters, including earthquakes, where they are effectively utilized. Although UAVs are employed in pre-disaster, during-disaster, and post-disaster operations, they are primarily used in post-disaster operations to map affected areas, assist in damage assessment and search and rescue operations using collected images, and facilitate communication in the affected regions (Bravo and Leiras, 2015).

UAVs can be used in earthquakes in the following areas before, during, and after the disaster (Erdelj et al., 2017):

- Making predictions by analyzing information gathered through environmental monitoring as part of prevention efforts,
- Ensuring the accurate flow of information during natural disasters,
- Assessing the situation, evacuation, and logistical support after the disaster,
- Supporting field personnel in detecting and rescuing people trapped under rubble during search and rescue operations,
- Identifying and assessing damaged structures in damage assessment efforts,
- Detecting and preventing other disasters such as fires, chemical/radioactive leaks, and landslides that may occur due to the earthquake,
- Ensuring public order in affected areas and preventing potential crimes,
- Supporting communication infrastructure in case of damage to communication systems.

Türkiye have actively used UAVs in recent earthquakes. Specifically, during the Kahramanmaraş earthquakes on February 6, 2023, UAVs were employed in supporting search and rescue operations, damage assessment efforts, detection of other disasters caused by the earthquake, maintaining public order in the region, and supporting communication infrastructure (Anadolu Ajansı, 2023).

5. UAV Base Location Selection for a Possible Marmara Earthquake

The rapid initiation of search and rescue operations after an earthquake is crucial for saving as many lives as possible. Given the significant impact anticipated from a possible Marmara earthquake, it is emphasized in both research and statements from experts that a very swift response is necessary. Therefore, this study aims to select the location for an UAV base that can respond most rapidly to such an earthquake using the multi-criteria decision-making method TOPSIS. As for the UAV class, MALE (Medium Altitude Long Endurance) class UAVs, which are both produced in Türkiye and preferred due to their mission duration and payload capacity according to NATO classification, have been chosen. The criteria used in the study are determined based on the capabilities and features of MALE class UAVs, while the alternatives are identified as airports that are least likely to be damaged in a possible earthquake and are also close to the Marmara region.

6. TOPSIS Method

The TOPSIS method, initially developed by Hwang and Yoon (1981), is one of the multi-criteria decision-making methods that uses "n" decision criteria and "m" decision alternatives. The TOPSIS method is fundamentally based on ranking decision alternatives according to their distances from the computed positive ideal and negative ideal solution points. When the objective is to maximize returns, proximity to the positive ideal solution point maximizes returns and minimizes costs, while proximity to the negative ideal solution point minimizes returns and maximizes costs (Behzadian et al., 2012).

6.1. Steps of TOPSIS Method

The TOPSIS method begins with the construction of the decision matrix, followed by the normalization and weighting of this matrix. The positive ideal and negative ideal solution values are then determined, and the proximity of the alternatives to these values is calculated. Finally, the process is completed by calculating the relative closeness to the ideal solution.

Step 1: Construction of the Decision Matrix

In the TOPSIS method, the first step before proceeding with the solution is to construct the decision matrix. In this matrix, the rows represent the decision alternatives to be compared in terms of their superiority, and the columns represent the decision criteria used to compare the alternatives (Ömürbek and Kınay, 2013). The decision matrix has dimensions of "m x n" and is shown below in Equation 1.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{m1} & \cdots & a_{nj} & \cdots & a_{mn} \end{bmatrix} \tag{1}$$

In matrix A, "m" represents the number of decision alternatives, and "n" represents the number of decision criteria.

Step 2: Construction of the Normalized Decision Matrix

To construct the normalized decision matrix, the column totals are calculated by taking the sum of the squares of the elements in each column for each a_{ij} element. Then, each a_{ij} element is normalized by dividing it by the square root of the column total in which it is located (Alp and Engin, 2011). This process is shown below in Equation 2.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \ (i = 1, \dots, m \ ve \ j = 1, \dots, n) \tag{2}$$

The normalized decision matrix is shown in Equation 3.

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1j} & \cdots & r_{1n} \\ \vdots & & \vdots & & \vdots \\ r_{i1} & \cdots & r_{ij} & \cdots & r_{in} \\ \vdots & & \vdots & & \vdots \\ r_{m1} & \cdots & r_{nj} & \cdots & r_{mn} \end{bmatrix} \tag{3}$$

Step 3: Construction of the Weighted Normalized Decision Matrix

Each element in the normalized decision matrix is weighted by a w_i value. The w_i values, or criterion weights, must sum to 1. During the weighting process, each column in the Normalized Decision Matrix (R) is multiplied by the corresponding weight value (Alp and Engin, 2011). Since each column represents a decision criterion, the criteria are effectively multiplied by their respective weights. This results in the weighted standardized decision matrix (V), as shown in Equation 4.

$$V = \begin{bmatrix} w_1 r_{11} & \cdots & w_j r_{1j} & \cdots & w_n r_{1n} \\ \vdots & & \vdots & & \vdots \\ w_1 r_{i1} & \cdots & w_j r_{ij} & \cdots & w_n r_{in} \\ \vdots & & \vdots & & \vdots \\ w_1 r_{m1} & \cdots & w_j r_{nj} & \cdots & w_n r_{mn} \end{bmatrix} \tag{4}$$

Step 4: Obtaining Positive Ideal and Negative Ideal Solution Values

To obtain the Positive Ideal solution values (A^*), the largest values of the columns in the Weighted Normalized Decision Matrix (or the smallest if the decision criterion is for minimization) are selected. This selection is carried out using the equation $A^* = \{(max v_{ij} | j \in J)\}$ and is represented as $A^* = (v_1^*, v_2^*, \dots, v_n^*)$. Similarly, to obtain the Negative Ideal solution values (A^-), the smallest values of the columns in the Weighted Normalized Decision Matrix (or the largest if the decision criterion is for minimization) are selected. This selection is derived from the equation $A^* = \{(min v_{ij} | j \in J)\}$, and is represented as $A^- = (v_1^-, v_2^-, \dots, v_n^-)$ (Ömürbek and Kınay, 2013).

Step 5: Calculating the Distances to Positive Ideal and Negative Ideal Points

In this step, the distances of the decision alternatives from the Positive Ideal and Negative Ideal solutions are calculated. The Euclidean distance approach is used for this calculation. The distance of each decision alternative to the Positive Ideal point is shown in Equation 5 (Kallo, 2015).

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^*\right)^2} \tag{5}$$

As a result, there will be S_i^+ and S_i^- values for each decision alternative.

Step 6: Calculating the Relative Closeness to the Ideal Solution

To calculate the relative closeness of the decision alternatives to the ideal solution, the distances obtained in the previous step from the positive ideal and negative ideal points are utilized. This calculation is performed by dividing the distance of each alternative to the negative ideal point by the total distance, as shown in Equation 7.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^+} \tag{7}$$

Here, the C_i^* value is $0 \leq C_i^* \leq 1$. A C_i^* value of 1 indicates that the decision alternative is absolutely close to the ideal solution, while a C_i^* value of 0 indicates that the decision alternative is absolutely close to the negative ideal solution (Çağlı, 2010).

7. UAV Base Location Selection for a Possible Marmara Earthquake with TOPSIS Method

In this study, the location for establishing a MALE-class UAV base that can respond to a possible Marmara earthquake as quickly as possible was evaluated using the TOPSIS method. After discussing the alternatives and criteria used in the application below, the alternatives will be evaluated based on these criteria.

7.1. Alternatives Used in Application

MALE-class UAVs have been considered the most effective UAV class for post-earthquake support activities due to their flight endurance (up to 40 hours) and the type and amount of payload they carry (such as electro-optic/infrared cameras, base stations). Therefore, it was preferred to establish a MALE-class UAV base in the study. These UAVs, as they perform take-offs and landings from runways, were selected as alternative airports in the application.

When selecting airports, civil airports were chosen that are not located on any active fault lines according to the Türkiye Earthquake Map, to avoid being affected by a possible earthquake, and that are within a 600 km distance from the

Marmara Region to ensure quick access to the area post-earthquake. The airports that meet these criteria and were used as alternatives in the application include Ankara/Esenboğa (1), Gazipaşa-Alanya (2), Konya (3), Nevşehir/Kapadokya (4), Sinop (5), Sivrihisar Aviation Center (6), and Zonguldak (7) Airports. These alternatives have been shown in Figure 1, respectively.

7.2. Determination of Criteria Used in the Application

In determining the criteria, factors such as meeting the needs of MALE-class UAVs, susceptibility to earthquakes, and the ability to respond quickly to earthquakes were considered. Six criteria were established based on the opinions of five UAV pilots. The criteria weights were also determined based on evaluations made by these five UAV pilots. Each of these five UAV pilots are actively flying MALE-class UAVs, with flight experience ranging from 3 to 5 years and between 1200 and 2500 flight hours. Additionally, three of the experts participated in UAV operations after the 2020 Elazığ/Sivrice and 2023 Kahramanmaraş earthquakes, while two were involved in operations after the 2023 Kahramanmaraş earthquakes. The criteria used in the study and their definitions are provided below:

Distance to Fault Lines: To ensure that the UAV base to be established is not damaged by earthquakes and that support activities can be carried out without disruption, the selected location should be far from fault lines. The distance to the nearest active fault for the alternatives was measured from the Türkiye Earthquake Hazard Map. This is a criterion that is desired to be maximized.

Distance to the Marmara Region: Since the goal is to select a location that can respond to a possible Marmara earthquake as quickly and effectively as possible, the distances of the alternatives to the Marmara Region and to Istanbul, which is the largest city in Türkiye, were measured. This is a criterion that is desired to be minimized.

Distance to City/Town Centers: To meet the basic, social, and cultural needs of the personnel who will work at the planned UAV base, the distance of the alternative airports from city centers is important. The road distances of the alternatives to the nearest city or town centers were measured. This is a criterion that is desired to be minimized.

Airport Traffic Density: Since UAV systems have lower descent and climb performance compared to manned aircraft, and due to potential traffic disruptions during UAV take-offs and landings, the daily flight numbers of the alternative airports were obtained from internet sites and Flight Radar applications. This is a criterion that is desired to be minimized.

Meteorological Conditions: UAVs cannot operate on cloudy and rainy days, so the annual average number of rainy days in the cities where the alternatives are located was obtained from the website of the General Directorate of Meteorology. This is a criterion that is desired to be minimized.

Runway Length: This is a necessary criterion for ensuring that aircraft used in UAV systems can take off and land safely. This is a criterion that is desired to be maximized.

7.3. Evaluation of Criteria and Alternatives by Decision Makers

The first step in using the method is the creation of the decision matrix. Based on the determined alternatives and criteria, the decision matrix, constructed according to Equation 1, is presented in Table 3.

Table 3. Decision Matrix

Alternatives	**Distance to Fault Lines (km) Max**	**Distance to the Marmara Region (km) Min**	**Distance to the City/Town Centers (km) Min**
Ankara/Esenboğa	85	354	13
Gazipaşa-Alanya	227	594	42
Nevşehir/Kapadokya	174	532	30
Konya	99	453	12
Sinop	94	521	7
Sivrihisar	144	284	21
Zonguldak	107	269	11

Alternatives	Airport Traffic Density (Number of Flights) Min	Meteorological Conditions (Day) Min	Runway Lenght (m) Max
Ankara/Esenboğa	253	103	3752
Gazipaşa-Alanya	15	74	2500
Nevşehir/Kapadokya	13	107	3000
Konya	16	83	3348
Sinop	2	132	2000
Sivrihisar	2	70	2131
Zonguldak	4	147	1810

After determining the decision matrix, the normalization process is carried out. The R Normalized Decision Matrix obtained using Equation 2 is shown in Table 4.

Table 4. Normalized Decision Matrix

R	Distance to Fault Lines (km) Max	Distance to the Marmara Region (km) Min	Distance to the City/Town Centers (km) Min
Ankara/Esenboğa	0.22729	0.30017	0.21703
Gazipaşa-Alanya	0.60700	0.50367	0.70117
Nevşehir/Kapadokya	0.46528	0.45110	0.50084
Konya	0.26473	0.38411	0.20033
Sinop	0.25136	0.44177	0.11686
Sivrihisar	0.38506	0.24081	0.35058
Zonguldak	0.28612	0.22809	0.18364
R	Airport Traffic Density (Number of Flights) Min	Meteorological Conditions (Day) Min	Runway Lenght (m) Max
Ankara/Esenboğa	0.99478	0.36796	0.51855
Gazipaşa-Alanya	0.05898	0.26436	0.34551
Nevşehir/Kapadokya	0.05111	0.38225	0.41462
Konya	0.06291	0.29651	0.46271
Sinop	0.00786	0.47156	0.27641
Sivrihisar	0.00786	0.25007	0.29452
Zonguldak	0.01573	0.52515	0.25015

Table 5. Defuzzified Importance Weights

Importance Weights	Defuzzified Values
Very Low (VL)	0
Low (L)	0.1
Medium Low (ML)	0.3
Medium (M)	0.5
Medium High (MH)	0.7
High (H)	0.9
Very High (VH)	1

In the TOPSIS method, since the sum of the criterion weights must equal 1, the weights assigned by the five experts for each criterion were averaged. Then, each criterion's average was divided by the sum of all criterion weight averages to calculate the final criterion weights. The resulting W Importance Weights are shown in Table 6. The criterion weights, listed from highest to lowest, are as follows: distance to the Marmara Region, distance to fault lines, meteorological conditions, airport traffic density, distance to city/town centers, and runway length.

Table 6. Criteria Importance Weights

W	Distance to Fault Lines (km) Max	Distance to the Marmara Region (km) Min	Distance to the City/Town Centers (km) Min
Weights	0.19262	0.19672	0.13525
W	Airport Traffic Density (Number of Flights) Min	Meteorological Conditions (Day) Min	Runway Lenght (m) Max
Weights	0.16803	0.18033	0.12705

Subsequently, the importance weights of the criteria were associated with the normalized decision matrix using Equation 4, resulting in the weighted normalized decision matrix V as shown in Table 7.

Table 7. Weighted Normailzed Decision Matrix

V	Distance to Fault Lines (km) Max	Distance to the Marmara Region (km) Min	Distance to the City/Town Centers (km) Min
Ankara/Esenboğa	0.04378	0.05905	0.02935
Gazipaşa-Alanya	0.11692	0.09908	0.09483
Nevşehir/Kapadokya	0.08962	0.08874	0.06774
Konya	0.05099	0.07556	0.02709
Sinop	0.04842	0.08691	0.01581
Sivrihisar	0.07417	0.04737	0.04742
Zonguldak	0.05511	0.04487	0.02484

V	Airport Traffic Density (Number of Flights) Min	Meteorological Conditions (Day) Min	Runway Lenght (m) Max
Ankara/Esenboğa	0.16716	0.06635	0.06588
Gazipaşa-Alanya	0.00991	0.04767	0.04390
Nevşehir/Kapadokya	0.00859	0.06893	0.05268
Konya	0.01057	0.05347	0.05879
Sinop	0.00132	0.08504	0.03512
Sivrihisar	0.00132	0.04509	0.03742
Zonguldak	0.00264	0.09470	0.03178

The fourth step of the TOPSIS application involves finding the positive ideal and negative ideal solutions, or in other words, the maximum and minimum values. In this stage, the maximum and minimum values for each column are determined. Since there are 6 criteria in this study, there will be 6 maximum and minimum values. These values are determined and shown in Table 8.

Table 8. Positive Ideal and Negative Ideal Solutions

A^*	0.11692	0.04487	0.01581
A^-	0.04378	0.09908	0.09483
A^*	0.00132	0.04509	0.06588
A^-	0.16716	0.09470	0.03178

The fifth step of the TOPSIS method involves finding the distance values to the positive ideal and negative ideal points. In this stage, the distances from each decision point to the maximum and minimum values, i.e., the positive ideal and negative ideal points, are calculated. Since the decision points in this application are UAVs, there are 7 negative ideal and ideal distance values. The distances to the positive ideal and negative ideal points are determined using the calculations in Equations 5 and 6 and are provided in Table 9.

Table 9. Distances to the Positive Ideal and Negative Ideal Points

Alternatives	Distances to the Positive Ideal Points	Distances to the Negative Ideal Points
Sivrihisar	0.03369	0,00786
Konya	0.00975	0,03243
Nevşehir/Kapadokya	0.00616	0,02919
Zonguldak	0.00562	0,03214
Sinop	0.00900	0,03402
Gazipaşa-Alanya	0.00364	0,03584
Ankara/Esenboğa	0.00753	0,03503

The sixth and final step of the TOPSIS method is the calculation of the relative closeness to the ideal solution. In this stage, the solution is reached and the performance values of the analyzed alternatives are determined by performing the calculations in Equation 7. In the final process, a ranking is made from the best alternative to the worst alternative as shown in Table 10.

Table 10. Ranking of Alternatives Based on Their Closeness to the Ideal Solution

Closeness to the Ideal Solution	Alternatives
0.907722808	Sivrihisar
0.851118387	Konya
0.825678903	Nevşehir/Kapadokya
0.823133448	Zonguldak
0.790765669	Sinop
0.768912139	Gazipaşa-Alanya
0.189111002	Ankara/Esenboğa

As a result of the ranking using the TOPSIS method, the most suitable airport for establishing a UAV base to respond to a possible Marmara earthquake is Sivrihisar Aviation Center. In contrast, Esenboğa received the lowest value among the other alternatives.

In the TOPSIS method, since expert opinions are utilized in the stages of determining and weighting the criteria, it should be noted that the results are aligned with these perspectives and are not entirely based on objective data. Changes made to the criteria and their weights may also affect the results.

8. Conclusion

In modern times, UAVs are used effectively in various fields, including disaster management. One of the most significant disasters that comes to mind is earthquakes. UAVs play a widespread role, especially in supporting search and rescue operations following an earthquake. In Türkiye, the role of UAVs in a potential Marmara earthquake is crucial. The selection of a UAV base location for the quickest and most effective response to such an earthquake can be determined using multi-criteria decision-making methods.

In this study, the focus was first on Unmanned Aerial Vehicles (UAVs), earthquake disasters, and the use of UAVs in earthquakes. Subsequently, the selection of a UAV base location for the quickest response to a potential Marmara earthquake was evaluated using the multi-criteria decision-making method, TOPSIS.

For the TOPSIS method, alternatives were chosen as airports near the Marmara Region (within 600 km) and located in areas not affected by earthquakes, including Ankara/Esenboğa, Gazipaşa-Alanya, Konya, Nevşehir/ Kapadokya, Sinop, Sivrihisar Aviation Center, and Zonguldak Airports.

When determining the criteria, factors such as meeting the needs of MALE-class UAVs, susceptibility to earthquakes, and the ability to respond quickly to earthquakes were considered. Six criteria were established based on the opinions of five UAV pilots. These criteria are distance to fault lines, distance to the Marmara Region, distance to city/town centers, airport traffic density, meteorological conditions, and runway length. The criteria weights were also determined based on the evaluations of these five UAV pilots.

As a result of applying the TOPSIS method, the selected alternatives were ranked from worst to best for their suitability as UAV bases in post-earthquake disaster operations in the Marmara region. The ranking was as follows: Esenboğa Airport, Gazipaşa Airport, Sinop Airport, Zonguldak Airport, Kapadokya Airport, Konya Airport, and Sivrihisar Aviation Center.

Researchers can explore the use of UAVs for other types of disasters in their future studies. Other methods such as deep learning and machine learning could be used alongside the TOPSIS method. Similar studies can also be conducted for different regions of the country. Furthermore, research can be done using the same alternatives but with different criteria and criteria weights. Additionally, the criterion weights can be determined using a multi criteria decision making method instead of expert opinion, or the impact of changing one or more criterion weights in the same application can be evaluated.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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The Role of the Beechcraft C90 GTi Aircraft Used Within the Scope of Basic Flight Training

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Abstract

The Beechcraft C90 GTi aircraft is considered one of the technically advanced aircraft under today's conditions. Technological developments in aircraft have raised the question of how such technically advanced aircraft can be integrated into flight training. In this regard, this study investigates the use of the Beechcraft C90 GTi aircraft, which is technologically more advanced than the multi-engine aircraft used in basic flight training, in the multi-engine rating training phase of the ATP integrated training. The aim of the study is to determine the training process for this aircraft, along with its training requirements and student pilots' perceptions during the training process. To this end, a case study, one of the qualitative research designs, is conducted. The data are collected through semi-structured interviews and analyzed using the descriptive analysis method. The study participants consist of 14 student pilots who have received multi-engine rating training on the Beechcraft C90 GTi aircraft at the Department of Flight Training of Eskişehir Technical University. Findings are supported by direct quotations. As a result, the advantages and disadvantages of training on the Beechcraft C90 GTi aircraft and student pilots' recommendations for improving the training are presented.

1. Introduction

In the dynamically developing aviation industry, it is necessary to ensure the suitability and applicability of flight training programs and update the aspects that need improvement. Generating training programs that can maximize the potential of student pilots during flight training is of critical importance for ensuring quality and safety in air transportation service. The Department of Flight Training of Eskişehir Technical University Faculty of Aviation and Astronautics was established to train pilots in line with the needs of the aviation industry. The program designed to provide training for this purpose uses different aircraft. Beechcraft C90 GTi is one of these aircraft. The Beechcraft C90 GTi aircraft is used to train pilots for an Airline Transport Pilot License (ATPL) at the Department of Flight Training of Eskişehir Technical University. This aircraft started to be used in the multi-engine rating phase of the ATP integrated training in May 2010. Multi-engine rating training is a process where students acquire the skills to fly as the pilot-in-command of an aircraft with more than one engine. Undergoing this training is among the requirements for becoming an airline pilot. For most pilots, multi-engine rating training can be considered the first step of flying complex aircraft. During the period when the Beechcraft C90 GTi was used, training was provided to 263 students, reaching a total of 3130.7 flight hours.

During the inspection carried out by the Directorate General of Civil Aviation on May 28-29, 2019, it was stated that "The ATP integrated course offered, which is not supposed to include type rating training, is conducted with the BE-C90 GTi aircraft, which requires type rating contrary to the relevant regulation" by referring to SHT-FCL Appendix-1.3 A.9. Hence it was decided that it is inappropriate to provide training on the Beechcraft C90 GTi aircraft in the ATP integrated course and this should be corrected.

With the development of general aviation, technically advanced aircraft have recently been used in general aviation. These aircraft generally consist of a main flight screen, a multifunctional screen with a global positioning system (GPS) containing traffic and terrain information, and a cockpit system with a fully integrated autopilot. Fatal accidents have increased with the use of technically advanced aircraft in general aviation. The inadequate training format in the field of general aviation and the necessity for improving training programs provided on these aircraft have been indicated as the reasons for this increase (Aircraft Owners and Pilots Association, 2005).

Today, the C90 GTi aircraft is considered a technically advanced aircraft. Technically advanced aircraft may include a range of specifications such as digital flight controls, high-performance engines, environmentally friendly design, modern cockpit technology, communication systems, and safety measures. With the widespread use of technically advanced aircraft, how pilot training will be integrated with the evolving technology in these aircraft has become an important issue. In this respect, the importance of developing decision-making, situational awareness, risk management, and single-pilot resource management, along with scenario training in pilot training, has been stressed (Dornan et al., 2018).

According to the study conducted by Sülla in 2005, the transition from the single-engine phase to the multi-engine training phase in basic flight training means a new cockpit for student pilots with which they have no experience. This change means an increased mental workload for student pilots. Students were asked about stages of instrument training at which the highest mental workload occurs. According to students' answers, they experienced more workload in multi-engine training for three of the five different stages of training. The speed of the aircraft and the design of the flight indicators are regarded to be the main reasons for the increased mental workload at different stages of single-engine and multi-engine flights. It was found that flight preparation is very important to avoid such difficulties in the transition from single-engine to multi-engine training (Sülla, 2005).

The training of pilots who transition from traditional analog cockpits to modern technological cockpits, defined as glass cockpits, has been one of the important problems in the aviation industry from the 1980s to the present day. Considering incidents and accidents in the aviation industry, it has been proven that these technological advancements have changed the functioning of the cockpit, and the change in question cannot be given as an add-on to existing training. A study was conducted by Lund University School of Aviation to investigate the impact and transformation of technically advanced aircraft on basic flight training. The study revealed that the precision of the numerical information on the primary flight display (PFD) did not pose a problem for student and instructor pilots. Furthermore, it was found that the higher speed of the aircraft compared to other single-engine training aircraft posed fewer problems for student and instructor pilots. In the surveys conducted with flight instructors after the training, instructor pilots stated that they had problems finding the right information on the flight screens at the right time. According to another finding of the study, planning and preparing the training material before the training is among the main causes of successful training. Carrying out pre-airline training in modern cockpits creates an improved learning environment and contributes to both increased safety and subsequent training for pilots (Nahlinder et al., 2006).

According to the study conducted by Socha et al. in 2020, cockpit changes can affect the perception of flight data and the psychophysiological state of the pilot, especially among inexperienced pilots. The study on the effect of cockpit changes shows that the sudden change in flight data is a potential stress factor for the pilot, but the sudden change in flight data may not be regarded as a factor affecting the workload. In addition, cockpit changes may result in reduced performance. Therefore, the transition from analog to glass cockpits in basic flight training should be considered a factor affecting performance. According to another result, the acquisition of piloting habits and familiarization with the cockpit are the most important factors affecting participants (Socha et al., 2020).

Technically advanced aircraft with glass cockpits have become popular in the field of general aviation following the high-tech cockpit integration of airlines. A study conducted to investigate how the pilot, who has learned to fly in an analog aircraft, responds to emergencies in an aircraft with a high-tech glass cockpit found that pilots transitioned from emergency to safe status on analog displays more quickly. In addition, this study showed that advanced technology glass cockpits in aircraft may not be beneficial for pilots' performance (Hiremath et al., 2009).

Flight training programs should not be considered only as training of flight training organizations. This training is also a shared management process involving aircraft manufacturers, operators, pilots, and aviation safety authorities. For successful flight training, it is very important that these stakeholders receive the necessary training, as well as their awareness, experience, and opinions about the training. The goal of an effective training program is to ensure that every student pilot trained acquires the competency and proficiency required to operate safely in complex and challenging environments, considering both psychomotor skills and aviation knowledge. Although competency is defined as fulfilling basic requirements, the purpose of flight training is beyond this and is to ensure that a pilot exhibits a sustainable performance throughout their life. The Beechcraft C90 GTi aircraft used in multi-engine rating training at the Department of Flight Training of Eskişehir Technical University differs from the aircraft used for multi-engine training in other flight training organizations. Hence it is essential to receive the opinions of students who have completed their multi-engine rating training on the Beechcraft C90 GTi aircraft at the Department of Flight Training and collect data about the training program to develop and organize flight training programs.

This study's purpose is to investigate the role of the Beechcraft C90 GTi aircraft used in multi-engine rating training at the Department of Flight Training of Eskişehir Technical University. Through experiences of student pilots undergoing training at the Flight Training Department, this study aims to identify and present the training process for Beechcraft C90 GTi, the training requirements, and student pilots' perceptions of the Beechcraft C90 GTi aircraft. Furthermore, the findings of this study serve as a valuable resource for organizing the multi-engine rating training offered at Eskişehir Technical University and regulating the training provided for the aircraft used.

To achieve the stated objectives, answers are sought to the research questions below:

1. What are the opinions of student pilots about using the Beechcraft C90 GTi aircraft in multi-engine rating training?
2. What are the opinions of student pilots about the advantages and disadvantages of using the Beechcraft C90 GTi aircraft in multi-engine rating training?
3. What do student pilots recommend for more effective and efficient implementation of the training process in multi-engine rating training?

A case study, which is used to examine a specific event, group, or subject in detail, was used as the research method in this study.

2. Method

This study employs a qualitative research method to investigate the role of the Beechcraft C90 GTi aircraft in basic flight training by collecting qualitative data from student pilots at Eskişehir Technical University Department of Flight Training in multi-engine rating training. Qualitative research is a research method that presents situations or perceptions realistically and as a whole, using data collection methods such as interviews and document analysis (Yıldırım & Şimşek, 2013). In contrast to quantitative methods, it does not aim for broad generalization to large populations. Qualitative methodology focuses on understanding specific contexts, cases, or phenomena in-depth. The findings are often not intended to be statistically representative of a larger population (Yıldırım & Şimşek, 2013, Creswell 2020).

There are different methods used in qualitative research. Different classifications are available in the literature regarding these methods. Narrative research, phenomenological research, theory-building research, ethnographic research, and case study designs are the main qualitative research designs in social sciences and health sciences literature. In this study, a case study was conducted. The case study is a qualitative research design where the researcher creates case themes and describes the situation using multiple information sources such as interviews and observations in real life or a current situation(s) (Creswell, 2020). A case study starts with identifying a specific situation involving an individual, group, or organization. The study's objective plays an important role in how the case is examined. In case studies, the emphasis is on understanding and describing the unique context and details of this specific situation—referred to as the "internal situation." Additionally, in problems with a clear purpose, research conducted to describe and understand the problem in the best way possible is defined as an instrumental situation. Presenting a detailed and in-depth perspective in case studies is essential. Data analysis in case studies may differ depending on the chosen approach. In some cases, the analysis involves the analysis of different units or components within a situation, while in others, it focuses on analyzing the situation in its entirety. Furthermore, the detailed description of the situation in the research study is important for understanding the analysis (Creswell, 2020).

In qualitative studies, semi-structured interviews are a source of data where open-ended questions included in the semi-structured interview form provide qualitative data about the situation (Büyüköztürk et al., 2014). The purpose of using semi-structured interviews in qualitative research is to benefit from people's experiences regarding the determined subject and explain how they make sense of the subject, contrary to testing a hypothesis (Türnüklü, 2000). In this data collection technique, the researcher prepares the questions they want to ask about the subject in advance. However, according to the flow of the interview, the interviewer can acquire in-depth information about the subject by asking sub-questions or more details based on the answers given.

In the present study, a semi-structured interview was used. In preparing a semi-structured interview form, expert opinion from a flight engineer and an instructor pilot was obtained to ensure that questions serving the research question are accurate, not directive, and comprehensible. This semi-structured interview form is used to obtain data regarding the opinions of student pilots who have received training on the Beechcraft C90 GTi aircraft used in multi-engine rating training at the Department of Flight Training of Eskişehir Technical University on the aircraft in question, the advantages and disadvantages of having received training on this aircraft, and students' recommendations for more effective and efficient multi-engine rating training.

The semi-structured interview form comprises eighteen questions aiming to find answers to the three research questions provided in the Introduction section. In the first section of the semi-structured interview form prepared, the participant was informed about the interview with a preliminary information text. Owing to the preliminary information text, the participant was provided with detailed information to warm up to the interview and answer the questions sincerely. Moreover, if the participant had any questions about the interview, they were answered sincerely in this section, and permission was requested to start the interview. In the second section, the prepared eighteen questions were asked to the participants. These questions included questions asked differently for the same research question. Using these questions, it was aimed at conducting interviews more reliably, collecting more detailed data by asking questions from different perspectives, and creating an environment for the participants to express themselves sincerely.

The purposive sampling method was used to determine the study group in the research. The purposive sampling method includes a sample group determined by considering whether individuals are directly related to the research subject when selecting individuals for a detailed study (Karataş, 2015). Within the scope of the study, fourteen student pilots who had received multi-engine rating training on the Beechcraft C90 GTi aircraft were interviewed.

Table 1 contains detailed information about the date, time, duration, and data collection method of the interviews with the student pilots.

Table 1. Semi-Structured Interview Data Collection Table

Code Name	Date	Time	Duration	Way of Data Collection
P1	26.08.2021	22:00	35 MIN	Semi-structured interview and audio recording
P2	26.08.2021	18:00	28 MIN	Semi-structured interview and audio recording
P3	12.08.2021	14:00	29 MIN	Semi-structured interview and audio recording
P4	25.08.2021	14:00	86 MIN	Semi-structured interview and audio recording
P5	28.08.2021	14:00	24 MIN	Semi-structured interview and audio recording
P6	19.08.2021	14:00	29 MIN	Semi-structured interview and audio recording
P7	29.08.2021	14:00	47 MIN	Semi-structured interview and audio recording
P8	27.08.2021	16:00	15 MIN	Semi-structured interview and audio recording
P9	06.08.2021	14:00	31 MIN	Semi-structured interview and audio recording
P10	18.08.2021	14:00	42 MIN	Semi-structured interview and audio recording
P11	11.08.2021	14:00	34 MIN	Semi-structured interview and audio recording
P12	13.08.2021	14:00	32 MIN	Semi-structured interview and audio recording
P13	09.08.2021	14:00	27 MIN	Semi-structured interview and audio recording
P14	23.08.2021	21:00	23 MIN	Semi-structured interview and audio recording

A code name is allocated to each participant to maintain their anonymity, keeping their identities confidential. Necessary permissions were received from the Ethics Commission of Eskişehir Technical University to conduct the interviews. Information about the research was provided to the participants at the beginning of the interview. The student pilots to be interviewed were determined based on their being voluntary, and there was no pressure on them to participate in the interview. Interviews conducted in the Zoom video call environment lasted approximately twenty to twenty-five minutes and were audio- and video-recorded with the participants' permission.

Table 2. Semi-Structured Interview Data Collection Table

Research Questions	Data Collection Tool	Data Analysis Method
Research Questions	Semi-structured interview form	Descriptive analysis

The researcher first transcribed the audio recordings taken during the interviews separately for each participant using the Microsoft Word program. Fourteen documents consisting of forty-nine thousand words and ninety-four pages were obtained by transcribing the interviews with the fourteen student pilots. Then these documents were analyzed using the descriptive analysis method with the NVivo 12 application. The descriptive analysis method organizes and interprets the data obtained from the interview within the conceptual framework created before the research and presents it to the reader by quoting the participants' statements when necessary (Karataş, 2015). Direct quotations were made from the interview records under the determined themes.

3. Findings and Comments

This section presents the findings obtained from analyzing the qualitative data collected during the research process.

3.1. Opinions of Student Pilots About Using the Beechcraft C90 GTi Aircraft in Multi-Engine Rating Training

Table 3 lists the findings regarding the research question, "What are the opinions of student pilots about using the Beechcraft C90 GTi aircraft in multi-engine rating training?".

Table 3. Opinions of Student Pilots About Using the Beechcraft C90 GTi Aircraft in Multi-Engine Rating Training

Preparing for work in the airline
Improving communication within the cockpit
Efficient multi-engine training

The interviewed student pilots stated that the Beechcraft C90 GTi aircraft, which they used in multi-engine rating training, prepared them for working in the airlines. The training on the Beechcraft C90 GTi aircraft is the final phase of the flight training for Eskişehir Technical University Department of Flight Training students. At the end of this process, students aim to apply for a job in the airlines and, if they succeed, start the type training for the aircraft deemed appropriate by the airlines. Therefore, due to the advanced features of the Beechcraft C90 GTi aircraft, receiving multi-engine training on this aircraft is also the first step of working in the airlines and adaptation for them. The student pilots' opinions on ensuring preparation for work in the airlines are as follows:

"The systems of the aircraft are as they should be in multi-engine aircraft and as in the aircraft we will fly in the future. Hence I think it is a very sufficient aircraft to prepare ourselves for the future." P6

"*When we talked to our friends who graduated before us, they said that many systems on the aircraft are very similar to the systems on airline aircraft and they have subsystems. Therefore, they said that they adapted to work in the airlines very quickly."* P2

"When I look into the cockpit of airline aircraft, at some systems and equipment, I see that I already know some things due to training on C90." P3

The student pilots interviewed expressed an opinion that multi-engine training was more efficient because they received multi-engine rating training on the Beechcraft C90 GTi aircraft. The goal of the training process on the Beechcraft C90 GTi aircraft in basic flight training is to ensure that student pilots who have previously received training on single-engine aircraft learn the flight characteristics of multi-engine aircraft, manage emergencies in multi-engine aircraft, handle the aircraft, and experience the take-off, approach, etc. skills they have practiced on single-engine aircraft in multi-engine aircraft. Additionally, in multi-engine training, student pilots carry out flight training by reducing the power of one engine of the aircraft and creating asymmetrical thrust with the operation of the other engine, so they experience processes such as approach and go-around. The interviewed student pilots think that receiving this training on the Beechcraft C90 GTi aircraft enabled them to complete it fully and safely since the aircraft in question has powerful engines. P9 described this in the following way:

"The C90 aircraft is really much more powerful than the training aircraft in other flight schools and is among the aircraft with single-engine approach and go-around features. Especially the fact that it has a turboprop engine was very beneficial. As I said, during the single-engine go-around phase, there was not a lot of altitude loss, or we didn't need things like increasing vertical speed to gain speed." P9

Furthermore, the student pilots indicated in the interviews that they effectively used the auxiliary equipment in technically advanced aircraft. It can be thought that this reduces the potential stress factor caused by the change of cockpit and aircraft for students who start multi-engine flights after single-engine aircraft. The opinions of the other student pilots who expressed their opinions about the efficiency of multi-engine training are given below:

"I find the C90 aircraft sufficient, especially in terms of performance. One of the most important issues here is the ability to carry out single-engine training on twin-engine aircraft. I think the C90 aircraft is quite sufficient in this regard." P6

"This aircraft was very good in those matters. For example, ILS. While it was more difficult to keep the TB20 aircraft on the ILS line in very windy or turbulent weather, it was much easier to perform ILS on the C90 aircraft. Having a flight director is also a big plus. When you use the flight director, you can see the error and intervene very quickly." P11

"It is an aircraft that can provide more than required for multi-engine training. I do not see any negative aspects." P5

3.2. Opinions of Student Pilots About the Advantages and Disadvantages of Using the Beechcraft C90 GTi Aircraft in Multi-Engine Rating Training

Table 4 contains the findings for the research question, "What are the opinions of student pilots about the advantages and disadvantages of using the Beechcraft C90 GTi aircraft in multi-engine rating training?".

Table 4. Opinions of Student Pilots About the Advantages and Disadvantages of Using the Beechcraft C90 GTi Aircraft in Multi-Engine Rating Training

Advantages	Disadvantages
Similarity of the cockpit and avionics	Rigid flight control levers
Having a flight management system (FMS)	Being high-performance
Single-engine training	The long turnaround time of the aircraft
Type rating	License renewal cost
Aircraft size	

3.2.1. Findings on the advantages

The advantages were summarized into five sub-themes based on interviews with pilot students who had received multi-engine training on the Beechcraft C90 GTi aircraft. The student pilots interviewed in the similarity of the cockpit and avionics category stated that they found the cockpit of the Beechcraft C90 GTi aircraft similar to the cockpit of the aircraft they planned to fly in the airlines in the future and some of the avionic equipment in the Beechcraft C90 GTi aircraft would be an advantage for them in the future. P1 expressed his opinion on this issue as follows:

"When I sat in the cockpit of the C90 aircraft, it generally reminded me of airline aircraft, such as Boeing 737 and A320. Our goal after graduating from this school is to work for airline companies. In this respect, when I sit in the cockpit of the C90 aircraft, I feel like I am sitting in the seat of Boeing 737 or A320. And the fact that it is a light aircraft, and a training aircraft has made me feel that it is actually my first step before working directly in the airlines." P1

Some private airlines conduct simulator exams during the pilot recruitment process. Student pilots who have received training on the Beechcraft C90 GTi aircraft are expected to adapt to the exam environment more easily due to the similarity of the cockpit during these exams. After the multi-engine training on the Beechcraft C90 GTi aircraft, the students realized the similarities of the cockpits, which they set as their goal after graduation and would be their future working environments, with that of the C90 GTi aircraft. The opinions of the student pilots on this issue are presented below:

"The systems inside the aircraft are exactly the same. The only difference is that we have one FMS, but there will be two of them in the airlines; only the auto-throttle system will be added. Currently, when I watch the videos of the airlines' Airbus 320 or Boeing 737, I don't feel anything unfamiliar because since I have flown on the C90 aircraft, many things and all kinds of systems are familiar to me." P14

"The biggest advantage of having received multi-engine training on the C90 aircraft is that it is very similar to the Boeing and Airbus aircraft that we dream of and want to fly in the future. It is really very similar, from its FMS to its operating principle and cockpit layout." P2

"As I mentioned before, the cockpit environment is definitely very similar to the cockpit environment of a Boeing 737 aircraft." P10

For the sub-theme of having an FMS under the theme of the advantages of using the Beechcraft C90 GTI aircraft in multi-engine rating training, students indicated the FMS, used for performance management, flight plans, flight guidance, and monitoring flight operations in airline flights, as an advantage of the multi-engine training they received. The student pilots' opinions on this issue are given:

"We talk to other graduates. Those who fly Boeing 737 say, "We have actually learned the FMS at school." I've even learned that the FMS of the same company is used in some aircraft. I have become familiar with using these systems, and I have learned not only how to use this system but also how to use it during the flight. In fact, while performing an FMS flight, I saw how important it is to transition to a flight with a different instrument system due to malfunction or something else, to flight with systems such as VOR, and to maintain the adaptation here." P3

"I think the most important advantage is the FMS because when we talked to our older friends working in the airlines, they always used to mention that the FMS on our aircraft is very close to those of Boeing or A320 in the airline. So they used to say that working in the airline after having learned this FMS provided an extra advantage for them." P2

"The biggest advantage is the FMS. We have gained a great advantage, especially due to the routes we enter in the FMS and the procedures we implement in the FMS." P12

In the single-engine training sub-theme of the theme of advantages of using the Beechcraft C90 GTi aircraft, the student pilots stated that during their flights on the Beechcraft C90 GTI aircraft, they underwent the single-engine training required in multi-engine training without any problems on the Beechcraft C90 GTi aircraft due to the aircraft's performance, which was an advantage for them. The opinions of the student pilots on this issue are presented below:

"It is very important to receive multi-engine training on a high-performance aircraft very similar to the aircraft we want to fly in the future and to be able to truly undergo single-engine training, i.e., to be able to cut the torque of one engine and make a pass with the other engine. And the aircraft must have power for this. Being able to complete all of these is a great advantage for student pilots." P6

"As I've heard from instructor pilots, most multi-engine aircraft do not have single-engine approach and go-around features, and they cannot perform them due to insufficient power. However, each engine of the C90 aircraft has turboprop 750 shaft power, and we could easily make a pass around the runway or perform a single-engine approach with its single engine." P9

"I think the biggest advantage is single-engine training, as I also mentioned in the beginning. We experienced single-engine flight at every phase of the flight, in level flight, descent, climb, go-around, and landing. This is the biggest advantage." P13

In the type rating sub-theme of the theme of advantages of using the Beechcraft C90 GTi aircraft in multi-engine rating training, students consider this as an advantage since they also received the type rating for the aircraft during the multi-engine training on the Beechcraft C90 GTi aircraft. P5 expressed his opinion regarding this by saying, *"Since C90 is a type-rated aircraft, we acquire type rating for four types, BE90-99-100 and BE200, which provides us with a great advantage in working life."* The student pilots' opinions on this issue are given below:

"Type rating is definitely an advantage. Currently, our graduates who have received training on this aircraft have a type rating recorded in their licenses additionally, and when we talk to our friends who have graduated, I think that graduates adapt more easily to airlines because, in this type rating, we fly the glass cockpit and high-performance aircraft." P12

Considering the aircraft size sub-theme, P10 expressed his opinion on this issue in the following way:

"The aircraft size is also an advantage. It is better in size than other multi-engine aircraft. I mean, the aircraft used by other schools are usually smaller, and they can host only two people. However, since it is a slightly more VIP aircraft, we learn to fly a slightly larger aircraft. We actually learn doing environmental control and using a larger aircraft on taxiways and the apron." P10

3.2.2. Findings on the disadvantages

The student pilots' opinions on the disadvantages of using the Beechcraft C90 GTi aircraft in multi-engine rating training specified in Table 4 are classified into four sub-themes. In the sub-theme of rigid flight control levers, the student pilots stated that the flight controls were rigid, causing some difficulties for them. The opinions of the student pilots on rigid flight controls are presented below:

"What everyone says is actually that the yoke is very heavy. But the pedals are also very heavy and it is very difficult to hold the brakes, especially on the ground." P4

"The only disadvantage I mentioned in the aircraft was its brakes. It required a lot of strength, and of course, we could do this together with our instructors by asking for help from them. Apart from that, I did not mention any disadvantages in the C90 aircraft." P6

"The most difficult part for me was trying to control the aircraft at the take-off point and landing because pulling the yoke was very difficult for me. Apart from that, I can't mention any disadvantages." P14

In the second sub-theme of the disadvantages, the student pilots indicated the fact that the Beechcraft C90 GTi aircraft is a high-performance aircraft as a disadvantage. The student pilots' opinions on the aforesaid issue are given below:

"As a disadvantage, the high performance of the aircraft can actually cause difficulties for student pilots because things may escape our control. Since the aircraft is very high-performance, for example, we may miss the altitude at which we will reach level flight when climbing. Because it is a high-performance aircraft and the aircraft on which we have received training before have lower performance, I can miss the altitude at which I want to take a level flight while focusing on something else." P1

"In multi-engine training, sometimes there may be places where we experience difficulties during the flight. I mean, we also undergo engine failure training, especially in the single-engine training part. In this part, since the engine of the aircraft is very powerful, when we reduce it to a single engine, it becomes a little difficult to control the aircraft and it is a bit tiring physically. Apart from that, I did not mention any disadvantages." P10

P4 expressed his thoughts in the sub-theme of the long turnaround time of the aircraft, another sub-theme of the disadvantages, in the following way:

"A small disadvantage of the C90 aircraft is that since it is a very large aircraft and has many systems, the preparation on the ground takes a very long time. I mean, it normally takes an average of 30 minutes. After the engine starts, when starting to taxi, the chock is taken and the duty period begins. However, since the duty period is one and a half hours long and 30 minutes are spent on the ground, there is only an hour left for the flight. Therefore, the long preparation on the ground is a disadvantage of the aircraft." P4

In the license renewal cost sub-theme, the student pilots interviewed stated that the renewal cost of a multi-engine rating license is higher compared to other aircraft when its validity period expires, which is a disadvantage. P9 expressed his opinion on this issue as follows, *"If we consider it as training, I don't see any disadvantages. We only need to do a check flight, which we call license renewal, after a year, which is a bit costly."*

3.3. Recommendations of Student Pilots for More Effective and Efficient Implementation of the Training Process in Multi-Engine Rating Training

Three categories were determined regarding the research question, "What do student pilots recommend for more effective and efficient implementation of the training process in multi-engine rating training?," and these categories are given in Table 5.

Table 5. Recommendations of Student Pilots for More Effective and Efficient Implementation of the Training Process in Multi-Engine Rating Training

Increasing the MCC flight time
Increasing the instrument flight time
Increasing the avionics course hours

Three categories were developed based on the recommendations from student pilots interviewed, aimed at achieving a more effective and efficient implementation of the multi-engine rating training process. The student pilots interviewed in the category of increasing the MCC flight time stated that the MCC training they received before the multi-engine rating training facilitated the adaptation to the Beechcraft C90 GTi aircraft along with the practices aimed at improving the communication between pilots, they obtained prior knowledge about the systems of the aircraft, and this adaptation would be enhanced by increasing the MCC flight times. Hence, they recommended increasing the MCC flight time. The student pilots' opinions on this issue are presented below:

"We actually get used to the C90 aircraft while receiving MCC training. So, if we extend the MCC process, I think the complexity and high performance of the C90 aircraft will no longer be an obstacle for students. Hence MCC can be extended." P1

"The MCC hours related to the training process can be increased, we can get to know the aircraft better in the simulators, and perhaps we can get used to the cockpit better." P8

"Since the simulator we use in MCC training before we start flying and the C90 cockpit are exactly the same, I think it will be a significant advantage for cockpit adaptation if the MCC duration is increased." P14

Concerning the category of increasing the instrument flight time in line with the recommendations of the student pilots interviewed, they find the instrument flight time in the training they received on the Beechcraft C90 GTi aircraft inadequate and think that it should be increased. The opinions of the student pilots under this category are presented below:

"I think that increasing instrument flight times on the C90 aircraft and performing operations in other places will contribute more." P5

"On C90, we fly 6 sorties in visual flights, 2 sorties in instrument flights, and 2 sorties in simulators, and then we take control. The visual flight part could perhaps be reduced to 4 or 5 sorties, and the instrument flight part could be increased." P7

"I think the flight time of C90 should definitely be increased. I believe that flight times, both visual flight and instrument flight times, must be increased." P4

P1, one of the student pilots interviewed in the category of increasing the avionics course hours within the research question, "What do student pilots recommend for more effective and efficient implementation of the training process in multi-engine rating training?", expressed his recommendation for improving the multi-engine rating process as follows:

"If I had to summarize the training process again, I would like the avionics course to be extended in terms of ground courses. By the way, I want the avionics course to be extended because I find it very beneficial, and since the instructor who teaches the avionics course and the instructor's preparation for the course and the documents, he presents to us are also very useful, the course can be kept longer to benefit more from it and for students to reinforce what they have learned." P1

4. Discussion

This section provides a discussion of the findings presented in the previous section as well as recommendations developed based on these findings.

The thesis study titled "The Role of the Beechcraft C90 GTi Aircraft in Basic Flight Training" attempted to determine the opinions of the student pilots who completed the multi-engine rating training on the Beechcraft C90 GTi aircraft about the training process, the advantages and disadvantages of the training on the Beechcraft C90 GTi aircraft, and their recommendations for more effective and efficient implementation of the training process. The findings obtained within the scope of the research subject are presented under the three research questions.

Upon addressing the findings for the research question, "What are opinions of student pilots about using the Beechcraft C90 GTi aircraft in the multi-engine rating training?", it is seen that the student pilots interviewed regard receiving multi-engine rating training on the Beechcraft C90 GTi aircraft to be the first step of the type rating they will receive during the airline training process for student pilots who aim to work in private airline companies after graduation since the Beechcraft C90 GTi aircraft has similar systems and equipment with the aircraft in the airline fleets. According to the study by Nahlinder et al. (2006), cockpit operation changes with technological developments in the aviation industry. Flight training organizations have difficulty adapting to change due to limited funding. Considering the student pilots' opinions about the Beechcraft C90 GTi aircraft, it can be stated that the aircraft in question is oriented toward technological change in the aviation industry and cockpit operation and is suitable for the change expected from flight training organizations and the training of new pilots.

In the study, the student pilots stated that during the training on the Beechcraft C90 GTi aircraft, unlike the previous training flights, they communicated better with the instructor pilot due to the lower noise level in the flights on this aircraft. In the study by Nahlinder et al. (2006), flight instructors thought that conducting training flights on aircraft with advanced cockpit noise cancellation systems creates a better training environment for student pilots. In this case, it seems that flights on the Beechcraft C90 GTi aircraft are a more efficient training environment for student pilots.

Since the Beechcraft C90 GTi aircraft has high-performance turboprop engines, the requirements and training practices of the multi-engine rating training were fully met in the study. The study by Sülla (2005) found that the higher cruising speeds of multi-engine training aircraft compared to single-engine training aircraft increase the mental workload on student pilots. The researcher emphasized the importance of flight preparation to avoid such problems. In the training plan of Eskişehir Technical University Flight Training Department, student pilots receive MCC training on a simulator similar to the Beechcraft C90 GTi aircraft prior to multi-engine rating training. This process is considered a preparation for multi-engine training.

Upon examining the sub-theme of the advantages for the research question, "What are the opinions of student pilots about the advantages and disadvantages of using the Beechcraft C90 GTi aircraft in multi-engine rating training?", it is seen that there are more advantages than disadvantages. The student pilots interviewed regard the similarity of the cockpit of the Beechcraft C90 GTi aircraft to the cockpit of passenger aircraft as an advantage. The study by Socha et al. (2020) stressed that, according to the information from airline pilots, it is essential that the aircraft used in basic flight training have advanced cockpit equipment. Therefore, it is important to understand the impact of the cockpits of training aircraft used in basic flight training. The student pilots interviewed regard receiving training on an aircraft with a Flight Management System (FMS), being able to experience single-engine training at every stage of the flight, giving a multi-engine rating as well as a type rating for the Beechcraft C90 GTi aircraft to those who have successfully completed the training, and the size of the aircraft as advantages.

Upon examining the disadvantages sub-theme, the student pilots interviewed regard the rigid flight control levers as a disadvantage. In terms of flight safety, instructor pilots should consider this when student pilots are in control of the aircraft. Student pilots consider the fact that the aircraft is high-performance as a disadvantage. As indicated by Sülla (2005), the speed of the aircraft increases the mental workload on student pilots, which student pilots consider as a disadvantage. Another disadvantage reported by student pilots is the long turnaround time of the aircraft. Flight planning should be made by considering this preparation process. Multi-engine rating is a type of license that should be renewed. If license renewal is required after training, it is found that the license renewal cost for the Beechcraft C90 GTi aircraft is higher in comparison with other multi-engine aircraft.

The recommendations of the interviewed student pilots for the research question, "What do student pilots recommend for more effective and efficient implementation of the training process in multi-engine rating training?" were evaluated. The study by Sülla (2005) emphasized the great importance of flight preparation in the transition to multi-engine flight training after single-engine flight training in basic flight training. The interviewed student pilots recommend increasing the flight duration of the MCC training they received as simulator training before their flights on the Beechcraft C90 GTi aircraft. Increasing the MCC flight time can prepare student pilots better for their training on the Beechcraft C90 GTi aircraft. Moreover, increasing the weekly course hours of avionics ground lessons can contribute to flight preparation. Multi-engine rating training on the Beechcraft C90 GTi aircraft consists of two phases: type training and instrument flight training. Instrument flight training includes 5 hours in total, 3 hours of which take place in the FNPT II simulator. The interviewed student pilots think that the instrument flight training, which is conducted as 2 hours on the C90 aircraft except for the simulator, should be increased. If multi-engine rating training is continued on the Beechcraft C90 GTi aircraft, it may be considered to increase the duration of instrument flight training on the Beechcraft C90 GTi aircraft.

4. Conclusion

Aircraft are means of transportation using technology at the highest level. Their technologies are updated every day. The competencies expected from pilot candidates increase depending on these developments. Furthermore, the rules set by aviation authorities for basic flight training should also be applied in line with the requirements of the day, along with the above-mentioned developments. It is especially important to conduct research that reveals the experiences and opinions of student pilots and instructor pilots who are directly involved in basic flight training. Training practices can be regulated by considering the opinions of student pilots during the multi-engine rating training process.

In line with these thoughts, the Beechcraft C90 GTi aircraft used in the multi-engine rating phase of basic flight training was evaluated by receiving the opinions of student pilots.

The study results have demonstrated the evident and significant benefits of using the Beechcraft C90 GTi aircraft, which is considered a technically advanced aircraft, in the multi-engine rating training phase of the ATP integrated training.

Future research should investigate how to eliminate the issues specified as disadvantages and how more technological aircraft can be integrated into flight training without violating flight safety.

Conflicts of Interest

There is no conflict of interest with any person or institution.

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The Effect of Service Encounters at Airports on Visitors' Behavior within the Scope of Social and Environmental Sustainability

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Abstract

The aviation industry, and more specifically airport management and airport marketing, has continuously evolved and progressed from the past to the present. Contrary to what happened in the past, the importance of airport marketing, which has been kept in the background until today, has started to be better understood by managers every day. The fact that resources are scarce and needs are unlimited has made concepts such as sustainability and green marketing become the focal point. For this purpose, a hybrid scale was developed by utilizing scales that were used in different studies at different times, consisting of factors that are closely related to social, environmental sustainability and green marketing concepts such as green image, green trust, green customer satisfaction and green word-of-mouth communication. Within the scope of the research, the data collected from the participants with the questionnaire method were analyzed and interpreted with the relevant factors. A 5-point Likert-type scale was used in the questionnaire. The surveys were conducted face-to-face. As a result of the analyses performed with this hybrid model, it was determined that the model fit values remained within the required values. Since different levels of factor loadings were obtained as a result of the analyzes, the explanation of the relationships between the factors was realized at different levels. A Structural Equation Model was created in the light of the data collected within the scope of the study. The results obtained through this model contribute to the examination and interpretation of the effects of service encounters at airports on the behavior of passengers or visitors within the scope of social and environmental sustainability. At the same time, by focusing on which factors should be at the forefront of airport management and airport green marketing activities, it is very important to eliminate the deficiencies, to reveal the aspects that need to be developed, to question the validity of the rules that apply in basic marketing activities in this application and to determine whether the mentioned factors are valid in practice.

1. Introduction

Today, the aviation sector is one of the leading sectors where intense competition is experienced globally. In the aviation sector, which is a service-oriented sector, competition and interaction within the sector are at a very high level (International Air Transport Association, 2020). Understanding the relationships between aviation businesses in a global competitive environment and analyzing the effects of environmental awareness on consumers is a very important issue to ensure the sustainability of businesses and the environment.

In its simplest form, sustainability is the balancing of economic expectations on the axis of environmental and social sensitivity. Since the 1970s, the aviation industry has played a leading role in sustainability. Reducing the noise levels of aircraft engines, reducing fuel use in airline transportation, and the steps taken towards e-transformation in order to minimize paper waste explain the situation (Torum and Küçük Yılmaz, 2009).

As an indispensable part of the rapidly developing aviation sector, airports play an important role in the economic and social development of the region in which they are located. On the other hand, in parallel with the growth of the sector, the environmental pollution impacts of the airport also increase. The fact that environmental pollution causes not only regional but also long-term global environmental impacts has brought the activities within the airport under control (Turkish Standards Institute, 2024).

In addition to all these, customers interact with business employees, the business environment and during the preparation of the product offered during the service process. In this process, customers want to be informed about all the activities that take place from the beginning of the production possibilities until the finalization of the service (Kurnaz & Özdoğan, 2017).

When the literature on this subject is examined, it is determined that a wide variety of studies have been conducted. Mohd Suki (2017) aimed to investigate the structural links of product quality, corporate image, store image and price on customer satisfaction and loyalty towards green product use in

Malaysia. Baumeister et al. (2022) aimed to examine the relationships between environmental responsibility, customer satisfaction and customer loyalty in an environmentally conscious airline. In another research, Wang et al. (2018) aimed to identify the impact of greenwashing on green image and consumers' word-of-mouth marketing intention and how this effect is mediated by green satisfaction and green trust. In another study, Ha (2022) investigated whether consumers' green justification affects green brand equity and if so, how effective it is by integrating the mediating role of green brand image, green satisfaction and green trust through the moderating role of green concern using legitimacy and signaling theories.

In addition, Hashish et al. (2022) empirically investigated the link between green perceived quality, green satisfaction, green trust and customers' green behavioral intentions in a sample of five-star eco-friendly hotels. In addition to all these studies, Çavuşoğlu et al. (2020) conducted a study to determine the effect of attitude towards green behavior on green image, green customer satisfaction and green customer loyalty. Although there are many studies in the literature, there is no other study that examines the relationship between green image, green customer satisfaction, green trust and green word-of-mouth communication within the scope of social and environmental sustainability in the aviation sector. This situation reveals the main purpose of the research.

One of the concepts that is closely related to the sustainability efforts of businesses in the aviation sector in Turkey is the "Green Organization Certificate". It is a type of certificate issued by the Directorate General of Civil Aviation (DGCA) to the organizations operating at airports in order to systematically reduce and, if possible, eliminate the damages they cause or may cause to the environment and human health.

In order to obtain the "Green Enterprise Certificate", aviation enterprises operating in Turkey must establish, implement, document and maintain an Environmental Management System in accordance with the current version of the TS EN ISO 14001 standard and the sectoral criteria determined by Directorate General of Civil Aviation (DGCA) and TSE, and complete the TS EN ISO 14001 "Environmental Management System Certification" process performed by TSE; create a Greenhouse Gas Inventory Report for each calendar year in accordance with the current version of TS EN ISO 14064-1 standard and greenhouse gas criteria and complete the verification of the Greenhouse Gas Inventory Report by Turkish Standards Institute in accordance with TS EN ISO 14064-3 standard. "Green Organization Certificate" is given by Directorate General of Civil Aviation to the enterprises that meet the specified requirements (Directorate General of Civil Aviation, 2024).

2. Materials and Methods

The survey method, one of the quantitative research techniques used in social sciences, was used in the study. The research provides the interpretation and examination of the relationships between visitors, service encounters and values by quantifying and scientificizing them.

The data required for the study were obtained from questionnaires (İslamoğlu & Alnıaçık, 2016), which are systematic questionnaires prepared to collect information from primary sources. The questionnaire was constructed with a 5-point Likert-type scale. The answers to the questions in the questionnaire are organized as "Strongly Disagree", "Disagree", "Neutral", "Agree" and "Strongly Disagree".

The questionnaire forms were filled in face-to-face by the senior managers of the businesses operating at the airport and the people visiting the airport.

Frequently used SPSS/AMOS programs were used in the analysis of the study. The data obtained through questionnaires and secondary data collection methods were first transferred to the Microsoft Excel program and coded, and then the results were analyzed and evaluations were made by entering data into the matrices obtained through the relevant programs and programming languages.

The sampling frame of the research was determined as people who have been as visitors or passengers one or more times in 51 airports that have green organization certificates in different processes as of the date of the study. The aforementioned airports have a green organization certificate and are in an important position hosting passengers or visitors on both national and international flights with various studies and projects on sustainability. Accordingly, it is considered that the sample size and frame are at the most appropriate level for the study.

The data collected as a result of the process were analyzed by creating structural equation modeling through IBM SPSS 25, AMOS.

The questionnaire prepared for the model created within the scope of the study consists of seven main factors and 18 sub-expressions, namely "Green Image", "Green Trust", "Green Customer Satisfaction" and "Green Word-of-Mouth Communication" in parallel with the model. Reliability analysis was conducted with SPSS 25 program. The results of the reliability analysis are given in Table 1.

Table 1. Reliability Analysis Results

Cronbach Alpha (α)	Standardized α Value	Number of Expression
.936	.937	18

The Cronbach Alpha coefficient of the scale, which consists of 4 statements in total, namely "Green Image", "Green Trust", "Green Customer Satisfaction" and "Green Word-of-Mouth Communication", was determined as α=.937. In the existing literature, the scale is considered reliable when the Cronbach's Alpha coefficient is 0.70 or above (Hair, Anderson, Babin, & Black, 2010).

Table 2 shows the Cronbach Alpha values after item removal. When the item was removed, some of the alpha values decreased by ,001, some by ,002, some by ,003, and some did not show any increase or decrease. Accordingly, item removal was not deemed necessary.

The results in Table 2 were obtained when the scale was analyzed collectively with all factors. As a result of the reliability analysis, it was concluded that the Cronbach Alpha values of the factors in the model were acceptable values. Accordingly, since the Alpha value of the scale is α=.937 and α>0.70, the scale is accepted as reliable (Hair, Anderson, Babin, & Black, 2010).

Structural equation modeling was used in the study and the model created as a result of the analysis is given in Figure 1. Structural equation modeling is a statistical analysis method used to understand the relationships between variables. In the given model, the relationships between the measured variables (latent variables) and the observed variables that make up these variables are specified. The variables used in the model are divided into two groups: measured variables and observed variables.

Table 2. Alpha values of the scale after item removal

Statement	Cronbach's Alpha if Item Deleted
GI1	.933
GI2	.932
GI3	.932
GI4	.933
GI5	.932
GTR1	.933
GTR2	.934
GTR3	.932
GTR4	.935
GTR5	.934
GCS1	.935
GCS2	.932
GCS3	.931
GCS4	.932
GWOM1	.934
GWOM2	.931
GWOM3	.931
GWOM4	.932

The measured variables are green image (GI), green trust (GTR), green customer satisfaction (GCS) and green word of mouth (GWOM).

The observed variables are GI1, GI2, GI3, GI4, GI5 in green image; GTR1, GTR2, GTR3, GTR4, GTR5 in green trust; GCS1, GCS2, GCS3, GCS4 in green customer satisfaction; GWOM1, GWOM2, GWOM3, GWOM4 in green word of mouth.

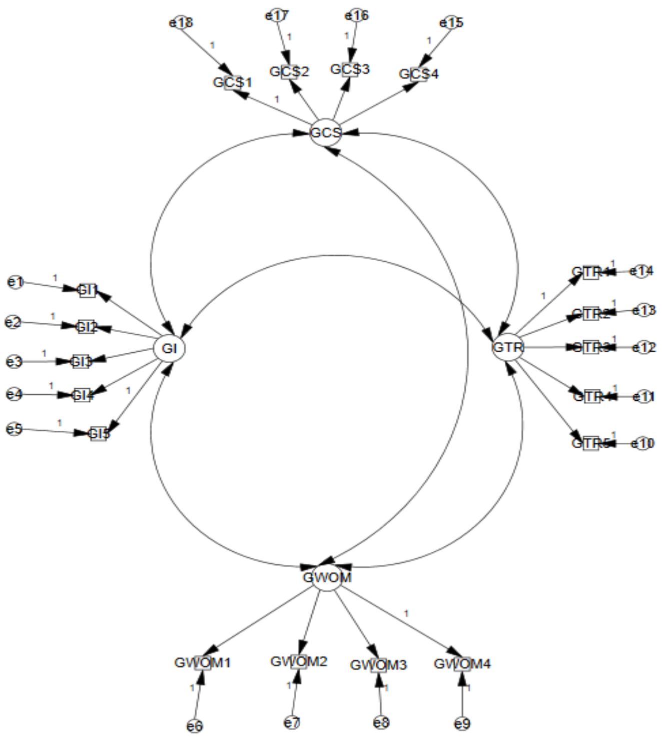

Figure 1. Structural Equation Model Created within the Scope of the Study

As given in Figure 13, the data collected within the scope of the research were analyzed with the Structural Equation Model. The model created for the study consists of a total of 4 measured variables and 18 observed variables, namely green image (GI), green trust (GTR), green customer satisfaction (GCS) and green word-of-mouth (GWOM). The hypotheses for the model are as follows:

H_1: There is a positive and significant relationship between green image of airports and green word-of-mouth activities of visitors.

H_2: There is a positive and significant relationship between visitors' green trust in airports and visitors' green word-of-mouth activities.

H_3: There is a positive and significant relationship between visitors' green customer satisfaction and visitors' green word-of-mouth activities.

H_4: There is a positive and significant relationship between green image of airports and green trust in airports by visitors.

H_5: There is a positive and significant relationship between green trust in airports by visitors and green customer satisfaction of visitors.

H_6: There is a positive and significant relationship between green image of airports and green customer satisfaction of visitors.

Explanatory factor analysis and confirmatory factor analysis were conducted by using SPSS 25 and AMOS 23 programs to determine whether the scale created in the study was appropriate and to conduct validity analysis. Factor analysis is a statistical method used to describe the variability between observed, related variables in terms of a smaller number of unobserved variables called factors (Johnson and Wichern, 2007).

Factor analysis is a mathematical technique that reduces a set of interrelated variables into a smaller number of dimensions or factors, each of which explains a significant portion of the variance in the observed variables (Gorsuch, 1983).

KMO and Bartlett's Test collectively provide important information about the suitability of the data set for factor analysis. Researchers use these tests to ensure that the variables selected for analysis are appropriate and that the data adequately represent the underlying structure (Meyer & Olkin, 1979).

In the study, firstly, exploratory factor analysis and then confirmatory factor analysis were conducted. In this direction, the factors explaining the maximum variance between the relevant variables were calculated separately. The KMO (Kaiser - Meyer - Olkin) and Bartlett's test values show to what extent the factor analysis is appropriate. In cases where this ratio is between 0.5 and 1, the appropriateness of the analysis is accepted, but it is generally considered by researchers that the research will be more acceptable when this ratio is above 0.7 (Altunışık et al., 2005: 132).

In the model created for the study, the content validity of the model was tested before testing the hypotheses between 7 measured variables, namely green image (GI), green trust (GTR), green customer satisfaction (GCS) and green word of mouth (GWOM). KMO and Barttlett test results are as follows.

Table 3. KMO and Bartlett Test Results

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.921
Bartlett's Test of Sphericity	Approx. Chi-Square	5596.757
	df	153
	Sig.	.000

In this direction, explanatory factor analysis was applied to the data obtained in the first stage. The suitability of the data for factor analysis was tested with KMO and Bartlett's test. The values obtained (KMO .937 and Barlett's test $\chi 2 = 11544.531$, $p < .000$) showed that the data set was compatible with factor analysis. The relevant results are given in Table 11.

In factor analysis, the data obtained from KMO and Bartlett's test, i.e. the Kaiser-Meyer-Olkin Measure of Sampling Adequacy, is considered good if it is between 0.5 - 0.7, very good if it is between 0.7 - 0.8 and excellent if it is greater than 0.9. According to the data obtained from KMO and Bartlett's test, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy was found to be .921. It can be said that this value can be accepted as an excellent value in line with the information given above.

As a result of the analysis, the measurement model, which aims to interpret the effects of visitors' and passengers' service encounters within the scope of social and environmental sustainability and the resulting effects on their behaviors and to reveal the relationships in detail, is compiled under 7 factors explaining 67.916% of the total variance. The total variance explained is given in Table 4.

Table 4. Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
Factor	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**
1	8.732	48.511	48.511	8.269	45.941	45.941	6.214
2	2.155	11.971	60.481	1.785	9.918	55.859	5.394
3	1.433	7.961	68.442	1.192	6.624	62.483	6.349
4	1.099	6.103	74.546	.978	5.433	67.916	6.012
5	.608	3.377	77.922				
6	.506	2.814	80.736				
7	.486	2.700	83.436				
8	.413	2.295	85.730				
9	.403	2.236	87.967				
10	.348	1.935	89.902				
11	.326	1.812	91.714				
12	.300	1.669	93.383				
13	.283	1.570	94.953				
14	.247	1.372	96.325				
15	.218	1.210	97.535				
16	.172	.958	98.493				
17	.156	.865	99.358				
18	.116	.642	100.000				

Extraction Method: Maximum Likelihood.
a. When factors are correlated, sums of squared loadings cannot be added to obtain a total variance.

In order to complete the information given in the total variance explained table and to better understand the model fit, the model matrix is given in Table 6. There should not be any nested dimensions in the table. This is undesirable. Each phenomenon should be separated within itself. When Table 6 is examined, it is observed that none of the dimensions are nested and therefore the expected result is achieved.

The data related to the model were collected under 7 factors explaining 67.916% of the total variance. The reliability level of all dimensions in the Explanatory Factor Analysis measurement model is .937. The results of the Exploratory Factor Analysis (EFA) showed that the measurement model was compatible with the purpose of the study. After this stage, a Confirmatory Factor Analysis (CFA) was applied to the dataset to test and confirm what was indicated by the Exploratory Factor Analysis.

Confirmatory Factor Analysis (CFA) is a statistical technique used to assess the extent to which observed variables measure underlying latent constructs, as hypothesized in a predefined theoretical model. It helps researchers assess the goodness of fit between the observed data and the proposed factor structure (Hair et al., 2018).

Confirmatory Factor Analysis (CFA) is a statistical method used in psychometrics and social sciences to assess the validity of a theoretical model that assumes relationships between observed variables and latent constructs. It is a subset of structural equation modeling (SEM) that focuses specifically on testing the factor structure of a set of observed variables (Byrne, 2016).

Table 6. Model Matrix

	Factor			
	1	**2**	**3**	**4**
GWOM3	.964			
GWOM4	.920			
GWOM2	.811			
GWOM1	.610			
GTR4		.860		
GTR5		.817		
GTR3		.789		
GTR2		.772		
GTR1		.697		
GI3			.873	
GI2			.818	
GI5			.739	
GI4			.736	
GI1			.695	
GCS3				-.916
GCS2				-.792
GCS4				-.766
GCS1				-.397

Extraction Method: Maximum Likelihood.
Rotation Method: Oblimin with Kaiser Normalization.a
a. Rotation converged in 9 iterations.

Within the scope of the study, an assessment was made for the factors explaining this situation by using the model created to measure the impact of service encounters at airports on visitors' behaviors within the scope of social and environmental sustainability. In this direction, the model created within the scope of the research was used. Confirmatory factor analysis was conducted after the exploratory factor analysis. Accordingly, hypothesis tests were carried out with confirmatory factor analysis. The hypotheses in question are as follows:

H_1: There is a positive and significant relationship between green image of airports and green word-of-mouth activities of visitors.

H_2: There is a positive and significant relationship between visitors' green trust in airports and visitors' green word-of-mouth activities.

H_3: There is a positive and significant relationship between visitors' green customer satisfaction and visitors' green word-of-mouth activities.

H_4: There is a positive and significant relationship between green image of airports and green trust in airports by visitors.

H_5: There is a positive and significant relationship between green trust in airports by visitors and green customer satisfaction of visitors.

H_6: There is a positive and significant relationship between green image of airports and green customer satisfaction of visitors.

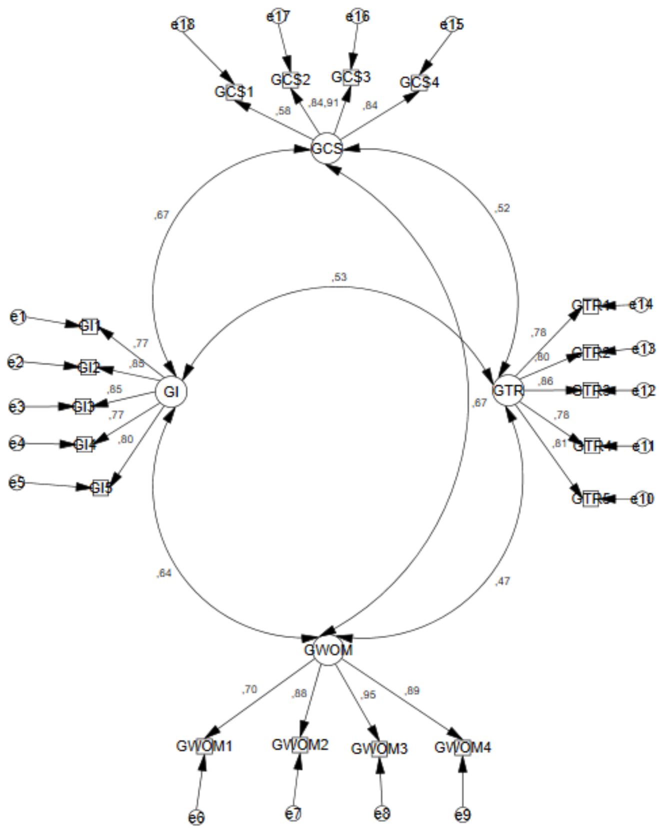

Figure 2. Confirmatory Factor Analysis

The model in Figure 2 shows the path coefficients. It was observed that the values obtained as a result of the analysis were generally above 0.50 and loaded at a high level (Cohen, 1988). In addition, the standardized regression coefficients are given in Table 7.

Table 7. Standardized Regression Coefficients

			Estimate
GCS1	<---	GCS	.576
GCS2	<---	GCS	.840
GCS3	<---	GCS	.915
GCS4	<---	GCS	.839
GWOM4	<---	GWOM	.893
GWOM3	<---	GWOM	.948
GWOM2	<---	GWOM	.877
GWOM1	<---	GWOM	.704
GTR1	<---	GTR	.782
GTR2	<---	GTR	.801
GTR3	<---	GTR	.862
GTR4	<---	GTR	.784
GTR5	<---	GTR	.805
GI5	<---	GI	.801
GI4	<---	GI	.773
GI3	<---	GI	.853
GI2	<---	GI	.850
GI1	<---	GI	.768

Table 8 shows the regression weights and significance levels of the statements. When the table is examined, it is seen that the relationships of the observed variables in the model with the factor they belong to (sub latent variables) are statistically significant since p<0.001.

Table 8. Regression Weights and Significance Levels

			Estimate	S.E.	C.R.	P
GCS1	<---	GCS	1.000			
GCS2	<---	GCS	1.392	.112	12.477	***
GCS3	<---	GCS	1.506	.116	13.006	***
GCS4	<---	GCS	1.327	.106	12.471	***
GWOM4	<---	GWOM	1.000			
GWOM3	<---	GWOM	1.075	.035	30.995	***
GWOM2	<---	GWOM	.976	.037	26.222	***
GWOM1	<---	GWOM	.869	.050	17.521	***
GTR1	<---	GTR	1.000			
GTR2	<---	GTR	1.055	.060	17.463	***
GTR3	<---	GTR	1.143	.060	19.062	***
GTR4	<---	GTR	1.040	.061	17.003	***
GTR5	<---	GTR	1.110	.063	17.566	***
GI5	<---	GI	1.000			
GI4	<---	GI	1.021	.059	17.314	***
GI3	<---	GI	1.012	.051	19.701	***
GI2	<---	GI	1.045	.053	19.623	***
GI1	<---	GI	1.013	.059	17.164	***

The statements were statistically significant and the model fit values were found to be at the desired level. Data on model fit are given in Tables 9, 10, 11 and 12. Although there are many values indicating model fit, it is seen that the values generally reported in the literature are CMIN, CMIN/DF, GFI, IFI and RMSEA, while some studies report RMR, NFI and AGFI values (Meydan & Şeşen, 2015).

Table 9. CMIN and CMIN/DF

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	42	364.322	129	.000	2.824

Table 9 shows the CMIN and CMIN/DF fit values, good fit values should be CMIN/DF≤3. At the same time, since the resulting value CMIN/DF =2.824, it can be said that there is good agreement.

Table 10. CMIN and CMIN/DF

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.936	.924	.958	.950	.958
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

In Table 10, since CFI=0.958 and the minimum acceptable fit values are ≥0.94-0.90, model fit is achieved. Since IFI=0.958 and the minimum acceptable values should be in the range of ≥0.94-0.90 and these values were found to be in this range, good fit was observed.

Table 11. CMIN and CMIN/DF

Model	RMR	GFI	AGFI	PGFI
Default model	.047	.916	.889	.691
Saturated model	.000	1.000		
Independence model	.462	.210	.117	.187

In Table 11, since GFI=0.916 and acceptable fit values should be between ≥0.89-0.85, it was seen that the model fit was realized. Since AGFI=0.889 and acceptable fit values are between ≥0.89-0.85, it was concluded that model fit was achieved.

Table 12. RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.066	.058	.074	.001
Independence model	.295	.288	.301	.000

In Table 12, RMSEA=0.66 and since the acceptable fit value should be between ≤0.06-0.08, it was determined that the value obtained from the model was within the fit limits. In the confirmatory factor analysis of the model, IFI, TLI, RMR, GFI, AGFI and RMSEA values are within the acceptable fit limits. Accordingly, it is seen that the model is compatible. Below, all hypotheses of the study are tested respectively.

According to the model, since the level of the correlation relationship between GI and GWOM is r=0.64 and r≥0.50 means a high level positive relationship, there is a high level positive relationship (Cohen, 1988). The covariance relationship between GI and GWOM is significant since p≤0.001.

The hypothesis "H_1: There is a positive and significant relationship between the green image of airports and visitors' green word-of-mouth communication activities." is confirmed and accepted.

According to the model, since the level of the correlation relationship between GTR and GWOM is r=0.47, which means a moderate positive relationship, there is a moderate positive relationship (Cohen, 1988). The covariance relationship between GTR and GWOM is significant as p≤0.001.

The hypothesis "H_2: There is a positive and significant relationship between green trust in airports by visitors and green word-of-mouth communication activities of visitors." is confirmed and accepted.

According to the model, the level of the correlation relationship between the GCS and the GWOM is r=0.67 and since r≥0.50 means a high level positive relationship, there is a high level positive relationship (Cohen, 1988). The covariance relationship between GCS and GWOM is significant since p≤0.001.

The hypothesis "H_3: There is a positive and significant relationship between visitors' green customer satisfaction and visitors' green word-of-mouth communication activities." is confirmed and accepted.

According to the model, the level of the correlation relationship between GI and GTR is r=0.53, and since r≥0.50 means a high level positive relationship, there is a high level positive relationship (Cohen, 1988). The covariance relationship between GI and GTR is significant as p≤0.001.

The hypothesis "H_4: There is a positive and significant relationship between green image of airports and green trust in airports by visitors." is confirmed and accepted.

According to the model, the level of the correlation relationship between GTR and GCS is r=0.52 and since r≥0.50 means a high level positive relationship, there is a high level positive relationship (Cohen, 1988). The covariance relationship between GTR and GCS is significant since p≤0.001.

The hypothesis "H_5: There is a positive and significant relationship between green trust in airports by visitors and visitors' green customer satisfaction." is confirmed and accepted.

According to the model, the level of the correlation relationship between GI and GCS is r=0.67, and since r≥0.50 means a high level positive relationship, there is a high level positive relationship (Cohen, 1988). The covariance relationship between GTR and GCS is significant since p≤0.001.

The hypothesis "H_6: There is a positive and significant relationship between the green image of airports and visitors' green customer satisfaction." is confirmed and accepted.

3. Result and Discussion

Since the fit values for the model created for the study and the path coefficients in the model for the path analysis performed were significant, the model worked harmoniously. Accordingly, all research questions were answered one by one and all hypotheses were confirmed.

The lower latent variables explained the upper latent variables in a healthy way and "The Impact of Service Encounters at Airports on Visitors' Behaviors within the Scope of Social and Environmental Sustainability", which is the focus of the research, was explained with different factor loadings. The dimension differences in the results obtained and the level of relationship between the factors in these results can be interpreted in different ways.

It was observed that the values obtained as a result of the path analysis were generally above 0.50 and loaded at a high level. In addition to this, standardized regression coefficients, regression weights, model fit tables, significance level tables of the relationships between each statement and factor, correlation values between factors, standardized regression coefficients and regression weights and significance level tables show whether the model is meaningful or not and at the same time the model's fit with the study subject. In the model created, it was observed that each statement affected the factors in different value ranges. After the confirmatory factor analysis, different r values were determined between the variables. If these values are greater than or equal to 0.50, the effect size value is at a high level. If between 0.30 and 0.50, the effect size value is at a medium level, and if less than 0.30, the effect size value is at a low level.

The path coefficients in Figure 2 show the relationships between the model, factors and statements in detail. Here, the relationships are as follows: a high level relationship between green image and green word-of-mouth (r=0.64), a medium level relationship between green trust and green word-of-mouth (r=0.47), a high level relationship between green customer satisfaction and green word-of-mouth (r= 0, 67) a high level relationship between green image and green trust (r=0.53), a high level relationship between green trust and green customer satisfaction (r=0.52) and finally a high level relationship between green image and green customer satisfaction (r=0.67). Accordingly, the strongest relationships were firstly between green customer satisfaction and green word-of-mouth and then between green image and green customer satisfaction. This is followed by the relationship between green image and green word-of-mouth, the relationship between green image and green trust, the relationship between green trust and green customer satisfaction, and the relationship between green trust and green word-of-mouth. The fact that there is a strong relationship between these factors is important in terms of illuminating the results of the study in the focus of these factors.

In addition, when the regression weights and the significance levels of the statements in Table 8 are examined, it is seen that the relationships of the observed variables in the model with the factor they belong to and the sub (latent) statements are statistically significant since p<0.001. In addition, it was determined that the statements were statistically significant and the fit values of the model were at the desired level.

4. Conclusion

In this study, it was aimed to create a hybrid scale by combining the concepts of sustainability and green marketing with many scales developed from the literature and different disciplines. These scales were developed or used by Hwang and Lyu (2019), Martinez (2015), Chang and Fong (2010) and Wang et al. (2018) and were used to create a hybrid scale for this study. The cultural adaptation and comprehensibility of these scales were ensured through cross-translation. These scales developed for different sectors were adapted to be based on airports, which are indispensable in the aviation sector. The purpose of this scale is to summarize all the relationships in the model, starting from the strongest relationship to the weakest relationship, on the basis of the relationship, how some practices that we call green or environmentalist in daily life within the scope of sustainability are perceived by visitors and passengers and what are the important factors here.

Participants from different professional groups from institutions and organizations working in the aviation sector or providing services in various fields of aviation were included in the application as visitors or passengers. In this context, the analysis of the collected data was carried out using quantitative research methods.

The study process started with the literature and conceptual framework section, followed by the determination of the model, development of the data collection tool, selection of the population and sample, analysis and findings, and the final conclusion and discussion, conclusion and recommendations.

It is seen that the model created within the scope of the study is used in different methods and disciplines. However, the scale used and the model created were adapted for the first time for the aviation industry within the scope of green marketing and sustainability.

Seven different scales used in the study were used within the scope of the research because they were compatible with the adapted scale and the sustainability and green marketing processes seen in the literature.

As previously discussed in the findings, it has been determined that the factors included in the model are suitable for service encounters within the scope of sustainability and green marketing and the factors used are included in the literature. This model consists of seven parts: environmental awareness, environmental sustainability, environmental value, green image, green trust, green customer satisfaction and green word of mouth communication. Other models used within the scope of the created model have been used in many studies in the literature.

Different effects on behavior were measured in studies conducted by Hwang and Lyu (2019), Martinez (2015), Chang and Fong (2010) and Wang et al., (2018). In related studies, it is seen that companies' green marketing and sustainability practices, especially in the service sector, contain predictive factors in terms of behavior. It was concluded that high compatible chi-square values were obtained with the predicted structural model. Accordingly, it is seen that the fit values obtained in the research conducted with the model created remain within the appropriate range.

Reliability and honesty resulting from excellent products and services have a significant impact on consumers' behavioral intentions, which provides trust (Lankton et al., 2010). Studies on green marketing practices have confirmed the importance of green trust in influencing behavioral intentions, including word-of-mouth intention. For example, Kang and Hur (2012) proposed several variables to investigate the antecedents of green brand equity in the context of electronic products in South Korea. The results showed that green trust was positively related to consumer repurchase intention. Rahman et al. (2015) investigated consumers' reactions to hotels' green initiatives and showed that green trust positively affects consumers' revisit intention. Konuk et al. (2015) argued that increasing green trust can increase green consumer trust and green consumer word-of-mouth communication.

When the studies in the literature on sustainability and green marketing practices are evaluated, it can be said that the research results are parallel to the findings obtained in other studies. Quantitative studies advocate the need for a holistic approach regarding sustainability and green marketing practices. Although the findings obtained within the scope of the research lead to the conclusion that some factors contribute less than others, it can be said that the results are similar since the model appears to work harmoniously and a very high level of explanatory power is detected for most factors. Final evaluations, recommendations and limitations regarding the results are given in the next section.

The development and transformation of airports over the years affects every aspect of the aviation industry directly or indirectly, and also affects the structure of the sector accordingly. Since its birth, the aviation industry has continued to develop as one of the largest and most comprehensive industries in the world. As an element that connects countries, cultures and people, air transportation enables cultural interaction to occur mostly in a demographic sense. The global expansion and networking of airports, especially airline companies, causes them to be culturally influenced by the geography in which they are located. People's different perceptions of events are also reflected in their behavior. Therefore, sustainability and green marketing practices in aviation are vital elements for airports.

When the studies in the literature are examined, it is seen that the common point of the above-mentioned studies is the human element and behaviors. It was tried to determine to what extent the relevant factors in the study (green image, green trust, green customer satisfaction, green word of mouth communication) are effective in understanding the behavior of visitors and passengers in airport management.

The values obtained in the study results contributed to the conclusion of the research. The relevant results aim to enable airport managers to better perceive passengers and visitors and manage processes better.

All results obtained, whether positive or negative, must be conveyed to the necessary authorities at the management level. The effect of each factor included in the study is reflected in the overall results at different rates. It is thought that taking these results into consideration will bring about development in management and related processes.

Providing the necessary training and awareness to airport personnel and managers will be effective in achieving positive results. With the advancement of technology day by day, the innovations emerging in the sector are diverse. In parallel with this diversity, the necessary training must be given to personnel and managers.

In addition, it is expected that employees' perception of the audits and inspections in these processes as a phase of improvement rather than seeing them as a burden will positively affect the results.

The findings obtained as a result of the analyzes carried out within the scope of the research were evaluated and the explanation levels of the factors were examined. Qualitative evaluation of the low-scoring answers given to the Likert-type scale was not possible because the survey was conducted anonymously. In this context, in future studies, an evaluation of the participants who responded negatively to the statements determined through focus group discussion and interview method can be examined within the scope of cause and effect relationship. By compiling the themes, common thoughts and most repeated words in the answers given by the participants in question, detailed results can be obtained and inferences can be made about the aspects where the model is lacking and its root causes.

The biggest limitation of the research is that the data cannot be disseminated to a wider sample due to reasons such as financial and time constraints during the study phase. For this reason, it was not possible to reach more people who could be included in the sample. Of the data collected entirely face-to-face, a certain number of participants could not be included in the study due to careless marking. Even though the data was collected physically, careless marking was observed, although very rarely. Therefore, these participants were not included in the data set. Another limitation is the sector, profession, age, gender, education level, etc. of the participants. This is because demographic elements such as are not evenly distributed in groups. For example, although the number of people in the 55-64 and 65 and over age groups is small compared to other people, it shows that the findings obtained are not biased and the factors do not have an effect on the prediction levels.

Conflicts of Interest

There is no conflict of interest regarding the publication of this paper.

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Financial Failure Analysis of Airline Companies by Altman Z'' and Springate S Score Models

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Abstract

Financial failure is a risk that must be measured, audited, and controlled. This study measures and evaluates the financial failure risks of Turkish Airlines and Pegasus businesses. Altman Z'' and Springate S Score methods were used in the study. In the context of descriptive and cross-sectional research methods, the analysis and interpretation of data were carried out by systematically addressing quantitative data. Therefore, the financial performance of the firms in the sample was calculated and analyzed using the Altman Z'' Score and Springate S Score. The main reason for choosing these two methods is to create a combination of the most commonly used quantitative methods in the literature to objectively evaluate the financial health and performance of firms. Thus, the aim was to increase the reliability of the results and provide concrete data about the financial situation. The equations in the relevant methods were used as variables, and financial statement data between 2012 and 2023 were analyzed. The results showed that there was a general risk of financial failure, and evaluations were conducted. The results obtained were aimed at guiding researchers, industry officials, and people interested in the subject.

This study was derived and expanded the summary paper titled "Measuring the Risks of Financial Failure of Airline Companies: The Case of Pegasus and Turkish Airlines", presented at "The 6th International Aviation Management Conference" between 19-20 December 2023.

1. Introduction

The aspiration for flight has persisted throughout human history, dating back to the earliest civilizations. Humans have long harbored dreams of flight, conducting various experiments inspired by observations of airborne creatures. Mythological narratives across civilizations often feature heroic figures capable of flight. However, the first practical designs for achieving flight emerged during the Renaissance, notably pioneered by Leonardo da Vinci. After this period, advancements in flight were pursued through experiments with hot air balloons and gliders. A significant milestone occurred in the late nineteenth century with the Wright brothers in Virginia developing the first piloted flying vehicle. The era of aviation saw rapid progress, particularly highlighted by the utilization of over 80,000 aircraft during World War I. Civil aviation took off in the early twentieth century, spearheaded by Germany. The aviation industry experienced exponential growth, leading to the production and commercialization of long-range aircraft prior to World War II. The year 1938 marked a pivotal moment, with Germany alone transporting nearly 320,000 passengers through its airports (Schmitt et al., 2016). This period witnessed revolutionary advancements in aviation within a remarkably short span of time. Today, the widespread adoption of air transportation has significantly reduced temporal and spatial barriers in both passenger and freight movements. This trend has not only facilitated global connectivity but has also played a crucial role in fostering globalization by bridging societal divides.

In recent years, the aviation industry has undergone significant development, driven by the increasing trend of globalization. This development has notably contributed to the economic growth of nations, particularly through the expansion of the tourism sector. Advancements in aircraft technologies, marketing strategies, and information technologies have collectively transformed air travel from being a costly alternative to a widely preferred mode of transportation for passengers (Adedoyin et al., 2020). Countries are increasingly favoring air transportation for several reasons. These include concerns over high mortality rates associated with road transportation, uncertainties surrounding oil supply, environmental issues such as air and noise pollution, inadequate transportation infrastructure, and the escalating number of vehicles on roads (Moriarty, 2021). As of 2022, Turkey stands out globally, ranking eighth in the world and fourth in Europe with a total of fifty-seven airports dedicated to civil aviation. Notably, Istanbul Airport claimed the title of Europe's busiest airport in terms of passenger traffic in 2022, underscoring Turkey's growing significance in the global aviation landscape. Also, Istanbul Airport have been an important stop center.

Air passenger traffic has lost around 60% due to the Covid-19 pandemic. However, Turkey was less affected by the impact of the pandemic on passenger traffic compared to Europe. The measures taken and the successes achieved in the fight against the pandemic are shown as the justification for this situation (DHMİ, 2022). The airline industry has been the sector most affected by the restrictions arising from the pandemic. These restrictions have increased costs and reduced passenger numbers. In the future, some experts and the World Health Organization (Prater, 2024) show that the airline industry may face difficult times again, as new pandemic will emerge. Due to the impact of the Covid-19 pandemic that occurred in 2019, more than sixty-four airline companies in the world went bankrupt. It is stated that the biggest reason why these companies go bankrupt is that the companies do not have strong financial structures due to the decrease in the number of passengers (Buckley, 2023). For this reason, determining in which aspects the sector is experiencing financial problems will enable companies to be prepared for negative situations that may occur in the future, such as pandemics, crises or war situations. In this way, companies will be able to identify their financial shortcomings and prevent losses for both them and their investors.

Recent trends highlight that airline companies, facing escalating costs and financial pressures, are increasingly adopting cost-cutting measures across their maintenance, procurement, and training policies. However, such measures may potentially compromise flight safety, posing security vulnerabilities (Fardnia et al., 2021). It is emphasized that financially robust companies with strong funding and high profitability are less likely to resort to measures that jeopardize passenger safety. Therefore, assessing companies' financial performance is crucial for uncovering potential risks of operational failure.

This study focused on Turkish Airlines (THYAO) and Pegasus Air Transportation (PGSUS), two airline companies operating within the Transportation and Storage Sector (XULAS) of Borsa Istanbul (BIST). The aim was to assess the financial failure risk of these companies (THYAO and PGSUS) using financial statement data from 2012 to 2023. The Altman Z" and Springate S Score models were employed to measure financial failure risk. The study progressed through sections covering literature review, methodology, analysis, and findings; presenting the results of the applied models; and offering various recommendations to investors, company executives, and stakeholders based on the evaluations.

2. Literature Review

Finance examines the activities carried out to manage funds effectively and ensure financial continuity. Financial success is important for individuals, businesses and governments. A sustainable and continuous structure can be established by creating effective financial strategies and monitoring the realization of the developed methods. Otherwise, the financial failure that occurs covers all processes ranging from the inability of businesses to carry out daily activities to the bankruptcy process. Literature extensively examines the financial situations of companies within the aviation sector, with a predominant focus on assessing their financial performance. These studies aim to identify the most effective financial ratios that contribute to enhanced financial performance. Recent literature in the sector predominantly delves into analyses of financial failure and performance specifically concerning two airline companies listed on the BIST. These analyses typically leverage company-specific ratios to evaluate financial performance and failure, employing methodologies such as the Altman Z" and Springate S Score models for assessing financial failure. For performance ranking, Multi-Criteria Decision Making Methods (MCDM) are often favored, with the TOPSIS method being the most used among MCDM techniques. Additionally, other MCDM methods like EDAS, WASPAS, GRA, and ENTROPY have also been applied in studies within this domain.

However, it is noted that there is a scarcity of studies specifically focusing on measuring the financial failure of companies within the aviation sector. The analysis conducted within this context aims to address these literature gaps and provide essential information required by stakeholders in the business ecosystem.

The Altman Z Score model, developed by Edward I. Altman in 1968, serves as a tool for assessing financial failure. This model defines score ranges within which a company's score indicates potential financial distress (Altman, 1968). Similarly, the Springate S Score model, developed by Springate in 1978, also identifies financial failure by setting a score threshold below which companies are considered at risk (Dizgil, 2018).

Financial performance measurement has long been a subject of research, involving analysis across various sectors to determine companies' standings and positions over time. Numerous studies in the literature delve into assessing the financial performance of airline companies, including THYAO and PGSUS. These studies were reviewed during the literature analysis to evaluate the financial performance of both companies over time, enabling more detailed insights into potential financial failure.

Ömürbek and Kınay (2013) utilized the TOPSIS method to evaluate the financial performance of airline companies. Their study compared the financial performances of two companies listed on the BIST and Frankfurt Stock Exchange using data from 2012, concluding that the BIST-listed airline company exhibited higher financial performance.

Akgün and Temür (2016) emphasized the significant contributions of aviation sector development to the country's tourism sector. Their research analyzed the financial performances of companies in the aviation sector, particularly focusing on THYAO and PGSUS for the years 2010-2015. Comparing twelve ratios using the TOPSIS method, they found that PGSUS outperformed THYAO in 2011, 2013, and 2014, with PGSUS's best performance observed in 2014 and THYAO's in 2012.

Gümüş and Bolel (2017) conducted a financial analysis of PGSUS and THYAO for the period from 2010 to 2015, utilizing ratio analysis. The study noted that THYAO consistently struggled with liquidity ratios throughout the years. In contrast, PGSUS, although starting with low liquidity ratios in 2010, significantly improved in this aspect by 2015. Both companies were observed to collect their receivables in less than a month without encountering difficulties, primarily financing their assets through foreign resources. Notably, PGSUS's financial performance surpassed THYAO's after 2012.

Avcı and Çınaroğlu (2018) evaluated the financial performance of five prominent European airline companies, including THYAO, using data from 2012 to 2016. They employed the Analytic Hierarchy Process (AHP) and TOPSIS methods in their analysis. The results positioned Ryanair as the top-performing company among the five, followed by EasyJet Airlines, with THYAO ranking third. The study highlighted the success of companies adopting a "low-cost transportation" strategy, contributing to their strong performance.

Kiracı and Bakır (2018) examined the financial performance of thirteen leading global passenger airlines between 2005 and 2012, highlighting the impact of the 2008 global crisis on airlines, particularly noticeable from 2010 to 2012. Notable performance shifts were observed among companies, with United Continental, Delta Air, China Eastern, and China Southern displaying improved performance during the crisis period compared to earlier years.

Kiracı and Asker (2018) investigated financial failure among seventeen airline companies using Altman Z and Springate S scores, analyzing data from 2012 to 2016. The research indicated that not all airlines adopting cost leadership strategies achieved substantial financial gains, with some companies falling short in this aspect.

Finally, Kızıl and Aslan (2019) analyzed the financial performance of two aviation companies listed on the BIST between 2013 and 2017, focusing on liquidity and debt ratios. Their findings indicated that PGSUS outperformed THYAO, especially in liquidity and debt ratios, while both companies exhibited fluctuating profitability ratios and made fixed asset investments primarily through long-term resources.

Deste and Şimşek (2019) conducted a comparative analysis of logistics performance among companies in the aviation sector, employing the ENTROPY and TOPSIS methods. They evaluated eleven indicators, including labor productivity, on-time departures, and average ticket prices, to assess logistics performance. The study highlighted differences in company performance based on criterion weighting, with closely ranked values indicating subtle variations in performance among companies.

Kiracı and Asker (2019) discussed the shift towards aircraft leasing in the aviation industry due to substantial fixed asset investments. They applied the TOPSIS method to evaluate the financial performance of five aircraft leasing companies for the period 2013-2017. The analysis revealed that CAPITAL LEASE demonstrated superior performance in the initial two years, followed by AIR LEASE. Notably, AERCAP HOLDINGS ranked second in 2013 but experienced a decline in subsequent years.

Güngör and Armutlu (2020) conducted a financial failure analysis specifically targeting the sixteen most successful airline companies among the top hundred global airlines. The study utilized Altman Z" score variables and regression analyses, revealing significant insights into the industry's vulnerability to crises, such as plane crashes or employee strikes, impacting companies' financial success. Among financial ratios, the study highlighted the importance of short-term debt payment ability, leverage ratio, and fixed asset profitability in achieving financial success.

Keleş and Özulucan (2020) conducted a ratio analysis to assess the financial situation of two airline companies in 2018. They found that while PGSUS exhibited stronger liquidity ratios, THYAO showcased better profitability and activity ratios. Both companies displayed similar leverage ratios.

Macit and Göçer (2020) utilized the GRA method to analyze financial performance using 2018 data, determining that PGSUS outperformed THYAO.

Ersoy (2020) measured the financial performance of eight companies, including PGSUS and THYAO, listed in the transportation index on BIST, using Gray Relational Analysis (GRA) and financial ratios for 2016-2018. The analysis indicated THYAO's superior performance over PGSUS in 2016 and 2018, while PGSUS exhibited stronger financial performance in 2017.

In a study by Köse (2020), the financial failure of THYAO PGSUS for the years 2014-2018 was examined. The analysis utilized the Altman Z, Springate S, and Fulmer H models. The results indicated that both companies were classified as financially distressed according to the Altman Z and Springate S models; however, the Fulmer H model suggested otherwise, attributing this discrepancy to the Fulmer H model's incorporation of more variables.

The mitigation of risks significantly impacts the financial success of airline companies. In a study conducted by the Purchaser in 2021, data from eleven airline companies spanning 2009 to 2019 was analyzed using the Altman Z" score method. The research concluded that factors such as cost per kilometer of available seating, labor expenses, and fuel costs exerted a negative influence on financial stability, highlighting the importance of risk assessment in averting financial distress.

Similarly, Özbek and Ghouchi (2021) analyzed the financial performance of five airline companies over a decade leading up to 2018, employing the Weighted Aggregated Sum Product Assessment (WASPAS) and Evaluation based on Distance from Average Solution (EDAS) methods. Their findings echoed those of Avcı and Çınaroğlu (2018), ranking Ryanair as the best performer and Lufthansa at the bottom.

In this study, Dağlı (2021) utilized the TOPSIS method to assess the financial status of the seven most successful companies in Europe, including PGSUS and THYAO, before and after the Covid-19 pandemic. Quarterly balance sheet data were used for the analysis. PGSUS ranked first in the second quarter of 2019, sixth in the fourth quarter of 2019, and second in the second quarter of 2020. On the other hand, THYAO ranked sixth, fourth, and third respectively during the same periods. The study indicated that PGSUS was significantly affected by the Covid-19 outbreak in 2019, but its financial performance recovered by the second quarter of 2020.

Alıcı (2021), a study was conducted to measure the financial failure risks of airline companies. Within the scope of the study, the study was carried out using 11 companies with data between 2009 and 2019. As a result of the analyzes carried out within the scope of the study, explanations and evaluations were made regarding the variables.

Köse (2021) focused on specific financial ratios such as "Cost per Available Seat Kilometer, Revenue per Available Seat Kilometer, Revenue per Passenger, Efficiency, Occupancy Rate, Break-even occupancy rate," which are not commonly included in other studies. Using the TOPSIS method, financial performance was assessed between 2014 and 2019, revealing that THYAO exhibited more successful financial performance compared to PGSUS.

Ağırkaya and Keleş (2022) aimed to gauge the impact of the Covid-19 pandemic on the financial performance of the aviation sector. The study highlighted issues faced by airline companies during the pandemic, such as difficulties in paying short-term debts, increased dependence on foreign resources and financing, heightened long-term borrowing, negative effects on asset turnover rates, and net losses incurred in 2020.

Karadeniz and Aydın (2023) evaluated the financial performance of sixty-four international airline companies between 2016 and 2021 using ratio analysis. They noted that while the cash ratio, a component of liquidity ratios, remained high, other ratios were found to be inadequate. Insufficient net working capital, heavy reliance on foreign resources, and limited internal resources were also highlighted. The study raised concerns about the aviation industry's ability to secure new resources due to heightened risk levels, particularly exacerbated by the challenges posed by the Covid-19 pandemic.

The study contributes to the analysis of two different methods with current data for two different companies operating in the XULAS sector. The measurement of the pandemic effect, comparative evaluation of the methods and comments and evaluations made to the sector enterprises are also among the contributions of the study.

3. Method of the Study

In this study, the financial risk of failure for Turkish Airlines and Pegasus, companies operating in the aviation sector, was analyzed. A dataset was compiled using financial statements from 2012 to 2023. Financial statement data was sourced from the Public Disclosure Platform, IS Investment, and Fintables (KAP, 2024; IS Investment, 2024; Fintables, 2024). Table 1 presents the companies in the BIST Transportation and Storage (XULAS) sector, which includes the sampled companies in this study. The reason for choosing the relevant sector is that the impact of the pandemic can be clearly seen. The impact of the pandemic, which has negatively affected almost all sectors, on aviation companies has been measured in this way. Another reason why the aviation sector is preferred is that the sector plays a critical role in the growth of economies and global trade. Especially in the pre- and post-pandemic period, changes and developments in the aviation sector are of great importance in terms of their impact on financial performance. In this context, the aviation sector was selected for the general financial health analysis.

In addition, two companies operating in the sector and carrying out passenger transportation were analyzed. The reason for this is the similarities in the business lines and financial structures of the relevant companies. THYAO and PGSUS are among the largest and best-known airlines in Turkey. In addition, to observe the impact of the pandemic more clearly, only passenger transportation companies were preferred among the companies in the BIST Transportation and Storage (XULAS) sector.

Table 1. BIST Transportation and Storage Sector (XULAS)

BEYAZ	Beyaz Fleet Car Rental
CLEBI	Celebi Air Service
GSDDE	GSD Marine
GRSEL	Gürsel Tourism Transportation
PASEU	Pasifik Eurasia Logistics Foreign Trade
PGSUS	**Pegasus Air Transportation**
RYSAS	Reysaş Transportation and Logistics
TLMAN	Trabzon Port Management
TUREX	Tureks Tourism Transportation
THYAO	**Turkish Airlines**

Source: Public Disclosure Platform (2024)

Altman Z" and Springate S Score models were utilized for detecting financial failure. These models were selected due to their widespread use in the literature. Employing two models allowed for a comparative analysis between them. While the Altman Z" score evaluates the general financial condition of the firm by considering various financial ratios, the Springate S score provides another perspective that examines the liquidity, profitability and financial stability of the firm. This diversity allows our study to provide a more comprehensive and balanced analysis.

The models developed by Altman over different years have been instrumental in assessing the risk of financial failure across various sectors, including public companies in manufacturing and service industries. Detecting financial failure risk is crucial for business sustainability and continuity (Altman, 1968; Altman, 2000; Altman & Hotchkiss, 2006). Given that this study focused on service businesses, the risk of financial failure was evaluated using the Altman Z" Score model tailored for service industries, as presented in Equation 1.

$$Z''Score = 6.56T_1 + 3.26T_2 + 6.72T_3 + 1.05T_4 \quad (1)$$

T_1 = Net Working Capital / Total Assets
T_2 = Retained Earnings / Total Assets
T_3 = Earnings Before Interest and Tax / Total Assets
T_4 = Equity Book Value / Total Debt Book Value

The Altman model resulted in score ranges, where a Z" Score below 1.10 indicated financial failure, a score between 1.10 and 2.60 reflected uncertainty, and a value exceeding 2.60 signified financial success.

The Springate S Score model indicates that businesses with a score below 0.862 are at risk of financial failure, while those with a score above 0.862 are deemed financially successful (Springate, 1978). The model is represented by Equation 2.

$$S\ Score = 1.03X + 3.07Y + 0.66Z + 0.40Q \quad (2)$$

X = Working Capital / Total Assets
Y= Earnings Before Interest and Tax / Total Assets
Z = Profit Before Tax / Short Term Liabilities
Q= Sales / Total Assets

4. Analysis and Findings

The sample was created by obtaining data from the THYAO and PGSUS enterprises between the years 2012-2023. Within the scope of this study, the Altman Z" and Springate S Score models were applied to the THYAO company. The values and results obtained from this application are listed in Table 2.

The table above shows the Altman Z" and Springate S score values of Turkish Airlines (THYAO) between 2012-2023. As stated before, the Altman Z" score is generally below 1.1, indicating a risk of bankruptcy, between 1.1-2.6 indicates a gray zone; and above 2.6 indicates a healthy financial structure. Scores were generally below 1.1 2012-2016, indicating that THYAO was at a high risk of bankruptcy. Although it exceeded 1.1 in 2017 (1.161), the company was still in the grey zone. In 2018, although it was between 1.0-1.1, the company was still in the gray zone, but due to the impact of the pandemic in 2019-2021, the scores dropped significantly and the company remained at low levels, such as 0.291 and 0.466, indicating a serious risk of bankruptcy. Recovery was observed in 2022 and 2023. In 2023, the score increased to 1.336, and it is seen that the company's financial situation has improved somewhat, but it is still close to a risky area.

Table 2. THYAO Altman Z" Score and Springate S Score Results

THYAO	2012	2013	2014	2015	2016	2017
T1	-0.035	-0.083	-0.061	-0.044	-0.049	-0.037
T2	0.074	0.085	0.090	0.098	0.118	0.111
T3	0.116	0.097	0.096	0.105	0.040	0.109
T4	0.288	0.274	0.287	0.296	0.275	0.294
Z" Score	1.094	0.672	0.841	1.049	0.623	1.161
THYAO	2018	2019	2020	2021	2022	2023
T1	-0.032	-0.048	-0.089	-0.070	-0.033	-0.014
T2	0.075	0.082	0.088	0.031	0.033	0.063
T3	0.105	0.093	0.055	0.082	0.138	0.114
T4	0.287	0.278	0.211	0.256	0.314	0.435
Z" Score	1.039	0.868	0.291	0.466	1.150	1.336
THYAO	2012	2013	2014	2015	2016	2017
X	-0.035	-0.083	-0.061	-0.044	-0.049	-0.037
Y	0.061	0.048	0.045	0.052	-0.013	0.052
Z	0.307	0.145	0.266	0.348	0.000	0.050
Q	0.761	0.724	0.741	0.591	0.443	0.567
S Score	0.753	0.558	0.652	0.744	0.309	0.555
THYAO	2018	2019	2020	2021	2022	2023
X	-0.032	-0.048	-0.089	-0.070	-0.033	-0.014
Y	0.057	0.034	-0.007	0.038	0.084	0.068
Z	0.192	0.143	-0.129	0.102	0.334	0.341
Q	0.563	0.497	0.240	0.268	0.527	0.466
S Score	0.668	0.550	0.200	0.513	0.846	0.819

According to the Springate model, values below 0.862 indicate that a company may experience financial difficulties. The decrease in S scores from 0.753 to 0.309 between 2012 and 2016 indicates that THYAO was at risk of financial distress. A recovery trend was observed in 2017 and 2019; the score varied between 0.555 and 0.668, and the company's financial health improved. In 2020 and 2021, low scores, such as 0.200 and 0.513, were observed during the pandemic, indicating that the company experienced serious difficulties during this period. However, recovery was experienced again in 2022 and 2023. In 2023, the score increased to 0.819, indicating that the company began to recover its financial health.

The figures representations of the Z" and S score results of the business are available below.

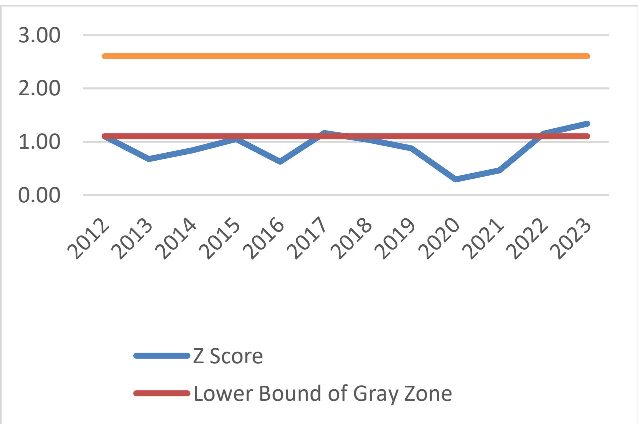

Figure 1. THYAO Altman Z" Score Results

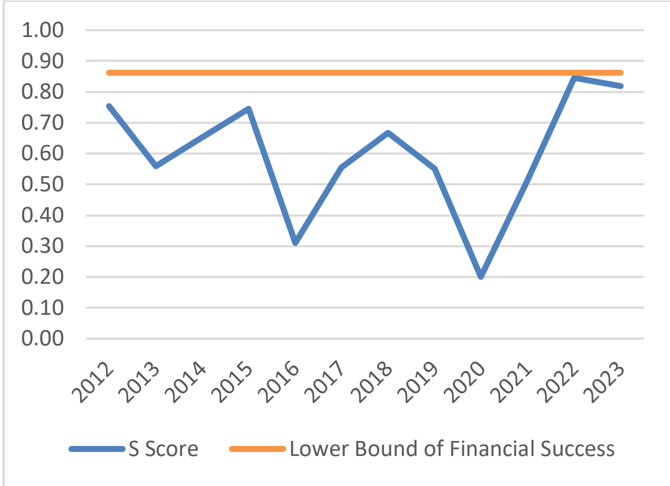

Figure 2. THYAO Springate S Score Results

THYAO experienced serious financial difficulties, especially during the pandemic period (2020-2021), but showed recovery in both the Altman Z" score and Springate S score in 2022 and 2023. However, the company's financial situation cannot be considered completely solid when looking at both scores; bankruptcy risk is still at a moderate level, and it is going through a period that needs to be monitored carefully.

The results of the Altman Z" and Springate S Score model applications for the PGSUS business are presented in Table 3.

Table 3. PGSUS Altman Z" Score and Springate S Score Results

PGSUS	2012	2013	2014	2015	2016	2017
T1	-0.090	0.155	0.184	0.205	0.075	0.153
T2	0.005	0.039	0.065	0.091	0.086	0.044
T3	0.139	0.113	0.139	0.109	0.021	0.098
T4	0.148	0.327	0.330	0.354	0.279	0.308
Z" Score	0.514	2.244	2.702	2.747	1.208	2.127
PGSUS	2018	2019	2020	2021	2022	2023
T1	0.063	0.063	-0.034	0.000	0.000	0.054
T2	0.061	0.043	0.077	0.005	-0.018	0.027
T3	0.097	0.171	0.028	0.042	0.148	0.103
T4	0.272	0.254	0.185	0.130	0.188	0.271
Z" Score	1.550	1.971	0.413	0.434	1.129	1.418
PGSUS	2012	2013	2014	2015	2016	2017
X	-0.090	0.155	0.184	0.205	0.075	0.153
Y	0.091	0.074	0.092	0.066	-0.019	0.057
Z	0.289	0.226	0.161	0.184	-0.138	0.326
Q	0.647	0.536	0.665	0.651	0.481	0.477
S Score	0.778	0.935	0.979	0.935	0.328	0.948
PGSUS	2018	2019	2020	2021	2022	2023
X	0.063	0.063	-0.034	0.000	0.000	0.054
Y	0.058	0.098	-0.047	-0.012	0.101	0.065
Z	0.153	0.293	-0.311	-0.162	0.319	0.272
Q	0.422	0.367	0.104	0.135	0.319	0.238
S Score	0.743	0.958	0.016	0.258	0.920	0.834

The table shows the Pegasus (PGSUS) Altman Z" and Springate S score values between 2012-2023. These scores were used to evaluate a company’s financial health. While the Altman Z" score measures the risk of bankruptcy, the Springate S score predicts whether a firm will experience financial distress. The Z score between 0.514 and 2.244 between 2012-2013 shows that Pegasus experienced significant fluctuations in its financial structure during these years. It achieved a high score of 2.244 in 2013. This may be due to Pegasus's public offering of BIST in 2013 or the fact that it started a strategy to expand its fleet and routes in 2013. The scores increased to 2.702 and 2.747 in 2014-2015, indicating that the company's financial structure was strong. In 2016-2019, the Z-score indicated that the company's solid financial structure continued. During this period, the score ranged between 1.208 and 2.127, indicating a transition between the grey zone and financial health. In 2020-2021, due to the impact of the pandemic, the Z score fell to low levels of 0.413 and 0.434, indicating a serious risk of bankruptcy. In 2022-2023, the company showed signs of recovery, and the Z score was 1.129 and 1.418, respectively, but it is still not in a completely safe zone and can be said to be in a situation that needs to be monitored carefully.

In 2012-2013, the S score ranged between 0.778 and 0.935, indicating that Pegasus was far from experiencing financial distress. In 2014-2015, the scores increased to 0.935 and 0.979, respectively, indicating a financially strong period. In 2016-2017, the scores fluctuated between 0.328 and 0.948, and, although a decrease was observed, especially in 2016, the company generally remained free of financial distress. to 2018-2019, the S score fluctuated between 0.743 and 0.958, indicating that the financial structure of Pegasus was strong during this period. In 2020-2021, due to the impact of the pandemic, the S score decreased to 0.016 and 0.258, indicating that the company was experiencing serious financial difficulties. In 2022 and 2023, the S score recovered and increased to 0.920 and 0.834, respectively, indicating that the company has improved its financial structure but still needs to be monitored carefully.

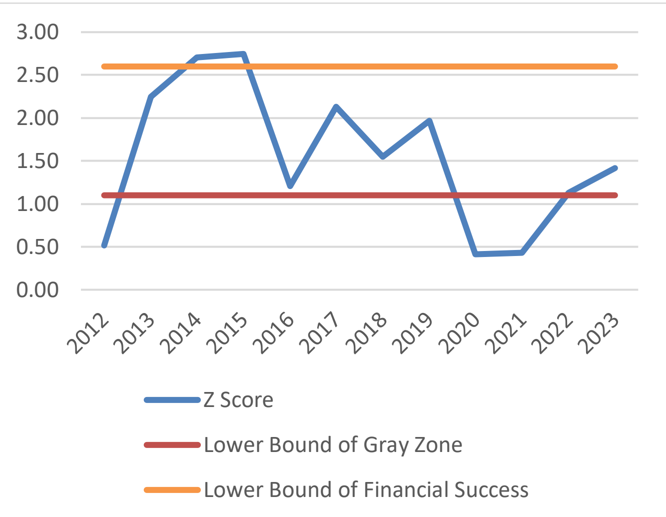

Figure 3. PGSUS Altman Z" Score Results

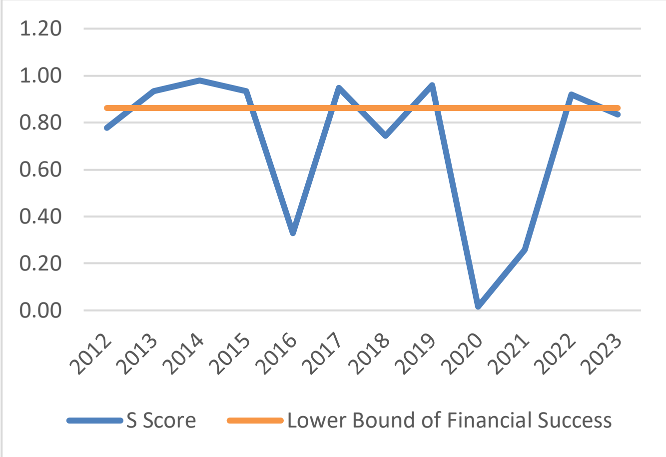

Figure 4. PGSUS Springate S Score Results

Pegasus experienced serious declines in both the Altman Z" score and the Springate S score due to the pandemic, especially in 2020-2021. However, there has signed of recovery by 2022 and 2023. According to the Z-score, it is still in the gray zone and cannot be said to be completely away from the risk of bankruptcy. However, according to the S-score, it recovered and moved away from the risk of financial distress. The company's financial situation has improved, but the risk elements continue.

5. Result and Discussion

The objective of this study was to assess the risk of financial failure and its impact on selected companies. Specifically, Turkish Airlines (THYAO) and Pegasus (PGSUS), operating within the BIST Transportation and Storage Sector, were chosen for the analysis. Financial data spanning from 2012 to 2023 were collected, and both the (Altman Z" Score) and (Springate S-Score) models were applied for comparative evaluation.

Utilizing these two models facilitates a thorough comparison of companies' financial health. The findings indicate that THYAO has consistently faced the risk of financial failure across the years, as indicated by both models, with the last two years placing it in an uncertain position. On the other hand, PGSUS demonstrates a lower risk of financial failure than THYAO, showcasing successful years, particularly evident in the S Score model's assessments. In recent years, PGSUS has either shown success or remains in an uncertain zone regarding financial failure risk. Kızıl and Aslan (2019) emphasize that the financial ratios of PGSUS are better than those of THY; Macit and Göçer (2020) emphasize that PGSUS performs better than THYAO and support the results obtained from our study. However, Köse (2021) yielded different results.

THYAO and Pegasus experienced serious declines in both the Altman Z" score and the Springate S score due to the pandemic, especially in 20 20-2021. However, these companies signed recoveries by 2022 and 2023. The fact that the effects of Covid-19 have decreased for both companies in the recent period is similar to that of Dağlı (2021).

An overarching conclusion is that both the companies are susceptible to financial failure. PGSUS's emphasis on cost-effectiveness appears to yield more favorable outcomes in managing financial risks, possibly due to differing strategic approaches between the two companies. (Avcı and Çınaroğlu, 2018) supports that the “low-cost transportation” strategy is an important indicator of financial success. It is important to note that future investments, profit distribution strategies, and financial policies can impact these scores, highlighting the dynamic nature of risk management within businesses. Furthermore, the study emphasizes the vulnerability of airlines to external factors such as pandemics, wars, and crises, necessitating heightened precautionary measures compared to other sectors. Effective risk management involves vigilant monitoring through early warning systems and development of proactive policies. Predicting financial failure, ranking financial performance, and conducting sectoral analyses are vital to ensuring business continuity.

When the findings are evaluated, it is seen that two companies operating in the passenger transportation sector and the XULAS sector generally carry a risk of financial failure. The main reason for carrying the relevant risk is the data obtained from the financial statements. The financial success of relevant companies is important because they are publicly traded, operating in an important sector, and their business volume. However, reasons such as the company maintaining its sustainable structure, making investments, and the fact that the investment cost will be obtained in the following periods are also important for interpreting financial failure. In this context, companies must review their risk management strategies, strengthen investment and financial planning, improve financial monitoring and reporting systems, and increase the use of predictive analysis.

The most important contribution of this study to the literature is the comparative analysis of the two models with the current data. Although a full comparison is not made because the methods, variables, and years used in the literature are different, the necessity of managing the risk of financial failure for companies is also expressed in this study. Turkey's uncertainty index significantly affects the financial performance of the firms included in the sample between 2012 and 2023. The pandemic period, especially in 2020-2021, combined with the high uncertainty index, has caused serious declines in the financial indicators of both companies. During this period, both the Altman Z" score and the Springate S score of the firms decreased significantly, and the firms faced financial difficulties. However, the improvement in Turkey's uncertainty index in 2022 and 2023 signals a recovery in the financial performance of both companies. When the synergy between the fluctuations in Turkey's uncertainty index and the financial situation of both companies is considered, Turkey's uncertainty index can be included as an independent variable in future studies on the subject.

A key recommendation of this study is to explore alternative methods and conduct comparative analyses to validate the findings and enhance our understanding of financial risk management in same-sector firms.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Exploring Cargo Potential of an Airport: Pre-Feasibility Study and Policy Recommendations for Hasan Polatkan Airport

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Abstract

Although air passenger transportation has grown steadily since liberalization movements, it has experienced a sharp decline with the COVID-19 pandemic. However, air cargo transportation has been relatively less affected by this crisis due to the increasing volume of e-commerce and the critical importance of supply chains. Air cargo positively affects the regional economy through the logistics and trade channels it provides. This study aims to investigate Eskişehir Hasan Polatkan Airport's cargo transportation potential and make its pre-feasibility as an air cargo hub. In this context, as a case study, interviews were conducted with stakeholders regarding the cargo potential of Hasan Polatkan Airport, and qualitative data were obtained. The authors qualitatively analyzed the data, and the findings were compiled under two headings: findings on demand and findings on technical/operational requirements. Considering these findings, alternative business models are discussed, and different policy recommendations are provided.

1. Introduction

With the increasing globalization, the importance of air cargo transportation has also been growing. Typically, small, light, compact, high-value-added new products are increasingly being transported by air at an accelerating pace and flexibly (Button and Yuan, 2013; Tuncer and Aydoğan, 2019). Despite a 65.9% decrease in revenue passenger kilometers (RPK) compared to 2019 across the industry due to the Covid-19 impact, the decline in cargo ton kilometers (CTK), supported by various aids and the increase in e-commerce, remained at only 9.1% for the same year (IATA, 2020). In Türkiye, according to the data for 2020, the first year affected by the pandemic, annual passenger traffic decreased by approximately 60% in parallel with the world, while cargo traffic decreased by only 10% (DHMİ, 2021). Air cargo transports only 1% of the volume of world trade but carries 35% of its monetary value (more than 6 trillion US dollars) (IATA, 2021). Air cargo operations contribute to increased income for airports and the surrounding community and increase the utilization rate of airport facilities (Golicic et al., 2003). Therefore, the occurrence of air cargo flights in a city will also increase the prosperity level of that city. However, before deciding to start air cargo operations at a new airport, airports should determine the feasibility of such an initiative. Airports must comprehensively assess the air cargo market to determine whether they can secure a satisfactory market share. In this context, the present study is designed to investigate the potential for air cargo in Eskişehir.

International freight is a fundamental requirement for the development of international trade. Numerous studies provide compelling evidence that air cargo services are a crucial driver of economic growth and international trade in today's dynamic global economy (Yu and Zou, 2022). In studies focusing on specific airports in the air cargo field, there has been a concentration on the general analysis of air cargo centers (Zhang, 2003), demand analysis and modeling (Lo et al., 2015; Magaña et al., 2017; Wadud, 2013), and air cargo tariff and planning (Derigs and Friederichs, 2013). However, no previous study has been conducted to investigate the air cargo potential of a city where regular air cargo flights have not been conducted before, and a pre-feasibility study has been conducted on it.

Research indicates that factors such as the volume of imports and exports, production, and employment opportunities explain the increase in air cargo traffic (Kupfer et al., 2017; Lakew and Tok, 2015). One of the reasons for choosing Eskişehir as a cargo case in this study is primarily due to its significant opportunities in terms of railway, highway, and airway transport. Additionally, with these opportunities, the city is centrally located among Türkiye's highly populated and industrialized cities, such as İstanbul, Ankara, İzmir, Bursa, Konya, and Antalya. Eskişehir, which has dense road and railway connections and is close to major ports, houses two logistics centers. Unlike the Turkish average, Eskişehir recorded a surplus between 2014 and 2018. Furthermore, Eskişehir monopolizes producing diesel locomotives, aircraft engines, and compressors (coolers). In 2018, the United States was the country with which Eskişehir conducted the most exports and imports. However, most of Eskişehir's significant export partners are European countries. The other countries with which Eskişehir conducts the most imports are France, China, and Germany, respectively.

2. Significance and Literature

Air cargo transportation is not a heavily researched area in the aviation literature. Some argue that cargo transportation at airports is an airline activity and has little impact on the economic performance of the airport; hence, it is not considered important. While air cargo may not be significant for many airports and airlines, for some airports, it constitutes a substantial portion of their revenue. For instance, at the Cincinnati/Northern Kentucky International Airport, cargo airlines operate half of the total flights, and DHL alone contributes to 14% of the airport's operational revenue (Mayer, 2016).

Several factors influence an airport's ability to attract cargo traffic. These factors include airport infrastructure capacity, regional and intercontinental airport network connectivity, service quality, and cost factors. Air cargo transportation is inherently a highly competitive sector. This is because, except for urgent cargo, many types of cargo are insensitive to routing. For a shipper sending cargo from New York to Kuala Lumpur, whether the cargo goes through Tokyo, Hong Kong, or Shanghai is not essential. What matters is that the cargo arrives in Kuala Lumpur on time. Shippers can often choose from multiple routes and carriers when sending their cargo. Therefore, airports compete more in air cargo than passenger transportation (Ohashi et al., 2005).

Air cargo transportation is experiencing rapid growth worldwide for several reasons. Firstly, the production of lightweight but high-value products is increasing. Between 80% and 90% of the international transportation of medical products and microelectronics is carried out by air transportation. Secondly, with the shortening of product life cycles and the adoption of just-in-time manufacturing philosophies, there is a growing need for rapid transportation to ensure products reach markets quickly. Thirdly, air transportation costs have significantly decreased over the past 20 years, particularly with the introduction of wide-body aircraft and cargo carriage in passenger aircraft (Yuan et al., 2010).

On the other hand, the increasing importance of air cargo necessitates airports to plan and develop their air cargo capacities to meet growing demands. This is particularly crucial for regional airports, especially when major airports reach their capacity limits. To effectively enhance air cargo operations, regional airports must understand the specific requirements of their industries and tailor their facilities accordingly. Market Opportunity Analysis (MOA) enables airport management to assess macro-opportunities, identify target industries, and develop marketing strategies to design appropriate air cargo facilities. Each city and airport is unique regarding target industries and customers, so the MOA process should be conducted specifically for each airport (Golicic et al., 2003).

Studies examining airport selection for air cargo transportation have identified several factors evaluating the cargo potential of selected airports. For instance, Zhang (2003) studied Hong Kong International Airport and concluded that airports closer to shippers, with lower total costs and faster cargo throughput, have a greater chance of becoming regional air cargo hubs. Zhang and Zhang (2002) emphasized the importance of customs efficiency in air cargo transportation. Airport fees could be a significant factor in air cargo carriers' choice of airports. However, Zhang (2003) found contrasting findings with the example of Hong Kong. According to this study, although Hong Kong is the world's most expensive airport, airport fees account for only 7% of the total costs for air cargo carriers. Buyck (2002) found that airports open 24/7 and without noise restrictions are much more preferred by air cargo carriers. Bakhitiyorjon and Lee (2017) comprehensively reviewed the literature on factors influencing cargo airlines' airport switching decisions. The findings indicated that constraint-related issues (such as night flight restrictions and customs management) harm the airport-airline relationship, followed by location issues (such as lack of demand between departure-arrival points). Hong and Zhang (2010) used data from 29 airlines from 1998 to 2002 and found that airlines carrying more cargo are more efficient than those carrying less cargo. In a study evaluating the suitability of Venango Regional Airport for air cargo operations, Baker (2020) found limited potential for the airport's current cargo operations. This was primarily attributed to the airport's proximity to existing air cargo hubs and airports. However, the study also highlighted the opportunity for Venango Regional Airport to provide specialized air carrier services based on demand.

This study evaluates the air cargo potential of Eskişehir Hasan Polatkan Airport, which has not been previously examined in the literature. The research results were first converted into a technical report, and then the updated version was published in this study (Şengür et al., 2019). The airport has been assessed in terms of aspects mentioned in the literature, such as noise restrictions, cost, and proximity to cargo centers, and recommendations have been made to contribute to the literature.

3. Materials and Methods

The study employed a case study method. According to Creswell (2007), case studies are conducted using a specific incident as a sampling tool to understand a problem, and they are researches that investigate a problem with one or more situations within a limited system. They are generally considered qualitative research and are an appropriate method for assessing contextual conditions (Yin, 2008). A detailed analysis of the data obtained from the interviews conducted in the study was carried out to provide evidence regarding Eskişehir's air cargo potential. While case studies can be supported with quantitative data, using qualitative data collection techniques is also a strong element of the method.

An in-depth literature review was conducted as part of the case study, and statistical information regarding air cargo transportation to/from Eskişehir and its surroundings was searched. Based on the literature, a survey was prepared. Still, it was understood through preliminary discussions with field experts that obtaining in-depth information from experts would provide more meaningful findings than using a multiple survey method. Therefore, semi-structured and unstructured interviews were preferred in the data collection phase. As a result, 12 participants with high experience in their field were interviewed. In this context, one-on-one interviews were conducted with MNG Airlines operating in the Turkish domestic air cargo market, BEBKA (West Black Sea Development Agency), Eskişehir Chamber of Industry, Eskişehir Chamber of Commerce, Hasan Polatkan Airport responsible manager, and senior executives of Eskişehir Customs Directorate.

All interviews were conducted by appointment in the managers' offices except an hour of a phone interview with MNG Airlines managers based in İstanbul and exclusively operating air cargo transportation. Additionally, group and individual meetings were held with various public and private stakeholders who may be involved in air cargo operations in Eskişehir. All interviews were conducted in late 2019, just before the COVID-19 pandemic. The list of organizations and representatives interviewed is provided in Table 1 below.

Table 1. Organizations and participants interviewed

Organization	Participants' positions
Bursa Eskişehir Bilecik Development Agency (BEBKA)	- Eskişehir Investment Support Office Coordinator
Eskişehir Chamber of Commerce	- President - Board members responsible for logistics and transportation - A representative of a major logistics company
Eskişehir Chamber of Industry	- Deputy Secretary General
Hasan Polatkan Airport	- Operations Manager - Search and Rescue and Firefighting Unit Manager
Eskişehir Customs Directorate	- Customs Director
CAN International Heavy Transport and Warehousing	- Operator
DHL Express Western Anatolia Agency	- Engagement director
MNG Airlines	- Planning director - MNG Bursa-Yenisehir Airport Cargo Hub Project Manager, UTİKAD Vice President

The qualitative data obtained from the interviews have been analyzed, and subsequently, research results and policy recommendations have been provided, benefitting from statistical cargo-related data of Eskişehir.

4. Case Study on Air Cargo Potential of Eskişehir Hasan Polatkan Airport

4.1. The features of Eskişehir Hasan Polatkan Airport

Opened to traffic on March 29, 1989, under the name of Anadolu Airport, Hasan Polatkan Airport is currently an international airport operated by the Faculty of Aeronautics and Astronautics on behalf of the Rectorate of Eskişehir Technical University. Table 2 shows the technical specifications of Hasan Polatkan Airport.

Table 2. Technical specifications of Hasan Polatkan Airport

ICAO Designator Code	LTBY
IATA Designator Code	AOE
Average Maximum Temperature (1928-2018)	17.4°C
Average Minimum Temperature (1928-2018)	5.3°C
Airport Elevation	2580 ft
Runway Orientation	09/27
Runway Length	3000 m
Runway Width	45 m
Runway Surface	Concrete
Distance from City Center	5 km
Coordinates	AD 39485N-0303114E
Fuel Type/Capacity	JET A-1/38 Ton
Cargo Loading and Unloading Facility	-
Anti-Icing Facility	-
Hangar Area and Maintenance Facility for Visiting Aircraft	-

Source: (ESTÜ, 2021)

The airport effectively manages airport operations, terminal operations, air traffic control services, maintenance hangars, and flight training activities. Additionally, faculty students can gain practical learning experiences in the field by participating in activities aligned with their educational topics. In this regard, the airport provides opportunities for education within the practical application field, aiming to enhance the education process's effectiveness, efficiency, and sustainability.

Figure 1 illustrates Hasan Polatkan Airport's cargo traffic (baggage + cargo + mail) (tons) between 2008 and 2023.

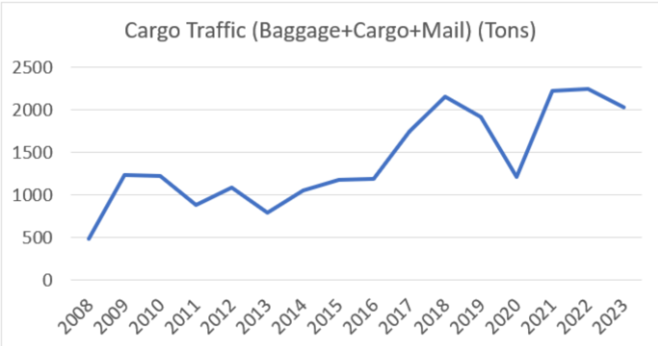

Figure 1. Cargo Traffic at Hasan Polatkan Airport (DHMİ, 2023)

Hasan Polatkan Airport has not had significant cargo traffic in the past. However, cargo traffic moves in parallel with passenger traffic.

4.2. The potential of Eskişehir by numbers

In general, cargo transportation, specifically air cargo, is a function of a country's and region's industrial and commercial volume and the country's key economic, demographic, and social indicators. Local air cargo traffic expectations depend on local manufacturing industries and the types of goods produced (Zhang, 2003). A city's industrial and commercial volume and surroundings are the main input for cargo potential. Eskişehir, which has significant railway, highway, and air transportation opportunities, is centrally located among Türkiye's most important cities: Ankara, İstanbul, Bursa, İzmir, Konya, and Antalya. Table 3 shows the distances and travel times from Eskişehir to these cities.

Table 3. Distance and travel times of Eskişehir to some important cities

	Ankara	İstanbul	İzmir	Bursa	Antalya	Konya
Distance (km)	233	324	411	155	424	339
Travel Time (hours)	1.5	2.5	5	2	5	2
Transportation Type	By train	By train	By road	By road	By road	By train

In Eskişehir, located close to important ports and with dense road and railway connections, there are two logistics centers: TCDD Hasanbey Logistics Center and Organized Industrial Zone Logistics Center. Various agreements have been made to establish a railway connection between these two centers, but they have not yet been finalized. In Eskişehir, where the railway is heavily used for freight and passenger transportation, approximately one-third of the population earns their living from the industrial sector (see Table 4).

Table 4. Various economic and commerce statistics of Eskişehir

	Value	Year	Source
Employment Rate	42.8%	2020	TÜİK (Turkish Statistical Institute)
Unemployment Rate	13.2%	2020	TÜİK
Number of Establishments	20009	2021	SGK (Social Security Institution)
Number of Active Employees	243.703	2020	SGK
Number of Newly Established Companies	1.783	2015	TOBB (Union of Chambers and Commodity Exchanges of Türkiye)
Number of Closed Companies	567	2015	TOBB
Number of Foreign Capital Companies	95	2016	Ministry of Economy
Number of Investment Incentive Certificates (Quantity)	69	2015	Ministry of Economy
Main Railway Line Passenger Count	3.048.579	2015	TCDD (Turkish State Railways)
Railway Freight Transport (tons)	737.815	2015	TCDD

Source: Compiled from the institutions provided in the source column by the authors

As of 2021, Eskişehir's gross domestic product (GDP) amounted to 81,527,000,000 TL (approximately 9,07 billion $). Figure 2 illustrates the change in Eskişehir's GDP between 2004 and 2017.

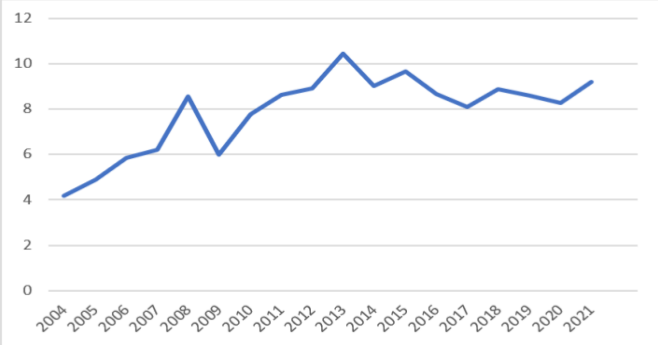

Figure 2. Gross Domestic Product of Eskişehir from 2004 to 2021 (in billion $) Source: TURKSTAT, 2021

Eskişehir's gross domestic product (GDP) has seen an increasing trend based on US dollar currency despite depreciating Turkish Lira. According to the graph, particularly in the years after 2009, a modest increase in growth rate stands out. Figure 3, on the other hand, illustrates the import and export activities of Eskişehir between 2014 and 2018.

Figure 3. Import and Export Activities of Eskişehir from 2014 to 2018 Source: TURKSTAT, 2019

According to Figure 3, Eskişehir has consistently maintained a trade surplus, unlike the Turkish average in previous years. The proportional increase in the trade surplus in 2018 is noteworthy. On average, $25,000 is transported per container exported from Eskişehir. The transportation cost of a container from Eskişehir to Gemlik Port is approximately 1500 TL, while the transportation cost to European countries is around 2500 € on average.

Figure 4 shows the number of exporting and importing companies in Eskişehir between 2014 and 2018.

In 2014, the number of exporting and importing companies was close to each other. In the following years, however, the difference between the numbers of exporting and importing companies increased in favor of importing companies. By 2018, the number of exporting companies had surpassed that of importing companies.

Figure 4. Number of Exporting and Importing Companies in Eskişehir, 2014-2018 Source: TÜİK, 2019

Figure 5 shows the monthly export and import values of Eskişehir. According to the figure, export values fluctuate throughout the year, reaching their highest levels at the end of the year. On the other hand, the trend of imports appears to be more stable.

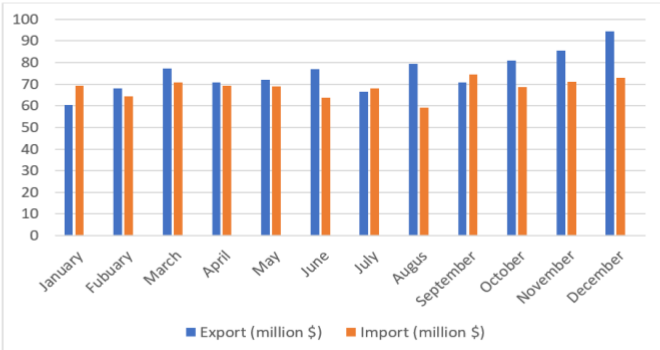

Figure 5. Export and Import Values of Eskişehir by Months Source: TÜİK, 2019

Table 5 shows the national shares of some products produced in Eskişehir. According to the table, Eskişehir monopolizes producing aircraft engines, diesel locomotives, and compressors (refrigeration). It also has significant weight in producing borax, jacks, refrigerators, and clothes dryers.

Table 5. National Shares of Some Products Produced in Eskişehir

Product	Eskişehir's Share in National Production
Aircraft engine	%100
Diesel locomotive	%100
Compressor (refrigerator)	%100
Borax	%73
Jack	%70
Refrigerator	%65
Clothes dryer	%50
Magnesite	%30
Biscuit, cake, cracker	%30
Roof tile	%30
Milk	%20
Truck	%20
Oven	%20
Ceramic floor and wall tiles	%15

Source: Eskişehir Chamber of Industry, 2016

Table 6 shows the distribution of imports by product groups in Eskişehir in 2018. According to the table, the top three product groups that Eskişehir imported the most are boilers, machinery, mechanical appliances, nickel articles, and plastics.

Table 6. Distribution of Imports by Product Groups in Eskişehir (2018)

Product	Import (million $)
Boilers, machinery, mechanical appliances, and equipment, nuclear reactors, and their parts and accessories	202.896
Nickel and articles thereof	119.045
Plastics and products thereof	70.742
Electrical machinery and equipment; sound recording or reproducing apparatus; television image and sound recording or reproducing apparatus and their parts and accessories	64.669
Other base metals (tungsten, molybdenum, tantalum, magnesium, cobalt, bismuth, cadmium, etc.)	59.643
Motor vehicles, tractors, bicycles, motorcycles, and other land vehicles; their parts and accessories	55.300
Vehicles and materials for railways, etc.; their parts and accessories; mechanical traffic signaling devices	47.697
Aluminum and articles thereof	36.261
Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus; their parts and accessories	30.754
Tanning or dyeing extracts; tannins and their derivatives; dyes, pigments, and other coloring matter; paints and varnishes; putty and other mastics; inks	29.526

Product	Export (million $)
Defense and aerospace industry	383.081
Iron and non-ferrous metals	97.891
Machinery and components	93.716
Chemicals and chemical products	79.171
Mining products	62.969
Cement, glass, ceramic, and clay products	59.540
Climate control industry	54.158
Grains, pulses, oilseeds, and their products	52.065
Electrical and electronic products	44.135
Ready-made clothing and apparel	40.823

Table 7 shows the distribution of Eskişehir's exports by product groups in 2018. According to the table, the top three product groups that Eskişehir exports the most are the defense and aerospace industry, iron and non-iron metals, and machinery and parts.

Table 7. Eskişehir's Exports by Product Groups (2018)

Product	Export (million $)
Defense and aerospace industry	383.081
Iron and non-ferrous metals	97.891
Machinery and components	93.716
Chemicals and chemical products	79.171
Mining products	62.969
Cement, glass, ceramic, and clay products	59.540
Climate control industry	54.158
Grains, pulses, oilseeds, and their products	52.065
Electrical and electronic products	44.135
Ready-made clothing and apparel	40.823

Source: Eskişehir Chamber of Industry, 2019

Table 8 shows the top ten countries where Eskişehir exported the most in 2018. According to the table, Eskişehir exported the most to the United States in 2018. Germany, France, and Austria, respectively, followed this. Upon examining the table, it is noticeable that most of Eskişehir's significant export partners are European countries.

Table 8. Top 10 countries in terms of export to Eskişehir (2018)

Countries	Export (million $)
USA	359.030
Germany	92.282
France	84.809
Austria	42.152
Spain	31.551
Romania	29.675
Belgium	29.539
Netherlands	24.678
Poland	20.274
United Kingdom	19.122

Source: Eskişehir Chamber of Industry, 2019

Table 9 shows the top 10 countries where Eskişehir imported the most in 2018. According to the table, Eskişehir sourced the highest value of products from the United States in 2018. France, China, and Germany, respectively, followed this.

Table 9. Top 10 countries in terms of import from Eskişehir (2018)

Countries	Import (million $)
USA	259.100
France	76.119
China	75.277
Germany	74.868
Spain	73.554
Italy	54.830
Czech Republic	36.288
United Kingdom	27.873
Netherlands	21.477
Japan	20.903

4.3. Findings Regarding the Cargo Potential of Hasan Polatkan Airport

In this section, findings obtained from stakeholders regarding the potential of Hasan Polatkan Airport to become a cargo hub have been compiled under two main headings:

- Findings related to demand
- Findings related to technical, operational, administrative requirements

Based on these findings, alternative business models have been discussed, and policy recommendations have been provided.

Findings related to demand

In air cargo transportation, small package shipments require urgent and fast delivery due to their characteristics. Therefore, excessive transfers are not desired to minimize time loss. Hence, regular and preferably direct flights are the most basic requirement for small package carriers. For other cargoes, air transportation is often an expensive alternative for transporting many products. Mostly, businesses prefer cheaper alternative routes. Only in cases such as sending samples or urgent part needs does the importance of price decrease, and there may be demand for air cargo. In such cases, cargo senders need to rely on and get used to the existence of regular flights. However, according to the discussions, there is not enough potential in Eskişehir and its vicinity to fill the capacity of a cargo aircraft and make regular flights daily.

The flow of cargo is different from that of passengers. While passengers generally demand a flow where they depart in the morning and return in the evening, cargo companies typically collect cargo until a certain time and send them with scheduled flights at airports with evening flights. The cargo aircraft usually depart after 6 pm. Special vehicles are dispatched for urgent cargoes arriving after 3-4 pm and transported to İstanbul by road. İstanbul is considered the center of cargo in Türkiye, and even cargoes originating from İzmir are sent to İstanbul via scheduled flights. Additionally, 75% of the cargo in Türkiye is distributed to İstanbul and its surroundings.

It has been noted that even if scheduled flights are organized regularly and prove reliable, it may not be easy for businesspeople to change their cargo habits. Despite the seemingly long distance by road, factors such as the short duration of the İstanbul-Eskişehir route by private vehicle, the numerous flights departing from İstanbul, the ability to dispatch vehicles by road at any time, and the affordability of sending from İstanbul may continue to be preferred. Discussions with MNG Airline Managers also support this thesis. MNG Airlines is a Turkish company based in İstanbul that exclusively carries cargo. MNG also manages DHL's activities in Türkiye. They indicate that they provide investment and equipment support to the management of Bursa Yenişehir Airport for flights. Thus, it aims to create cargo potential in Bursa with the initiative and support of city stakeholders. However, despite the provision of warehouses, depots, cargo handling equipment, customs, etc., it is stated that industrialists and traders in Bursa mostly continue to prefer İstanbul over Bursa. Price and habits are shown as the most important reasons for this. MNG Managers state that they will wait for demand to emerge for some time. It is also not certain that demand will emerge. Therefore, although it is possible to withdraw the equipment, there is a risk of investments being idle. Despite having made investments and Bursa's business volume is several times that of Eskişehir, the lack of regular demand for cargo operations in Eskişehir could also be an indicator. It is not considered very likely that regular cargo flights that do not operate in Bursa will operate in Eskişehir. On the other hand, in the possibility of cargo flights becoming regular in Bursa, when considering that Bursa Yenişehir Airport is close to Eskişehir and Bozüyük, where the industry is developed, it is also possible for demand to shift to Bursa.

Difficulties in directing demand were examined using Şanlıurfa GAP Airport as an example. At Şanlıurfa GAP Airport, an area of 3,800m² with 4 cold storage warehouses totaling 41.5m² has been allocated for air cargo services. Despite providing cooling between +5 and -25 degrees in these warehouses, these facilities cannot provide cargo services. The tender for finding an operator was canceled due to a lack of demand. (Şanlıurfa GAP Airport Feasibility Report, 2016) Şanlıurfa is one of the leading provinces in Türkiye in terms of cut flower and fresh fruit and vegetable exports using air cargo. Despite its export potential and existing facilities, even in this airport, cargo transport is preferred to İstanbul, and air cargo operations are not at the desired level. In this situation, it has been determined that there will not be a short-term potential to sustain cargo operations at Hasan Polatkan Airport solely through cargo aircraft.

Findings related to technical, operational, and administrative requirements

In terms of enough demand, starting cargo operations needs basic technical, operational, and administrative requirements such as procuring personnel, facilities, and equipment for cargo handling and storage requirements. These requirements and their prospective cost sides will be explained below.

Technical and equipment requirements

While basic equipment may be sufficient for baggage loading on a passenger aircraft, various loading equipment is required for cargo operations. Some of the equipment are listed below:

- Container (Boxes produced for transporting goods without damage)
- Pallet, dolly, and pallet dolly (Equipment used for transporting ULDs and pallets)
- High loader (Vehicles used for cargo loading and capable of moving loads up and down. There are two types: a) Main deck high loader and b) Lower deck high loader)
- Forklift (Used for loading or unloading heavy loads onto or from aircraft)

Various factors also influence the number and quality of the necessary equipment:

- Type, size, volume, and cargo weight to be served.
- Type, size, and characteristics of the aircraft to be served.
- Hourly and daily distribution of demand and service.

From the perspective of equipment and tools, it can be observed that cargo handling equipment is also quite expensive. Due to the low potential, the probability of preferring to purchase and keep this equipment at Hasan Polatkan Airport for ground handling operations is low as it would be considered a sunk-cost investment. On the other hand, the University purchases a single high loader, which costs approximately 370,000.00 USD, a single pallet dolly, around 3,500 USD, and a single container dolly, about 2,600 USD (Eski and Tasus, 2018). One high loader and numerous pallet and container dollies are required for each aircraft to be serviced simultaneously. As seen, cargo equipment is expensive and can only guarantee a return on investment and profitability if a high and sustainable demand justifies the investment.

Operational and Facility Requirements

Regarding facilities, a separate apron area is required for handling cargo (unloading, loading, preparation). Discussions have suggested that the West Apron at Hasan Polatkan Airport may suit this purpose. To open up this apron for use, apron lighting needs to be installed. According to international regulations, the current Search and Rescue and Firefighting (ARFF) technical capability is sufficient for cargo operations.

Many airports prefer to build an additional terminal based on cargo volume. A cargo terminal is required for pallet and container loading. When cargo volume does not require an additional terminal, a portion of the passenger terminal can be used as a cargo terminal. The existing terminal at Hasan Polatkan Airport is not always sufficient for passenger operations alone. During peak times, passengers may need to wait outside. In this case, there will be a need for an additional terminal for cargo operations.

Another aspect of facility requirements is the necessity of temporary and permanent storage areas, warehouses, and depots. The requirements for storage areas vary depending on the type of goods to be transported. Especially for perishable cargoes, there should be cold storage warehouses, and sufficient space should be allocated for hazardous materials. On the other hand, especially in international shipments, incoming cargoes are delivered to the warehouse under the supervision of customs officials, and the products are kept in the warehouse while the necessary documents are completed. After these procedures are completed, the cargo becomes ready for pickup by the consignee. However, the readiness of the cargo does not necessarily mean it will be picked up immediately. Storage services must be provided until the consignee retrieves the product. Outbound cargoes are also first received in the warehouse, and customs brokers wait for customs clearance and declaration procedures to be completed. Temporary storage is required until they are ready to be transported under the aircraft.

Therefore, cargo operations at Hasan Polatkan Airport will also necessitate the construction of a storage facility, creating a need for warehouse construction. The construction and operation of warehouses are defined in the relevant articles of the Customs Regulation in Türkiye and Annex 80, titled "Conditions and Required Documents for Opening and Operating Warehouses." Technical specifications and necessary conditions are detailed and quite extensive. Further detailed studies are required regarding the cost of warehouse investment. Annual fees must also be paid for opening and operating warehouses. According to data from 2023, the fee for a general warehouse operating permit is 202,961.40 TL, and an annual fee of 67,646.30 TL is required for operation. The same amounts are also required for temporary storage, place operating permits, and operations. In addition, application file fees, other charges, and commitment letters are required during the opening process (SHGM, 2015). The investment in the cargo business is quite high, and the return on investment takes a long time. Therefore, it is not considered very effective for the University to make this investment and bear the operating costs. The interviewees were also asked for their opinions on carrying out this warehouse investment using the Build-Operate-Transfer method. They mentioned that while there are some projects like this in land transportation, they have not yet been used in aviation in Türkiye. Although it generally seems feasible, it was noted that the return on investment would take a very long time. Due to the low cargo potential, it would not be an attractive investment for the private sector.

Administrative and human resource requirements

The equipment and requirements for pallet loading at airports where pallet loading is predominant may differ from container or bulk loading requirements. Especially in bulk loading, the need for handling personnel increases, while the need for specialized personnel to use specialized equipment will also increase. On the other hand, storage requirements at airports where live animals are predominant will differ from those where frozen fish or dangerous goods are sent.

A cargo business model requires changes in the administrative structure and managerial staffing in addition to operational personnel. The airport is managed by Eskişehir Technical University, which provides the necessary personnel for landside and airside operations, excluding the tower. However, because the university is subject to public personnel recruitment policies, it may face challenges in assigning skilled operational, administrative, and managerial staff to the airport or hiring new personnel.

Short operating hours have been identified as a utilization issue for some subsidized Turkish airports (Uzgör and Şengür, 2022). Extending operational hours for cargo operations at Hasan Polatkan Airport could introduce further administrative challenges, particularly regarding working hours or additional shifts. Such challenges may bring extra costs to the airport operator.

4.4. Discussion and policy recommendations

Nowadays, airports have become intermodal exchange points for passengers and cargo. Eskişehir Hasan Polatkan Airport is an airport that provides safe and secure services at international standards and has significant potential. It harbors important potential for both Eskişehir and Eskişehir Technical University regarding education and economic and social aspects. As Reynolds-Feighan (1995) and Grubesic and Wei (2013) noted, facilitating air carriers to deliver air services brings significant advantages, including economic growth and enhanced social cohesion. The present study acknowledges their studies regarding the potential benefits of air services while embracing the air cargo perspective. Considering that Eskişehir Hasan Polatkan Airport has not yet fully utilized its passenger potential, the present research has led to three alternative business models for cargo transportation. These are:

- Making the airport ready for general cargo aircraft operations
- Use of the airport as a cargo base by an airline
- Improving passenger-cargo transportation by increasing the number of scheduled flights at the airport

These alternatives have been discussed in detail under the following subheadings.

Alternative 1 – Investment for general cargo operations

Airlines consider various factors when selecting airports for their major cargo operations, including potential demand, physical characteristics of the airport, available facilities, operating costs, ground handling services, personnel costs, and others. Another important factor is the potential position of the airport within the airlines' flight network.

Considering the data mentioned earlier and the findings, it is evident that preparing Hasan Polatkan Airport for the operations of public cargo aircraft and making it attractive for airlines will incur significant infrastructure costs and operational expenses. The investment amount is high, and the return on investment is long-term. It does not seem realistic for the university to cover these costs. While it may be possible to address them through a structure established in collaboration with city stakeholders and the university, it has been found that Eskişehir industrialists and businesspeople do not have such a need for air cargo.

The individuals interviewed indicate that Eskişehir's export-import figures and domestic cargo potential are insufficient to fill a cargo aircraft daily. Statistics also show that products in Eskişehir and its surroundings are not suitable for air cargo as they are not time-sensitive. Products such as heavy machinery parts, white goods, or biscuits are expensive to transport by air. However, there is a need for air cargo in emergencies, such as the urgent delivery of samples or machine parts that prevent production from stopping. Customers must be convinced that a sustainable and reliable service is available even in such cases. Otherwise, they may opt for a more reliable method, such as road transportation to İstanbul, where they know continuous flights.

The competitive dynamics of other transportation systems should also be considered here. Eskişehir Hasanbey Logistics Center is a significant logistics hub because of its railway transportation and road connections. Rail transportation is the most cost-effective and environmentally friendly for carrying industrial products. Therefore, increasing its share in logistics networks is a key goal of global policies and supranational entities like the European Union. The world's logistics understanding is evolving towards integrated intermodal transportation systems that incorporate not only the road but also rail, sea, and even air transportation, with the road being the least used mode, especially for long distances. Cargo transportation via trains between China and Europe has already begun through the "New Silk Road Project," which is expected to shorten the duration and reduce costs for Türkiye, including Eskişehir, along the route. The first train passed through Türkiye recently and crossed the Bosporus to Europe. Therefore, rather than focusing on the competition between transportation modes, it is more beneficial to emphasize their complementarity. The railway can be used more actively and cost-effectively by connecting Hasanbey Logistics Center with Eskişehir Organized Industrial Zone and Gemlik Port, further limiting air cargo's competitiveness on these routes. Consequently, establishing a cargo market in Eskişehir, especially for domestic routes, seems challenging. It also seems difficult to generate sufficient cargo potential to support direct flights to different destinations for long-haul routes. However, initiating cargo flights that feed İstanbul could be considered, although this approach may not be highly preferable due to increased transfer costs.

Even with existing cargo facilities and regular flights at the current airport, there is a belief that shipments can be made faster and more affordably from İstanbul. Therefore, this investment does not seem feasible from the perspective of city stakeholders. While it may be considered to leverage private sector support for constructing and operating cargo warehouses, this option is not particularly attractive regarding private sector investment.

On the other hand, in evaluating this alternative, certain conditions may exist for obtaining investment support as part of a national strategy beyond university, city, or private-sector investments. Türkiye is located in an earthquake-prone zone, and a major earthquake is expected in İstanbul and the surrounding region in the near future. Airports are crucial logistics centers during natural disasters and emergencies, creating social benefits. They are essential for delivering aid teams and humanitarian supplies, restoring normalcy, and managing crises. Therefore, airports in the region are fundamental elements of urban resilience and disaster preparedness planning. İstanbul has two major airports, and while their terminal buildings are known to be resistant to high-intensity earthquakes, it is impossible to predict the location, intensity, and magnitude of a potential earthquake in İstanbul. Therefore, the possibility of both airports sustaining significant damage in a major earthquake cannot be ruled out. In such a scenario, the relatively nearby and less susceptible to earthquakes Hasan Polatkan Airport could serve as an "Emergency Aid Cargo Hub" for domestic and international flights. Eskişehir could take on this mission for İstanbul and neighboring regions. Moreover, since Eskişehir would likely be among the suitable landing sites for aircraft in the event of a large-scale disaster in İstanbul or another neighboring city, it is important to undertake relevant emergency planning now. In addition to public funds, the possibilities of utilizing international funds for these investments should also be explored. Hatay Airport, which stopped operating after its runway was damaged in the 2023 major earthquake, has demonstrated how important airports can be in the event of a disaster.

In conclusion, this alternative can be implemented through a phased cargo strategy spread over time. Along with other alternatives, Hasan Polatkan Airport can be reassessed in the long term in terms of its strategic strengths and weaknesses for additional investments and cargo services as demand matures.

Alternative 2 – The airport to be used as a cargo hub by an airline

Another alternative is to use the airport as a cargo hub. Cargo airlines typically choose an airport as their central hub for operations. FedEx's hub is located in Memphis, Tennessee. In recent years, DHL has selected Leipzig/Halle Airport in Germany as its hub and has received support from the government to make Germany a cargo hub. Additionally, cargo villages are becoming more widespread. While handling activities such as sorting, consolidation, and short-term cargo storage are usually carried out by airline or cargo handling agents or external carriers, there is a recent trend towards larger cargo terminals or cargo villages with numerous warehouses to accommodate these activities.

Amazon operates Prime Air (Amazon Air), which has 45 aircraft in the United States and serves 20 airports nationwide. Most recently, in September 2019, it was announced that Amazon had chosen Dallas' Fort Worth Alliance Airport, a general aviation and cargo-centric regional airport already used by FedEx, as a regional hub. In terms of cargo flights, this airport holds the distinction of being the first airport adapted to Amazon's business model (built-to-suit). This project is part of the "Alliance Global Logistics Hub" project, and it also includes an intermodal railway center operated by a private company within the complex. This will create a hub to serve Amazon's numerous daily flights and small package distribution. Amazon's main hub is located at the Cincinnati/Northern Kentucky International Airport, which became operational in 2021 (Freightwaves, 2019). With approximately 650,000 full and part-time employees worldwide as of 2018, Amazon is expected to create 300 full-time jobs at Fort Worth Alliance Airport (Freightwaves, 2019).

Public-Private Partnerships (PPPs) have been extensively utilized in Türkiye for new airport and terminal construction and operations (Sengur, 2020). This model could also be explored as an investment and operational strategy for airport cargo operations. Additionally, government subsidies effectively promote an airport within a region and stimulate demand (Uzgör and Şengür, 2022). To make this situation attractive, incentives such as free land and discounted landing fees could make operating as a regional hub for an airline at Eskişehir Hasan Polatkan Airport an appealing alternative. Additionally, businesses like Amazon participate in global distribution and can provide significant opportunities for cities and countries. Connecting Hasanbey Logistics Center to the airport could also be considered in this case. If the physical and technical capabilities are researched and feasible, the airport will become much more valuable in cargo intermodality.

Alternative 3 – Increasing scheduled passenger-cargo flights

Another alternative for developing cargo transportation is to reopen scheduled passenger flights, especially on the Eskişehir-İstanbul route, at Hasan Polatkan Airport, which currently serves the non-scheduled market. Flights conducted at suitable hours for cargo transportation and repeated regularly for a certain period can enable industrial and commercial individuals in Eskişehir to use the cargo compartments under the aircraft for their needs.

Therefore, it is important to make transporting cargo under passenger aircraft sustainable. With continuous and regular flights, industrial and commercial individuals in Eskişehir may be able to change their air cargo habits in the long term. While filling a cargo aircraft may be challenging, filling the belly cargo compartment under a passenger aircraft is relatively easier. Thus, passenger and cargo operations can support each other, increasing the airline's profitability. According to the Ground Handling Regulation, one of the common provisions to be applied in implementing tariff schedules is that, in addition to cargo service fees, ramp fees are also fully charged for aircraft carrying cargo in the passenger cabin (SHGM, 2018). This will lead to an increase in the airport's revenue.

For these reasons, it may be worthwhile to consider making passenger flights more regular than cargo aircraft transportation, connecting Eskişehir to İstanbul with smaller aircraft, and connecting to more distant cities with cross flights. The biggest problems in the Eskişehir-İstanbul flights previously initiated by Turkish Airlines (THY) and terminated due to lack of demand can be cited as aircraft size, flight time, and day. THY's business model is network transportation, and it provides full service. Eskişehir is geographically close to many cities, making it suitable for inexpensive flights without amenities. Encouraging low-cost carriers to open routes with support incentives could be facilitated.

On the other hand, based on participants' views, establishing an airline in Eskişehir to operate with small aircraft is another solution that would support this alternative. The establishment of an "Eskişehir Airline Operations" under the auspices of Eskişehir Technical University, which has been operating the airport for a long time, training human resources for the aviation system for 30 years, and now serves as a model for Public-Private Sector Cooperation, would facilitate regular flights and have a positive impact on economic and social development. Involving the city administration, chambers of commerce and industry, and other stakeholders as partners in this operation would not only share the financial burden and operational risk but also provide support in terms of marketing.

5. Conclusion

All stakeholders involved in establishing and developing the air cargo market in Eskişehir have voluntarily stated that they will support the diversification and growth of the region's cargo and passenger transportation activities. However, in the face of economic uncertainties within Türkiye and globally, as well as considering Eskişehir's air cargo potential, stakeholders are cautious about financing the airport cargo infrastructure.

Eskişehir's geographical location presents advantages and disadvantages in becoming a cargo center. Located in Central Anatolia, cargo distribution from this center appears advantageous. However, the range of products, services, and commercial activities in the surrounding provinces reduces the likelihood of creating air cargo potential. The investment required for cargo operations is high, and the return on investment takes a long time. Infrastructure and equipment costs are considered to be quite high. Therefore, it has been described as difficult for the university to handle this investment alone. On the other hand, a joint airport cargo investment with other stakeholders does not seem desirable due to low demand. However, a model of being an 'Emergency Aid Cargo Hub' for Hasan Polatkan Airport could provide new opportunities.

It is considered more effective for an airline to invest in Hasan Polatkan Airport and use it as a hub rather than investment by the university or stakeholders. Using Hasan Polatkan Airport as a hub for international flights will provide significant economic and social benefits for the university, the city, and even the country. When the airline invests in facility and equipment infrastructure, it will be easier to introduce services such as customs and ground handling. In this case, ensuring an increase in the university's personnel will be sufficient. Another alternative is to support scheduled, regular, and sustainable passenger transportation. It has been found that mixed flights carrying both passengers and cargo will be preferred in the region. Thus, it is stated that over time, the cargo habits of the region's businesspeople may change in favor of Hasan Polatkan Airport instead of İstanbul.

The tradition of conducting national and international commercial activities through İstanbul necessitates careful consideration of the smooth and efficient handling of air cargo and transfers connected to İstanbul Sabiha Gökçen Airport via road and railway connections. When the logistics center's connection to the Organized Industrial Zone is operational, the railway connection will become much more attractive and preferred due to its cost-effectiveness. However, it should not be forgotten that completing the air cargo infrastructure in Bursa province may negatively affect market potential. Additionally, demand to support cargo flights has not yet materialized at Bursa Yenişehir Airport. Furthermore, when all phases of İstanbul Airport are completed, it should be considered that it will become significantly more prominent in passenger and cargo traffic.

In conclusion, all these findings suggest that growth and investment plans should be carefully made and steps taken cautiously. A more detailed feasibility study should be conducted for the final investment decision, comprehensively addressing the issue's technical, economic, social, and environmental dimensions, and financial plans should be developed. Thus, the correct investment decision can be made by minimizing the risk of idle investment for the city, the university, and the country.

Ethical approval

Not applicable. The qualitative data were collected just before 2020. However, the writing was recently completed.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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An Examination of the Sustainability Activities of Global Airline Collaborations within the Scope of IATA's Sustainability Goals

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Abstract

This study aims to evaluate the sustainability activities of the global airline alliances Star Alliance, SkyTeam, and OneWorld within the framework of the International Air Transport Association's (IATA) sustainability goals. Specifically, it focuses on key areas such as achieving net-zero carbon emissions by 2050, promoting new aircraft technologies, enabling greener travel (in terms of noise and air quality), enhancing energy, resource, and operational efficiency, managing cabin waste and recycling, adopting sustainable aviation fuels (SAF), and protecting biodiversity. Using a content analysis methodology, data were gathered from publicly available sources, including airline sustainability reports, annual reports, and information from the IATA website. This systematic analysis provides an objective evaluation of how well these airline alliances are aligning their strategies with IATA's sustainability goals. The findings reveal significant disparities in the alliances' commitments. For instance, Star Alliance and OneWorld members exhibit deficiencies in biodiversity conservation, while SkyTeam members show slower progress towards achieving the net-zero carbon emissions target. Additionally, all three alliances demonstrate varying degrees of success in adopting SAF and implementing other sustainable practices, such as waste management and the promotion of new aircraft technologies. By identifying the strengths and weaknesses across the alliances, this research offers critical insights into how the aviation sector can more effectively contribute to global sustainability efforts.

1. Introduction

Globalization has eliminated borders and provided many international businesses with the opportunity to compete in the same markets and develop different strategies to achieve their goals. The intensity of competition has forced airlines to create new management styles and strategies to take the right steps and achieve sustainable existence. Global cooperation movements are emerging as one of these strategies and play a critical role in the success of airlines. Airlines have turned to modern management approaches to respond to changing passenger demands and needs. Global airline collaborations are strategies created to meet customer demands and strengthen their position in international markets. These collaborations can provide airlines with effective support in controlling their strengths and weaknesses, turning negative situations into advantages, and minimizing risks (Kanbur, Mazioglu, & Kanbur, 2023).

The aviation industry is a key driving force in facilitating the growth of the global economy and enabling people to move more swiftly and effectively around the world. However, aviation activities can also bring about environmental, social, and economic challenges. These challenges include environmental issues such as climate change, energy consumption, air pollution, and noise pollution.

Sustainable aviation represents a long-term approach developed in response to the aviation industry's need to build a cleaner, quieter, and smarter future. This approach sets various targets and commitments on issues such as climate change, noise pollution, and local air quality, with the aim of supporting a more sustainable future. Airline companies are taking significant steps, from carbon offsetting to reducing or eliminating single-use plastics, to address environmental concerns. This approach can reduce the environmental impact of aviation, enhance energy efficiency, promote innovation and technological development, and increase societal benefits. Sustainable aviation requires airline businesses to adopt various strategies to make their operations, flights, and services more environmentally friendly, respond more sensitively to community needs, and support the long-term growth of the sector. (Turkish Airlines, 2022).

IATA's goal of achieving net zero carbon emissions by 2050 is a cornerstone of global efforts to decarbonize the aviation industry. The aviation sector contributes approximately 2.5% of global CO2 emissions, and with projected increases in air traffic, these emissions are expected to rise significantly unless proactive steps are taken (World Economic Forum, 2022). This target aligns with the Paris Agreement, which aims to limit global temperature rise to

1.5°C, making IATA's goal essential in mitigating the aviation industry's impact on climate change (IATA, 2024).

Sustainable Aviation Fuel (SAF) is central to the International Air Transport Association's (IATA) strategy for achieving net-zero carbon emissions by 2050. SAF is regarded as one of the most effective tools for reducing the carbon footprint of the aviation industry, as it offers up to an 80% reduction in lifecycle greenhouse gas emissions compared to conventional jet fuels (IATA, 2024). The role of SAF in the industry is not merely one of technological adaptation but also a vital component of broader environmental and policy commitments aimed at curbing the aviation sector's significant contribution to global emissions. SAF is primarily derived from renewable sources such as agricultural waste, used cooking oil, and other sustainable biomass materials. Importantly, SAF can be utilised with existing aircraft engines and airport fueling infrastructure without requiring significant modifications. This feature allows for a more seamless integration of SAF into current airline operations, making it a practical short- to medium-term solution in the decarbonisation of the aviation sector (World Economic Forum, 2022). The successful deployment of SAF will rely on creating a market environment where SAF is cost-competitive with fossil fuels, and where supply can meet growing demand as airlines increasingly seek to fulfil their sustainability pledges (European Union Aviation Safety Agency, 2020).

IATA has placed significant emphasis on preventing wildlife trafficking, an issue that directly undermines biodiversity. Through collaborative efforts with governments and international organizations, IATA's Wildlife Trafficking Task Force is focused on disrupting illegal wildlife trade, which contributes to the decline of species populations and threatens global biodiversity. By working closely with various stakeholders, IATA aims to combat this global issue, highlighting the organization's commitment to not only addressing the ecological impacts of aviation but also promoting a holistic approach to environmental sustainability (IATA, 2024).

In this context, airline alliances can also play a significant role in achieving sustainable aviation goals. Alliances can encourage airline companies to share more resources, operate more efficiently, and collaborate towards sustainability objectives. Many airline alliances aim to enhance the industry's sustainability performance by encouraging member companies to collaborate in sustainability and share best practices. Airline alliances (Star Alliance, SkyTeam, and OneWorld) have become a crucial mechanism in transforming the dynamics of the sector and addressing these emerging challenges.

There are 58 companies that are members of global airline alliances. Of these, 26 are members of Star Alliance, 19 are affiliated with SkyTeam, and 13 are part of the OneWorld alliance. The sustainability activities of these companies are aligned with the (IATA) sustainability goals, which comprise seven key targets. This study examines the sustainability activities of the 58 member companies of these alliances to assess their alignment with these targets. The analysis was conducted using the content analysis method based on sustainability reports, annual reports, and information available on the websites of the companies, as well as the alliance groups (Star Alliance, SkyTeam, and OneWorld) and IATA. The study aims to explore how airline alliances contribute to sustainability efforts, with a particular focus on the contributions of major airline alliances such as Star Alliance, SkyTeam, and OneWorld. Alliances represent a significant strategy that enables airline companies to effectively reach passengers from different regions and utilize resources more efficiently. Additionally, this study aims to highlight the value proposition of such sustainability initiatives within the airline industry. The value of this study lies in providing a comprehensive assessment of the activities carried out by airline alliances towards sustainability goals. There is a limited amount of research in the existing literature that focuses on the impact of these alliances on sustainability. Hence, this study fills a significant gap by understanding how airline alliances contribute to sustainability efforts. Moreover, this in-depth analysis, utilizing sustainability reports, annual reports, and other publicly available information from airline companies, concretely outlines the sustainability commitments and practices of the alliances. Thus, it offers valuable insights to both the academic community and industry practitioners on the role played by airline alliances in achieving sustainability goals.

2.Conceptual Framework

2.1. The Concept of Globalisation in Airline Transport

Globalization is one of the most significant factors influencing change and development across all sectors. These factors transform people's lives and socio-economic phenomena, eliciting responses from both individuals and sectors. The air transport industry has become a part of the globalization process, experiencing considerable changes over time (Esin & Düzgün, 2021, p.20). The aviation sector is a vital component of the rapidly growing services category in the global economy. Due to technological innovations, lower fuel consumption, new employment opportunities, and lower ticket prices, aviation has become a key element of both individual lives and international trade. The aviation industry has become an intriguing subject for economic analyses (Bal, Manga, & Akar, 2017, p.354). With the increase in demand and globalization, airline companies observe a growth and globalization in the passenger market for business purposes. Today, passengers may desire to travel at any time, on any day or month, and at more convenient ticket prices, seeking a higher level of service. Airline companies must meet this demand. Therefore, air transport not only facilitates economic globalization but is also globalized by it, creating a mutually reinforcing cycle between air transportation and economic globalization. Since the early 1980s, the sector has increasingly trended towards globalization (Gerede, 2002, p.85).

2.2. Global Airline Collaborations in Air Transport

In the field of business management, collaboration refers to a business relationship established between two or more companies to achieve common goals and mutual benefits. In this definition, the creation of common objectives and mutual benefits forms the fundamental stages of the partnership. For a true partnership to exist, it is essential that each company derives certain benefits from the collaboration, operating within a win-win principle (Latrou, 2004, p.7).

For airline companies to be sustainable over the long term, it is crucial for them to participate in international strategic alliances, taking into account their current situation and aiming to maintain a sustainable competitive advantage. These alliances are vital for operating and achieving long-term success (Kanbur & Karakavuz, 2017, p.75). The primary goal of strategic partnerships is to merge the values each participant possesses in alignment with their common objectives, thereby creating synergy. Through these collaborations, members strive to achieve their common goals more effectively and efficiently (Huxham & Macdonald, 1992, p.51).

Global airline operations refer to airline companies that have an extensive flight route network covering a wide geographical area with numerous airports and intercity destinations within the aviation sector. These companies often become members of airline alliances such as Star Alliance, SkyTeam, or Oneworld and aim to increase the number of connected flights and destinations (Gerede, 2002, p.106). The formation of airline partnerships is associated with the development of supply chain design and the need for airlines to establish global and local networks. In particular, major airline companies in the United States have formed local partnerships by engaging in code-sharing agreements with more cost-effective local firms. This has enabled them to support more extensive and profitable regional and long-distance networks (Garcia, 2012, p.59).

2.3. Sustainable Business Concept

It is an undeniable fact that various factors encourage companies to promote sustainability. Some of these factors arise from companies' financial concerns, while others emphasize the importance of corporate identity in fostering a sense of social responsibility. However, when approaching the factors that promote sustainability from an economic perspective, it is essential to consider the primary goal of all commercial enterprises, which is profit maximization. In this regard, companies feeling responsible for preventing environmental pollution, responding to changing consumer habits with innovative production and marketing processes, or displaying a sustainable vision to remain competitive in the global market ultimately serve the purpose of profit maximization (Kuşat, 2012, p.228). Increased environmental awareness in society, customer environmental sensitivity, sensitivity to environmental events, and public reactions have led to a questioning of businesses' relationships with the environment today. This situation presents itself as both a necessity and an obligation. To ensure the suitability and continuity of the natural environment in which businesses operate, management strategies need to be adapted to these different situations. In this context, companies should give greater importance to environmental business activities within the framework of environmental sustainability while conducting their activities in line with the concept of environmental sustainability (Arı & Ergin, 2018, p.3). Business management strategists often focus on the concept of sustainability in the context of sustainable competitive advantage. According to this definition, firms successful in sustainability practices continually gain a competitive advantage. Additionally, researchers argue that if resources have valuable, rare, inimitable, and non-substitutable qualities, businesses can achieve sustainable competitive advantage with their resources (Kesen, 2016, p.556).

2.5. Similar Studies on the İssue

(Payan-Sanchez, Perez-Valls, & Plaza-Ubeda, 2019) In the literature, global alliances, particularly in the airline industry, have been associated with improvements in companies' economic and operational performance. However, there is limited information regarding the impact of such multilateral agreements on airlines' environmental performance. Some studies have employed various methods to examine whether membership in an alliance affects environmental performance. For instance, one study applied regression and Analysis of Variance (ANOVA) to data from 252 airlines (58 of which are members of the Star Alliance, Oneworld, and SkyTeam alliances), finding a strong and negative relationship between alliance membership and environmental performance. The same study provided empirical evidence on the impact of an airline's business model on its environmental performance. These findings offer important implications for airline managers facing sustainability challenges.

(Gursel & Orhan , 2023) The literature suggests that the environmental performance of airlines is currently measured on a mostly voluntary basis, though it is anticipated that these measurements will become mandatory in the future. Global strategic alliances impact the environmental performance of member airlines in different ways and at varying levels. Some studies indicate that membership in global alliances has the potential to contribute positively to environmental sustainability within airline operations. These alliances set common sustainability goals for their members and encourage them to share these objectives with stakeholders. For example, analyses conducted on members of alliances such as Oneworld, Star Alliance, and SkyTeam reveal that these alliances have significant effects on environmental performance. In this context, studies focusing on the environmental performance of Oneworld members demonstrate that the alliance's shared sustainability commitments significantly influence the environmental efforts of its member airlines.

(Kim & Rhee, 2021) Through this research, we examined whether airlines vicariously learn more from accidents of alliance members. We set organizational learning as our dependent variable and defined it as a reduction in the subsequent accident rate. Our research also examined the moderating effect of liability (U.S. air carriers) by hypothesizing that U.S. air carriers are more likely to learn from alliance memberships. In sum, the results of our analyses showed that an airline is more likely to learn from alliance members' failure experiences. Furthermore, findings of the moderating effect of liability (U.S. air carriers) revealed that U.S. air carriers are more likely to learn from alliance memberships. In addition, findings on the moderating effect of environmentally sustainable airlines revealed that an environmentally sustainable airline is more likely to learn from alliance memberships.

(Tanrıverdi & Doğan, 2022) The study reviewed the top 30 most cited studies out of 156 studies from the WoS database. In addition, all the studies in the dataset were subjected to citation network and co-word analysis, supporting the findings of the review of the most cited studies. The findings confirm that strategic alliances are seen as a network and that airlines achieve a sustainable competitive advantage through access to network resources. The study contributes to the literature by determining the conditions to be considered in the success of strategic alliances

(Seo & Itoh, 2020) This research seeks to assess whether global airline alliances outperform non-alliance airlines, explore the differences in passenger perceptions among the three major alliances, and identify their competitive advantages. A hybrid text mining approach was employed for the analysis. The methodology included frequency tests, t-tests, one-way ANOVA tests, and a three-step mediated regression analysis, utilizing 6,393 pieces of ordinal and word-of-mouth (WOM) data. The results indicate that passengers have a generally low perception of alliances, with non-alliance airlines outperforming those in alliances. Additionally, there were no notable differences in service ratings or sentiment scores across the alliances. Only oneworld showed a competitive edge tied to service ratings and sentiment scores.

(Steven & Merklein, 2013) In this paper we analyze the influence of a strategic alliance membership on determinants of carbon intensity in passenger transportation by using a unique data sample of the years 2004–2008. We find that alliance members on average had a higher utilization rate than non-aligned airlines, but their older average fleet age indicates that they did not take full advantage of the potentials offered through common aircraft investment activities. With regards to the planned Emissions Trading Scheme we show that European carriers on average had a better carbon intensity than Non-European airlines, so that competitive disadvantages for European airlines might be less than expected, if their carbon intensity maintains on this level.

3. Materials and Methods

3.1. Purpose and Importance of the Research

The aviation sector is a crucial part of global transportation infrastructure, essential for economic development and cultural exchange. Despite its importance, the sector faces significant sustainability challenges, including excessive energy consumption, greenhouse gas emissions, and broader environmental impacts. These challenges underscore the urgent need for improved sustainability practices within aviation to meet global environmental goals and foster a sustainable future.

Although the aviation industry has undertaken various initiatives to address these issues, a comprehensive understanding of these efforts, especially in the context of global collaborations, remains limited. This research aims to fill this critical gap by providing an in-depth analysis of sustainability initiatives within the aviation sector, with a particular focus on global airline alliances.

The primary objective of this research is to examine the sustainability initiatives of global airline alliances, specifically within the framework of the (IATA) sustainability goals. The study focuses on identifying and analyzing the activities and practices of leading airline alliances Star Alliance, SkyTeam, and OneWorld that align with these sustainability objectives. Furthermore, it evaluates how effectively these alliances are achieving sustainability goals and explores the methods they employ towards this end.

By concentrating on these areas, the research aims to offer a clearer understanding of the current status of sustainability practices within the aviation industry and to suggest pathways for their enhancement. This investigation is pivotal for advancing sustainability within the aviation sector, contributing to the broader efforts to mitigate environmental impact and promote sustainable development.

3.3. Scope and limitations of the research

This study aims to examine the sustainability initiatives of global airline alliances, specifically Star Alliance, SkyTeam, and OneWorld, within the framework of IATA's sustainability objectives. The research focuses on the strategies these alliances employ to achieve specific sustainability goals and assesses the extent to which they have succeeded in reaching these objectives.

The study primarily derives its data from publicly available sources, including airline company websites, sustainability reports, annual activity reports, and the IATA website. Consequently, the absence or non-disclosure of certain information in these sources may potentially influence the research findings. Sustainability encompasses various factors and criteria. Given that this study centres on the processes through which airline alliances attain particular goals, it may not encompass other facets of sustainability. Furthermore, the research evaluates the sustainability activities of airline alliances using the content analysis method. However, it is essential to acknowledge that this approach may not fully encapsulate the intricacies of qualitative data and the diversity of sustainability practices among different airline alliances.

3.2. Research Methodology

In this research, content analysis is employed as the method for data collection and analysis. Content analysis is a research technique used to examine and systematically analyze specific content within a defined framework. This method enables us to evaluate information related to the sustainability activities of airline alliances and relevant organizations in a systematic and objective manner.

The data have been gathered from publicly available sources of airline alliances such as Star Alliance, Sky Team, One World, and member airline companies. These sources include the companies' websites, sustainability reports, and annual activity reports. Additionally, the IATA website has played a significant role in the data collection process.

The collected data have been analyzed in association with IATA's sustainability objectives. Content analysis has been utilized to determine the extent to which specific sustainability goals have been adhered to. These analyses have helped us understand which airline alliance aligns with particular objectives and which strategies are more effective.

In qualitative research, the data coding process typically consists of several steps. Initially, researchers identify key elements within the data, conducting open codin (Younas, Cuoco, Vellone, Fabregues , & Barrios, 2022; Mutlu, 2024). These codes are then grouped under broader concepts to form themes (Brailas, Tragou, & Papachristopoulos, 2023). In this study, similar stages were applied during the data analysis process. Additionally, user codes were reported to indicate not only the identified themes and sub-themes but also the frequency of their occurrence.

To ensure the validity and reliability of the study, the data were reviewed multiple times. Furthermore, providing a detailed report of the collected data and explaining how the researcher arrived at the conclusions is one of the validity criteria in qualitative research (Yıldırım & Şimşek, 2021). Expert review, which is a method used to enhance the accuracy and reliability of the data, is one of the approaches recommended by Holloway & Wheeler, 1995. In this study, an academic specializing in sustainability in aviation was selected as the expert, and they were asked to assess the accuracy of the coding. Both the expert and the researcher confirmed the consistency of the coding.

Defining the Coding Scheme

In the tables, seven main categories have been identified to evaluate the sustainability performance of each airline:

- Net zero carbon emissions
- Sustainable aviation fuels (SAF)
- Promotion of new aircraft technologies
- Waste management and recycling in the cabin
- Greener travelling (noise and air quality)
- Energy resources and operational efficiency
- Biodiversity conservation

For each category, two symbols were used to indicate performance: a checkmark (✓) for success and a cross (×) for failure. To ensure consistency and reliability, the coding criteria for each category have been clearly defined:

A checkmark (✓) signifies that the sustainability targets in that category have been met by the airline.

Conversely, a cross (×) indicates that the company has deficiencies in that specific category.

4. Findings

Aegean Airlines is undertaking sustainability efforts within the framework of IATA to achieve net-zero carbon emissions by 2050. These efforts encompass various sustainability activities, including the promotion of sustainable aviation fuels (SAFs), the encouragement of new aircraft technologies, cabin waste management and recycling, greener travel practices (noise and air quality), energy, resource, and operational efficiency, as well as biodiversity conservation. In the realm of waste management and recycling, the airline is adopting strategies to reduce waste generation and ensure proper disposal. In the domain of water management, Aegean Airlines is focusing on water conservation and efficient water management practices to reduce water usage and enhance its efficient utilization. Within the scope of biodiversity conservation and support activities, the company aims to contribute to the preservation of natural habitats and the prevention of biodiversity loss. In the field of social responsibility, Aegean Airlines supports various social responsibility projects with the goal of giving back to the community and contributing to social needs.

Table 1. Examination of Sustainability Activities of Star Alliance Member Companies within the Scope of IATA's Sustainability Goals

Number	Companies	Achieve net zero carbon emissions by 2050	Sustainable aviation fuels (SAFs)	Promoting new aircraft technologies	Cabin waste management and recycling	Greener travelling (noise and air quality)	Energy, resource and operational efficiency	Protecting biodiversity
1	Aegean Airlines	✓	✓	✓	✓	✓	✓	✓
2	Air Canada	✓	✓	✓	✓	✓	✓	✓
3	Air China	✓	×	✓	✓	✓	✓	✓
4	Air İndia	✓	✓	×	✓	✓	✓	×
5	Air New Zealand	✓	✓	✓	✓	✓	✓	✓
6	All Nippon Airways	✓	✓	✓	✓	×	×	✓
7	Asiana	✓	✓	✓	✓	✓	✓	✓
8	Austrian Airlines	✓	✓	✓	✓	✓	✓	×
9	Avianca Airlines	×	×	×	✓	✓	✓	×
10	Brussels Airlines	×	✓	✓	✓	✓	✓	✓
11	Copa Airlines	✓	✓	✓	✓	✓	✓	×
12	Croatia Airlines	×	×	✓	✓	×	✓	×
13	EgyptAir	✓	×	×	×	×	×	×
14	Ethiopian Airlines	×	×	×	✓	✓	×	×
15	EVA Air	✓	✓	✓	✓	✓	✓	✓
16	LOT Polish Airlines	✓	✓	✓	×	✓	✓	✓
17	Lufthansa	✓	✓	✓	✓	✓	✓	×
18	Scandinavian Airlines	✓	✓	✓	✓	✓	✓	✓
19	Shenzhen Airlines	×	✓	✓	✓	✓	×	✓
20	Singapore Airlines	✓	✓	✓	✓	✓	✓	✓
21	South African Airways	✓	✓	✓	✓	✓	✓	✓
22	Swiss Airlines	✓	✓	✓	×	✓	×	×
23	TAP Portugal	✓	✓	×	✓	✓	✓	×
24	Thai Airways	×	✓	✓	✓	✓	✓	✓
25	Turkish Airlines	✓	✓	✓	✓	✓	✓	✓
26	United Airlines	✓	✓	×	✓	×	✓	×

Aegean Airlines is also taking measures to enhance the efficiency of its aviation operations, with the aim of reducing energy and resource consumption. By incorporating new aircraft technologies that are more environmentally friendly and fuel-efficient into its fleet, the airline strives to reduce carbon emissions. Additionally, Aegean Airlines collaborates with its business partners to strengthen sustainability strategies through joint efforts. Regarding energy and resource efficiency, the airline is developing practices to reduce energy consumption and make more efficient use of resources. Moreover, Aegean Airlines is making efforts to use sustainable aviation fuels, and it is actively engaged in related initiatives and projects. Overall, Aegean Airlines is committed to a comprehensive sustainability agenda that encompasses various aspects of environmental and social responsibility while also focusing on operational efficiency and the reduction of carbon emissions.

Air Canada, like other major players in the aviation sector, is committed to achieving the goal of net-zero carbon emissions by 2050 within the framework of IATA objectives. To reach this target, the company is implementing various strategies, including increasing fuel efficiency, collaborating in the use of sustainable aviation fuels, and engaging in carbon offset projects. Simultaneously, the airline is adopting environmental objectives such as improving waste management, increasing the use of recyclable materials, and reducing single-use plastics. It also places importance on embracing innovative technologies to contribute to technological advancements in the aviation sector and enhance operational efficiency. This includes the adoption of new aircraft technologies that produce fewer carbon emissions. Furthermore, Air Canada aims to collaborate with airports, ground service providers, and other airlines to work collectively towards achieving sustainability objectives

Air China has committed to achieving the goal of net-zero carbon emissions by 2050 under the IATA framework. Additionally, the company aims to improve its sustainability performance by implementing various strategies in areas such as waste and water management, biodiversity conservation, and social responsibility.

The company is actively working to reduce waste generation and promote the use of recyclable materials. Efforts are also being made to minimize water usage and enhance water management practices. Furthermore, Air China is investing in new aircraft technologies, collaborating with other companies, supporting sustainable airports, promoting sustainable travel, and undertaking initiatives to improve energy efficiency.

When evaluated within the framework of IATA goals, Air India commits to achieving the target of net-zero carbon emissions by 2050 and implements various strategies to reach this goal. The company focuses on waste management and recycling policies, promoting employee well-being, and enhancing operational efficiency. It engages in sustainability efforts for airports, greener travel, energy and resource efficiency, and sustainable aviation fuels (SAFs). However, upon reviewing the company's published reports and official website, it is observed that Air India does not invest in new aircraft technologies and activities related to biodiversity conservation.

Within the IATA context, Air New Zealand has established policies in waste management and demonstrated environmental sensitivity by striving to preserve local biodiversity. The company develops strategies to use energy and resources efficiently, takes measures to enhance operational efficiency, and adopts aircraft technologies that reduce carbon emissions. Providing sustainable options to customers and reducing the environmental impact of airport operations are among the company's key sustainability objectives.

In the IATA framework, ANA strengthens its commitments by setting concrete and measurable goals in sustainability. ANA adopts a proactive approach to achieve the target of net-zero carbon emissions by 2050. Notably, the company is committed to reducing the use of single-use plastics in flights and promoting recycling. ANA's activities in these areas contribute to IATA goals and exemplify a proactive approach. The company also strives to improve operational efficiency and embrace innovation in the aviation sector. Promoting the use of aircraft that produce fewer carbon emissions by adopting innovative flight technologies is a significant step towards advancing sustainable aviation. ANA's commitments reflect both a pioneering role and a spirit of collaboration in the field of sustainability. However, there is no official information regarding its efforts to improve noise and air quality or enhance efficiency.

Within the framework of IATA goals, Asiana Airlines has declared its commitment to achieving net-zero carbon emissions by 2050 and is implementing various strategies to attain this objective. In the context of waste management and recycling, the airline has put in place a concrete program that focuses on reducing the use of single-use plastics and promoting waste recycling. Regarding water management, it has adopted strategies to reduce water consumption and waste. To support biodiversity conservation, Asiana Airlines is actively involved in various projects aimed at preserving biodiversity and habitats, playing a significant role in this regard. In the realm of social responsibility, the company fulfills its social responsibilities by investing in employee education and development and providing support to local communities. To enhance operational efficiency, the airline takes measures to improve fuel efficiency and actively works to make its operations more efficient. Asiana takes a pioneering role in investing in new aircraft technologies aimed at reducing carbon emissions and enhancing energy efficiency. To achieve sustainability goals, the company adopts a strategy of collaborating with suppliers and other business partners. In efforts to increase the sustainability of airports, the company collaborates with airport operators to enhance airport operations' sustainability. Asiana also continues its efforts to promote carbon offset programs and support greener travel options for customers. Furthermore, in alignment with its goal of using energy and resources more efficiently, the company embraces energy-efficient technologies and works towards making its operations more efficient.

In the context of IATA goals, Austrian Airlines has set sustainability goals as a significant step in addressing environmental issues in the aviation industry. Particularly, the commitment to achieving net-zero carbon emissions demonstrates the company's dedication to environmental concerns. In pursuit of this goal, Austrian Airlines takes steps such as using more efficient aircraft and opting for sustainable fuels. Additionally, its efforts in waste management and recycling contribute to reducing the aviation industry's environmental impact. With a sense of social responsibility, the company invests in employee education and development and provides support to local communities, aiming to enhance operational efficiency and contribute to economic sustainability. However, there is no official information regarding Austrian Airlines' activities related to biodiversity conservation.

In accordance with IATA guidelines, Avianca Airlines embraces a sustainable aviation vision. The company takes various measures to achieve this goal, focusing on minimizing the environmental impact of operational processes and services. This includes various activities such as waste management and recycling programs. Additionally, Avianca assists customers in reducing their environmental footprint by offering sustainable travel options. By leading the transformation of the aviation industry as a whole, it makes a significant contribution to creating a more sustainable air transportation model for future generations. However, the company lacks sufficient information on sustainability activities, reports, annual activity reports, and its website regarding zero carbon goals, sustainable aviation fuels, new aircraft technologies, and biodiversity conservation.

Brussels Airlines, in line with IATA objectives, represents airline companies and carries the mission of promoting sustainability throughout the industry. The promotion of alternative fuels, investment in energy efficiency projects, and technological advancements reflect IATA's determination to contribute to a sustainable aviation industry in the future. Moreover, its efforts to establish collaboration and partnerships among all industry stakeholders demonstrate how IATA strives to achieve its sustainability objectives. The company does not have a zero carbon emission target.

In line with IATA's sustainability mission, Copa Airlines has been a decisive factor in reducing the environmental impact of the aviation industry. By embracing significant commitments such as IATA's net-zero carbon emission goal, it contributes to the evolution of the aviation sector towards a sustainable future. Copa Airlines' efforts, such as fuel efficiency strategies and waste management programs, align with IATA's roadmap, contributing to environmentally friendly flight operations. This reflects IATA's commitment to promoting sustainability standards among airline companies and minimizing environmental impact across the industry. Collaboration among airlines like Copa Airlines assists in making sustainable aviation a global priority. However, the company has not made specific commitments related to biodiversity conservation.

When examined in the context of IATA goals, Croatia Airlines partially assumes a role in sustainability within the aviation sector compared to other companies. The company's efforts in waste management and recycling, as well as its support for energy and resource efficiency, new aircraft technologies in aviation, energy and resource efficiency, operational efficiency, and social responsibility projects, contribute to the development of sustainability. Additionally, its collaborations in the industry help to promote the understanding of sustainability and strengthen the sense of social responsibility.

Within the framework of IATA, EgyptAir exhibits a low profile regarding sustainability in the aviation sector. It commits to minimizing environmental impact by adopting the net-zero carbon emission goal. However, there is no evidence of any initiatives or support in their official sources related to waste management, water management, biodiversity, or investment in new technologies. The company aims to provide social benefits by investing in employee education and development within the context of social responsibility and by collaborating with local communities. This places EgyptAir behind other companies in the industry in terms of sustainability activities when compared

In line with IATA's goals, Ethiopian Airlines is actively engaged in sustainability efforts within the aviation sector. The company collaborates with local communities and undertakes initiatives to promote green travel programs and reduce carbon emissions through projects aimed at energy efficiency and environmental efficiency at airports. Additionally, the company engages in sustainable practices and social responsibility activities in partnership with its business associates.

Within the framework of IATA, EVA Air is an airline company that is committed to reducing its environmental impact in the aviation sector with significant commitments and strategies in sustainability. Efforts to renew its fleet and invest in efficient aircraft are crucial steps in reducing carbon emissions. Moreover, its goal of promoting sustainable aviation fuels and focusing on research and development reflects its commitment to reducing its carbon footprint. Waste management and recycling programs mirror EVA Air's commitment to waste reduction and recycling. Water management strategies highlight its efforts to reduce water consumption and protect sustainable water resources. The company is dedicated to conserving biodiversity and preserving sensitive ecosystems. Its social responsibility commitments and emphasis on employee education and development demonstrate its efforts to provide societal benefits and enhance operational efficiency. EVA Air aims to expand sustainability goals across its entire supply chain through collaboration with suppliers and business partners. Sustainability efforts for airports aimed at reducing their environmental impact also align with EVA Air's environmental commitments. Awareness campaigns promoting green travel and carbon reduction programs underscore the company's commitment to offering environmentally friendly travel options. Similarly, policies aimed at enhancing energy and resource efficiency reflect its commitment to sustainable energy sources.

Within the framework of IATA, LOT has committed to achieving net-zero carbon emissions by 2050 and has taken significant steps towards environmental sustainability. Playing a crucial role in strategies such as investing in more efficient aircraft and using sustainable aviation fuels is paramount. Furthermore, the company adopts and implements policies related to sustainability in various other areas. LOT is focused on making its operations more sustainable by implementing policies and projects to reduce its environmental impact in terms of biodiversity and social responsibility. Providing education and development opportunities for its employees and collaborating with business partners and suppliers are also part of its social responsibility commitment. Strategies in areas such as operational efficiency, energy and resource efficiency, and promoting greener travel are important steps to both enhance cost efficiency and reduce environmental impacts. Lastly, efforts to invest in and use sustainable aviation fuels aim to transition to sustainable energy sources that can replace fossil fuels, a significant commitment in reducing the airline's carbon emissions.

Within the scope of IATA, Lufthansa aims to achieve net-zero carbon emissions by 2050. To reach this goal, the airline is adopting various strategies such as improving fuel efficiency, using sustainable aviation fuels (SAFs), and implementing carbon offset programs. Additionally, Lufthansa aims to reduce waste and increase recycling by implementing waste management and recycling policies. The company respects the rights of its employees, communities, and suppliers within the framework of social responsibility. Lufthansa is focused on reducing operational costs and carbon emissions by concentrating on operational efficiency and energy efficiency and by investing in new aircraft technologies. It also collaborates with business partners to make its supply chain more sustainable. In the context of sustainability at airports, Lufthansa adopts policies and strategies to increase energy efficiency and improve waste management. The airline aims to offer greener travel options and provide carbon offset choices to customers. Lastly, Lufthansa is committed to reducing carbon emissions by investing in and expanding the use of sustainable aviation fuels that can replace fossil fuels.

International Air Transport Associationis an organization committed to reducing the environmental impacts of the aviation sector through commitments and strategies in sustainability. Member airlines of IATA are making various efforts to reduce carbon emissions. They focus on adopting innovative technologies, improving fuel efficiency, using sustainable aviation fuels, and waste management. Additionally, they engage in activities in the realm of social responsibility with the aim of contributing to society. IATA's commitment to reducing environmental impacts and sustainability plays a significant role in the aviation sector. In this context, Scandinavian Airlines (SAS) is in full compliance with commitments such as achieving net-zero carbon emissions by 2050, promoting sustainable aviation fuels (SAFs), encouraging new aircraft technologies, managing cabin waste and recycling, promoting greener travel (noise and air quality), enhancing energy, resource, and operational efficiency, and conserving biodiversity.

From the perspective of IATA, Shenzhen Airlines places significant importance on new aircraft technologies, waste management, and recycling policies to support environmental sustainability. Similarly, it actively engages in cabin waste management and recycling, promoting greener travel (noise and air quality), conserving biodiversity, and focusing on various initiatives to improve the well-being of employees and the community.

Within the framework of IATA's sustainability goals, airlines such as Singapore Airlines are supported in their sustainability efforts, promoting a green transformation across the industry. In this context, the focus of Singapore Airlines, a major player in the aviation industry, on achieving net-zero carbon emissions by 2050 aligns with IATA's global environmental sustainability goals. IATA encourages airlines to adopt more sustainable practices in areas such as waste management and recycling, water usage, energy efficiency, clean energy usage, and sustainable aviation fuels. Additionally, social responsibility projects and community service initiatives are seen as integral parts of the aviation sector's sustainability efforts.

Under the umbrella of the IATA, South African Airways is committed to reducing its carbon footprint in line with its environmental sustainability goals. The company places significant emphasis on waste management and recycling practices to work towards waste reduction and minimizing environmental impact. SAA also demonstrates a conscientious approach to water management, aiming to optimize water usage and operate sustainably in regions facing water scarcity. Biodiversity conservation is among the company's priorities, with a focus on preserving biodiversity areas and designing operations accordingly. Within the framework of social responsibility, SAA aims to increase societal impact through community projects and sharing sustainability standards with its business partners. Embracing technological innovations and offering environmentally friendly travel options to customers are integral parts of SAA's sustainability commitment. In this context, SAA's sustainability strategies encompass significant steps toward minimizing the environmental and societal impacts of the aviation industry.

Within the context of IATA's sustainability initiatives, Swiss Airlines is committed to focusing on environmental sustainability goals, aiming to achieve net-zero carbon emissions by 2050. The airline is engaged in various initiatives in water management and social responsibility to minimize its environmental impact. It is taking steps such as researching sustainable fuel options and aligning its supply chain with sustainability. Embracing eco-friendly policies for airports, offering green travel options to customers, and adopting technological advancements are also part of its efforts.

TAP Air Portugal, under the IATA framework, is intensifying its efforts to achieve the goal of net-zero carbon emissions by 2050. To accomplish this objective, the airline is adopting comprehensive strategies, including energy efficiency and operational improvements. Additionally, it demonstrates a determined approach to waste management and recycling, aiming to reduce plastic usage and promote waste recycling. TAP Air Portugal also commits to areas like water resource management, social responsibility projects, and sustainable supply chain management. By embracing technological innovations and collaborating with others, the airline supports efforts to reduce its environmental impact and strengthen sustainability. In this regard, TAP Air Portugal is promoting a transformation, both in its own operations and across the aviation industry, to achieve sustainability goals.

Within the framework of the IATA, Thai Airways is taking significant steps in waste management, aiming to minimize waste and promote recycling. In terms of water management, the airline is adopting strategies to reduce water consumption and preserve water quality. Its commitment to biodiversity conservation and efforts to support local ecosystems are among the company's priorities. The social responsibility policies demonstrate a strong commitment to diversity, equal opportunities, and community service. The strategies for reducing carbon emissions include fleet modernization and the adoption of efficient aircraft technologies. Efforts to spread sustainability standards across the supply chain involve collaboration with business partners and suppliers. The efforts shown for the sustainability of airport operations contribute to the overall sustainability goals. By aiming to reduce the environmental impact of travel, the airline offers options such as carbon offset programs to its customers. The more efficient use of energy and resources is a significant step towards reducing environmental impact and also targets cost reduction.

From the perspective of IATA, Turkish Airlines has set a goal of achieving net-zero carbon emissions by 2050 in line with IATA's sustainability objectives and is implementing various strategies to reach this target. These strategies include modernizing the aircraft fleet, developing operations to reduce carbon emissions, and research and development on Sustainable Aviation Fuels. Significant efforts are also made in waste management and water management. The airline shows a substantial commitment to biodiversity conservation and aims to reduce the impact of its operations on biodiversity through environmental impact assessments.

Aligned with IATA goals, United Airlines has adopted the target of achieving net-zero carbon emissions by 2050 and is working on various strategies to reach this goal. These include investing in low carbon emission technologies and improving the efficiency of flight operations. In waste management and recycling, United Airlines places special emphasis on reducing waste and promoting recycling. The airline aims to reduce waste and encourage recycling through various strategies. With a commitment to social responsibility, the airline places great importance on employee welfare and promoting equality and diversity. It also supports social responsibility projects by collaborating with local communities and engaging in community services. United Airlines' strategies for airport sustainability involve making the airline's airport operations more sustainable. The airline aims to provide greener travel options by offering carbon offset programs and green flight alternatives to its customers. In terms of energy and resource efficiency, the airline seeks to reduce its environmental impact while lowering costs and aims to use energy and resources more effectively.

Table 2. Examination of the Sustainability Activities of SkyTeam Member Companies within the Scope of IATA's Sustainability Goals

Number	Companies	Achieve net zero carbon emissions by 2050	Sustainable aviation fuels (SAFs)	Promoting new aircraft technologies	Cabin waste management and recycling	Greener travelling (noise and air quality)	Energy, resource and operational efficiency	Protecting biodiversity
1	Aerolíneas Argentinas	✓	✓	✓	×	✓	✓	×
2	Aeromexico	✓	✓	✓	✓	✓	✓	✓
3	Air Europa	×	×	✓	✓	✓	✓	×
4	Air France	✓	✓	✓	✓	✓	✓	×
5	China Airlines	✓	✓	✓	✓	✓	✓	×
6	China Eastern Airlines	✓	✓	✓	✓	✓	✓	✓
7	Czech Airlines	×	×	✓	✓	×	✓	✓
8	Delta Airlines	✓	✓	✓	✓	✓	✓	×
9	Garuda Indonesia	×	×	✓	✓	✓	✓	✓
10	ITA Airways	✓	✓	✓	✓	✓	✓	×
11	Kenya Airways	✓	✓	✓	×	✓	✓	✓
12	KLM Royal Dutch Airlines	✓	✓	✓	✓	✓	✓	✓
13	Korean Air	✓	✓	✓	✓	✓	✓	✓
14	Middle East Airlines	×	×	×	×	✓	×	×
15	Saudia	×	×	×	✓	✓	×	✓
16	The Romanian Air Transport	×	×	×	×	×	×	✓
17	Vietnam Airlines	×	×	✓	✓	✓	✓	×
18	Virgin Atlantic	✓	✓	×	✓	✓	✓	✓
19	XiamenAir	×	×	✓	✓	✓	✓	×

Within the framework of the IATA, Aerolineas Argentinas is adopting various strategies to achieve IATA's sustainability objectives. Foremost among these strategies are the use of sustainable aviation fuels to reduce carbon emissions and efforts to increase energy efficiency. Additionally, significant steps are being taken in waste management and recycling, as well as investment in water-saving technologies. In terms of social.

Aligned with IATA's goals, Aeromexico is also adopting various strategies to realize IATA's sustainability targets. Primary among these are the use of sustainable aviation fuels to reduce carbon emissions and efforts to increase energy efficiency. The airline is making significant strides in waste management and recycling, and is investing in technologies for water conservation. In the realm of social responsibility, Aeromexico is committed to fair employment practices and community giving programs, supporting both its workforce and local communities. To boost business efficiency, the airline employs more efficient flight routes and energy-efficient aircraft technologies, along with digitizing its operations.

Within the IATA framework, Air Europa is prioritizing energy-efficient aircraft to achieve the goal of net-zero carbon emissions. The company reduces waste and encourages recycling through its waste management and recycling programs. Air Europa is fulfilling its water management objectives by adopting water-saving technologies and practices to reduce water consumption. Its social responsibility goals are realized through fair and equitable policies and programs aimed at employees and communities. Air Europa enhances operational efficiency through methods such as more efficient flight routes, energy-efficient aircraft, and digitized operations. The company supports its emissions reduction goal by investing in new aircraft technologies. To achieve its sustainability targets, it collaborates with suppliers, airport operators, and other business partners. Air Europa reduces the environmental impact of airport operations by collaborating with airport operators. It offers greener travel options by providing carbon offset choices to customers and promoting energy-efficient flights. The company achieves its energy and resource efficiency objectives by investing in energy-saving technologies and flight methods. Ultimately, Air Europa integrates sustainable practices into its operations and collaborates with partners, a commitment that can facilitate its steady progress towards a sustainable future.

Under the auspices of the IATA, Air France is contributing to sustainable aviation. The company, in line with IATA's defined targets, is conducting a series of initiatives to achieve the net-zero carbon emissions goal by 2050, focusing on reducing carbon emissions through the use of energy-efficient aircraft. Air France has taken serious steps in waste management and recycling, adopting policies to reduce waste and prioritize eco-friendly practices. It is also fulfilling its responsibilities in areas like water management, maintaining its commitment to sustainability. Additionally, the airline is engaged in social responsibility projects aimed at generating societal benefits.

Within the context of the IATA, China Airlines is taking comprehensive steps towards the development of sustainable aviation. The airline is focusing on incorporating energy-efficient aircraft into its fleet as a means to reduce carbon emissions. It is adopting waste management and recycling policies to diminish waste and encourage recycling, reflecting its commitment to environmentally friendly practices. In the realm of water management, China Airlines follows strategies to lessen the impact of its operations on natural ecosystems, employing water-saving technologies and practices. The company collaborates with partners in the supply chain to broaden its sustainability objectives and foster innovation. By working with airport operators, it is reducing the environmental impact of airport operations. Offering customers carbon offset options and promoting more eco-friendly travel, China Airlines aims to spread awareness about sustainability. Investing in efficient utilization of aviation fuels and renewable energy, the airline seeks to enhance energy and resource efficiency. In this framework, it aims to lay a solid foundation for future sustainable aviation by expanding its strategies for reducing environmental impacts.

China Eastern Airlines operates in line with IATA's sustainability standards. By adding high energy-efficient aircraft to its fleet and improving operational efficiency, the airline contributes to sustainable aviation goals. These high energy-efficient aircraft form part of its strategy to reduce carbon emissions. Additionally, China Eastern actively contributes to reducing its carbon footprint through participation in carbon offset programs. Adopting waste management and recycling policies, it aims to contribute to the sustainable use of natural resources. Optimizing waste management processes is crucial for minimizing environmental impacts. Measures taken to adopt water-saving technologies and improve water management contribute to the sustainable use of water resources. China Eastern Airlines employs various strategies to support biodiversity goals, including policies and awareness activities to prevent illegal wildlife trade. Noise pollution reduction strategies are an essential part of the airline's social responsibilities. In this regard, China Eastern contributes to reducing noise pollution around airports by opting for modern aircraft with quieter engines. Its goal of improving air quality is a reflection of its efforts to minimize environmental impacts, with steps like using low-emission aircraft and transitioning to alternative fuels. Acting with a social responsibility ethos, China Eastern Airlines adopts strategies such as paying fair wages to its employees and investing in local communities, demonstrating its commitment to responsible interactions with society. Its economic sustainability goal involves making operations more efficient and reducing costs to operate sustainably from an economic perspective. Achieving this goal necessitates embracing innovation and new business models. Promoting technology and assuming technological responsibility reflects the company's approach to investing in environmentally friendly technologies and using technology ethically. China Eastern Airlines aims to achieve sustainability goals in alignment with IATA, collaborating with suppliers, business partners, and other aviation companies. These collaborations aim to spread sustainable practices across the industry. Additionally, developing sustainability strategies for airports, China Eastern collaborates with airport operators to take steps towards reducing the environmental impact of airports. By offering green travel options and encouraging more eco-friendly travel with carbon offset options, the airline supports environmentally friendly practices.

Under the guidance of the IATA, Czech Airlines is exerting efforts in the realm of sustainability by incorporating energy-efficient aircraft into its fleet and optimizing flight routes. Additionally, environmental measures such as waste reduction, recycling, and water management policies reflect Czech Airlines' commitment to the efficient use of clean water, waste management, and environmental protection. IATA supports the airline's objectives to preserve biodiversity, promote social responsibility, and encourage technological advancement, believing these efforts will contribute to the development of a sustainable aviation sector.

Within the framework of the IATA, Delta Airlines sets a precedent in the industry by adopting sustainable aviation practices. Delta is progressing towards its goal of net-zero carbon emissions by renewing its fleet with more energy-efficient aircraft and optimizing flight routes. The airline balances its environmental impacts by participating in carbon offset programs and investing in waste management programs. Additionally, Delta demonstrates exemplary efforts in water efficiency, making it a model practitioner in water management. Reflecting IATA's vision for sustainability, Delta offers environmentally friendly travel options to its customers.

In line with IATA standards, Garuda Indonesia plans to invest in projects that support carbon offsetting to reduce its environmental impact and continues its efforts in waste reduction and recycling through its waste management programs. In the context of social responsibility, the airline adopts policies focused on equality, diversity, and social benefit. Garuda Indonesia focuses on technological advancement, supporting innovative solutions and collaborating with business partners to achieve sustainability goals. The airline aims to offer green travel opportunities by promoting eco-friendly flights and plans to use sustainable aviation fuels to enhance energy and resource efficiency.

ITA Airways, in alignment with IATA objectives, adopts strategies to reduce and offset carbon emissions in pursuit of the Net Zero Carbon Emissions goal. The airline is taking steps in waste management and recycling policies to reduce and recycle waste. In terms of social responsibility, ITA Airways aims to provide societal benefits by implementing equality and diversity policies and investing in communities. The airline targets support for eco-friendly technologies through its efforts in technological advancement and investment in sustainable aviation technologies. Collaborating with business partners and suppliers, ITA Airways aims to achieve sustainability goals. The airline adopts strategies for environmentally friendly airport operations and collaboration to operate sustainably. ITA Airways is committed to reducing carbon emissions through the use of sustainable aviation fuels and enhancing energy and resource efficiency.

Kenya Airways is supporting the IATA efforts to reach net-zero carbon emissions. The airline is continuing its efforts to balance carbon emissions by investing in more efficient aircraft and participating in sustainable projects. Additionally, it plans to take responsibility by investing in water-saving technologies to reduce water usage and developing strategies to minimize its impact on biodiversity. The company is contributing to sustainability by conducting activities in areas such as water management, biodiversity, social responsibility, operational efficiency, new aircraft technologies, collaboration with business partners, greener travel, energy and resource efficiency, and sustainable aviation fuels (SAFs).

Within the scope of IATA, KLM is implementing various initiatives in sustainability in line with IATA's goal of net-zero carbon emissions by 2050. To this end, it is accelerating the transition to low-carbon flight operations by investing in more efficient aircraft. KLM is focusing on waste reduction and recycling efforts by raising passenger awareness through waste management and recycling programs. The airline is also actively participating in biodiversity projects to reduce its impact on the natural environment. In terms of social responsibility, KLM is adopting policies of diversity, equality, and inclusivity, aiming to collaborate with local communities. These efforts by KLM significantly contribute to achieving IATA's sustainability goals.

Under the IATA framework, Middle East Airlines (MEA) is enhancing its societal impact by investing in more energy-efficient aircraft and supporting local communities with a sense of social responsibility, as well as promoting workforce diversity. The company's sustainability reports, annual activity reports, and website indicate various initiatives to reduce noise pollution and improve air quality as part of its greener travel efforts. However, there is a lack of activities towards achieving other IATA goals.

From an IATA perspective, Saudia's efforts in using sustainable aviation fuels, considering its ties with the petrochemical industry, play a critical role in reducing carbon emissions. Its sustainable goals, when aligned with the petrochemical industry, hold vital importance for both the company's and the aviation sector's sustainability. Economic sustainability and collaboration, through seeking innovative solutions for cost savings, are key aspects of Saudia's approach.

Regarding IATA's objectives, TAROM reflects its commitment to biodiversity and ecosystem protection through policies aimed at reducing its impact on biodiversity, in consideration of the European Union's stringent environmental policies. The airline's social responsibility goals are prominent in its commitment to and activities supporting the rights of its employees and local communities. Efforts to increase operational efficiency will enhance TAROM's competitiveness. However, TAROM appears to lag behind other companies in the sector, and achieving these goals is critical for both the airline's long-term success and environmental sustainability.

Vietnam Airlines' approach, in the context of IATA, represents a significant example of reducing the environmental impact of air transport. The airline demonstrates its commitment to waste reduction and recycling targets through various effective strategies in waste management and recycling. Thus, it successfully fulfills IATA's emphasized goals like waste management.

From the perspective of IATA, Virgin Atlantic's sustainability efforts offer a model example in reducing the environmental impact of air travel. The airline is working determinedly towards the goal of net-zero carbon emissions, taking steps such as using more efficient aircraft, employing sustainable aviation fuels, and enhancing energy efficiency. Active steps in waste management, recycling, and water management support environmental sustainability. Virgin Atlantic plays a crucial role in collaborating with business partners to contribute to making the aviation sector overall more sustainable.

Xiamen Air operates in alignment with IATA's sustainable aviation goals. The airline adopts significant strategies to reduce carbon emissions, such as enhancing energy efficiency and using sustainable fuels. Incorporating more efficient aircraft into its fleet and increasing the use of sustainable aviation fuels are effective methods to reduce its environmental impact. Its efforts in waste management and recycling support environmental sustainability, and steps in areas such as water management continue its efforts to minimize environmental impacts. Xiamen Air aligns with sustainability goals through strategies to increase operational efficiency and reduce energy consumption.

Table 3. Examination of OneWorld Member Companies' Sustainability Activities in the Scope of IATA's Sustainability Goals

Number	Companies	Achieve net zero carbon emissions by 2050	Sustainable aviation fuels (SAFs)	Promoting new aircraft technologies	Cabin waste management and recycling	Greener travelling (noise and air quality)	Energy, resource and operational efficiency	Protecting biodiversity
1	Alaska Airlines	✓	✓	✓	✓	✓	✓	×
2	American Airlines	✓	✓	✓	✓	✓	✓	×
3	British Airways	✓	✓	✓	✓	✓	✓	×
4	Cathay Pacific	✓	✓	✓	✓	✓	✓	✓
5	FinnAir	✓	✓	✓	✓	✓	✓	✓
6	Iberia Airlines	✓	✓	✓	✓	✓	✓	×
7	Japan Airlines	✓	✓	✓	✓	✓	✓	✓
8	Malaysia Airlines	✓	×	×	✓	✓	✓	×
9	Qantas Airways	✓	✓	✓	✓	✓	✓	✓
10	Qatar Airways	×	✓	✓	✓	✓	✓	✓
11	Royal Air Maroc	×	×	×	×	×	×	×
12	Royal Jordanian	×	×	✓	✓	×	✓	×
13	SriLankan Airlines	×	×	✓	×	×	✓	×

Within the framework of the (IATA), Alaska Airlines has committed to combatting climate change. In 2020, the airline set a goal to reduce the carbon emissions of its flights to net-zero by 2040, a plan that precedes the 2050 target set by IATA by a decade. Alaska Airlines has adopted various strategies to achieve this goal, including using more efficient aircraft, employing sustainable aviation fuels (SAFs), balancing carbon emissions, and enhancing operational efficiency. For instance, in 2017, Alaska Airlines led the aviation industry in the use of biofuels with its first biofuel flight from Seattle-Tacoma International Airport to San Francisco International Airport. The airline has also adopted an environmentally friendly approach to waste management and recycling. Its "Fill Before You Fly" program encourages passengers to fill their reusable water bottles to reduce plastic waste. While the company may not have articulated a specific strategy on water management, it continues to work towards reducing its overall environmental impact. It is also thought that Alaska Airlines could collaborate with airports on sustainability and new aircraft technologies. However, for current and more detailed information, it is important to refer to Alaska Airlines' official website or relevant sustainability reports. Lastly, Alaska Airlines is taking significant steps in social responsibility. With community service programs and commitments to diversity and inclusion, the airline aims to create a positive impact in the social sphere.

In line with the (IATA), American Airlines has made significant commitments regarding carbon emissions, adopting the goal of achieving net-zero carbon emissions by 2050. This commitment encompasses emissions from both flights and ground operations. The company plans to follow various strategies to achieve this goal; these include using more efficient aircraft, employing sustainable aviation fuels (SAFs), enhancing operational efficiency, and increasing carbon offsetting. American Airlines has also taken significant steps in waste management and recycling. For example, in 2020, it became the first airline to initiate an in-flight plastic recycling program. Additionally, the airline is working on innovative solutions such as recycling used uniforms and repurposing them for new products.

In terms of water management, American Airlines has implemented water conservation and energy efficiency measures at many airports. In the area of social responsibility, the airline places importance on community service programs and commitments to diversity and inclusion. It has made commitments to sustainability at airports, greener travel, and energy and resource efficiency. Regarding new aircraft technologies and collaboration with business partners, American Airlines commits to using advanced technologies and strategies to make its flights more efficient and reduce emissions. This includes significant steps like using next-generation aircraft, optimizing flight paths, and enhancing air traffic control technologies. Finally, active in sustainable aviation fuels, American Airlines aims to increase the commercial use of these fuels through collaboration with biofuel producers and suppliers, thereby contributing to a more environmentally friendly and sustainable future in the aviation industry.

Aligned with the (IATA) goals, British Airways can be considered a committed airline in achieving sustainability targets within the aviation industry. It has pledged to reach net-zero carbon emissions by 2050, in line with the objectives set by IATA. To attain this goal, the airline plans to adopt strategies such as using more efficient aircraft, enhancing operational efficiency, and employing sustainable aviation fuels (SAFs). In terms of waste management and recycling, British Airways continues efforts to reduce and recycle waste generated from its flights. The company has also committed to reducing plastic waste from its operations.

As part of its sustainability strategy, British Airways supports various environmental conservation projects. It has made commitments to sustainability at airports and greener travel options. For example, it is taking measures to increase energy efficiency at airports and also offers passengers the opportunity to offset their carbon emissions. In terms of operational efficiency, British Airways commits to optimizing energy and resource usage through new aircraft technologies and efficient operations.

Lastly, in the realm of social responsibility, ritish Airways is dedicated to supporting local communities and addressing various social issues. This comprehensive approach underlines the airline's commitment to contributing to a more sustainable and responsible aviation sector.

In line with the (IATA) targets, Cathay Pacific has committed to achieving net-zero carbon emissions by 2050, a goal that mirrors IATA's objectives. To reach this target, the airline plans to adopt strategies such as utilizing more efficient aircraft and operations, using sustainable aviation fuels (SAFs), and implementing carbon emission balancing strategies. Regarding waste management and recycling, Cathay Pacific has set a goal to reduce waste generated from its flights by 50% by 2030. To achieve this, the airline will offer reusable or recyclable products to passengers and improve waste management on its aircraft to reduce its environmental impact. In water management and biodiversity, Cathay Pacific continues efforts to reduce its environmental footprint, focusing on reducing water usage and supporting biodiversity conservation projects and programs. In social responsibility, the airline is committed to various community service programs and diversity and inclusion initiatives. Cathay Pacific has also made significant commitments to sustainability at airports and greener travel options. In terms of operational efficiency and new aircraft technologies, it is committed to adopting various technologies and strategies to make flights more efficient and reduce emissions. Finally, Cathay Pacific is actively committed to energy and resource efficiency and sustainable aviation fuels, supporting various projects and initiatives to develop and utilize SAFs, contributing to a more environmentally friendly future in aviation.

Under IATA targets, Finnair has pledged to reach net-zero carbon emissions by 2050 and is taking various measures to achieve this goal. The airline plans to reduce carbon emissions by incorporating more efficient aircraft into its fleet and making its operations more efficient. It also aims to increase the use of sustainable aviation fuels (SAFs) and implement emission balancing strategies. Finnair has made significant commitments in waste management and recycling, focusing on reducing waste from its flights and increasing recycling to lessen its environmental impact. In water management and biodiversity, Finnair is dedicated to reducing water consumption and preserving biodiversity, while also supporting environmental conservation projects. In the realm of social responsibility, Finnair implements various programs and policies related to diversity and inclusion, community service, and employee welfare, aiming to create a positive social impact. For operational efficiency and new aircraft technologies, Finnair plans to reduce emissions by incorporating more efficient aircraft into its fleet, optimizing flight paths with modern navigation technologies. In energy and resource efficiency, the airline commits to using energy-efficient technologies and renewable energy sources to reduce energy and resource consumption. Finally, regarding sustainable aviation fuels, Finnair aims to increase the use of SAFs and support projects for the development and commercialization of these fuels, contributing to a greener future in aviation.

Under the auspices of the (IATA), Iberia is actively monitoring significant developments in the industry and contributing to sustainable aviation goals. The company has set its commitments towards achieving net-zero carbon emissions by 2050, adopting various strategies to this end. These include embracing innovative technologies, utilising more efficient aircraft, preferring sustainable aviation fuels, and enhancing operational processes. Additionally, Iberia is aligning with IATA's sustainable development goals in areas like waste management and recycling, water management, gender equality, and economic growth.

Japan Airlines (JAL), another member within the IATA framework, has committed to a net-zero carbon emission target by 2050. It adopts diverse strategies to achieve this objective, including a commitment to reduce flight-generated waste through waste management and recycling. In water management, JAL pledges to reduce water consumption, focusing on efficient use and recycling of water. For biodiversity conservation, JAL supports projects aimed at preserving and sustaining biodiversity, including the protection of natural habitats and support for local ecosystems. In social responsibility, JAL prioritises community service projects and commitments to diversity and inclusion. Regarding operational efficiency and new aircraft technologies, JAL adopts various technologies and strategies to promote more efficient aircraft and operations. This encompasses embracing new technologies for more efficient aircraft and flight operations. In airport sustainability, JAL is committed to increasing energy and resource efficiency, which involves adopting energy-efficient technologies and optimising the use of energy and resources. In its commitment to offering more sustainable travel options, JAL aims to provide passengers with options to offset carbon emissions and promote the use of sustainable aviation fuels. Lastly, JAL is committed to sustainable aviation fuels (SAFs), which entails increasing the use and development of SAFs to contribute to a more sustainable and environmentally friendly future for the aviation industry.

Within the scope of the (IATA), Malaysia Airlines is a leading airline aiming to achieve net-zero carbon emissions by 2050. The company is committed to reducing its environmental impact through comprehensive strategies such as waste management, water conservation, energy efficiency, and the use of sustainable fuels. It also pledges to address areas like employee health and safety, gender equality, diversity promotion, and social responsibility. The company aims to contribute to the sustainable future of the aviation industry by investing in modern technologies and innovative solutions.

Under IATA, Qantas has made significant commitments in waste management and recycling. It aims to reduce waste from its flights and ground services and to promote recycling. In this regard, it adopts waste reduction and recycling strategies with a specific focus on reducing plastic usage. In water management, the company is committed to reducing water consumption and promoting more effective water use. Additionally, Qantas places importance on environmental and societal sustainability by contributing to biodiversity conservation projects and social responsibility initiatives. For operational efficiency, Qantas aims to adopt modern technologies, use more efficient aircraft, and renew its fleet.

Qatar Airways, another IATA member, has committed to achieving net-zero carbon emissions by 2050. To reach this goal, it is taking various steps in waste management and recycling. Within its waste reduction and recycling strategies, the airline aims to decrease plastic usage, thereby minimising its environmental impact. Similarly, in water management, it pledges to encourage water conservation and reduce water consumption. The airline also supports projects aimed at protecting and sustaining biodiversity. In the realm of social responsibility, Qatar Airways aims to support local communities and provide educational opportunities. For operational efficiency and technology usage, the airline plans to adopt strategies for more efficient flight operations and energy efficiency.

Regarding social responsibility within the IATA framework, Royal Air Maroc (RAM) aims to support local communities and promote economic and social development. In terms of operational efficiency, RAM has adopted strategies to enhance energy and operational efficiency. With regard to new aircraft technologies, RAM continues its efforts to incorporate more efficient and environmentally friendly aircraft into its fleet. Specific policies and practices related to sustainability at airports, greener travels, and energy and resource efficiency for RAM have not been detailed.

Under the (IATA) framework, RJ (Royal Jordanian Airlines) is aiming to achieve net-zero carbon emissions by 2050. In line with this objective, the company plans to reduce carbon emissions by using more efficient aircraft and operations. However, specific commitments regarding the net-zero target are not detailed. General information exists about RJ's waste management and recycling strategies, but specific targets or initiatives are not sufficiently detailed. There is a lack of precise information about RJ's specific goals or initiatives in water management. Regarding biodiversity, there is no specific information available on RJ's efforts to minimize its impact on biodiversity. Socially, RJ commits to contributing to local communities and supporting the social and economic development of Jordan. RJ aims to increase operational efficiency by optimizing more efficient aircraft and flight operations. In terms of new aircraft technologies, RJ aims to reduce carbon emissions by using more efficient and environmentally friendly aircraft. Information on RJ's specific targets or strategies regarding collaboration with business partners, sustainability at airports, greener travel, and energy and resource efficiency is limited. There is no definitive information on RJ's strategy or commitment to the use or development of Sustainable Aviation Fuels (SAFs).

Within the scope of IATA's objectives, SriLankan Airlines supports the goal of net-zero carbon emissions by 2050. The company has made commitments to reduce carbon emissions and use sustainable aviation fuels. However, it is unclear whether there is a specific commitment to the net-zero emission target by 2050. SriLankan Airlines has developed waste management and recycling strategies, but detailed information on specific targets and initiatives in these areas is lacking. There is no information available on SriLankan Airlines' specific goals or initiatives in water management. There is no specific information about SriLankan Airlines' efforts to minimize its impact on biodiversity. In terms of social responsibility, SriLankan Airlines commits to contributing to community services and social responsibility projects. The company has taken various steps to increase operational efficiency and reduce energy consumption. SriLankan Airlines aims to reduce carbon emissions through the use of more efficient aircraft. Information on the airline's specific targets or strategies regarding collaboration with business partners, sustainability at airports, greener travel, and energy and resource efficiency is limited. While SriLankan Airlines may have shown interest in the use or development of Sustainable Aviation Fuels (SAFs), specific information on this is not available.

5. Discussion and Conclusion

This study's analysis, rooted in the sustainability commitments of airlines within the Star Alliance, SkyTeam, and OneWorld alliances, under the (IATA) sustainability framework, has illuminated varied levels of commitment to achieving the outlined sustainability goals by 2050. Key findings across these alliances reveal a concerted focus on adopting sustainable aviation fuels, enhancing energy and operational efficiency, and advancing in the adoption of new aircraft technologies. However, disparities emerge in commitments to biodiversity conservation and the achievement of net-zero carbon emissions, with these objectives being less frequently embraced. The variability in commitments can be attributed to several factors. Firstly, the technological and financial challenges associated with transitioning to sustainable aviation fuels and achieving net-zero carbon emissions are substantial, possibly hindering more aggressive adoption. Secondly, the less frequent adoption of biodiversity conservation goals may reflect a narrower focus on direct operational impacts over broader environmental considerations. This discrepancy underscores a potential underestimation of the aviation sector's influence on global biodiversity.

As a member of Star Alliance, Lufthansa has played a leading role in sustainability initiatives, particularly through its commitment to Sustainable Aviation Fuel (SAF). Lufthansa has actively invested in SAF to reduce carbon emissions by up to 80%, as well as exploring carbon-neutral flight options. The airline also incorporates energy-efficient aircraft and is committed to reducing its overall environmental impact through cabin waste management and recycling programmes (Lufthansa Group, 2021). Moreover, Lufthansa has made significant progress in reducing cabin waste, improving operational efficiency, and reducing its carbon footprint through technology advancements (Lufthansa Group, 2023).

Air Canada: Air Canada has committed to achieving **net-zero carbon emissions by 2050**. This commitment includes investments in SAF, fleet modernisation, and carbon offset initiatives. The airline has also introduced measures to enhance fuel efficiency, optimise flight routes, and improve overall operational sustainability (Air Canada, 2023).

Delta, a prominent member of SkyTeam, has undertaken several sustainability initiatives, including a strong commitment to SAF. Delta is investing in the development and large-scale procurement of SAF, which has a significantly lower carbon footprint than traditional jet fuels. In addition, Delta has implemented various waste reduction strategies and energy efficiency measures in its operations, alongside offering carbon offsetting options for passengers (Delta Airlines, 2023).

Air France has also embraced sustainability as a key strategic priority. The airline has committed to reducing its emissions by incorporating SAF into its operations and by modernising its fleet with more fuel-efficient aircraft. Additionally, Air France has engaged in initiatives to reduce cabin waste and improve overall operational sustainability (Air France-KML, 2024).

Within the Oneworld alliance, British Airways has been a frontrunner in sustainability efforts. The airline has integrated SAF into its fuel supply, launched initiatives to achieve **net-zero emissions by 2050**, and promoted carbon offsetting schemes for passengers. British Airways has also invested heavily in technology that supports energy efficiency and waste reduction (British Airways , 2021). Its comprehensive sustainability strategy focuses on minimizing carbon emissions, waste, and noise pollution.

As part of its commitment to sustainability, Qantas has pledged to achieve **net-zero emissions by 2050**. The airline's initiatives include extensive investment in SAF, reducing cabin waste, and implementing energy-saving measures. Qantas has also invested in more fuel-efficient aircraft and optimised its operations to reduce overall emissions (Qantas, 2023).

Notably, airlines within the Star Alliance network demonstrate a relatively higher engagement with sustainability goals, compared to their counterparts in SkyTeam and OneWorld. This variation may be influenced by the alliances' strategic priorities, the geographical and regulatory environments of member airlines, and the availability of resources to implement sustainability initiatives. Such differences highlight the complex interplay between global sustainability ambitions and localized operational realities. Future research should explore the barriers to adopting more comprehensive sustainability measures, particularly in the areas of biodiversity conservation and net-zero carbon emissions. Investigating the economic, regulatory, and technological challenges that airlines face in these domains will provide deeper insights into how the aviation industry can more effectively contribute to global sustainability efforts.

Enhanced Collaboration: Airlines should seek greater collaboration with technology providers, governments, and international organizations to overcome barriers to sustainability. Sharing best practices and innovations in fuel efficiency, carbon offsetting, and sustainable aviation fuels could accelerate progress.

Biodiversity Conservation Initiatives: Given the lower adoption of biodiversity conservation goals, airlines and alliances should integrate these into their sustainability strategies more robustly. This could involve supporting conservation projects and adopting flight and ground operations that minimize impact on natural habitats.

Public Engagement and Transparency: Increasing transparency about sustainability efforts and actively engaging the public and stakeholders can build trust and support for the airlines' sustainability initiatives. Public awareness campaigns and sustainability reporting can enhance accountability and encourage broader participation in sustainability efforts.

Policy Advocacy: Airlines and alliances should advocate for supportive policies and incentives that facilitate the transition to sustainable aviation, including investment in research and development for new technologies and sustainable fuels, and policies that support carbon pricing and biodiversity conservation.

By addressing these recommendations, the aviation industry can make more substantial contributions to global sustainability goals, ensuring that efforts to enhance operational efficiency and innovation are balanced with the imperative to reduce environmental impact and promote biodiversity conservation.

Based on the findings from the evaluation of global airline alliances and their sustainability initiatives, several promising areas for future research are apparent. These areas are critical for both advancing academic knowledge and providing practical insights for the industry as it strives to meet global sustainability goals.

Firstly, scaling the use of Sustainable Aviation Fuels (SAF) remains a significant challenge. While SAF can dramatically reduce carbon emissions, its widespread adoption has been hindered by economic and technical barriers. Future research should investigate these obstacles in depth, focusing on how policy frameworks and investments can drive SAF production and adoption. Comparative studies across different global regions and alliances would provide valuable insights into the varying levels of SAF integration and the factors contributing to its success or failure.

Secondly, technological innovations in aircraft design, such as electric and hydrogen-powered planes, represent a critical frontier in reducing aviation's environmental impact. However, the feasibility, cost implications, and readiness of the industry to adopt these technologies remain underexplored. Further studies could assess the role of collaborations within alliances to accelerate the development and deployment of these technologies, particularly examining how shared investments can reduce costs and risks for individual airlines.

Thirdly, the effectiveness of carbon offset programmes offered by many airlines requires more rigorous analysis. While carbon offsetting is widely promoted as a tool for reducing environmental impacts, the actual effectiveness and transparency of these schemes are often questioned. Future research could examine the real-world outcomes of carbon offset programmes, including their ethical implications and how passengers perceive their value. Investigating the role of customer perceptions in the success of these programmes would provide insights into their long-term viability.

The protection of biodiversity also emerges as a crucial but under-researched area. Airlines' operations, particularly around major airports, can have significant impacts on local ecosystems. Future studies could explore how airlines are managing these impacts and the effectiveness of their biodiversity protection efforts. This research would contribute to a better understanding of how aviation can align with broader environmental conservation goals, especially in terms of habitat preservation and wildlife protection.

Another area of inquiry is customer perception and behaviour regarding airline sustainability initiatives. While airlines increasingly promote their environmental efforts, it remains unclear how these initiatives influence passenger choices. Future studies could explore whether passengers are willing to pay more for environmentally responsible flights and how airlines' sustainability marketing shapes customer behaviour. This research could provide airlines with actionable insights into how to effectively communicate their sustainability efforts to build customer loyalty.

Lastly, there is an opportunity to explore the role of airline alliances in setting and enforcing sustainability standards. Global alliances such as Star Alliance, SkyTeam, and Oneworld play a crucial role in shaping the sustainability practices of their member airlines. Future research could assess the extent to which alliances influence individual airline policies and the potential for collaborative sustainability projects within alliances. Understanding how alliances can drive industry-wide sustainability standards would provide critical insights into the future of sustainable aviation.

These research areas are essential for helping the aviation industry navigate its path towards greater sustainability. By addressing these issues, future studies will not only deepen academic understanding but also offer practical solutions for airlines striving to meet international sustainability targets.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Flight in Transition: Navigating the Skies of Automation and Human Judgement

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Abstract

Integrating automation systems within the aviation sector signifies a critical juncture, presenting significant advancements in operational efficiency and safety protocols. However, this technological evolution mandates a comprehensive reassessment of decision-making processes, particularly as pilots navigate the intricate interaction between human cognition and automated support. This study aims to enhance academic discourse by conducting a thorough analysis of the implications of automation systems on decision-making in aviation, with a specific focus on the tragic incidents involving Lion Air Flight 610 on October 29, 2018, and Ethiopian Airlines Flight 302 on March 10, 2019. The impact of automation systems on decision-making in aviation will be examined in detail to understand their role in these incidents. Employing a rigorous case analysis methodology upon a diverse array of secondary sources, this study seeks to unravel the multifaceted dynamics at play and shed light on the influence of automation on pilot actions and responses. Anticipated outcomes of this study include providing invaluable guidance to aviation stakeholders, encompassing regulatory bodies, aircraft manufacturers, airlines, and pilots, concerning the challenges and opportunities inherent in automation integration. By identifying knowledge gaps and delineating avenues for enhancement, this research endeavours to inform evidence-based strategies and optimal practices for enhancing safety and resilience in contemporary air travel. Ultimately, the significance of this scholarly endeavour lies in its potential to advance scholarly understanding and facilitate informed decision-making processes, thereby contributing to the pursuit of safer and more efficient aviation operations on a global scale.

1. Introduction

The aviation landscape is undergoing a profound transformation driven by technological advancements, particularly the widespread integration of automation systems. These systems, designed to enhance safety, efficiency, and operational capabilities, have become integral to modern air travel. (Read et al., 2012) However, their implementation has also raised critical questions about their impact on decision-making processes within the aviation domain, particularly concerning safety (Zhou, 2018). This study delves into the complex relationship between automation systems and decision-making in aviation, with a specific focus on safety implications. Examining the interaction between pilots and automation technologies aims to gain insights into how these systems influence decision-making dynamics, especially in critical scenarios. Our inquiry begins by acknowledging the pivotal role of automation systems in shaping contemporary aviation practices. As aircraft increasingly rely on automation, understanding its implications for pilot decision-making becomes paramount (Chan & Soeriaatmadja, 2018). It is sought to explore the cognitive and behavioral aspects of pilots' interaction with automation, aiming to uncover both the benefits and challenges associated with its integration. Moreover, it is recognized the importance of informing aviation stakeholders about the evolving nature of decision-making processes in the context of automation (Weinzimmer & Esken, 2017). By synthesizing existing literature and analyzing real-world incidents, it aspires to contribute valuable insights that can inform training protocols, operational procedures, and regulatory frameworks aimed at enhancing aviation safety. Lion Air Flight 610, which occurred on October 29, 2018, and Ethiopian Airlines Flight 302, which occurred on March 10, 2019, accidents have underscored the increasing significance of endeavors to comprehend the role of automation systems in the aviation industry (Pranesh et al.,2017). These accidents have occurred because of a multitude of factors, including misunderstandings of automation systems, inadequate interactions between pilots and these systems, or failure to execute appropriate interventions during emergencies. Hence, a thorough examination and analysis of these accidents hold critical importance in terms of aviation safety. In essence, this study provides a comprehensive understanding of how automation systems influence decision-making in aviation, particularly concerning safety considerations. By elucidating the complexities of this relationship, it strives to pave the way for informed strategies that promote safer and more efficient air travel in the digital age.

2. The Rise of Automation Systems

The proliferation of automation systems within the aviation industry represents a paradigm shift driven by various factors, each contributing to its ascent as a cornerstone of modern air travel (Salmon et al., 2020). One of the primary drivers behind the rise of automation systems is the rapid advancement of technology (Barbosa, 2016). Breakthroughs in computing power, sensor technology, and data analytics have paved the way for increasingly sophisticated automation solutions (Weinzimmer & Esken, 2017). These innovations enable automation systems to handle complex tasks with precision and efficiency, revolutionizing how aircraft are operated and controlled. Flight safety has always been a paramount concern in aviation, and automation systems play a pivotal role in bolstering safety standards (Hancock, 2013). By automating routine tasks and providing real-time monitoring and feedback, these systems act as a safeguard against human error, a leading cause of aviation accidents (Motlagh et al., 2016). Enhanced safety standards, coupled with regulatory mandates and industry best practices, have spurred the widespread adoption of automation systems to mitigate risks and improve overall safety outcomes (Waldinger, 2016).

In an increasingly competitive aviation landscape, operational efficiency is critical to success. Automation systems allow airlines and operators to streamline workflows, optimize resource utilization, and minimize costs (Shah, 2015). By automating tasks such as navigation, flight planning, and system monitoring, airlines can achieve higher levels of operational efficiency, leading to improved profitability and a competitive edge in the market (Deloitte, 2016). One of the most tangible benefits of automation systems is the reduction of pilots' workload (Li & Harris, 2006). By automating routine tasks and providing advanced assistance features, these systems empower pilots to focus on higher-order decision-making and strategic planning (Moreno et al.,2017). This enhances operational efficiency and mitigates the risk of fatigue and cognitive overload, ensuring that pilots remain alert and responsive throughout a flight (Liu et al., 2008). Ultimately, the overarching goal of automation systems is to create a safer flight environment for passengers and crew alike (Chen & Tsai, 2016). By leveraging advanced technologies such as predictive analytics, collision avoidance systems, and automated emergency response mechanisms, these systems can anticipate and mitigate potential hazards in real time, thereby enhancing overall safety outcomes and instilling confidence in the flying public (Saadat & Saadat, 2016). In conclusion, the rise of automation systems in the aviation industry represents a transformative shift driven by technological innovation, safety imperatives, and operational efficiencies (Beier et al., 2017). As these systems continue to evolve and mature, they will undoubtedly play an increasingly integral role in shaping the future of air travel, paving the way for safer, more efficient, and more sustainable aviation operations.

2.1. Managing Aircraft Automation

Before pilots can proficiently utilize aircraft automation, they must acquire fundamental flying skills (Chialastri, 2021). Maneuver training remains a crucial aspect of flight instruction due to the significant proportion of general aviation (GA) accidents occurring during landing, which remains a manual process. A notable percentage of GA accidents transpire during take-off and initial climb. A significant safety concern highlighted by the Federal Aviation Administration (FAA)(2007) relates to pilots developing an undue reliance on avionics systems, mistakenly believing that these systems can compensate for their limitations. (FAA, 2007) This over-reliance on avionics often intersects with Aeronautical Decision Making (ADM), a critical factor in accidents involving high-performance aircraft engaged in cross-country flights. The FAA's study on advanced avionics safety revealed that novice pilots with advanced avionics tend to demonstrate poorer decision-making skills than the GA population. Analysis of accidents involving advanced avionics reveals that the majority stem not from aircraft malfunctions but rather from pilots' lack of experience and poor decisions (Salmon et al., 2015). A recurring theme in many fatal accidents is the persistence of visual flight rules (VFR) flight into instrument meteorological conditions (IMC) (Labib, 2015). Therefore, pilot proficiency in both standard and emergency operations relies on physical control of the aircraft and the cognitive mastery of Electronic Flight Displays (EFD). Three essential flight management skills—information management, automation proficiency, and risk assessment—are indispensable for the safe operation of advanced avionics systems (ICAO, 2013).

2.2. Information Management

For pilots transitioning to aircraft equipped with Primary Flight Displays (PFDs), Multi-Function Displays (MFDs), and GPS/VHF navigator screens, the abundance of information presented in colorful menus and submenus can initially seem overwhelming (Barbosa, 2016). In such instances, pilots may find themselves inundated with data, needing help to locate specific pieces of information amidst the complexity of the interface (Beier et al., 2017). It is crucial to recognize that these systems function like computers, with some folders readily accessible on a desktop while others are nested within a hierarchical structure (European Union Aviation Safety Agency, 2020). The primary skill required for proficiently operating advanced avionics systems is grasping the system's conceptual framework (Shmelova et al.,2017). Understanding the organizational structure of the system facilitates effective information management, enabling pilots to navigate through the available data efficiently (Chen & Tsai,2016). More than memorizing knob-and-dial procedures is required; a deeper comprehension of how these systems operate enhances procedural memory and equips pilots to troubleshoot unfamiliar situations (Comitz &Kersch,2016). However, it is essential to comprehensively acknowledge the limitations of understanding complex avionics systems. Given their intricacies, it is often impractical to anticipate every system's behavior (Labib, 2015). Instead, pilots should be ready for unexpected scenarios and embrace continuous learning. Simulation software and comprehensive literature specific to the avionics system in use are invaluable resources for enhancing understanding and proficiency. (Moreno et al.,2017). The second critical skill in information management involves adopting a methodical approach—stop, look, and read. Novice pilots often fixate on manipulating knobs and memorizing sequences of button inputs. A more effective strategy is to pause, observe the display screens, and read the relevant information before acting (Aircare International, 2022). This approach minimizes errors and optimizes the utilization of available resources. Once engaged with the advanced avionics interface, pilots must focus on regulating and prioritizing the flow of information to accomplish specific tasks efficiently. Certified Flight Instructors (CFIs) and pilots transitioning to advanced avionics can benefit from strategies to streamline information flow (Li et al.,2006). These tactics include customizing PFD and MFD displays according to individual preferences, such as selecting map orientation options and adjusting the amount of information displayed

(Mejdal et al., 2021). Furthermore, pilots can tailor information presentation to suit the requirements of different flight phases or operations, which helps optimize situational awareness and decision-making capabilities (FAA, 2023). This approach ensures that decision-making and situational awareness are key tactics in managing aviation operations effectively. Examples of managing information display for specific operations include programming map scale settings for different flight phases, utilizing terrain awareness features during night or instrument meteorological conditions (IMC) flights in mountainous regions, incorporating nearest airport data during challenging conditions, and configuring weather datalink settings to display pertinent meteorological information (Madsen & Desai, 2010). By honing these critical information management skills and employing effective strategies for navigating advanced avionics interfaces, pilots can enhance operational safety and efficiency in modern cockpit environments (Casner et al.,2014).

2.3. Situational Awareness

Ensuring the accuracy of all programmed data before take-off is fundamental to establishing a secure foundation for flight. This practice not only guarantees precision but also fosters a mindset of thoroughness and accuracy (Mahler & Casamayou, 2009). By cross-referencing planned routes with programmed data and confirming waypoints, pilots proactively intercept potential errors that may compromise flight safety. Furthermore, employing diverse navigation equipment not only offers redundancy but also enhances the pilot's comprehension of the surroundings, augmenting overall situational awareness (EASA, 2022). The real challenge is to balance automation with expertise. Although advanced avionics offer many capabilities, pilots need to stay aware of their personal skill levels and operational constraints (Chen & Tsai, 2016). Thus, realistic flight planning emerges as a pivotal factor, guiding pilots to navigate effectively while maintaining acute awareness of their environment. Additionally, the imperative to verify data entries underscores the significance of vigilance in high-pressure scenarios, averting oversights that could result in grave consequences (Beier et al., 2017).

3. Changes in Decision-Making Processes

The integration of automation systems within aviation brings about a significant transformation in decision-making processes, presenting a blend of opportunities and challenges for pilots. Traditionally, pilots have been entrusted with the primary responsibility of decision-making, drawing upon their training, experience, and judgment to navigate through diverse flight scenarios (Liu et al., 2008). However, the emergence of advanced automation alters this dynamic considerably. With the introduction of sophisticated automation, a portion of decision-making tasks is delegated to these systems, thereby altering the traditional pilot-centric approach. While this can enhance operational efficiency and accuracy in routine flight operations, it also raises concerns regarding pilots' sustained engagement and proficiency in decision-making (Casner et al.,2014). The delegation of decision-making authority to automation systems may inadvertently lead to a gradual erosion of pilots' skills, particularly if they excessively rely on these systems. Furthermore, the influence of automation on decision-making processes is intricately linked to aviation safety (Chialastri, 2021). Research indicates that increased reliance on automation systems can potentially impair pilots' ability to effectively manage unforeseen circumstances or anomalies. This phenomenon, commonly known as automation dependency or bias, may result in diminished situational awareness and heightened risk of pilot errors or accidents (Nguyen et al., 2019) In essence, while automation systems offer undeniable advantages in terms of operational efficiency and workload management, they necessitate a reassessment of pilots' involvement in decision-making processes (Gil et al. 2012). Aviation stakeholders must prioritize the maintenance of pilots' cognitive skills and vigilance amidst automation integration. This entails ensuring that pilots retain their proficiency in navigating complex situations and exercising sound judgment when confronted with critical decisions (Wickens et al., 2019). Moreover, ongoing training programs and proficiency assessments should be tailored to address the evolving role of automation in decision-making. By doing so, aviation stakeholders can foster a culture of safety and resilience, thereby mitigating the potential risks associated with automation integration in modern aviation operations (Soori et al.,2024).

3.1. Automation and Pilots: Harmony and Challenges

The seamless integration of automation systems with pilots is a pivotal aspect of modern aviation, aimed at optimizing operational efficiency while ensuring flight safety. While automation systems offer a myriad of benefits, including enhanced precision, reduced workload, and improved situational awareness, achieving perfect harmony between these systems and human operators is not always straightforward (Giannaros et al.,2023). One of the primary challenges lies in the complexity of automation systems. The intricate functionalities and interfaces of these systems can sometimes overwhelm pilots, leading to difficulties in understanding and effectively utilizing them, especially in high-stress or time-critical situations. Additionally, the design and presentation of information within automation interfaces play a crucial role in facilitating or impeding pilot comprehension and decision-making (Johnsen et al.,2020). Moreover, automation systems are designed to operate within specified parameters and assumptions about the environment and aircraft state (Chen & Tsai, 2016). However, when faced with unexpected or abnormal conditions, such as system failures, adverse weather, or air traffic congestion, these systems may not always respond optimally. In such cases, pilots must possess the skills and knowledge to intervene appropriately, potentially reverting to manual control to safely navigate the situation. Pilot proficiency and training are fundamental factors in ensuring effective interaction with automation systems (Soori et al.,2024). Pilots require comprehensive training not only in operating the automation itself but also in understanding its underlying principles, limitations, and potential failure modes. Regular proficiency checks and recurrent training programs, such as simulator sessions and scenario-based training, are essential to maintain and enhance these skills over time, ensuring pilots remain adept at handling automation in various scenarios (Casner et al., 2014). These programs typically include manual flight operations, emergency procedures, and decision-making exercises to prepare pilots for both routine and unexpected situations. By continuously evaluating and updating these training methods, aviation stakeholders can ensure that pilots retain their cognitive skills and remain vigilant in managing automated systems effectively. Furthermore, fostering a culture of collaboration and communication between pilots and automation systems is essential. Pilots should feel empowered to provide feedback on system design and functionality based on their operational experience, contributing to ongoing improvements and refinements. Additionally, clear communication channels between pilots and other stakeholders, such as air traffic controllers and maintenance personnel, are critical for effective coordination during all phases of flight (Wickens et al., 2019). In conclusion, while automation systems offer numerous benefits to aviation operations, achieving optimal compatibility with pilots requires addressing various technical, training, and operational considerations. By investing in comprehensive pilot training programs, improving the design of automation interfaces for better usability, and encouraging clear and consistent communication protocols, aviation stakeholders can create a balanced interaction between pilots and automated systems. This approach will ultimately enhance flight safety and operational efficiency.

4. Methodology

The research methodology employed in this study is designed to facilitate a comprehensive investigation into the impact of automation systems on decision-making processes within the aviation sector, with a specific focus on two significant incidents: Lion Air Flight 610, which occurred on October 29, 2018, and Ethiopian Airlines Flight 302, which occurred on March 10, 2019 (Al Jazeera, 2018, October 29; ASN, 2018; Boeing Commercial Airplanes, 2018; CBS News, 2018; Ethiopian Airlines, 2019a,2019b,2019c,2019d; Gebrekidan & Glanz, 2019; Jolly, 2019; Langewiesche, 2019 Labib et al., 2019). Through a meticulously structured approach, this study aims to elucidate the intricate dynamics underlying the interaction between automation systems and decision-making in aviation, shedding light on their implications for operational safety.

To achieve this objective, a rigorous case analysis framework is employed, allowing for a detailed examination of the circumstances surrounding the accidents (Baker, 2018; Boeing Commercial Airplanes, 2018). By dissecting these cases methodically, the study seeks to uncover the underlying factors and mechanisms through which automation systems influence decision-making processes among pilots (Damarjati, 2018; Gröndahl et al., 2018). This analytical approach enables the research to identify patterns, correlations, and causal relationships, thereby facilitating a deeper understanding of the role played by automation in shaping human actions and responses within the aviation context (Eurocontrol, 2023; Evdokimova, 2019). Moreover, the research methodology encompasses a comprehensive review of diverse secondary sources, including accident reports, scholarly literature, industry publications, and reputable online databases (Hashim, 2018; Kunert et al., 2018). These sources provide valuable insights into the specific factors contributing to the accidents, such as the functioning of automated systems, pilot training protocols, and organizational factors (Langewiesche, 2019; Mahtani & Rohmah, 2018). By examining multiple instances of automation-related incidents, the research is better positioned to discern commonalities, variations, and underlying trends, thereby facilitating a more comprehensive understanding of the overarching phenomenon under investigation. Specifically, the study highlights how the MCAS can trigger disorientation among pilots, leading to critical errors in decision-making. Overall, the research methodology adopted in this study is characterized by its systematic, rigorous, and interdisciplinary nature, aimed at providing valuable insights into the evolving dynamics of decision-making in aviation automation (Waldinger, 2016; Zhou, 2018). Through its analytical rigor and methodical approach, this study contributes meaningfully to the scholarly discourse on aviation safety and human-automation interaction, particularly in understanding the impact of systems like MCAS on pilot performance and situational awareness (McKirdy et al., 2018). By integrating insights from these varied sources, this study aims to provide a detailed and specific analysis of how automation systems impact decision-making in aviation. The focus is on understanding the intricate dynamics at play and offering targeted recommendations for enhancing pilot training and operational procedures. Furthermore, the inclusion of multiple case studies, namely Lion Air Flight 610 and Ethiopian Airlines Flight 302, serves to enhance the robustness and generalizability of the findings (Reuters, 2018a; Reuters, 2018b; Al Jazeera, 2018, October 29; ASN, 2018; Boeing Commercial Airplanes, 2018; CBS News, 2018; Ethiopian Airlines, 2019a,2019b,2019c,2019d; Gebrekidan & Glanz, 2019; Jolly, 2019; Langewiesche, 2019 Labib et al., 2019).

4.1. Data Collection

In this study, secondary data plays a central role as the primary source of information. Secondary data, sourced from reputable sources such as official accident investigation reports by aviation regulatory bodies (National Transportation Safety Committee, 2024) and entities like the National Transportation Safety Board (NTSB), Komite Nasional Keselamatan Transportasi, (2018) and Ethiopian Civil Aviation Authority, Ministry of Transport and Communications (2019;2022) offer comprehensive insights into the Lion Air Flight 610 and Ethiopian Airlines Flight 302 accidents. Peer-reviewed academic journals and research articles (Baker, 2018; Mahtani & Rohmah, 2018) provide theoretical frameworks, empirical studies, and expert analyses, enriching the research with nuanced perspectives and foundational knowledge. Additionally, industry reports and publications disseminated by stakeholders such as aircraft manufacturers (Boeing Commercial Airplanes, 2018), regulatory authorities, and aviation safety organizations offer industry-specific insights and empirical evidence pertinent to the study. Established online repositories (Reuters, 2018a; Reuters, 2018b), including the NTSB database and the Aviation Safety Network database, serve as repositories housing a wealth of accident data, investigation reports, scholarly literature, and related research materials (Miriri,2019). These databases facilitate convenient access to a diverse array of secondary data essential for conducting a comprehensive analysis of the accidents under scrutiny. By harnessing secondary data from these diverse sources, the research endeavors to thoroughly understand the influence exerted by automation systems on decision-making processes in aviation, with a specific focus on the Lion Air Flight 610 and Ethiopian Airlines Flight 302 accidents (People,2019).

4.2. Analysing the Cases

The analysis of the Lion Air Flight 610 and Ethiopian Airlines Flight 302 incidents constitutes a pivotal endeavor in understanding the intricate dynamics at play within the aviation industry. These tragic events, both resulting in catastrophic crashes, underscore the critical importance of scrutinizing the role of automation systems in modern flight operations (BBC News, 2019). By meticulously examining these cases, the nuanced interplay between human factors, technological systems, and operational contexts is unraveled, shedding light on the multifaceted factors contributing to aviation accidents and informing strategies for enhancing safety and resilience within the industry. Table 1 compares key features between Lion Air Flight 610 and Ethiopian Airlines Flight 302 incidents, providing a structured overview of the similarities and differences between the two events (Reuters, 2019a; Reuters, 2019b).

Table 1. Comparison of Lion Air Flight 610 and Ethiopian Airlines Flight 302 Incidents

Feature	Lion Air Flight 610 (October 29, 2018)	Ethiopian Airlines Flight 302 (March 10, 2019)
Airline	Lion Air	Ethiopian Airlines
Flight Number	JT610	ET302
Aircraft Model	Boeing 737 MAX 8	Boeing 737 MAX 8
Departure Location	Jakarta, Indonesia	Addis Ababa, Ethiopia
Destination	Pangkal Pinang, Indonesia	Nairobi, Kenya
Date of Incident	October 29, 2018	March 10, 2019
Casualties	189 fatalities	157 fatalities
Primary Issues	MCAS system malfunction, sensor failure, pilot errors	MCAS system malfunction, sensor failure, pilot errors
Post-Incident Actions	Temporary grounding of Boeing 737 MAX flights, MCAS system review, enhancement of safety measures	Temporary grounding of Boeing 737 MAX flights, MCAS system review, enhancement of safety measures

The comparison Table-I utilized structured criteria adapted from various sources, including accident investigation reports, human factors studies, and industry publications. Specifically, it drew on the methodology used in accident investigation reports for Lion Air Flight 610 and Ethiopian Airlines Flight 302, research on pilot training and automation impacts, and regulatory documents from the FAA and Boeing. These sources provided a framework for identifying primary issues, contributing factors, and post-incident actions, ensuring a comprehensive analysis of the incidents.

Lion Air and Ethiopian Airlines are both esteemed carriers within their respective regions, with Lion Air recognized as a prominent low-cost airline in Indonesia (ANSA, 2022) and Ethiopian Airlines serving as the flag carrier of Ethiopia and one of the largest airlines in Africa (Ethiopian Airlines, 2019a). The flight numbers, JT610 for Lion Air Flight 610 and ET302 for Ethiopian Airlines Flight 302, serve as unique identifiers crucial for tracking and communication between air traffic control and the respective airlines (Al Jazeera, 2018, October 29). Both tragic incidents involved the Boeing 737 MAX 8, a contemporary narrow-body aircraft model manufactured by Boeing (Boeing Commercial Airplanes, 2018). The occurrence of these accidents with the same aircraft model sparked concerns regarding its safety and prompted widespread scrutiny of the Boeing 737 MAX series (Reuters, 2019a). Lion Air Flight 610 took off from Jakarta, Indonesia, while Ethiopian Airlines Flight 302 departed from Addis Ababa, Ethiopia (Al Jazeera, 2019, March 10a). Lion Air Flight 610, bound for Pangkal Pinang, Indonesia, tragically crashed into the Java Sea shortly after takeoff on October 29, 2018 (Al Jazeera, 2019, March 10b). Ethiopian Airlines Flight 302, en route to Nairobi, Kenya, met a similar fate, crashing near the town of Bishoftu (Debre Zeit) shortly after takeoff on March 10, 2019 (Reuters, 2018a). The Lion Air incident resulted in 189 fatalities, marking it as one of the deadliest aviation accidents in Indonesian history (Al Jazeera, 2019, March 10b). Ethiopian Airlines Flight 302 claimed the lives of all 157 individuals on board, representing one of the deadliest accidents involving a Boeing 737 MAX aircraft (Reuters, 2018b). Investigations into both accidents uncovered common issues, including malfunctioning MCAS, erroneous sensor readings, particularly from the angle of attack sensors, and challenges in crew response and coordination during high-pressure situations (Reuters, 2019b). In response, regulatory authorities worldwide temporarily grounded all Boeing 737 MAX aircraft pending further investigation and safety assessments (National Transportation Safety Committee, 2024). Boeing subsequently initiated modifications to the MCAS software and provided additional training for pilots flying the 737 MAX series, aiming to address the identified safety concerns and restore confidence in the aircraft's airworthiness (Boeing Commercial Airplanes, 2018; ANSA,2022). This comparative analysis serves as a foundation for deeper exploration and interpretation of the findings, guiding the research towards meaningful insights and actionable recommendations for improving aviation safety.

5. Discussion

The exhaustive examination of the Lion Air Flight 610 and Ethiopian Airlines Flight 302 Boeing 737 MAX accidents, along with their implications for automation systems in aviation, elucidates critical insights into the intricate nexus of technology, human factors, and safety. Firstly, the investigation underscores the indispensable role played by automation systems, notably the maneuvering MCAS, in shaping aircraft operations and pilot decision-making processes. The malfunction of the MCAS, triggered by erroneous sensor data, precipitated a cascading sequence of events culminating in the loss of aircraft control. This underscores the imperative of robust system design, redundancy, and comprehensive pilot training to ensure the seamless integration and operation of automation systems within aircraft platforms.

Secondly, the analysis sheds light on the formidable challenges posed by automation dependency and complacency among flight crews. The undue reliance on automation and insufficient proficiency in manual flight control techniques compromised the crew's capacity to effectively manage emergent scenarios. This accentuates the exigency for holistic pilot training initiatives, including comprehensive simulator sessions, scenario-based training, and regular proficiency checks. These programs should focus on both the technical aspects of automation systems and the development of critical decision-making acumen and situational awareness skills. The expected impact of such training is to enhance pilots' ability to effectively manage automated systems, maintain manual flying skills, and respond adeptly to emergent situations, thereby improving overall flight safety and operational efficiency. Furthermore, the examination underscores the pivotal role played by human-machine interface (HMI) design in facilitating effective communication and decision-making during high-pressure situations. Identified deficiencies in the cockpit design of the Boeing 737 MAX, particularly pertaining to alert prioritization and annunciator displays, underscore the significance of enhancing HMI design to alleviate the risk of information overload and augment pilots' situational awareness. Additionally, the analysis highlights the crucial role of crew resource management (CRM) and effective communication protocols in handling complex situations involving automation systems (Macleod, 2021). Collaborative teamwork within the cockpit is essential for addressing automation-related issues and ensuring safe flight operations. Furthermore, the study emphasizes the need for stronger regulatory oversight and certification processes to ensure the proper integration of automation systems into aircraft design. Enhanced collaboration between regulatory bodies and industry stakeholders, coupled with more stringent testing regimes, can engender heightened confidence in the safe integration of automation systems within aircraft platforms. In sum, the comprehensive interpretation of findings underscores the imperative of adopting a holistic approach to aviation safety, encompassing resilient system design, comprehensive pilot training initiatives, optimized human-machine interface design, and fortified regulatory mechanisms. By diligently addressing these pivotal facets, the aviation industry can effectively mitigate the inherent risks associated with automation systems and uphold the paramountcy of flight safety in future operations.

5.1. Automation Systems and Aircraft Operation

Lion Air Flight 610 and Ethiopian Airlines Flight 302 involved Boeing 737 MAX aircraft, which integrate advanced automation systems, notably the MCAS, aimed at enhancing flight stability and handling attributes. However, these accidents spotlighted deficiencies in the design and implementation of the MCAS, primarily its reliance on a single sensor for activation and inadequate redundancy, leading to uncommented nose-down trim actions and loss of aircraft control. Consequently, the incidents underscored the imperative of rigorous testing, robust system redundancy, and comprehensive pilot training to ensure the effective integration and operation of automation systems within aircraft platforms. Moreover, the integration of automation systems posed challenges for pilots, particularly concerning their comprehension of system functionality and response to abnormal situations. The crew's encounter with erroneous angle of attack (AOA) sensor data on Flight 610 triggered MCAS activation, exacerbating flight control issues. Despite their efforts to rectify the situation through manual trim inputs, the crew grappled with regaining control amidst escalating failures and heightened workload, accentuating the complexities of decision-making under such circumstances. Furthermore, the accidents highlighted the peril of automation dependency and complacency among flight crews, exacerbated by insufficient proficiency in manual flight control techniques and inadequate training on MCAS failure modes. The investigation revealed deficiencies in the pilots' understanding of MCAS functionality and runaway stabilizer procedures, compromising their ability to effectively manage emergent scenarios and contributing to catastrophic outcomes. Additionally, challenges pertaining to the human-machine interface (HMI) design of the Boeing 737 MAX cockpit were brought to the fore. Pilots encountered difficulties in interpreting system alerts, particularly in high-stress situations, necessitating intuitive HMI design improvements to facilitate clear communication and decision-making amidst operational exigencies. Moreover, effective crew resource management (CRM) and communication emerged as pivotal factors in managing complex situations, especially in the presence of automation systems. The accidents underscored deficiencies in crew coordination and communication, emphasizing the need for enhanced CRM training and fostering a culture of open communication and teamwork within the cockpit to bolster crew effectiveness and decision-making capabilities. Furthermore, scrutiny of regulatory oversight and certification processes ensued, raising questions about the sufficiency of regulatory requirements for evaluating the safety and reliability of new automation features like MCAS. Enhanced regulatory oversight, coupled with more stringent testing protocols and increased transparency in certification processes, is deemed imperative to ensure the safe integration of automation systems into aircraft platforms. Training and proficiency maintenance also garnered attention, highlighting the necessity for comprehensive pilot training on automation systems' operation, limitations, and failure modes, coupled with recurrent training and proficiency checks to reinforce critical skills and decision-making abilities.

Table 2. Comparative Analysis Accidents Based on Key Operational Factors

Aspect	**Lion Air Flight 610**	**Ethiopian Airlines Flight 302**
Primary Cause	MCAS activation due to erroneous sensor data	MCAS activation due to erroneous sensor data
Contributing Factors	Insufficient redundancy in MCAS system	Inadequate crew response to MCAS activation
Impact on Decision Making	Crew struggled to regain control amidst failures	Crew experienced difficulty managing situation
Automation Dependency	Crew reliance on automation exacerbated situation	Crew reliance on automation hindered response
Human-machine interface (HMI)	Challenges in understanding system alerts	Difficulties in interpreting system alerts
Crew Resource Management (CRM)	Deficiencies in crew coordination and communication	Lack of effective collaboration among crew
Regulatory Oversight	Scrutiny of regulatory requirements for automation systems	Questions raised about adequacy of oversight
Training and Proficiency	Inadequate pilot training on MCAS functionality	Need for comprehensive pilot training reinforced
Lessons Learned	Emphasis on robust training and proficiency maintenance	Implementation of safety enhancements

The comparison criteria in Table 2 were adapted from detailed accident investigation reports, human factors studies, and regulatory publications. Specifically, they were informed by accident reports for Lion Air Flight 610 and Ethiopian Airlines Flight 302, research on pilot training and automation impacts, and documents from aviation authorities like the FAA and Boeing. Key sources include ANSA (2022), Al Jazeera (2018, 2019), Boeing Commercial Airplanes (2018), and Reuters (2019), which provided the framework for analyzing primary causes, contributing factors, and regulatory oversight. The findings from the comparative analysis of the Lion Air Flight 610 and Ethiopian Airlines Flight 302 accidents reveal several critical insights into the factors influencing aviation safety and operational performance. Firstly, the analysis underscores the significant role of automation systems, particularly the MCAS, in shaping the outcome of both accidents. Deficiencies in the design and integration of these systems, coupled with inadequate pilot training, contributed to the crew's inability to effectively manage automation-induced anomalies, leading to catastrophic consequences. Moreover, the analysis highlights the impact of automation dependency and complacency among flight crews, emphasizing the importance of maintaining proficiency in manual flight control techniques and fostering a culture of vigilance and situational awareness. Human factors, including human-machine interface (HMI) design, crew resource management (CRM), and communication, also emerged as critical determinants of operational performance. Challenges related to cockpit interface design and crew coordination underscore the need for intuitive HMI design and effective CRM practices to enhance crew effectiveness and decision-making capabilities. Furthermore, the analysis raises questions about the adequacy of existing regulatory oversight and certification processes in ensuring the safe integration of automation systems into aircraft design. Closer collaboration between regulators and industry stakeholders, as well as more rigorous testing protocols, may be necessary to address these concerns and enhance aviation safety. The findings also underscore the importance of comprehensive pilot training and proficiency maintenance in preparing crews to handle automation-related contingencies effectively. Scenario-based training and recurrent simulations can help pilots develop the cognitive skills and operational proficiency necessary to mitigate the risks associated with automation systems. Lastly, the analysis highlights the importance of institutionalizing lessons learned and implementing targeted safety enhancements to prevent similar accidents in the future. By addressing these key findings, aviation stakeholders can work towards enhancing safety standards and ensuring the continued safe operation of automation-equipped aircraft.

6. Conclusion

The impact of automation systems on decision-making processes in aviation is multifaceted and dynamic, encompassing myriad factors that interact in complex ways. While these systems offer undeniable benefits in enhancing operational efficiency and flight safety, they also introduce new challenges and considerations that must be carefully navigated by aviation stakeholders. At the heart of this issue lies the intricate interplay between technological advancements and human factors, highlighting the need for a balanced approach that acknowledges both the capabilities of automation and the inherent complexities of human cognition and behavior.

Automation systems in aviation have evolved significantly over the years, revolutionizing the way aircraft are operated and managed. From autopilots to advanced flight management systems, these technologies have greatly contributed to improving flight safety, fuel efficiency, and overall operational performance. However, as automation systems become more sophisticated and pervasive, their impact on pilots' decision-making processes has come under increasing scrutiny.

One of the key challenges posed by automation systems is their potential to erode pilots' situational awareness and decision-making capabilities, particularly in high-stress or unexpected situations. While automation is designed to assist and augment human performance, overreliance on these systems can lead to complacency and a loss of critical thinking skills. Moreover, the complexity of modern cockpit interfaces and automation modes can sometimes overwhelm pilots, making it difficult for them to effectively monitor and intervene in the event of automation-related anomalies.

The tragic incidents of Lion Air Flight 610 and Ethiopian Airlines Flight 302 serve as poignant reminders of the risks associated with automation in aviation. In both cases, the malfunction of the MCAS played a central role in the accidents, highlighting the importance of understanding and managing automation-induced risks. These incidents underscore the need for comprehensive training and proficiency assessments for pilots operating in highly automated environments, ensuring they possess the skills and knowledge necessary to effectively interact with automation systems and make informed decisions during routine operations and emergencies.

However, it's essential to recognize that the integration of automation systems into aviation operations is an ongoing process that requires continuous monitoring, evaluation, and adaptation. As technology continues to evolve, so too must our understanding of its implications for aviation safety and decision-making processes. This necessitates a collaborative effort among industry stakeholders, regulators, researchers, and aviation professionals to stay abreast of emerging trends and developments in automation technology and human factors research.

The harmony and challenges inherent in the relationship between automation and pilots underscore the need for a holistic approach to integrating technology in aviation operations. One study that discusses such an approach is by Dekker and Woods (2017) in *The Field Guide to Understanding Human Error*. This study emphasizes the importance of considering human factors and the broader system context when integrating new technologies into aviation. It highlights that successful integration requires addressing both technological capabilities and the needs and limitations of human operators. By addressing the complexities of human factors and technology, stakeholders can optimize the benefits of automation while mitigating its potential risks, ultimately leading to safer and more efficient aviation practices. The study does not explicitly detail the methods employed to ensure the validity and reliability of the secondary data utilized. Several limitations should be acknowledged, such as the reliance on secondary data sources, which precluded direct interviews with key individuals involved in the incidents. Additionally, the focus on only two specific accidents may constrain the generalizability of the findings. These limitations underscore the necessity for cautious interpretation of the results and suggest that future research should incorporate primary data collection methods and examine a broader array of incidents to enhance the robustness and applicability of the conclusions. Moving forward, future research should focus on longitudinal studies that track the implementation of automation systems over time and their impact on decision-making processes. Comparative analyses across different aviation contexts can also provide valuable insights into commonalities, differences, and best practices for managing automation-induced challenges. Additionally, human-centered design principles should be explored to optimize human-machine interaction and decision-making support, mitigating the risks associated with automation dependency, complacency, and cognitive workload.

Regulatory frameworks and industry standards must also evolve to keep pace with advancements in automation technology, ensuring that safety and human factors considerations remain paramount in the design, implementation, and oversight of these systems. Addressing ethical and legal implications associated with the use of automation systems in aviation is equally crucial, fostering accountability, transparency, and trust among stakeholders.

In conclusion, while automation systems hold great promise for enhancing aviation safety and efficiency, they must be approached with caution and careful consideration of their impact on human performance and decision-making. By fostering a culture of continuous learning, collaboration, and innovation, the aviation industry can harness the potential of automation while safeguarding against its unintended consequences, ultimately ensuring safer skies for all.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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The Safety Management System (SMS) As A Tool for Building Safety Culture in Aviation: A Qualitative Research

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Abstract

Safety culture is conceptualized as the combination of beliefs, values, norms, attitudes, roles, and practices—both social and technical—within an organization, aimed at mitigating the exposure to adverse or hazardous conditions for both internal and external individuals. In entities where a safety culture is deeply ingrained, efforts are made to formulate a framework that encourages employee adherence to safety regulations, promoting safe behaviours, particularly in high-risk environments. The efficacy of safety culture in substantially reducing accidents, incidents, errors, hazards, and risks, especially those related to human factors, is pivotal in attaining elevated safety standards. At the heart of fostering such a culture lies the implementation of a robust Safety Management System (SMS), which, through its effective and dynamic execution, paves the way for cultivating a safety-centric ethos.

This study conducts a detailed empirical analysis of aviation enterprises in Türkiye to evaluate the hypothesis that the Safety Management System (SMS) is a crucial instrument in cultivating a safety culture within the aviation industry. The study employs qualitative research methodologies to discern the correlation between the effectiveness of SMS and its components and the level of safety culture within these organizations. Findings from the study reveal a direct relationship where entities with inadequately implemented SMS and its elements exhibit lower levels of safety culture. Conversely, enterprises that demonstrate effective implementation of SMS are characterized by a high level of safety culture, affirming the critical role of SMS in fostering safety within aviation organizations. This inquiry not only substantiates the integral role of SMS in developing a safety culture in aviation but also highlights the necessity for meticulous implementation of SMS components and processes to achieve a superior safety standard in the industry.

This study was created from the master's thesis study.

1. Introduction

Given the critical importance of safety in the aviation industry, numerous incidents and accidents have been attributed to safety deficiencies (Von Thaden and Gibbons, 2008, p. 1). (2008, p.1). To mitigate these occurrences, various legal and institutional measures have been implemented over time. Despite these efforts, the anticipated reduction in accidents and incidents has not been fully achieved. This outcome indicates that solely technical approaches to safety are insufficient. As a result, the importance of cultural factors, in addition to technical considerations, has become recognized. Safety culture has thus emerged as a crucial behavioral regulator in accident prevention, warranting its consideration as a fundamental aspect of safety management (Aytaç, 2011a, p. 31).

Literature review reveals that research on establishing a safety culture within aviation organizations primarily includes conceptual analyses of safety culture development (Gürsel et al., 2020) and recommendations for fostering a positive safety culture (Erdener, 2019). Furthermore, another study suggests that the concept of safety culture entails the successful and effective operation of a Safety Management System (SMS) in organizations with an established positive and effective safety culture (Gerede, 2005).

This study investigates the role of SMS and its components as intermediaries in developing a safety culture within aviation organizations, based on the hypothesis that strategic SMS implementation can facilitate a safety culture. In doing so, it aims to contribute a novel perspective to future research in this domain.

2. Conceptual Framework

In this section, a theoretical overview will be provided on safety culture, the safety management system, and the relationship between safety culture and safety management system.

2.1. Safety Culture

Although accidents in aviation are not frequent events, they cause great losses and damages when they occur. When the development of the concept of safety culture, which aims to minimize accidents, is examined, it can be stated that three basic periods come to the fore in which the causes of accidents are approached from different perspectives. The *first* of these periods; it is a period of ***technical factors*** including underdeveloped technology and inadequate regulations. *Second*; it is the ***human factor*** period in which accidents have decreased significantly due to the development of technology and the human factor has come to the fore in increasing safety. The *third* is the ***organizational factors*** period, which started in the 1990s and continues to be important today, and the organizational factors underlying the unsafe situations experienced began to be taken into consideration (Uslu and Dönmez, 2016, p. 235-236).

In periods when the safety culture was not yet widespread, many accidents occurred due to deficiencies in the system as well as the human factor. For this reason, research began to focus on organizational factors such as tools, technologies, procedures, and reducing errors (Von Thaden and Gibbons, 2008, p. 1). As organizational factors began to be taken into consideration, interest in safety culture also increased. The concept of safety culture was first used after the nuclear accident at Chernobyl in 1986 (Wiegmann et al., 2004, p. 121). In the report prepared as a result of the accident, the cause of the disaster was attributed to violations caused by nuclear power plant personnel and the deterioration in safety culture (Kurnaz and Deniz, 2018, p. 126; Ustaömer and Şengür, 2020, p. 98). After this disaster, the concept of safety culture spread to other industries such as medicine, chemicals, oil and gas, railway, and aviation (Wang, 2011, p. 61). The definitions compiled by Wiegmann et al. (2004, p. 121) from studies in sectors such as medicine, chemistry, oil and gas, railway, and aviation are given below:"

- Cooper defines safety culture as "*a sub-dimension of organizational culture that is thought to influence the attitudes and behaviors of employees in relation to the safety performance of an organization*" (Cooper cited Wiegmann et al., 2004, p. 122).
- Ciaverelli defines the concept of safety culture as *"shared values, beliefs, assumptions and norms that can govern individual/group attitudes regarding safety as well as organizational decision-making*" (Wiegmann et al., cited in Ciaverelli, 2004, p. 122).
- Turner et al. define safety culture as *"a set of beliefs, norms, attitudes, roles, social and technical practices aimed at minimizing the exposure of employees, managers, customers, and the public to conditions considered dangerous or harmful*" (cited in Cooper, 2002, p. 31).
- Pidgeon and O'Leary, on the other hand, define safety culture as "the *set of beliefs, norms, attitudes, roles, and social and technical practices within the organization that are concerned with minimizing the exposure of individuals inside and outside an organization to adverse or dangerous conditions*" (cited in McDonald et al., 2000, p. 152).

ICAO defines the concept of safety culture as *"the behavior of people towards safety and risks even when no one is watching them*". Safety culture is the expression of how managers and employees in the organization perceive, value, prioritize safety and how it is reflected to employees.

Creating a safety culture and ensuring its sustainability is an effective tool for improving safety in aviation organizations (Choudhry et al., 2007, pp. 1004-1005). However, it takes a long time for the safety culture to be fully established in aviation organizations. It is not difficult to predict how the negative consequences of accidents and incidents that may occur in this process may affect the aviation organization, employees, and the country's economy (Olcay and Erdem, 2021, p. 84-85).

Various studies have been conducted on how to improve a safety culture in organizations. Firstly, Hale (2000) listed a number of elements for improving a safety culture. These include emphasis on safety, the participation of employees at all levels, the role of safety personnel, trust, openness in communication, belief in improving safety, and the integration of safety into the organization (cited in Choudhry et al., 2007, pp. 1004-1005). Wiegmann et al. (2002, p. 12) emphasized five key points in the creation of a safety culture: organizational commitment, participation of management, employee empowerment, reward systems, and reporting systems. Vecchio-Sudus and Griffiths in 2004 stated that to create and promote a safety culture, awareness about safety can be increased by changing attitudes and behaviors, management commitment, employee participation, promotional strategies, training, and seminars (Vecchio-Sudus and Griffiths cited in Choudhry et al., 2007, pp. 1004-1005).

2.2. Safety Management System

SMS is of great importance in ensuring safety in the aviation sector. The occurrence of an accident indicates a major failure in the functioning of the aviation system. Failures in the functioning of the SMS have a significant share in this failure (Labodova, 2004, p. 572). A Safety Management System (SMS) is a systematic approach to managing safety in aviation and other safety critical industries. Airlines that implement an SMS are able to identify and mitigate safety risks that they are exposed to during their day-to-day operation, ultimately improving safety performance (IATA, 2024). The SMS is a mechanism integrated into the organization and designed to control the hazards that may affect the health/safety of employees (Labodova, 2004, p. 572). In that it is a set of strategies, practices, procedures, roles, policies, and safety-related functions, the SMS (Fernandez-Muniz et al., 2007, p. 54) can be likened to a toolbox that explores ways to identify, analyze, reduce, or control the factors that create safety risks before they cause an accident with a predictive approach, beyond the classic accident investigation that conducts post-accident investigation and investigation (SHGM, 2013, p. 17)."

The following four basic elements, which are accepted as the basis of the SMS in the aviation sector, are very important for the elimination of risks and hazards and effective realization of safety management activities (ICAO, 2018, p. 9-2):

- *Safety policy and aims:* It covers the determination, implementation and coordination of the policies necessary for the effectiveness of safety management in the aviation organization. In addition, policies and rules related to safety culture include determining the system and the creating documentation (Erceylan and Atilla, 2021, p. 357).
- *Safety risk management:* It includes decision-making processes such as identifying potential hazards and reducing risks by carefully evaluating the organization's systems and working environment (Chatzi, 2018, p. 192).
- *Securing safety*: While the first two components of the SMS aim to increase safety, this component ensures that the safety that is supposed to be increased is guaranteed.

For this reason, it is necessary to check whether the measures taken to reduce the risks have been implemented and whether they are still effective. These controls are provided through audit processes. Because if the measures foreseen by the risk management application are not taken or applied at an insufficient level, safety may decrease again. These are revealed by audits and necessary measures are taken (Gerede, 2018, p. 204).

- *Promoting safety:* This last component of the SMS is designed to improve safety performance by promoting safety among the employees of the organization. All personnel, including senior management and new hires, should be familiar with safety policies and procedures, existing reporting procedures and risk controls, and should be aware of their responsibility for safety (Chatzi, 2018, p. 193).

These components, created by ICAO, allow the organization to adapt to existing conditions and legislation (Fernández-Muñiz et al., 2007, p. 54). However, in order for this system to be effective, senior managers who determine the SMS policy must show that they support the SMS and are committed to its execution in accordance with this climate (Chen and Chen, 2012, p. 177). In addition, employees need to participate and internalize the system. In other words, the system must promote a positive safety environment. To do this, a strong commitment and support from all managers and employees in the organization is required (Fernández-Muñiz et al., 2007, p. 54).

2.3. The Relationship Between Safety Culture and Safety Management System

Based on the view that threats to safety in aviation organizations can always occur, the SMS aims to detect and prevent hazards before accidents occur (Gill and Shergill, 2004, p. 233). Although SMS is necessary for the safe maintenance of operations in aviation, it is not sufficient alone for an acceptable safety performance. In order for the SMS to ensure safety, employees must be aware of the existence of the SMS, understand it and be willing to implement it. This is only possible with the presence of a positive safety culture. For this reason, SMS and safety culture are interrelated concepts. While SMS covers the competencies required to ensure safety, safety culture represents commitment to establishing safety. The main purpose of both is to develop and maintain safety (Ustaömer, 2020, p. 47).

In summary, to create a positive safety culture and to maintain this culture permanently; it depends on how well the SMS and its components penetrate the fabric of the organization and the ways things are done (Gill and Shergill, 2004, p. 233). In this context, ICAO includes the following statements within the scope of the *safety risk management component*; a culture of safety in aviation organizations can be strengthened by effectively involving employees in safety risk management and making management's commitment to safety clear. When safety is accepted as a priority by management, it will also be prioritized by employees and become part of operations (ICAO, 2018, pp. 1-2).

Developing an effective method for identifying possible hazards within the organization, determining the necessary safety improvements in this context, and evaluating whether they are effectively implemented in the organization will contribute to the establishment of a safety culture (ICAO, 2018, p. 3-5). In this context, the inclusion of employees in the safety risk management of the SMS will increase the loyalty to the organization as well as the adoption of the safety culture. Employee engagement is of great importance in terms of creating a safety culture.

The 'management's commitment' component, which is part of the safety policies and objectives component, allows management support to become visible and enable employees to participate actively in managing safety risk. It also supports efforts to achieve a positive safety culture (ICAO, 2018, p. 3-2). Senior management should sincerely commit to achieving and maintaining a high level of safety and provide support to employees in this direction. Commitment to safety; it reflects the level of having a positive attitude towards safety by senior management and realizing the importance of safety. Management should contribute to the formation of a safety culture in the organization by providing safety-oriented trainings and resources as a role model for employees to take care of safety (ICAO, 2018, p. 3-4). Effective safety management should be implemented by providing high-level support to increase the safety performance of the employees in the organization. This support will influence the attitudes and behavior of everyone involved in the organization and contribute to the creation of a safety culture within the scope of management's commitment (ICAO, 2018, pp. 4-2). ICAO states that by making this commitment clear, the safety culture will be strengthened and the safety of employees will be a priority.

Within the scope of the 'monitoring and measurement of safety performance' component of the safety assurance component, it is stated that a continuous monitoring of the safety-related behaviors of the employees will contribute to the creation of a safety culture (ICAO, 2018, p. 3-5). In addition, recommendations on establishing a safety culture within the scope of this component are included below (ICAO, 2018, pp. 3-4 - 3-7):

- Continuous monitoring of safety-related behaviors,
- Rewarding employees who show high performance in relation to safety,
- Providing trainings on safety,
- Prevention of communication problems that lead to dangerous situations.

Within the scope of "Continuous improvement of the SMS", which is another sub-component of the “assurance of safety component”, it is emphasized that employees who perform well in terms of safety are recognized and rewarded regularly (ICAO, 2018, p. 3-7). In this context, it is thought that rewards will contribute to the formation of a safety culture.

Within the scope of the "training and development" and "safety communication" sub-components of the “safety promotion component”; it is stated that trainings on aviation safety should be provided effectively. It is also emphasized that safety-related information should be conveyed to relevant people in a meaningful and useful manner in order to prevent communication deficiencies that will lead to dangerous situations (ICAO, 2018, p. 3-6). In this context, it is thought that training on safety, regular provision of information and prevention of communication deficiencies will contribute to the creation of a safety culture.

In summary, in order for the components of the SMS (safety policies and objectives, safety risk management, safety assurance, safety promotion) to become an effective element in the creation of a safety culture, the following points should be given importance:

- Inclusion of employees in risk management within the scope of the safety risk management component,
- Within the scope of the safety policies and objectives component, the management is sincerely committed to achieving and maintaining a high level of safety and supporting the employees in this direction,
- Regular monitoring of the safety behavior of employees within the scope of the safety assurance component and rewarding employees with high safety performance,
- Within the scope of the safety promotion component, safety training should be organized and important information about safety should be conveyed and a safety culture should be established.

2.4. Literature Review on the Relationship between Safety Management Systems and Safety Culture

Upon reviewing the literature, the following studies are notable in the context of Safety Management Systems (SMS) and safety culture:

Gürsel et al. (2020) discuss the methods used to develop a safety culture in their study titled "Developing Safety Culture in Aviation." This study introduces safety culture and the models for developing safety culture.

Teke and Şimşek (2020) aim to determine the impacts of SMS applications on corporate image in their study titled "Effects of Safety Management System Applications on Corporate Image: A Study in Flight Training Organizations." In this context, an application was conducted in flight training organizations affiliated with the General Directorate of Civil Aviation located in Istanbul, Ankara, Samsun, and Adana.

Ustaömer and Şengür (2020) aim to contribute to the Turkish literature by examining Reason's Safety Culture Model in their study titled "Safety Culture in Aviation: Examination of Reason's Safety Culture Model."

Erceylan and Atilla (2021) investigate the impact of SMS processes on corporate reputation through the mediating role of employee job satisfaction in their study titled "The Effect of Safety Management System Processes on Corporate Reputation in Aviation Training Organizations: The Mediating Role of Job Satisfaction." An application was conducted in aviation training organizations within this scope.

Tunç (2021), in his study titled "Safety Management System Applications in Air Traffic Control Services," examines SMS applications in air traffic control services. This study aims to determine the impacts and contributions of a positive safety culture on SMS and processes implemented in air traffic control units.

This study, on the other hand, addresses the mediating role of SMS and its components in establishing a safety culture within aviation organizations. Therefore, this study is significant in terms of utilizing SMS as a tool for creating a safety culture. In this context, the article holds unique value as it aims to provide a perspective on associating the SMS system with organizational culture, contributing a novel viewpoint to future studies in the field.

3. Methodology

In this section; information about the purpose and importance of the research, research model, data analysis, data collection and findings are included.

3.1. Purpose and Importance of the Research

This study was created with the idea of utilizing SMS components to facilitate the creation of safety culture in all aviation organizations and its internalization by all employees.

The main objective of the research is to examine the use of SMS as a tool in the creation of a safety culture in aviation organizations. In addition to the stated main purpose six more research questions have been established:

- What do employees at all levels of the organization think about the safety culture and SMS?
- Are they considering the SMS as a necessity or a requirement?
- What kind of activities are carried out in order to establish safety in the organization?
- What kind of activities are carried out in order to create a safety culture in the organization?
- Has safety been made a culture in the organization?
- Is SMS used to create a safety culture in the organization?

In this context, the study examines the use of SMS and its components as a tool in the creation of a safety culture in aviation organizations; determining the positive impact of SMS and safety culture in civil aviation is important in terms of examining the safety culture in aviation in detail in the context of SMS and its applications. For this reason, this study is important for creating a safety culture by using SMS as a tool. In this respect, it has the purpose of providing a perspective to the studies to be carried out in this field.

In the study, the issues that are emphasized as important in terms of creating a safety culture in the SMS components were determined as research code. It was tried to determine the extent to which the enterprises attach importance to the relevant subject from their emphasis on these codes and their thoughts about these codes and it was aimed to seek answers to the research questions.

3.2. Research Model

The model of the study is the interview-based inductive analysis method, which is one of the qualitative research methods. Qualitative research is research in which human behaviors are observed, recorded and interpreted in natural environments (Bayramoğlu, 2007, p. 169). Qualitative research, which uses data collection techniques such as observation, interview and document analysis for the solution of a problem, expresses a subjective-interpretive process aimed at the perception of previously known or unnoticed problems and the realistic handling of natural phenomena for the problem (Baltacı, 2019, p. 369-370).

Social reality in qualitative research; reality is not investigated because it varies according to people and situations. Only the characteristics of a particular situation are tried to be described. Since it is not possible to create a certain environment with social, physical or psychological dimensions, it is very difficult to generalize the research findings and results obtained from a certain environment to other environments. In this sense, qualitative research can only reveal a number of experiences and descriptions and these can give perspective to an individual working on the field (Bayramoğlu, 2007, p. 169).

In this study, the most important reason for choosing the interview-based inductive analysis method from the qualitative research methods is to obtain detailed information about the subject by meeting face-to-face with the managers in order to investigate all aspects of the research aimed at creating a safety culture through the SMS in aviation organizations.

With this method, the drawbacks such as filling out the questionnaire to someone else or not showing the necessary care that can be seen in quantitative tools have been tried to be eliminated. In this research carried out with qualitative research methods, the fact that the data were obtained through interviews and analyzed qualitatively allowed the real thoughts of the people interviewed within the scope of the research to be examined in depth.

3.3. Collection of Data

The interviews were conducted in line with the information obtained from the managers. The data were collected between 08.06.2022 – 05.10.2022.

In order to search for answers to the research questions, 18 interview questions were created. While preparing the questions, importance was attached to determining the questions for investigating the basic and sub-objectives of the research. The prepared questions are also designed to meet the main and sub-objectives of the research. Since the scopes and concepts for literature review are taken into consideration in the preparation of the questions, the number of questions is arranged to cover all dimensions for purposes involving different dimensions. It was preferred that the questions were open-ended questions and care was taken not to be directing.

3.4. Data Analysis

The existing answers obtained during the analysis of the data were deciphered and transferred to the Word program. It was then transferred to the MAXQDA qualitative data analysis program. Here, the content analysis method was analyzed by inductive type. The data were primarily encoded, the related contents were collected under the same codes and interpreted by tabulation. Table-1 shows the codes that help the research:

Table 1. Code to aid research

Code	Explanation of the code
SMS	Safety Management System
SC	Safety Culture
S	Safety
HR	Hazards and Risks
RP	Reporting
J	Justice
RE	Rewarding
P	Punishment
E	Education
C	Communication
HF	Human factor

SMS and SC codes were created to determine the thoughts of managers and employees about the SMS and safety culture and to determine whether SMS is considered as a necessity or a requirement. Safety code was created to determine what kind of activities are carried out to establish safety and to be used as an auxiliary factor in creating a safety culture.

Education code is emphasized by ICAO in three components of SMS. Within the scope of these components; it is emphasized that safety-related education should be provided effectively and educational activities should be measured.

Justice code emphasizes the importance of employees' belief in justice in reporting hazards, risks, intentional errors, and violations. If employees believe in the strength of the justice system in their institution, they will report without hesitation.

Reporting code; reporting is one of the most important elements in aviation activities. Through reporting, businesses learn, improve themselves, and take precautions against hazards and risks. For these reasons, reporting contributes to the formation of a safety culture and is important.

Punishment code; when employees know that they will not be punished for unintentional mistakes and violations, they feel safe and do not hesitate to report. This issue, which indirectly contributes to issues such as reporting, hazards and risks, is important in terms of creating a safety culture.

Rewarding code; ICAO emphasizes the issue of rewarding in two separate components. In this context; it emphasizes that employees who perform well in terms of safety are recognized and rewarded regularly, and that the rewarding activities of businesses are important in order to create a safety culture.

Hazards and Risks code; within the scope of the "safety risk management" component of SMS, businesses should include their employees in risk management, prioritize safety, and identify hazards while raising awareness on this issue. By involving employees in these issues and raising their awareness, it will be possible to contribute to the formation of a safety culture.

Human Factor code; the human factor is one of the most important elements in aviation. By solving and preventing human factor-related problems, success can be achieved in areas such as safety, communication, hazards and risks, and reporting.

Communication code; ICAO emphasizes communication in two separate components. In this context; it emphasizes that businesses should prevent communication deficiencies that can lead to dangerous situations and that their effords to prevent communication deficiencies should be measured.

3.4.1. Findings

While determining the managers to participate in the research, phone numbers and e-mail addresses were obtained from the websites of the enterprises. Additionally, in order to facilitate access, middle and lower-level managers of the enterprises were reached through contact who knew the people working in these enterprises. Table-2 provides information about the managers participating in the research.

Table 2. Personal Information About the Managers Participating in the Research

Code Name	Title	Seniority in the enterprise
A	Manager	20
B	Chief Operating Officer	8
C	Chief Operating Officer	22
D	Chief Operating Officer	10
E	Chief of Operations Services	9
F	Chief of Passenger Services	14
G	Chief of Passenger Services	7
H	Chief of Passenger Services	13

The information given for each code is summarized in Figure 1 to facilitate the analysis of how often administrators highlight each code.

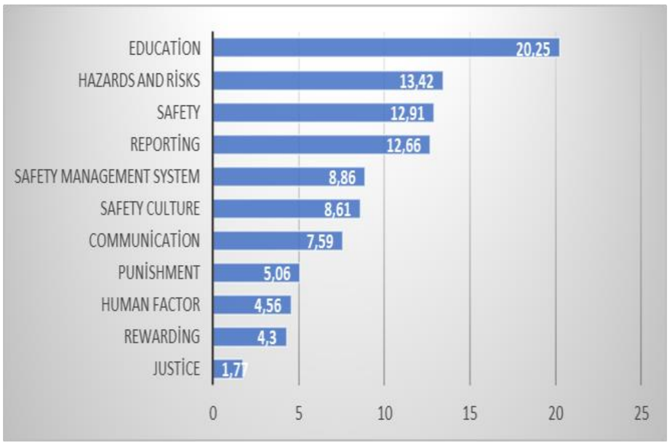

Figure 1. Percentage distributions of data numbers for research codes

When the general distribution of the codes is examined, it is seen that the education code is emphasized with the highest rate of 20.25%. The least data is related to the justice code with a rate of 1.77%.

Separate graphs were created to analyze in detail which code the business managers emphasized and how much. Figure 2 shows the percentage distribution ratio of codes in relation to the responses given by the manager of business A.

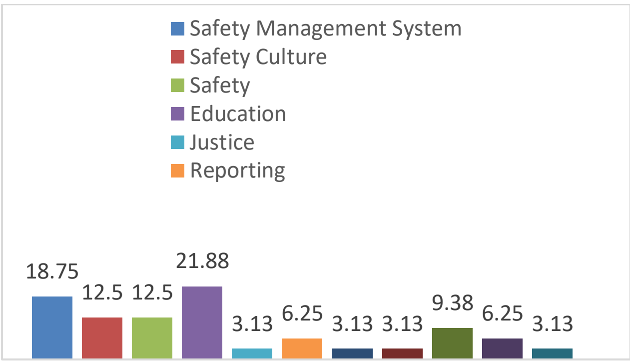

Figure 2. Distribution Ratio of Data Received from Business "A" According to Codes

As can be seen in Figure 2, the code that the manager of business A emphasizes the most is education with a rate of 21.88%. This code is followed by the SMS with 18.75%. The least information is related to justice, punishment, reward and communication with a rate of 3.13%. Figure-3. shows the percentage distribution rate of the codes for the answers given by the manager of business B.

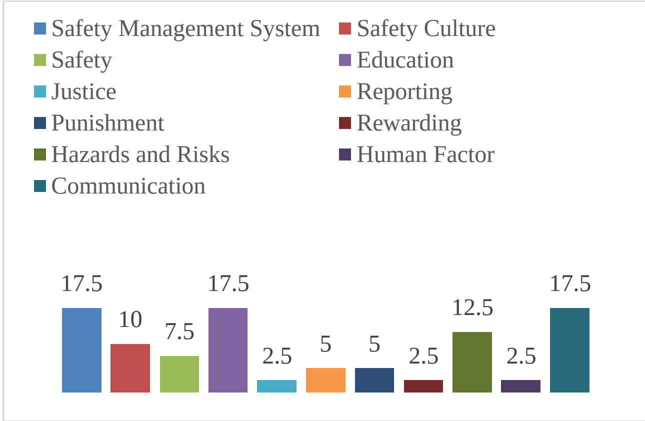

Figure 3. Distribution Ratio of Data Received from Business "B" According to Codes

In the data obtained from enterprise B, it is seen that the most emphasis is placed on issues related to SMS, training and communication. Business B shared 17.50% of the information on these issues. These codes are followed by hazard and risk with a rate of 12.50% and a safety culture with a rate of 10.00%. The least information was received from business B regarding justice, reward and human factor with a rate of 2.50%.

Figure 4 shows the percentage distribution rate of the codes in relation to the answers given by the manager of business C.

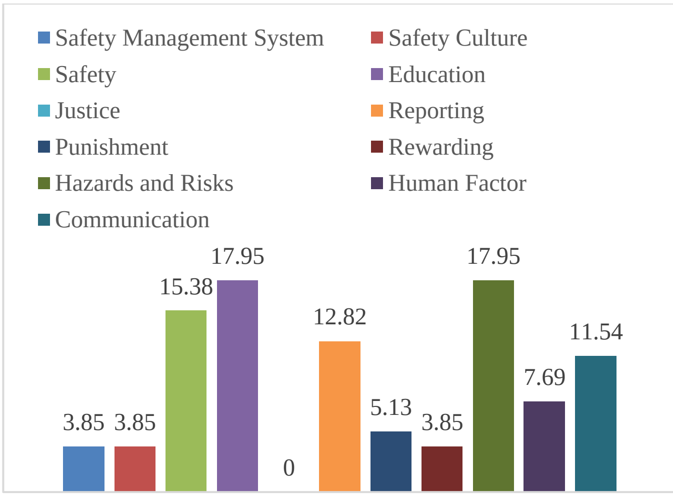

Figure 4. Distribution Ratio of Data Received from Business "C" According to Codes

Among the data received from business "C", the highest rate is related to education and hazard and risk code with 17.95%. The information given about safety is in second place with 15.38%. While 3.85% of the information on the SMS, safety culture and rewarding were received, no information was given regarding the justice code.

Figure 5 shows the percentage distribution rate of the codes in relation to the answers given by the manager of business "D".

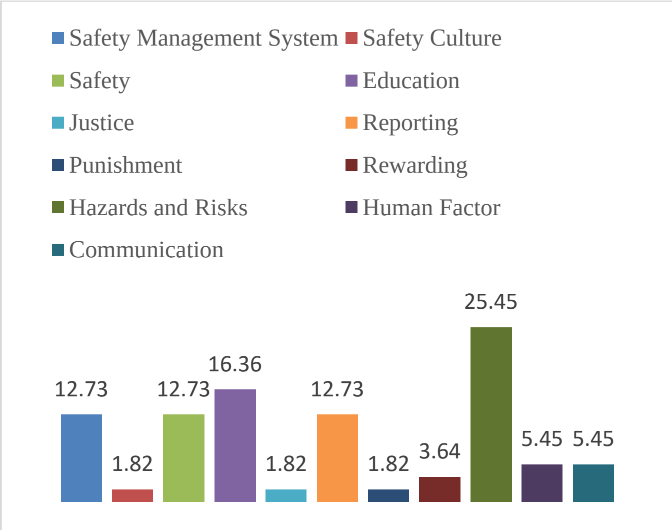

Figure 5. Distribution Ratio of Data Received from Business "D" According to Codes

With a rate of 25.45%, information about the most hazards and risks was obtained from the "D" business. Hazard and risk are followed by the education code with 16.36%. Business "D" provided at least 1.82% of the information on safety culture, justice and punishment.

Figure 6 shows the percentage distribution rate of the codes in relation to the answers given by the manager of business "E".

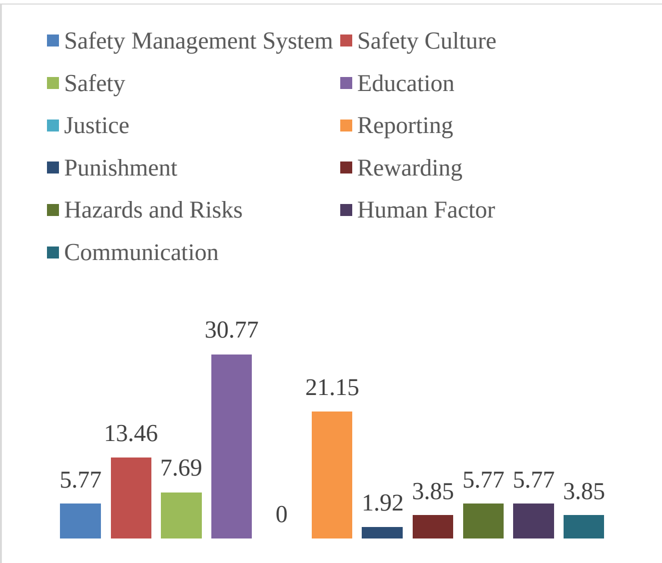

Figure 6. Distribution ratio of business "E" by codes

Among the data received from the "E" enterprise, the highest rate is related to the education code with 30.77%. This code is followed by reporting code with 21.12%. Business "E" gave the least information about the punishment code with a rate of 1.92%. We were unable to obtain any data from this business regarding the justice code.

Figure 7 shows the percentage distribution ratio of the codes in relation to the responses given by the manager of business "F".

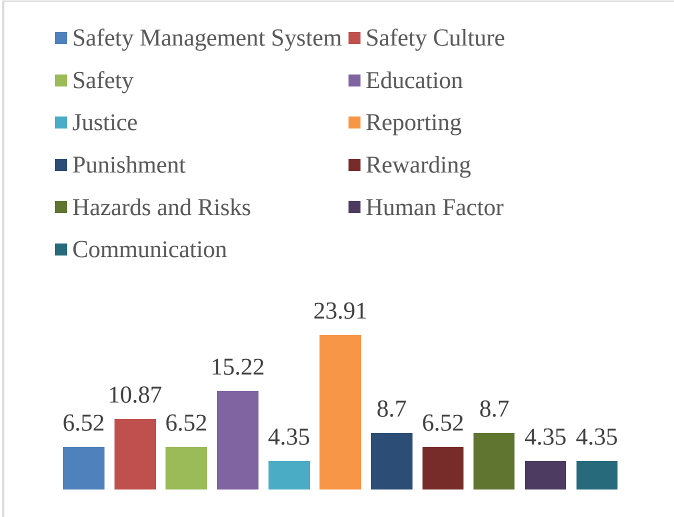

Figure 7. Distribution Ratio of Data from Business "F" by Code

The most emphasized code of business "F" is reporting with a rate of 23.91%. This code is followed by education with 15.22%. The least information is for justice, human factor and communication with a rate of 4.35%.

Figure 8 Shows the percentage distribution rate of codes for the answers given by the "G" business manager.

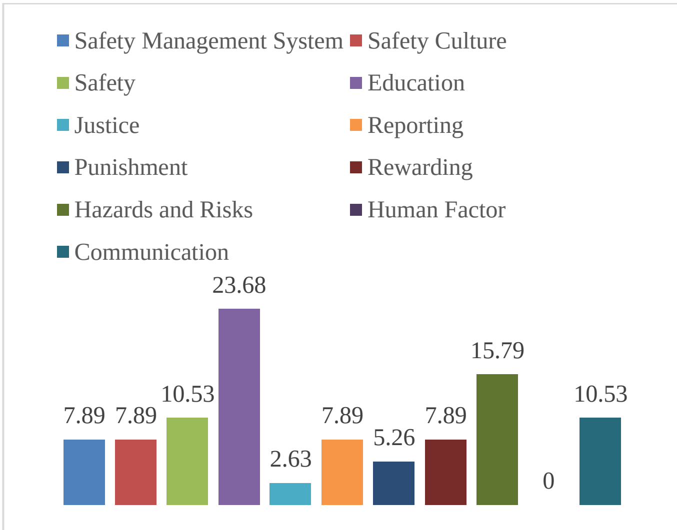

Figure 8. Distribution Ratio of Data Received from "G" Business by Code

The "G" business highlighted the education code the most with a rate of 23.68%. This code is followed by hazards and risk with a rate of 15.79%. In the data received from the "G" business, the data for the least justice code was taken with a rate of 2.63%. No data on the human factor code could be obtained from business "G".

Figure 9 shows the percentage distribution rate of codes in relation to the answers given by the manager of business "H".

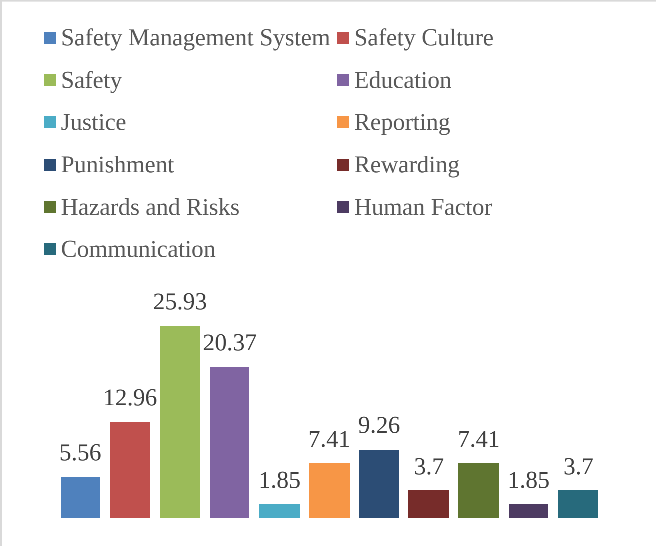

Figure 9. Distribution Ratio of Data Received from Business "H" by Codes

Among the data received from the "H" business, the highest rate is related to the safety code with 25.93%. The information given about education is in second place with a rate of 20.37%. With a rate of 1.85%, the "H" business conveyed the least information about justice and the human factor.

3.4.2. Analyzing Data for Businesses

When the details of the interview were examined, it was determined that the level of safety culture of enterprise "A" was low and the level of safety culture of enterprise "B" and "E" was high. Although a safety culture has been formed in "C", "F", "G" and "H" enterprises, it has been determined that it is not at the desired high levels. In enterprises "D", the level of safety culture could not be determined.

In the interview with the manager of enterprise "A", although the "safety culture" code was emphasized by 12.5%, it is considered that the level of safety culture of enterprise "A" is low. In the details of the interview, the business manager shared the following information:

- On the subject of communication; "correspondence-related problems may occur".
- On the subject of punishment; "Depending on the nature of the unsafe situation, warning punishment are given to the personnel, but as a result of the unsafe situation, the necessary punishment (warning, reprimand, deduction from salary, etc.) are applied to the relevant personnel."
- On rewarding; "We don't have any reward system. This is the primary duty of the employees".
- On the subject of reporting; Stating that there is a software program for reporting, the business manager said, "Some personnel do not enter data into the software program we have specified for certain reasons.
-

Since the business manager often emphasizes that "our safety culture is strong, our safety culture is formed", the safety culture code rate is high. When the details of the interview are examined, it can be easily seen that the enterprise does not show the necessary sensitivity and care in communication, reward, hazards and risk, safety and reporting. Detailed information on safety, hazard and risk issues was also not shared.

In the interview with the "E" enterprise manager, it is seen that the "safety culture" code is emphasized by 13.46%. High level of safety culture of "E" enterprise is determined and uses the SMS as a tool in creating a safety culture. In the details of the interview, the business manager shared the following information:

- **Punishment**: "We do not impose any punishment other than for intentional violations. We commit to this to our employees in writing and verbally."
- **Rewarding**; As part of the incentive system, every report is acknowledged with a formal letter to the employees. An official letter of appreciation is written and at the end of the year we evaluate the companies in all our organizations throughout Türkiye on the basis of our business and award the top three. In addition, we give a small gift to the employee who does the most reporting in our own station, and we try to reward it.
- **Danger and risk**; emphasizing that he attaches importance to the participation of all personnel in the matter of danger and risk and that success can be achieved by involving them, the business manager also emphasizes that expert support is obtained in this regard.
- **Education;** stating that training is often given in the institution, the manager said, "We try to understand the safety culture of employees with training. We already have a training called SMS on this subject. Every 3 years, these employees are already given these trainings by our institution. Our training activities are in this direction and we also have radio communication trainings."
- **Reporting**; emphasizing that they are informed about the reporting via the boxes and the internet, the business manager states that they bring up the importance given to this issue in every meeting. It is stated that the staff is frequently reported without naming names.

4. Conclusion and Recommendations

In the aviation sector, the concept of safety culture serves as a critical behavioral regulator in preventing accidents, errors, incidents, near-miss events, violations, hazards, and risks. Consequently, there is a growing consensus on the utilization of SMS (Safety Management System) components to develop and internalize safety culture across all aviation organizations.
This study aims to explore how safety culture can be promoted through the effective and dynamic implementation of SMS components and processes. The collected data were analyzed in the context of the four fundamental components of SMS to evaluate the development of safety culture. The findings related to the objectives of the study are summarized as follows:

- A significant portion of personnel in aviation organizations lacks comprehensive knowledge about SMS and safety culture.
- In many organizations, SMS is viewed more as a compliance obligation rather than a mandatory requirement.
- Notable efforts include organizing training, defining safety, identifying hazards and risks, enhancing reporting mechanisms, and implementing reward practices.

- Few organizations have successfully integrated safety into their culture.
- Training, rewarding, disciplinary practices, addressing hazards and risks, focusing on human factors, communication, and reporting initiatives have been identified as important in developing a safety culture. However, almost all organizations fall short of the expected standard in terms of "justice," a fundamental infrastructure element of safety culture.

Remarkably, only one of the eight examined enterprises uses SMS as a strategic tool. The research revealed that two of the participating enterprises (B and E) exhibited a high level of safety culture due to the effective implementation of SMS components, with an emphasis on safety, training, hazard and risk management, rewards, and communication.
Organizations with an existing but not yet desired level of safety culture showed deficiencies in areas such as safety, training, hazard and risk management, rewards, and communication. SMS should be included in the organizational chart as a department and experts in this field should work. Organizations with low levels of safety culture tended to neglect these areas. The study suggests that organizations actively and effectively implementing SMS components tend to develop a safety culture. Although a positive safety culture exists with less application, it falls below the required standards. In contrast, enterprises neglecting SMS requirements tend to exhibit very low levels of safety culture. The identified shortcomings in achieving a positive and high-level safety culture include:

- **Underestimating the value of rewards**: Organizations that do not prioritize rewarding tend to have low safety culture levels, leading to a lack of ownership and commitment among employees.
- **Punitive Approach:** Firms strictly adhering to punitive measures often record low safety culture levels. A balanced and fair approach to discipline is essential to foster a positive safety culture. Additionally, efforts should be made to develop a non-punitive disciplinary policy. In this context, “informing” emerges as one of the most critical elements. An informing culture is crucial for raising awareness among employees about the organization's safety status and priorities. Thus, all employees can clearly understand the difference between acceptable and unacceptable actions and can report faulty behavior without fear of punishment in a working environment.
- **Employees' perception of justice**: Many companies do not prioritize justice, which affects employee loyalty and reporting rates. Establishing a fair culture is primarily dependent on the existence of a sense of "trust." Another important requirement is understanding the mitigating effect of non-punitive reporting on safety management. Knowing that unsafe actions will be addressed and that voluntary reports will not result in punishment can foster a sense of justice and balance. In this context, "a fair organizational culture" can significantly enhance the safety culture.

To elevate safety culture in aviation, emphasis on safety, education, hazard and risk management, rewards, and communication is crucial, along with supporting elements such as justice, reporting, punishment, and human factors. Finally, the study highlights a general lack of comprehensive understanding of 'safety culture' among many organizations. The training content is predominantly focused on safety, SMS, hazards and risks, reporting, and communication, yet lacks safety culture-specific training. There is a need for more in-depth research and resources on safety culture and SMS in Türkiye.

Ethical approval

Ethics Committee Approval of this study was obtained with the decision of Hitit University.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Workplace Romance: A Research on Flight Attendants in Aviation Industry

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Abstract

The aim of this research is to examine different aspects of workplace romance experienced by flight attendants in the aviation industry. Qualitative research method was used to examine the research subject in depth. The research was guided by using the phenomenology design, which is one of the qualitative research designs. The sample of the research was determined according to purposeful sampling and saturation point methods. In this context, the sample of the research consists of 11 flight attendants working in different airline companies in Turkey. Online interview method was used as a data collection tool. The data obtained was subjected to content analysis using MAXQDA 24 qualitative data analysis program with an inductive and descriptive approach. As a result of the content analysis, the research findings were collected under five themes. These themes include: factors affecting workplace romance, factors obstructing workplace romance, types of romantic relationships at workplace, results of workplace romance and management of workplace romance. According to the findings, the reasons why male and female employees have romantic relationships at work differ; It has been observed that different romantic relationships emerge depending on the position of the partners and the reasons for the relationship, and that workplace romance have positive and negative results individually/organizationally. It is thought that the research results will contribute to the literature on the concept of workplace romance and organizational behavior in the aviation industry.

1. Introduction

Workplaces are important social spaces where people who come together to earn their living exhibit activities and behaviors within certain organizational processes (Stephens et al., 2012). In today's modern living conditions, most people spend most of their time working in workplaces and establishing both business and social relationships with other employees (Diener and Seligman, 2002). Workplace relationships, which have an important place in directing employee behavior, refer to the relationships that arise as a result of the interactions and changes that occur between employees in order to achieve organizational goals as a natural result of business life (Ferris et al., 2009). Workplace relationships are unique interpersonal interactions that have significant implications for employees and organizations. People's need to be social and belong; dynamic structure of relationships; The fact that organizational activities are carried out through business relations and the different quality of business relations are the factors that make workplace relations important (Rosales, 2016). Workplace relationships are at the center of organizations, and sustainability of organizational stability depends on workplace relationships. It is possible to see different workplace relationships in a workplace, such as formal business relationships, customer relationships, workplace friendships and romantic relationships between employees (Abe and Mason, 2016).

Romantic relationships, which are common in the workplace, are a phenomenon with social and sexual content (Büyükyılmaz and Shehadeh, 2023). This type of relationship, also defined as workplace romance, refers to the mutual emotional and physical attraction between two employees within the same organization (Pierce and Aguinis, 2003). Romantic relationships at work are one of the important relationships affected by the dynamics of business life. Because intimate interactions between employees in the workplace lead to the emergence of romantic relationships among employees. Although the workplace environment requires logical and formal behavior, employees often act with their emotions (Çoban, 2020). Today's modern business conditions create the basis for more romantic relationships in the workplace. Employees spending long periods of time with each other in close proximity at work creates opportunities for workplace romance to emerge. Many studies show that most employees have experienced or witnessed a romantic relationship at work (Pierce, 1998; Pierce and Aguinis, 2003; Salvaggio et al., 2011). It is also assumed that different types of romantic relationships experienced at work have important results on many organizational variables (Büyükyılmaz and Shehadeh, 2023).

When the literature is examined, it is seen that different factors trigger workplace romance, but it is seen that workplace romance is more common in funny and friendly organizational climates where physical attraction is at the forefront (Mano and Gabriel, 2006). The aviation is an important industry that operates internationally, employs different employee groups, and gradually increases its share in the transportation sector (Çoban, 2022). In the aviation industry, flight attendants are a group of employees who work as a team, communicate sincerely and spend intense time with their colleagues. In addition, flight attendants are employees with high physical and social attractiveness due to the commercial concerns and corporate impressions of the aviation industry. For these reasons, it is thought that the possibility of flight attendants having romantic relationships with both the cabin and cockpit crew will increase and these relationships will affect the organizational behavior of flight attendants. In this context, this study, conducted with qualitative research method, aimed to examine different aspects of workplace romance experienced by flight attendants. It is thought that the research results will contribute to the literature on the concept of workplace romance and organizational behavior in the aviation industry.

2. Conceptual Framework

2.1. Workplace romance

Workplace romance is a relationship based on mutual desires, including sexual attraction, between two employees within the same organization (Pierce and Aguinis, 2001). In workplace romantic relationships, which express the mutual spiritual and physical attraction between two employees in the same workplace, partners are interested in each other and share personal information. Since romantic relationships include physical attraction, behaviors such as touching, hugging, kissing and even sexual intercourse can be seen between employees. (Pierce, 1998). Romantic relationships refer to mutual feelings shared between two people, behaviorally, emotionally and cognitively. These feelings increase over time and can turn into love. Attachment, intense interest and responsibility behaviors are seen in romantic relationships (Çoban, 2020). In workplace romance between two employees who flirt with each other, there are mutual desires, sexual attraction and intimate behaviors (Mainiero, 1986; Powell and Foley, 1998). Romantic relationships differ from friendship in many ways. There are differences between the two concepts in terms of liking, passion, intimacy, arousal, love and affection. Although there are emotional components in friendship, the intensity and sharing of emotions is greater in romantic relationships. Due to both its emotional and physiological nature, the organizational repercussions of workplace romance may cause managers to fear these relationships (Ouinn, 1977).

When the relevant literature is examined, it is seen that there are different factors that cause workplace romance. First of all, workplaces are natural environments that allow emotional relationships between employees in many respects. The long hours that male and female employees spend together for work purposes provide a suitable atmosphere for employees to get closer, get to know each other well, and share sincere relationships (Anderson and Fisher, 1991). Today, in modern workplaces, many employees work together for a long time in the same environment, without gender discrimination and based on teamwork. Logically, these environments and interactions lead to increased romance, dating, and informal intimate relationships among coworkers (Rabin-Margaloith, 2006). Working together at work allows employees to know each other. As employees become more familiar with each other, the likelihood of having emotional relationships with their counterparts or managers increases (Lickey et al. 2009). In fact, the workplace is an ideal environment for the development of romantic relationships. Because employees who are constantly interacting with each other evaluate each other in a non-threatening and time-limited environment. As a result of this evaluation, employees can see who has personality traits that suit them, are kind, loyal and emotionally stable (Amaral, 2006).

Many scientific studies reveal that as more women enter working life, romantic relationships at work increase. Although workplace romance was seen as an undesirable situation by many commercial organizations in the past, workplace romance began to be accepted, especially since the 1960s, with the increase in female employees in working life and their appearance in management levels (Swartz et al. 1987; Appelbaum et al., 2007). The reasons why men and women have romantic relationships at work may be different. Generally, men seek excitement, ego satisfaction, love adventures and to increase their social status; Women, on the other hand, enter into romantic relationships at work in order to access organizational rewards more easily (Quinn, 1977). While romantic relationships are less common in organizational cultures where change is slow, such as the banking and finance sector; Romantic relationships are more common in friendly and freer organizational cultures where physical attractiveness is at the forefront, such as the advertising, hotel, tourism, retail and media sectors (Williams et al., 1999; Mano and Gabriel, 2006).

2.2. Types of romantic relationships at workplace

It is possible to classify romantic relationships at work in different ways. In this classification, the reasons for the relationship and the organizational positions of the partners in the relationship come to the fore. According to the factors that motivate the relationship, romantic relationships at work can be divided into three types: friendly, utilitarian and ego-oriented. In friendly romantic relationships, partners have sincere and friendly feelings towards each other. In utilitarian romantic relationships, partners try to benefit from the relationship. In ego-oriented romantic relationships, there is a desire to satisfy the egos of both partners (Powell and Foley, 1998). A common classification in the literature on romantic relationships at work is made according to the positions of the partners in the relationship at work. According to this classification, romantic relationships are divided into three groups: hierarchical, peer-to-peer, and romantic relationships involving married employees (Lickey et al., 2009).

Hierarchical romantic relationships occur between employees with different hierarchical positions within the organization. In these relationships, one of the partners is in a managerial or superior position. (Lickey et al., 2009) This type of romantic relationship is often not seen as fair and appropriate by other employees. Because the subordinate partners of the relationship may abuse the power gained through the relationship (Segal, 2005). This kind of problem is especially likely to occur in mentor-trainee relationships. Because trainees have less authority and power than their mentors, they may be exposed to abuse (Morgan and Davidson, 2001).

Peer-to-peer romantic relationships occur between employees who hold similar positions within the organization. These relationships may be seen as more harmless compared to hierarchical romantic relationships in terms of their organizational results. Counterpart employees share long working hours with each other to perform routine tasks or work on projects. These sharings also continue in non-work social environments such as meal breaks, sports activities, meetings and volunteer activities (Shellenbarger 2004; Powell and Soley, 1998). In peer romantic relationships, partners have similar education, interests, and work history. These types of relationships are usually kept secret at the beginning of the relationship. In peer-to-peer romantic relationships, organizational confidential information is likely to be shared between the partners and inappropriate sexual behavior is likely to occur in the workplace (Powell, 2001). Romantic relationships involving married employees are relationships that occur when one or both employees are married. Since these types of romantic relationships are seen as unprofessional in many parts of the world and damage organizational reputation, they are viewed negatively by both organizational management and employees (Schwartz and Storm, 2000).

2.3. Results and management of workplace romance

Workplace romance can produce different results depending on their level and type. When the literature is examined, it is seen that workplace romance have both positive and negative results in the workplace (Çoban, 2020). Some studies reveal that the positive energy generated by romantic relationships increases employees' work performance and that employees are happier and more productive compared to before the relationship. Additionally, workplace romance reduce stress and communication conflicts; It has been shown to increase organizational commitment, job satisfaction, communication, cooperation and innovative behaviors (Berman et al., 2002; Wilson, 2015: 7; Pierce and Aguinis, 2003). Since some of the romantic relationships in the workplace result in marriage, this leads to positive organizational results in the workplace (Wilson et al., 2003). According to Pierce (1998), the more satisfied employees are with their private and romantic relationships, the more satisfied they are with their jobs.

When the relevant literature is examined, a significant part of the research reveals the negative results of workplace romance. Behaviors such as gossiping, long meal breaks, arguments between partners, coming to work late or leaving work early are some negative results of workplace romance (Quinn and Judge 1978). In particular, hierarchical romantic relationships may cause perceptions of injustice and favoritism among employees. Additionally, in romantic relationships that end badly, partners may blame each other. The accusation that employees fear most in this regard is sexual harassment (Lickey et al., 2009). Female employees who have romantic relationships at work are often emotionally and moody; Men, on the other hand, are seen as spiritually balanced. Employees mostly have negative perspectives on the factors that lead women to romantic relationships. This is because women want to rise faster in the organizational hierarchy through romantic relationships. For this reason, unpleasant ascriptions are made to women who have romantic relationships at work (Morgan and Davidson, 2008; Riach and Wilson, 2007).

Managers and employees may not look favorably on workplace romance because it has more negative results. However, it is not possible to completely prevent romantic relationships at work. Organizations can manage workplace romance by carefully analyzing the factors that lead employees to romantic behavior at work and without ignoring the positive results of romantic relationships. In this context, managers must act logically and sensitively within the scope of their organizational sensitivities. Otherwise, imposing strict rules, prohibiting romantic relationships at work, or firing employees may harm organizational performance (Ariani et al., 2011). Organizations may view workplace romance in different ways depending on their own values and norms. While some organizations consider romantic relationships in the workplace normal, others may not. In this context, organizations can inform their employees about their ethical values and policies against workplace romance (Aguinis, 2009). According to Quinn (1977), managers can act against workplace romance in three different ways. First, managers may not react by ignoring romantic behavior in the workplace. Second, sanctions may be imposed against romantic relationships. Finally, romantic relationships can be managed by approaching them positively and providing counseling.

3. Methodology

The aim of this research is to examine different aspects of workplace romance experienced by flight attendants in the aviation industry. For this aim, qualitative research method was used to examine the research subject in detail. The research was guided by the phenomenology design, which is one of the qualitative research designs. The phenomenology pattern both guides and gives flexibility to the researcher without leaving the focus of the research, allowing the phenomena that are a part of daily life to be examined in depth and detail (Yıldırım and Şimşek, 2018).

3.1. Sampling and data collection

The employees participating in the research were selected according to the purposeful sampling method. The purposeful sampling method allows the researcher to select participants who provide the best understanding of the research problem (Creswell, 2017). For this reason, flight attendants working in different civil aviation companies in Turkey were included in the scope of the research. The reason why flight attendants were included in the scope of the research is that flight attendants of different genders, men and women, work in a physically narrow work environment with frequent and long-term communication with their counterparts and the cockpit crew. Semi-structured interview method was used to collect data from the determined sample. The research questions prepared by taking into account the literature review and scales regarding the concept of workplace romance and addressed to the participants are presented in Table1.

Table 1. Research questions

	Questions
1	For what reasons do you or other employees at your workplace have romantic relationships? Do you think these reasons are different for male or female flight attendants?
2	What organizational factors make it easier or more difficult to have romantic relationships in your workplace?
3	What kind of romantic relationships are most common in your workplace? What are the reasons?
4	How do managers and employees react to romantic relationships at your workplace?
5	What are the individual and organizational results of romantic relationships in your workplace?
6	In your opinion, what should be done to manage workplace romance?

Due to the intensity of the participants' workload, flexible working hours and time constraints, the interviews were held separately and online with each participant between May and July 2023. Each participant was interviewed for approximately 45 minutes. The data collection process was completed when the saturation point was reached. In qualitative research, data collection is completed if the data obtained for the creation of research themes reaches a certain saturation and no new perspectives emerge (Creswell, 2017). The data collection process was completed by interviewing 11 participants within the framework of the saturation point. The demographic characteristics of the participants are presented in Table 2.

Table 2. Demographic characteristics of the participants

Participant	Job Title	Gender	Marital status	Age	Working Time	Education Level
P1	Cabin Chief	Female	Married	38	14	Master's degree
P2	Cabin Chief	Female	Single	46	20	Master's degree
P3	Cabin Chief	Female	Single	37	12	Bachelor's degree
P4	Flight Attendant	Male	Single	28	6	Bachelor's degree
P5	Cabin Chief	Male	Married	37	11	Bachelor's degree
P6	Flight Attendant	Female	Single	27	5	Bachelor's degree
P7	Flight Attendant	Male	Single	26	3	Bachelor's degree
P8	Flight Attendant	Male	Married	29	4	Bachelor's degree
P9	Cabin Chief	Female	Married	37	13	Bachelor's degree
P10	Cabin Chief	Female	Single	41	13	Bachelor's degree
P11	Flight Attendant	Male	Married	38	6	Master's degree

3.2. Data analysis

The data collected in the research was analyzed according to the content analysis method. The aim of content analysis; It is to summarize and interpret the data in a descriptive and inductive way, and to reach unrecognized codes, categories and themes by subjecting them to in-depth processing, and to interpret them by arranging them in a way that readers can understand (Yıldırım and Şimşek, 2018). MAXQDA 24 qualitative data analysis program was used to analyze the data. During the analysis process, the data were systematically examined by both researchers separately and then together to reach the final version of the research themes. The emerging themes were supported by quotes from participant statements, and the findings were interpreted by the researchers in the conclusion. In addition, qualitative data were supported by graphs and quantitative data.

The approaches adopted regarding the validity and reliability of the research are listed below (Creswell, 2017; Yıldırım and Şimşek, 2018; Sığrı, 2021):

• While determining the research topic and questions, experts working in the aviation industry were interviewed and the content of the research was guided according to their feedback.

• Information about the research method, process and results are explained in detail.

• The sample of the research was determined according to the purposeful sampling method.

• Triangulation method was used in the research. Thus, different participants were included in the research, and the research topic was tried to be explained by supporting the data obtained through interviews with different data sources.

• Long-term interaction was achieved with the data obtained in the research; The data were cross-examined separately by two researchers and the raw data was stored.

4. Findings and Analysis

The themes of the research resulting from the content analysis are presented in Table 3.

As seen in Table 3, research findings; They are grouped under five themes: factors affecting workplace romance, factors obstructing workplace romance, types of romantic relationships at workplace, results of workplace romance, and management of workplace romance. Each theme was divided into categories within itself, and codes that create semantic integrity with each other were taken into account in creating the categories. The content analysis carried out by the researchers, taking into account the themes and categories is presented below respectively.

Table 3. Themes of the research

Themes	Categories	Codes	Code Frequency	Category Frequency
Factors Affecting Workplace Romance	Expectations Related to Gender	Men's Search for Excitement and Flirting	20	62
		Men's Ego Satisfaction and Desire to Experience Freedom	4	
		Women's Desire to Benefit from the Power of the Captain Pilot	13	
		Women's Desire to Become a Captain's Wife	9	
		Women's Desire for Long-Term Emotional Relationships	5	
		Women's Desire to Be Flirtatious	4	
		Women's Interest in Young and Single Copilots	4	
		Women's Financial Concerns for the Future and Desire for Marriage	3	
	Nature of Flight Task	The Charm of Layover Duty	17	46
		Spending Long Time at Work and Teamwork	15	
		Flight Crew is Variable and Has Many Options	8	
		Comfortable and Friendly Communication Environment	6	
	Similar Characteristics of Flight Crew	Attractiveness and Politeness of the Flight Crew	16	46
		Flight Crew Understanding Each Other	15	
		A Lover Outside the Flight Crew Cannot Understand the Flight Attendants	11	
		Similar Demographic Characteristics	4	
	Place-Based Physical and Social Interaction	Close Physical Contact During Flight	11	26
		Galley Chats	10	
		Regular Cockpit and Cabin Communication	3	
		Crew Rest Room Interaction	2	
	Passenger and Cabin Crew Interaction	Flirting Requests from Passengers	5	10
		Focusing on Rich and Powerful VIP Passengers	3	
		Contacting on Social Media	2	
		Total	190	
Factors Obstructing Workplace Romance	Obstacles Related to Flight Task	Being Task Oriented and Lack of Time on Short Flights	6	10
		Constant Change of Flight Crew	4	
	Obstacles Related to Status	Women's High Status	3	6
		Having a High Managerial Role	3	
	Organizational Obstacles	Being Subject to the Love Contract	3	4
		High Institutionalization	1	
		Total	20	
Types of Romantic Relationships at Workplace	Hierarchical Romantic Relationships	Male Captain Pilot - Female Cabin Chief	4	14
		Male Captain Pilot - Stewardess	4	
		Male First Officer - Stewardess	2	
		Company Manager - Cabin Crew	2	
		Female Captain Pilot - Steward	1	
		Cabin Chief - Cabin Crew	1	
	Romantic Relationships Between Counterparts	Cabin Crew - Cabin Crew	9	13
		Stewardess - Maintenance Technician	2	
		Stewardess - Flight Cook	1	
		Stewardess - Ground Services	1	
	Harmful Romantic Relationship	Relationship with Married Flight Crew	5	5
		Total	32	
Results of Workplace Romance	Positive Results	Sharing Loneliness on Long Missions	4	16
		Business Motivation	4	
		Limited Number of Marriages	3	
		Women's Promotion and Immunity	3	
		Solidarity Between Lovers	1	
		High Organizational Loyalty	1	
	Negative Results	Jealousy	12	92
		Emotional Harm to Women	10	
		Dismissal	10	
		Negative Organizational Impression in the Media	8	
		Disruption of Duty and Deterioration of Business Relations	8	
		Behaviors that Risk Flight Safety (Distraction, Favoritism, Indifferent Behaviors)	6	
		Marriage Endangerment and Divorce	5	
		Competition Between Men (Between Pilot-Steward)	5	
		Bad Names and Social Exclusion	4	
		Organizational Gossip	4	
		Casual and Careless Behavior of Men	4	
		Women's Loss of Power and Performance	3	
		Don't Care About Your Ex	3	
		Favoritism	3	
		Immoral Relationships	2	
		Manager's Loss of Authority or Job	2	
		Pilot's Wife and Stewardess Quarrel	2	
		Stewardess Boyfriend and Pilot Fight	1	
		Total	108	
Management of Workplace Romance	Individual Perspective	Thinking Romantic Relationships Are Natural at Work	14	30
		Acting According to Ethics and Organizational Rules	7	
		Intervention for Negative Behaviors	5	
		I Am Against Emotional Relationships at Work	3	
		Reaction to Intermarital and Negative Relationships	1	
	Organizational Perspective	Staying Neutral and Ignoring	8	10
		Psychological Support in Adverse Situations	1	
		Disclosure of the Company's Code of Ethics	1	
		Total	40	

4.1. Theme 1: Factors affecting workplace romance

Theme 1 was examined under five categories: expectations related to gender, nature of the flight task similar characteristics of the flight crew, place-based physical and social interaction, and passenger and cabin crew interaction. The distribution percentage of the theme of factors affecting workplace romance, consisting of 190 codes, according to categories is presented in Figure 1.

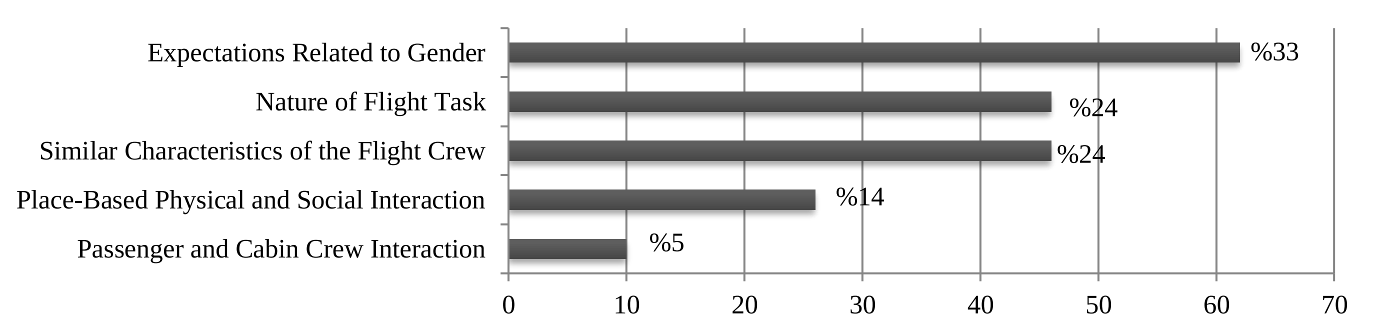

Figure 1. Factors affecting workplace romance

Expectations related to gender

P2: "Men are for flirting and excitement. There are very few serious ones. Women to gain power. For example, if you have a date with the captain, you can immediately rise in the private sector, get a promotion or become untouchable."

P5: "Men want to have a good time and have short-term relationships for excitement. Women, on the other hand, want to get married and have a serious relationship. Women's target is the cockpit. It is intended for the captain. Since stewardesses will have to quit their job when they become mothers in the future, pilots who are paid three times more than themselves may be targeted. First officers are more popular in this regard. Because he is younger."

P9: "I see or hear of stewardesses who get a job just to marry a pilot due to financial concerns. I think it might make sense to marry a pilot since pilots have good social rights."

P11: "Men generally seek short-term excitement for a week or ten days. They are not looking for affection and love. Women, on the other hand, focus on the captain's salary. There are also women who say, "I won't do this job if I marry a captain." However, there are also women who have short and flirtatious relationships."

P3: "Making a pilot lover creates competition in the cabin. For stewardesses, making pilot lovers is like extras around an artist. "The fact that the pilot is a leader, has technical and expert skills, has a high salary, has a strong uniform, has self-confidence and is arrogant (those fingers you see can lift 200 tons) affect stewardesses."

It has been observed that the most important factor among the factors affecting workplace romance is expectations related to gender (33%). The reasons for male and female flight attendants to have romantic relationships at work differ depending on their gender. According to the findings, men mostly seek excitement, flirt, have sex, etc.; As for women, they generally aim to gain power at work, financial concerns for the future, get married and meet their emotional needs; However, it has been observed that some women turn to emotional relationships at work in order to be flirtatious.

Nature of the flight task

P3: "Stewardesses look beautiful because they wear civilian clothes in the layover duty and the girls wear make-up and let their hair down. The layover duty environment is a more flexible place. There are hotels ready for emotional affairs and plenty of free time."

P2: "You are in close contact with each other during the flight task and you definitely establish a dialogue with your colleague because you are in very close contact. When you stay at layover duty after the flight, you have to adapt to the team. The hotel has a nice and comfortable environment. Going to meals together in a hotel, sharing loneliness in distant places like Africa, and sharing difficulties together provide the opportunity to get to know each other closely and get romantically close with our colleagues."

P4: "The friendly atmosphere, teamwork and easy communication during the flight make the work environment attractive. Feeling comfortable and free, and having a long layover duty at the end of the flight can make you fall into the wind of romantic relationships."

P1: "Since the flight crew flies with different teams, there are many options. When you see the other person's expectation, you take your stance accordingly."

P3: "Single pilots will definitely have many dates until they get married. Because there are so many options for flirting in the cabin."

It has been observed that some factors arising from the unique nature of the flight task pave the way for romantic relationships. Particularly after long flights, the flight crew staying together to rest is seen as an attractive environment for romantic relationships to emerge. A comfortable hotel environment, flight attendants communicating closely with each other, away from work stress, and sharing their loneliness can increase the interaction between opposite-sex flight attendants. Since the flight task is based on teamwork, it requires close communication and time sharing for a long time, which gives attendants the opportunity to know each other closely. After sharing difficult conditions during the flight, relationships can become closer in the comfortable environment of the rest period. In addition, changing the flight crew for each task can help attendantss get to know different people and increase their options in terms of emotional interaction.

Similar characteristics of the flight crew

P9: "You see the flight crew at their politest and best in terms of their speech, attitude and behavior on the plane. This situation also affects."

P10: "Stewardesses are beautiful and attractive. Stewards are also intellectual, attractive and know how to have fun at the layover duty. Appearance is important for romantic *relationships. Stewardesses who gain too much weight are warned by the company."*

P11: "Flight attendants have a certain physical standard. Everyone is physically fit. Men are attracted to tall women. This situation also affects.

P1: "Anyone other than the flight crew can hardly understand the work environment we live in. The flight crew often have romantic relationships with each other because they understand each other."

P3: "People outside may not understand us. However, the flight crew understand each other, so a romantic relationship develops easily between us."

P7: "It is very important for employees to understand each other. It can be a problem because someone who is loved from outside does not understand our work. We work side by side in a tight environment and go to layover. Those who have lovers from outside are jealous or think badly about us."

P1: "Generally, the same training levels of the flight crew increase their communication and sharing. Most people are highly educated and bilingual. In such a situation, it is very natural for romantic relationship to develop."

It has been observed that the flight crew's similarity in many aspects facilitates workplace romance. Due to the commercial concerns of the aviation industry, the fact that flight attendants are always physically attractive and well-groomed, communicate sincerely and politely, and have similar demographic characteristics such as education level causes flight crew to prefer each other in terms of romantic relationships. However, all of the participants stated that employees' ability to understand each other is an important reason for workplace romance. Because overcoming difficulties together and acting in solidarity during the flight task; At the end of the flight, sharing their loneliness together while resting in different places away from their homes allows the attendants to understand each other. It has been stated that a lover who does not know the nature of flight task is often a source of trouble in such situations.

Place-based physical and social interaction

P6: "The places we work in are narrow. This physical closeness affects romantic relationships."

P2: "Romantic relationships occur as much or more in our work than in any other work. Because we work in a comfortable environment in terms of communication. Additionally, since the plane interior is narrow, we come into close physical contact in the same environment. Therefore, there is definitely a dialogue between us."

P7: "Touching and contact may occur in narrow-body aircraft. Especially in galley. Inevitably, we sit down and are impressed. When you are alone in the galley, there is a lot of chatting and interaction. This interaction continues on the layover time and in the hotel."

P4: "The most suitable place for romantic interaction is the rear galley. In large aircraft, passengers and cockpit crew cannot hear what is said in the rear galley. Since galleys are friendly places away from work, you will be calm and comfortable. Informal topics can be discussed there and a romantic relationship can develop."

P6: "We have time to chat on long flights. There is about two hours of rest on long flights of 12-13 hours. During this time, we can chat in the galley."

P3: "Usually communication takes place in the galley. In terms of physical or verbal contact, the galley is a place of attraction."

P10: "In the crew rest room, attendants undress without distinguishing between men and women, with a curtain in between. Here the attendants change their clothes and go to bed. Even though there is a curtain in between, the opposite sex can be affected here."

Physical and social interactions that occur depending on the place in which flight attendants work while doing their jobs can trigger romantic relationships. Especially in narrow-body aircraft, sexual attraction may occur between attendants of the opposite sex and the cockpit crew due to physical closeness and teamwork. Eye contact or physical contact during work may cause attendants to be influenced by each other. According to most of the participants, the most suitable place where attendants communicate more sincerely and comfortably is the galley at the back of the aircraft. Even though attendants in the cabin are physically close, they act formally towards the passengers and each other because they are duty-oriented. However, the galley is a place away from the passengers, where attendants stay alone and have friendly and informal communication. The crew rest room is another physical place where attendants rest and see each other in different situations.

Passenger and cabin crew interaction

P2: "Outside the cabin, stewardesses prefer strong, wealthy male passenger candidates who work free and flexible hours and can go abroad for dating. For this reason, sometimes passengers flying in the VIP or business section may be more approachable if stewardesses catch their eye."

P4: "Stewardesses may sometimes come into close contact with wealthy or businessman passengers and treat them more friendly than usual. A friend of mine had romantic relationship emotional affair with a passenger."

P5: "Male passengers are generally bold towards stewardesses. There are incidents of giving business cards, writing on a napkin, and asking for a phone. Flight attendants do not come into contact with many passengers out of the blue. However, if a request comes from the passenger, the attendant may consider it. But this situation is a risk for the stewardess."

P6: "Passengers make daring compliments. Sometimes they give their phone number when getting off the plane. Or they find your name and surname on social media and make a connection."

P7: "I have friends who establish romantic relationships with passengers. A female friend of mine took the name of a volleyball player sitting in the economy section from the passenger list on one of her flights. Then she connected with that passenger on social media and they eventually got married."

P10: "An Indian passenger gave me his card to star in his movie. On the layover time, passengers offer us to go to dinner and entertainment. A friend of mine married an economy passenger."

When the research findings are examined, it is seen that flight attendants can have romantic relationships not only with their colleagues at work but also with passengers. In particular, stewardesses' offers to flirt or have a relationship are sometimes met with a response. It is thought that the flight attendants's physical attractiveness and politeness are effective in the passengers' offers. However, it has been observed that stewardesses pay closer attention to VIP passengers, especially those who seem powerful, rich and influential, triggering emotional relationships. It has been observed that social media tools, which are widely used today, are an important tool for passengers and flight attendants to reach each other, get to know each other and engage in romantic relationships.

4.2. Theme 2: Factors obstructing workplace romance

Theme 2 were examined under three categories: obstacles related to flight task, obstacles related to status and organizational obstacles. The distribution percentage of the theme of factors obstructing workplace romance, consisting of 20 codes, according to categories is presented in Figure 2.

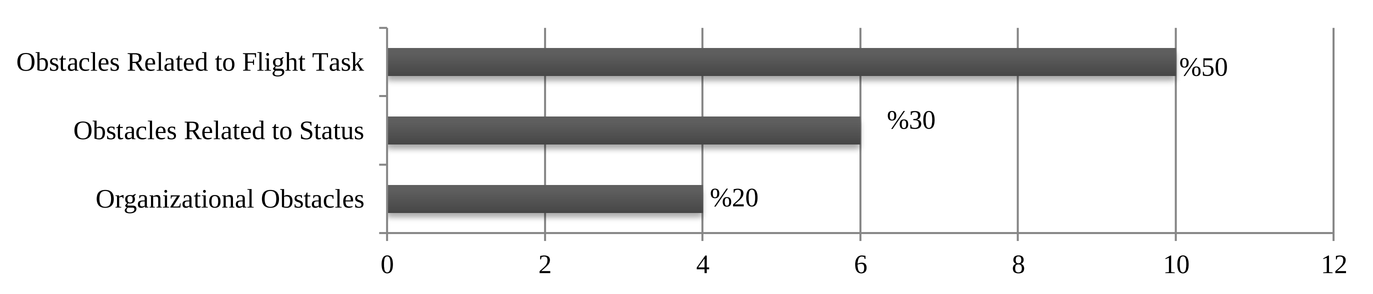

Figure 2. Factors obstructing workplace romance

Obstacles related to flight task

P2: "Everyone does their duty on short flights. There is no time for romantic interaction. We can't even go to galley."

P5: "On short flights, opposite sexes are task-oriented and do not have the opportunity to get to know each other and chat. Long flights are more suitable for getting to know each other."

P11: "On short flights, you are task-oriented and you cannot lift your mind because of work. You don't have time to chat with your co-worker or have a romantic relationship."

P8: "We always work with different people. Sometimes you can see a colleague of yours after a year or two. You don't see each other for a long time. In this respect, it is a little more difficult for us to establish romantic relationships than someone who always works in the office."

P11: "Flying constantly with different people due to duty rotations triggers short relationships, not long romantic relationships. If the attendants like each other, it happens, but if not, they get away. Then they never see each other again."

P5: "Due to rotations, you constantly see new colleagues. Employees can act relaxed because it is difficult for them to encounter each other again. This rotation is a chance for those looking for a short or overnight romantic relationships."

It is seen that obstacles related to flight task have an important place (50%) among the factors that obstruct romantic relationships. It has been determined that especially on short-term flights, flight attendants are task-oriented and cannot find enough time for social or romantic interactions. In this respect, long flight tasks are thought to be more suitable for romantic interactions. However, the fact that different crews take part in each flight task is seen as an obstacle to long-term emotional interactions. However, constantly changing crews create an opportunity for employees who want to experience short-term excitement and romantic interaction with different people

Obstacles related to status

P10: "I have never seen a relationship where the woman is in a higher position in a romantic relationship. I guess a relationship like this can be difficult. In general, men are in a higher position."

P2: "The relationship between female cabin chief and steward is low. Generally, the man's position in the relationship is high. I have never seen a relationship between a female pilot and a steward. The relationship between the two flight attendants is getting better. They feel comfortable because they do not have a superior-subordinate relationship and they are in the same position."

P4: "Stewardesses are focused on establishing relationships with pilots with higher salaries or status than themselves, or employees of equal rank to them. The relationship between a female cabin chief and a steward is a bit unusual. It would be a difficult relationship and I haven't seen much of it. In my opinion, women should be equal to me or below me in status."

P6: "The relationship between a male supervisor and stewardess is more common than the relationship between a female supervisor and a steward. When a woman is a supervisor, she can avoid emotional relationships with a subordinate employee due to her position. The female cabin chief generally prefers to flirt with the pilot due to her position."

P7: "In romantic relationships, men generally have a high status. I have never seen a relationship between a female pilot and a steward. But the number of female pilots is increasing. Why not in the future?

P9: "Having an emotional relationship with a subordinate employee may harm the authority of the manager."

P1: "The manager who represents the company at a high level should be more careful about romantic relationships. Since corporate impression is very important, managers may be afraid or hesitant to have emotional relationships with employees."

It has been observed that status is an important determining factor in the romantic relationships that flight attendants have at work. Stewards often tend to have romantic relationships with stewardesses whose positions are equal to or inferior to theirs. Because a woman's high job status may disturb the male partner in a romantic relationship, which is an informal relationship. Stewardesses, on the other hand, generally prefer romantic relationships with men with higher status than themselves due to their search for power at workplace. For this reason, the high status of a woman in a romantic relationship can often be seen as a problem by the male partner, and men avoid such a relationship. In addition, it has been observed that especially senior managers avoid romantic relationships with employees in the workplace. Managers may avoid romantic interactions with employees out of concern that romantic relationships at work will reduce their authority and damage the corporate image.

Organizational obstacles

P9: "I heard that some airline companies make you sign a love contract stating that you will not have children or have emotional relationships at work. It is difficult to implement such contracts in our industry."

P5: "People get married and have children thanks to flirting at work. How will employees get married if there is a love contract? Even if it were, this contract would not be very valid."

P7: "In our work, no one accepts the love contract. The love contract does not suit us."

P8: "I think as institutionalization increases, romantic relationships decrease. Because employees in corporate companies have to pay attention to their behaviors in accordance with the rules, they will avoid romantic relationships at work."

It has been observed that the contracts implemented by some businesses to prevent employees from having romantic relationships at work are a factor that obstruct romantic relationships at work. Despite the love contract, some employees may not hesitate to have romantic relationships at work. However, in cases where romantic relationships negatively affect organizational performance and image, employees may be subject to criminal proceedings due to the contracts in question. Employees who are aware of this situation will avoid having romantic relationships at work. Having a love contract at work can be seen as a situation related to institutionalization. Because in corporate enterprises, there is a formal organizational structure since the rules and processes regarding both the business and social behavior of employees are certain.

4.3. Theme 3: Types of romantic relationships at workplace

Theme 3 was examined under three categories: hierarchical, between counterparts and harmful romantic relationships. The distribution percentage of the theme of romantic relationship types, which consists of 32 codes, according to categories is presented in Figure 3.

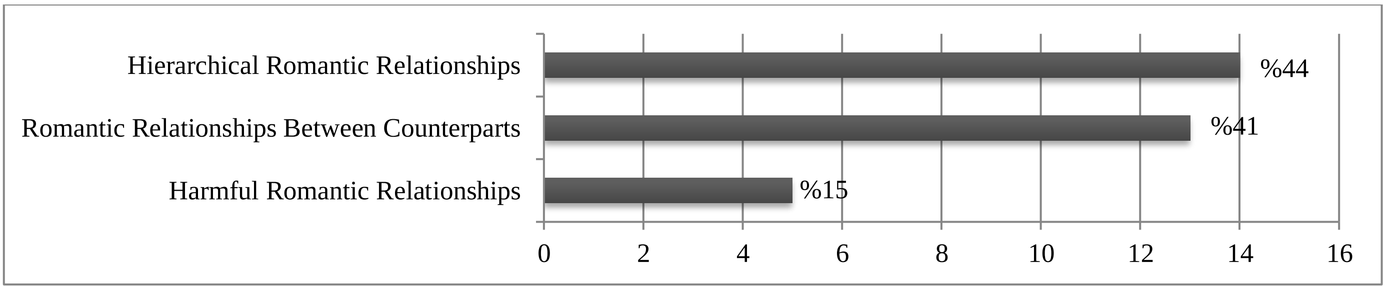

Figure 3. Types of romantic relationships at worplace

Hierarchical romantic relationships

P1: "There can be a romantic relationship between the cabin crew and the captain pilot. The fact that the captain and especially the cabin chiefs have high communication levels and generally have the same education levels increases their communication and sharing."

P11: "The captain pilot and stewardess relationship is the most common. The reason for this is the captain's salary and power. Stewardesses always dream of marrying a captain."

P7: "First officers are more flirtatious because they are young. Because first officers are so attached to their cabin crew, they tend to have romantic relationships with them."

P10: "There is a greater romantic relationship between the cabin and cockpit crew. Due to the financial means of pilots, cabin crew's target is always the cockpit. First officers are very valuable, especially for stewardesses. Because the first officers are young, have just finished flight school and are blindfolded. If you catch them, you are in heaven."

P7: "The most romantic relationship occurs between the captain pilot and the cabin chief. In the cabin, there is more of a relationship between two attendants."

P5: "There is a cabin chief and attendant relationship in the cabin. The superior's position has no effect on this relationship. They both met in the cabin. In our work, everyone does their duty. Romantic relationships do not reflect on the flight task."

P3: "There can be a romantic relationship between a company manager and a flight attendant. However, this relationship is dangerous and causes gossip within the company."

P9: "I saw a female pilot who was married to a steward."

When we examine the types of romantic relationships at work, it is seen that hierarchical romantic relationships experienced by employees with different statuses are in the majority (44%). Hierarchical romantic relationships mostly occur between the cockpit and cabin crew. Because cockpit and cabin crew, separated from each other due to their duties and status, are two different hierarchical groups of the flight crew. Although the captain pilot is usually the target in hierarchical emotional relationships, first officer pilots are also preferred because they are mostly young and single. Although romantic relationships between company managers and flight attendants were rare, they were seen as other hierarchical romantic relationships.

Romantic relationships between counterparts

P9: "Romantic relationships are most common among flight attendants. Because this group sees each other the most and works together. Also, the number of flight attendants is higher. There are also flight attendants who marry ground crew or maintenance technicians. However, since our communication with the ground crew is limited, the number of relationships with them is limited."

P4: I see more romantic relationships between two flight attendants. Because they share the same work environment and responsibilities, Romantic relationships between counterpart employees are the most natural."

P8: "Romantic relationships are more common among flight attendants in the cabin. In these relationships, the man's position is generally higher and the woman's position is lower."

Romantic relationships between counterpart employees are relationships that flight attendants do not have a hierarchical relationship with and have with employees who are in the same position as them. Romantic relationships between counterpart employees appear to be as common a type of romantic relationship in the workplace as hierarchical romantic relationships. It has been observed that the most common romantic relationships between counterpart employees are among flight attendants. Because at work, cabin crew constantly see each other for long periods of time, work in close contact and help each other in difficult situations. Additionally, the large number of flight attendants increases their options for romantic relationships. Although less common, flight attendants have been found to have romantic relationships with aviation employees in the same hierarchical position as them, such as maintenance technicians, ground staff and flight cooks.

Harmful romantic relationships

P2: "I believe in the superiority of love. But the most dangerous type of romantic relationships are relationships between married employees. The relationship between the married captain pilots was heard and events broke out in the company. The captain pilot's wife caused a stir."

P10: "There are people who are married and have romantic relationships. This is the most harmful romantic relationship."

P4: "The romantic relationship between a married senior manager and a captain pilot is the most dangerous relationship."

P11: "Actually, the most dangerous thing is the romantic relationship between a married person and a single person. Generally, the captain is married and the stewardess is single. The stewardess knows that the captain is married. But in the long run, the stewardess hopes to get the captain pilot."

P5: "The most harmful type of romantic relationship is between married employees. In this type of relationships, partners at first hide that they are married. Then, when this situation is realized, it becomes a problem. Moreover, this type of relationship is immoral."

According to the participants' statements, when the types of romantic relationships were examined, it was seen that hierarchical and counterpart's romantic relationships were considered natural, while a romantic relationship with a married employee was both harmful and immoral. It has been observed that captain pilots, who are a partner of such relationships that contradict social value judgments, are generally married, and in some cases, stewardesses knowingly have romantic relationships with married pilots for different reasons. However, in romantic relationships where one of the partners is married, the probability of negative situations such as fighting, divorce, and damaging the corporate impression is very high.

4.4. Theme 4: Results of workplace romance

Theme 4 was examined under two categories: positive and negative results. The distribution percentage of the theme of the results of romantic relationships, which consists of 108 codes, according to categories is presented in Figure 4.

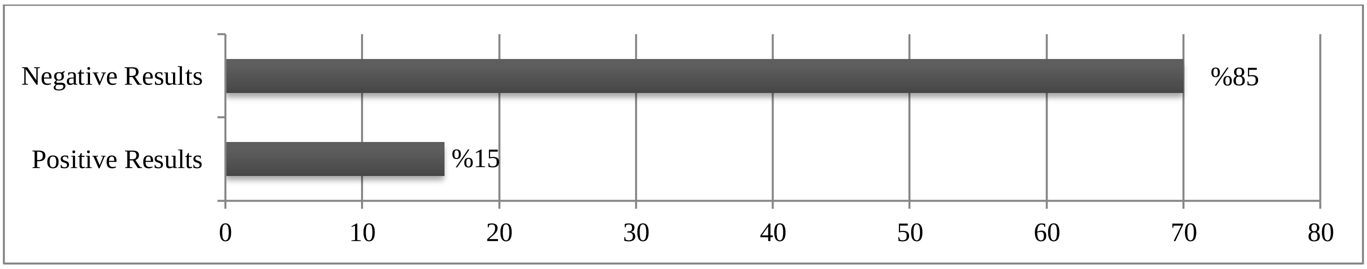

Figure 4. Results of workplace romance

Positive results

P1: "Due to our job, we often work alone and away from our family. In such situations, if we get sick or are in a difficult situation, your lover will provide great support. Working together with employees who are lovers increases their motivation."

P2: "Where can employees see flirting? However, he can see it at work or in his immediate surroundings. I saw friends who got married and were happy thanks to these dates."

P2: "If you have a romantic relationship with the captain pilot, you can immediately rise in the private sector, get a promotion or become untouchable."

P3: "If romantic relationships go well and have positive results, beautiful marriages can happen."

P10: "Falling in love with and marrying someone in the environment where I work improves my sense of belonging to the workplace. I would happily go to work to see my loved one."

According to the participants' statements, it appears that having a romantic relationship at workplace has different positive results. First of all, it has been observed that lovers support each other and share their loneliness while doing their duties or during long rest periods after work. This mutual close support and sharing increases the partners' work motivation and commitment. However, some participants also stated that they are professional workers and that partners, even if they are lovers, must be capable of doing their own work without support. Additionally, romantic relationships at work have the potential to turn into happy marriages in the long run. On the other hand, having a romantic relationship with a manager or a powerful employee can contribute to female employees, especially, being promoted or gaining positions.

Negative results

P3: "Leaving a pilot who is well-known in the workplace will have a serious negative impact on the stewardess's future relationships. A stewardess deprived of the captain's power may become jealous and quarrel."

P6: "There may be jealousy because we know each other on the plane. There are bold compliments from passengers. If your partner is with you, there may be a problem."

P8: "I think that romantic relationships at work have more negative results. In romantic relationships, an employee with a high position may favor his or her lover. This situation creates unrest and injustice among crew members."

P9: "Women are harmed more after romantic relationships. As a result, women may continue to work but still be subject to gossip. In our society, they talk behind *women's backs. Men are more comfortable in this regard. In addition, if romantic relationships are reflected on social media and damage the corporate impression, dismissal may occur."*

P3: "The romantic relationship between someone from the upper management and someone from the cabin tires the stewardess a lot. It would be a big problem if the manager and stewardess romantic relationship got out. Respect for the manager decreases or he may lose his job. I have seen nepotism in the manager-stewardess relationship. A bad manager-hostess relationship will unseat the manager."

P7: "You should continue to behave professionally after the relationship ends. In negative relationships, there are couples who change their ways when they see each other and do not greet or talk. There are negative relationships that lead to fights or jealousy. This situation may lead to dismissal. My three relationships ended well."

P2: "Romantic relationships can harm the seriousness of business. Even if employees do their job, they can do it sloppy. If a stewardess has a lover in the cockpit, the stewardess may disrupt her work in the cabin. In such cases, the stewardess intends to finish her work as soon as possible and go to her lover."

P3: "I have witnessed many fights between the pilot's wife and the stewardess. Sometimes the stewardess' lover may quarrel with the pilot. The marriage of married pilots may break down. I've seen too many married playboy pilots."

P10: "A woman's low position is an important factor in her being harmed after intercourse. Women suffer more than men in terms of emotional pain, labeling and exclusion. Men generally do not suffer much because they start relationships for flirting purposes. The aim of men is sexuality."

P4: "Sometimes there is competition between pilots and stewards due to romantic relationships at work. This competitive situation may cause pilots to exhibit unethical or negative behavior towards stewards during the performance of their duties. This situation is very negative for CRM (Crew Resource Management)"

According to participant statements, it appears that workplace romance has more negative results (85%) than positive ones (15%). Jealousy, emotional harm to stewardesses, dismissal, damage to the corporate image, deterioration of work relations, and unsafe employee behavior are among the important negative results of workplace romance. As a result of negative romantic relationships, men are less affected and indifferent than women; On the other hand, it has been observed that women face more harmful results such as bad epithets, gossip, and dismissal. However, it has been observed that negative romantic relationships have damaging results for organizational relationships, such as divorce, competition between employees, fighting, and loss of authority.

4.5. Theme 5: Management of workplace romance

Theme 5 was examined under two categories: individual and organizational perspectives. The distribution percentage of the theme of management of workplace romance, which consists of 40 codes, according to categories is presented in Figure 5.

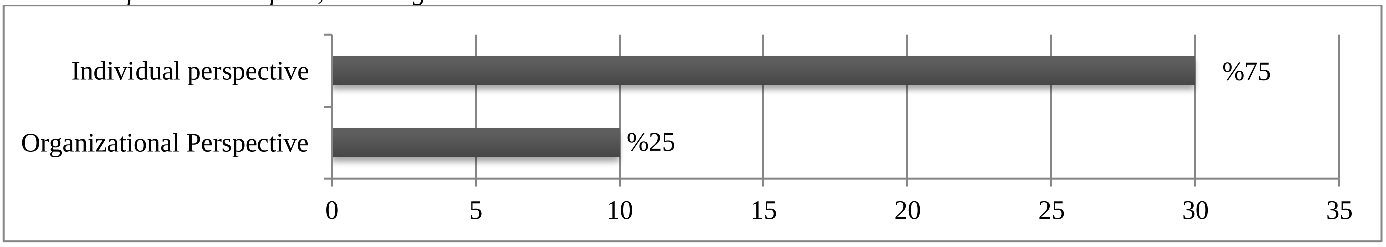

Figure 5. Management of workplace romance

Individual perspective

P5: "It is quite natural to have a romantic relationship at work as long as there is no indifference and things are not disrupted. These are normal things that occur in human nature."

P4: "Romantic relationships are not harmful to the organization. However, there must be certain rules in order for these relationships to occur in this workplace. If that happens, it will have positive results."

P2: "I consider romantic relationships at work normal as long as they are not diverted. Where there are men and women, there are bound to be romantic relationships."

P10: "Workplace romance is quite natural and should not be a problem. These are normal where men and women work together."

P8: "If partners are distracted by their romantic relationships during work and this has a negative impact on their work, I intervene. We need to be constantly careful while flying. Romantic and sexual approaches can be very distracting in an environment where even reading books is prohibited."

P9: "If there is a problem with people having romantic relationships on my plane, I can intervene or report it."

P4: "When there are romantic relationships during the flight, indifferent behavior is often displayed and things are disrupted. Like the management, I do not welcome this."

P2: "Romantic relationships between married employees are not tolerated among friends."

Most participants find workplace romance natural and do not object to romantic relationships. However, participants think that in order to manage romantic relationships at work, these relationships should be lived within the framework of ethics and organizational rules. It was observed that the participants agreed that employees who disrupt their work or exhibit negative behavior due to romantic relationships should be intervened. Participants do not find romantic relationships between married employees right in terms of general moral rules.

Organizational perspective

P5: "Flirting is not something that can be prevented. The company does not object to romantic relationships that are balanced and do not cause problems. People get married and have children thanks to these flirting."

P11: "The company generally does not create a problem with romantic relationships or ignores them. However, if these relationships damage the company's corporate reputation, the company intervenes. The company has no rules regarding *romantic relationships. He evaluates it according to general moral rules."*

P5: "The company does not get involved in romantic relationships if it does not disrupt the flight task, if there are no complaints from the passengers, and if there is no incident that will spoil the corporate impression of the company. But if gossip arises due to these relationships and the corporate impression is damaged, the company will intervene."

P8: "There is no corporate policy against romantic relationships in the workplace. But if these relationships reach a stage where they disrupt business, the partners are warned."

P1: "Those who have relationships in our workplace are not viewed negatively. Our company generally wants to support them psychologically."

P9: "It is difficult to implement the love contract in our industry."

Within the framework of managing workplace romance, it has been observed that organizations mostly remain neutral and ignore these relationships. However, at the point when romantic relationships begin to harm work relationships, organizational interventions can be made against these relationships. In some cases, psychological support is provided by the organization to employees who are harmed by romantic relationships. In order to manage romantic relationships in the workplace correctly, it may be beneficial for organizations to explain and implement ethical rules on this subject. However, it has been observed that love contracts developed to manage emotional relationships at work are not very applicable in our country and are not accepted by employees.

5. Discussion and Conclusion

Workplaces are social spaces where employees who come together for organizational purposes spend most of their time during the day. Employees establish both business and social relationships during the execution of organizational activities. Workplace romance has become an important phenomenon in the organizational behavior literature due to reasons such as the increase in the number of female employees today compared to the past, the fact that male and female employees spend long time together at work and teamwork. Workplace romance refers to emotional relationships shared between two employees in a workplace, involving spiritual and physical attraction and sexual desires being at the forefront. In romantic relationships, which are different from friendship, there is intense sharing between employees in terms of liking, closeness, interest, affection and love (Ouinn, 1977; Pierce and Aguinis, 2001; Powell and Foley, 1998). In this study, conducted in the light of literature review, the concept of workplace romance was tried to be examined in depth with qualitative research method on a sample of 11 flight attendants working in the civil aviation sector in Turkey. The data obtained from the participants through interviews were subjected to content analysis. As a result of the analysis, five main themes regarding the concept of workplace romance emerged. These themes; factors affecting workplace romance, factors obstructing workplace romance, types of romantic relationships, results of workplace romance and management of workplace romance.

When the factors affecting workplace romance are examined; Expectations related to gender, the nature of the flight task, similar characteristics of the flight crew, place-based physical and social interaction, and passenger and cabin crew interaction have been shown to affect workplace romance. In particular, male and female cabin crew's demands for romantic relationships at work differ. Consistent with the findings in the literature (Quinn, 1977; Çoban, 2020), mostly men use it for excitement seeking, flirting and adventure; Women, on the other hand, want to gain power within the organization, get married, or enter into a romantic relationship for emotional sharing. However, it has been observed that there are also flirtatious stewardesses who seek excitement and adventure like men. It has been observed that the similar characteristics of the flight crew, the friendly communication environment, the employees' ability to understand each other, teamwork and interaction with passengers are important factors affecting workplace romance. Galley has been seen as the most suitable place for flight attendants to have close physical contact and sincere communication.

It has been determined that some factors at work obstruct romantic relationships. Factors such as being task-oriented on short flights, constant change of flight crew, high status of female employees or managers, and high institutionalization prevent romantic relationships. It has been observed that romantic relationships, especially in which women have a high position, are extremely limited. Generally, male employees prefer to have romantic relationships with women who are lower than themselves in position. There may be two important reasons for this situation: female employees generally work in low positions in the workplace (Appelbaum et al., 2007) and men see women's high status as a threat to themselves.

When the types of romantic relationships experienced by flight attendants at work were examined, it was seen that there were hierarchical, between counterparts and harmful romantic relationships. It has been seen to observed that there are more hierarchical relationships among these relationships. Hierarchical romantic relationships occur especially between employees with different positions and are relationships focused on gaining power within the organization (Lickey et al., 2009). According to the findings, hierarchical romantic relationships that are frequently seen occur between the captain pilot and the cabin chief or flight attendants. The desire to gain power in hierarchical romantic relationships can damage organizational relationships (Segal, 2005). Since pilots are higher than cabin crew in terms of salary and position, pilots become especially attractive for stewardesses. It has been observed that romance between colleagues occurs mostly among cabin crew members. Romantic relationships between counterparts include spending time together for a long time, teamwork, solidarity and similar features (Shellenbarger 2004; Powell and Soley, 1998; Powell, 2001). From this perspective, it can be considered natural to have romantic relationships between cabin crew who constantly work side by side and are in solidarity. Finally, romantic relationships involving married employees are not seen as appropriate or ethical by other employees, but it is a fact that this type of relationship is experienced among employees.

Workplace romance have been shown to have positive and negative results. According to the findings, the positive results of workplace romance are limited. Work motivation, sharing loneliness, marriage, solidarity, gaining power within the organization and organizational belonging are the positive results of romantic relationships at workplace. Romantic relationships have been shown to have many negative results. Jealousy, emotional harm to women, dismissal, disruption of business relationships, and unsafe behavior are among the important negative results of romantic relationships. However, when romantic relationships end, harmful employee behaviors such as low productivity, retaliation, sexual harassment allegations, cynicism, and hostility may be observed in employees (Greenwald 2000; Schaner 1994; Balaban. 2019).

Flight attendants evaluated the management of workplace romance from individual and organizational perspectives. When evaluated from an individual perspective, participants mostly see workplace romance as a natural phenomenon. Participants who are against romantic relationships at work are in the minority. However, participants think that romantic relationships at work should be lived in accordance with the organization and general ethical rules. From an organizational perspective, romantic relationships are generally ignored unless they cause harm. According to Quinn (1977), ignoring is one of the general reactions of managers to workplace romance. However, the organization's code of ethics has been shown to be a tool in managing workplace romance.

The findings of this study, which evaluated the perceptions of flight attendants on workplace romance in the aviation industry, are thought to be generally in harmony with the basic studies in the literature (Quinn 1977; Powell and Foley, 1998, Pierce and Aguinis, 2003; Lickey et al., 2009). As a general result; It is thought that workplace romance is a reality of modern business life and that workplace romance should be managed due to its individual and organizational results. In organizational activities, especially managers should act by taking these two basic results into consideration. Ignoring workplace romance or imposing criminal sanctions against romantic relationships will negatively affect employees' work motivation and organizational relationships.

Conducting this study with a qualitative research method on a limited number of flight attendants may create limitations in terms of generalization of the findings. Because in the study, the concept of workplace romance was tried to be examined in depth on its own. Other limitations of the research include the difficulties experienced by employees in conveying their experiences due to strict organizational rules and the biased answers they gave. In this context, the concept of workplace romance can be examined on different employee groups and with different variables. Since workplace romance has more negative results, the relationships between negative employee behaviors such as revenge intention, organizational cynicism, negative workplace gossip and intention to quit and workplace romance can be examined. It is thought that the research results will contribute to the literature on the concept of workplace romance and organizational behavior in the aviation industry.

Ethical approval

Ethics committee approval was received for this study with the decision of the Istanbul Gelişim University Ethics Committee Presidency meeting dated 20 October 2022 and numbered 2023-08.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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The Interaction of Global Economy Mobility on the Financial Performance of Flagged Airlines

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Abstract

This study examines the impact of global economic mobility and domestic production on revenue and EBITDA, which are income statement performance indicators of flagged carrier's airline companies. The research question is whether the global economic trade mobility and domestic production will lead to an effect in the number of individuals traveling, and thus eventually affect the revenue and profitability performance of airline companies. There are studies in the literature that have selected macroeconomic indicators as affecting travel volume and financials. In this study, trade openness and direct investments represent the global economy's mobility. Short-term interest rates, oil prices and exchange rates are included in the model as a control variable. The results of the panel model indicate that trade openness have a positive effect on firms' revenues. Airline companies should develop their financial forecasts by monitoring the macroeconomic indicators that have shown significant results from empirical analysis.

1. Introduction

The global economy is currently undergoing a period of significant transformation. This is having a notable impact on the airline industry. Factors such as the growth of global mobility and shifts in production are influencing the performance of flag carrier airlines. In particular, the adoption of economic expansion policies by governments and efforts to boost domestic production may lead to an increase in the number of individuals traveling. This, in turn, affects the performance of airline companies.

In the literature, the effects of global economic mobility and domestic production on travel and the airline industry have been examined from various perspectives. Studies such as Adıgüzel (2013) and Şahin (2021) emphasize that trade openness and direct investments play a pivotal role in the process of integration into the global economy. Research on the impact of the components of economic globalization on airline companies shows that trade openness and global investments, such as direct investments, are important. Kulendran and Wilson (2000) argue that trade openness and real income are key components in explaining business travel. There are also studies on the critical role of air transport in economic growth. Eğilmez (2020) emphasizes the long-term relationship between the air travel export volume and economic growth. Choi (2023) analyzes the impact of GDP growth on air traffic volume, finding that GDP growth leads to an increase in passenger and cargo volume. Furthermore, Hazel et al. (2014) indicates that airline revenues in the United States are closely related to nominal GDP. They posit that economic growth increases both business and leisure travel demand.

Earnings before interest, taxes, depreciation, and amortization (EBITDA) is an important income statement element in measuring the performance of firms. EBITDA is a metric that is frequently employed to assess the profitability of a firm's primary operations, as it excludes certain elements that are not directly related to the firm's core facilities. EBITDA is a performance indicator that is used for a variety of purposes, including measuring equity, managing performance, and valuing companies. This metric reflects the profit that a business generates from its core activities, allowing a clearer assessment of its financial position and performance (Bouwens et al., 2019).

The novelty of this study is to examine the effects of the global economy and countries' production on flag carrier airline companies in more detail. While the existing literature has examined the impact of economic globalization on the airline industry, this research distinguishes itself by specifically analyzing the role of trade openness, foreign direct investment and economic growth on the revenue and EBITDA performance of major flag carriers from economically significant countries in several regions, including North America, Europe, Asia and the Pacific.

In this research, revenues and EBITDAs of 10 major flag carrier airlines operating in North America, Europe, Asia and the Pacific region are obtained from their annual financial reports, from 2009 to 2022, in USD and assigned as dependent variables in the panel models. Selected flagged airlines are Air Canada, Air China, Air France, Australia Qantas, Japan Airlines, Korean Airlines, Germany Lufthansa, Russia Aeroflot, Singapore Airlines, Turkish Airlines. The key consideration in selecting these airlines is that they represent flag carriers with substantial revenue and significant positions within the aviation industry. Furthermore, their home countries have considerable economies and are influenced by global mobility. The relevant macro variables of the countries of the flag carrier airlines' flags are added to the model as control independent variables such as bond interest rate, exchange rate USD over local currency and oil. In addition, the dummy variable representing the Covid-19 period is also included in the model as an independent variable. Two model are established; one is revenue, and the other is EBITDA as dependent variables. Results of the model selection tests the pooled OLS model is found to be statistically appropriate for revenue model. The findings of the panel model shows that trade openness positively affect firms' revenues. The control variable exchange rate, oil and Covid-19 dummy variable are also significant in the revenue model. However, there is no significant model for EBITDA among the numerous models tried. It is recommended that flagged airlines consider the trade openness policies of the countries of which they are a part when planning their budgets.

This study aims to understand the effects of countries' macroeconomic factors such as trade openness, direct investments and economic growth on the revenue and EBITDA performance of their flagged airline companies. In this context, it makes an important contribution to a deeper understanding of the effects of the global economy on the airline industry and reveals role these effects play on the performance of airline companies. A review of the literature, the data and methods, the study's findings, and conclusions follow.

2. Literature

The literature examining the impact of the global economy and production on airline companies and travel reveals the significant effects of the components of economic globalization on the airline industry. Particularly, the effects of trade globalization and investment, which are components of economic globalization, on airline travel have been observed. In this study, the variables representing global economic mobility are chosen as trade openness and direct investments. Adıgüzel (2013) and Şahin (2021) emphasize that trade openness and direct investments, which are elements of economic globalization, play a key component role in the process of integration into the global economy. Dorman (2000) argues that economic globalization is measured by the increase and development of international trade which is measured by the ratio of foreign trade (sum of imports and exports) to GDP, known as the openness index. Although trade openness is measured by different methods, this is the most popular method (Fujii 2017; Balavaca & Pughb, 2016). Wiredu et al. (2020) and Alabi (2019) state that foreign direct investment (FDI) ensures economic growth and integration with international trade, and in this context, FDI facilitates the integration of countries into the world economy. As a proxy of the global economy, FDI and trade openness are included as independent variables in this study's models.

Eğilmez (2020) investigates the long-term relationship between export volume, air transport and economic growth, emphasizing the critical role of aviation in economic growth. Kulendran and Wilson (2000) examine the economic variables affecting business travel to Australia, finding that trade openness and the real income of the source country are important factors in explaining business travel. Choi (2023) analyses the relationship between GDP growth and air traffic volume through the case of Incheon Airport (ICN). The findings indicate that GDP growth leads to an increase in passenger and cargo. Additionally, Hazel et al. (2014) report that airline revenues in the US are closely related to nominal GDP. Furthermore, they claim that economic growth increases business and leisure travel demand. Pamungkas and Suhadak (2017) examine the impact of macroeconomic variables (exchange rates, GDP, and inflation) on the profitability of the Asian airline industry, concluding that economic growth (GDP) plays an important role in increasing the profitability of airlines. Elien Van De Vijver et al. (2014) examines the interrelationship between trade and air passenger traffic, and finding that trade facilitates air passenger traffic, vice versa. Tsui and Fung (2016) investigate the causality relationship between business travel and trade volumes between Hong Kong and Mainland China, Taiwan, and the US. Their results demonstrate that business travel has a determinant effect on trade volumes. Tanaka (2019) emphasizes the critical role of transport infrastructure in economic activities, stating that more frequent flights increase new foreign direct investment (FDI) inflows in Japan.

A review of the literature reveals no direct link between revenue and oil prices. However, they indicate that oil price risk has a significant, strong and widespread negative impact on airline share prices. This suggests that variations in oil prices have a major effect on the airline business. The negative impact of oil price risk on airline share prices is found to be significant, strong and pervasive, as well as a worrying exposure to US dollar currency risk (Horobet et al., 2022). Mollick and Amin (2021) conduct a study showing a positive relationship between seat occupancy rate and stock returns, but they demonstrate that this relationship weakens with oil prices. Additionally, the study reveals that the impact of oil prices is asymmetric, with increases in oil prices having a more pronounced effect than decreases. Empirical findings from Hsu (2017) indicate that fuel price shocks have a statistically significant negative impact on airline stock returns. Furthermore, the study demonstrates that fuel price shocks have a stronger effect on airline stock returns during periods of rising fuel prices, but this interaction is not observed during periods of falling fuel prices. Alıcı (2024) analyzes the daily macroeconomic data of 14 airlines from 2009 to 2018, revealing significant relationships among variables including oil prices, interest rates, and airline stock prices. He also analyzes 11 conventional airline firms operating between 2009 and 2019 to determine the relationship between financial failure, calculated using the Altman Z-score, with exchange rates and interest rates. This highlights the importance of interest rates and exchange rates in airline financials (Alıcı, 2023). The extant literature indicates that oil prices, interest rates, and exchange rates exert a significant influence on the financial performance and financial structure of airline companies. Therefore, these variables are also included as independent variables in the empirical models.

Literature addresses the impact of the global economic mobility and domestic production on the performance of airline firms from various aspects and reveal the effects of factors such as economic growth, trade openness, and direct investments on the airline industry. A review of existing literature indicates a positive correlation between economic growth and airline revenues. Moreover, a rise in open trade is linked to an increase in aviation sector earnings. Similarly, the expansion of direct investments also exerts a positive influence on airline revenues. Nevertheless, it is also emphasized in the literature that oil price risk is a source of concern. Evaluating these factors together is important for understanding the revenues of the airline industry. The variables selected in the study are chosen from among similar variables mentioned in the literature aligned with the research's purpose.

3. Materials and Methods

This part of the study contains the data used for employed and the research method for panel modelling. All calculations are performed using the R statistical program.

3.1 Data

Trade openness, direct investment and growth variables are accepted as representative variables in this study as indicators of a country's global trade activities. In addition to these, bond interest rate, West Texas Intermediate oil price and exchange rates (USD over local currency) which is thought to affect the revenue and profitability of the airlines, are included in the model as control variables. The selected macroeconomic data of the countries belonging to flag carrier airlines are downloaded from the World Bank website (Table 1). Revenue and EBITDA data from 2009 to 2022 are obtained annually from the facility report of 10 major flag carrier airlines in Europe, North America, Asia and Pacific region. All revenue and EBITDA values are converted to USD from local currencies. The financial reports of Lufthansa and Air France airlines are in Euros instead of USD, so their values are converted to USD at the average annual cross rate. Canada, China, Korea and Russia flagged airlines reported their numbers in local currency in their annual reports, and these are also converted to USD, too. Figures 1 and 2 show the annual revenues and expenses of the companies in USD. Due to the Covid-19 effect, revenues and EBITDA decreased in 2020 and beyond. To eliminate this effect in the model, a dummy variable representing the post-Covid period is used for the years 2020 and 2021.

Table 1. Meta Data Description.

Variable	Description
REV_USD	Flag Airlines' Revenues in USD.
EBITDA_USD	Flag Airlines' EBITDA in USD.
FDI	Foreign direct investment, net inflows in USD.
Openness	Exports of goods and services + Imports of goods and services in USD.
GDP	GDP (annual) in USD.
BOND	Short-term government bond interest rate (1 year).
EXC	USD/Local Exchange rate.
WTI_USD	West Texas Intermediate oil price in USD.

To ensure the integrity of the constructed models, it is essential to check for stationarity in the financial series. To avoid potential unit roots and non-stationary conditions, a percentage return transformation (R) is applied to the variables (Equation 1). The changes in value between the variables are analyzed using the models applied in this context.

$$R = \frac{X_t}{X_{t-1}} - 1 \quad (1)$$

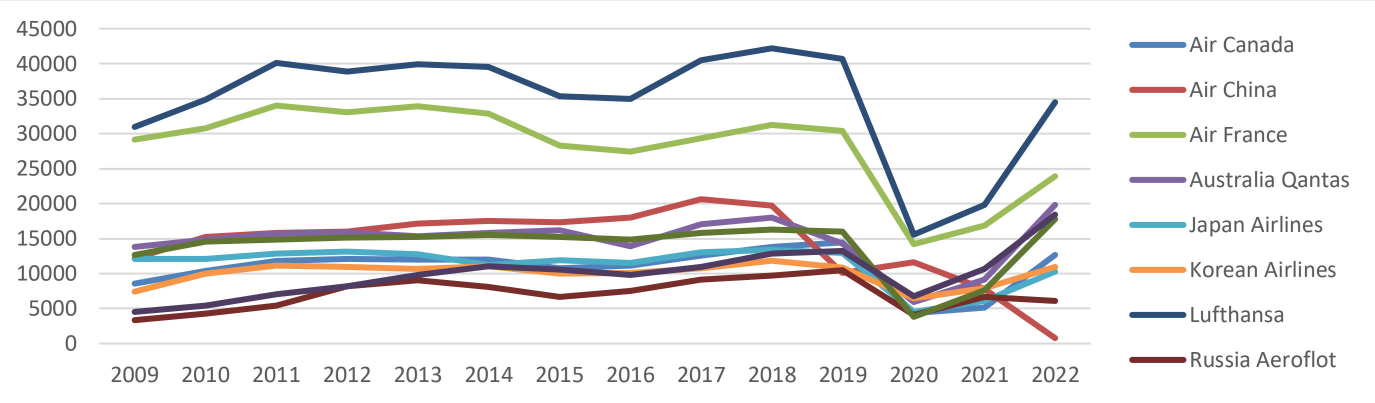

Figure 1. Flagged Airlines' Revenue (in Million USD), * Compiled by the author.

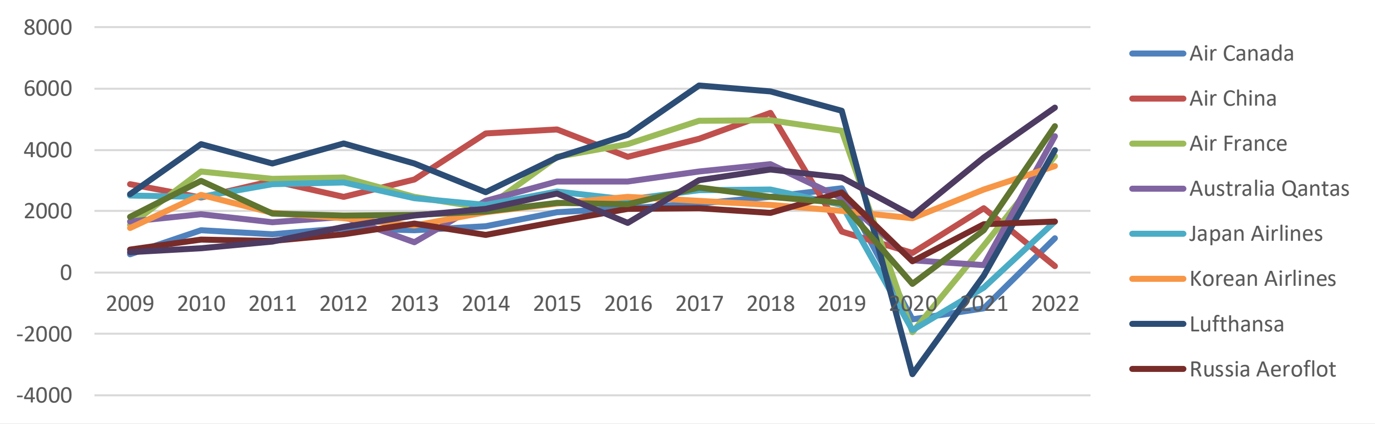

Figure 2. Flagged Airlines' EBITDA (in Million USD), * Compiled by the author.

3.2 Panel Regression

A typical specification of the simple linear model used in panel data regression analysis, where the dependent variable Y is stated as a linear function of the independent variable X and an error term u, is as follows (Equation 2):

$$Y_{it} = \alpha_{it} + \beta_{it} X_{it} + u_{it} \quad (2)$$

Panel data include time periods and cross-sectional dimensions. In formula, i is cross-sectional units: 1, 2, ..., N, t is 1, 2, ..., T time periods, Y_{it} is the value of the i'th unit of the dependent variable at time t, X_{it} is the value of the i'th unit of the independent variable at time t, u_{it} is the error term with zero mean and constant variance, and β is the slope coefficient. In this study, the variables of the panel model are used as in equation 3 and 4, as variables follows, D_Revenue is flagged airlines' revenues in USD, D_EBITDA is flagged airlines' EBITDA in USD, D_FDI is foreign direct investment inflows, D_GDP is GDP growth (annual %), D_Openness is exports of goods and services + imports of goods and services in USD, D_Bond is short-term government bond interest rate (1 year), D_EXC is the USD over local currency exchange rate, D_WTI is the West Texas Intermediate oil price in USD and a dummy variable representing the covid-19 period is also included in the model (Equations 3 and 4).

$$D_{Revenue_{it}} = \alpha_{it} + \beta_{1it} D_{FDI_{it}} + \beta_{2it} D_{Openness_{it}} + \beta_{3it} D_{GDP_{it}} + \beta_{4it} Dummy_{it} + \beta_{5it} D_{Bond_{it}} + \beta_{6it} D_{EXC_{it}} + \beta_{7it} D_{WTI_{it}} + u_{it} \quad (3)$$

$$D_{Ebitda_{it}} = \alpha_{it} + \beta_{1it} D_{FDI_{it}} + \beta_{2it} D_{Openness_{it}} + \beta_{3it} D_{GDP_{it}} + \beta_{4it} Dummy_{it} + \beta_{5it} D_{Bond_{it}} + \beta_{6it} D_{EXC_{it}} + \beta_{7it} D_{WTI_{it}} + u_{it} \quad (4)$$

The concept of cross-sectional dependence in panel data analysis pertains to the interdependence among units (e.g., countries, firms, or individuals) in a panel data set. In other words, variables within one unit can influence variables in other units. The presence of cross-sectional dependence can give rise to several challenges in panel data models. These include the potential for estimation bias and inconsistency, which can result from cross-sectional dependence. To ascertain the cross-sectional independence in panel data, it is necessary to consider both the time and cross-sectional dimensions of the series. The Breusch and Pagan (1980) CD-LM test can be employed when the time dimension of the panel is greater than the cross-sectional dimension (T>N). Conversely, the Pesaran (2004) CD-LM test can be applied when the time dimension is smaller than the cross-sectional dimension (T<N) or when the time dimension is equal to the cross-sectional dimension (T=N). In this study, given that T (Year) = 13 and N (Airline) = 10, the Breusch and Pagan (1980) CD-LM test is performed, which adheres to the T>N constraint.

Panel data, which are a combination of cross-section and time series data, also exhibit time series characteristics similar to those of their individual components. Consequently, the same statistical problems that arise in time series analysis are also evident in panel data studies. In panel data analysis, it is expected that the series should be stationary, as this is also the case with time series. The unit root tests, employed to ascertain the stationarity of the sample series in panel data analysis, are categorized into two distinct groups: first-generation and second-generation panel unit root tests. This classification is based on the presence or absence of cross-sectional dependence among the units comprising the panel. In this study, the Cross-sectional Augmented Dickey Fuller (CADF) test, one of the new second generation unit root tests proposed by Choi (2001) and Demetrescu, Hassler and Tarcolea (2006), is employed to analyze series exhibiting cross-sectional dependence.

As in regression analysis, the assumption of no correlation between the errors of different observations is a fundamental a priori expectation of panel data analysis. If the error terms of the series in the model are correlated with each other, this is called autocorrelation or serial correlation. Prior to proceeding to panel regression analyses, it is necessary to investigate whether there is autocorrelation in the model. If the probability value of the panel autocorrelation test statistic is lower than the desired confidence level (1% or 5%), the null hypothesis is rejected and the alternative hypothesis (H1) is accepted (Breusch, 1978; Godfrey, 1978; Wooldridge, 2010). This indicates that there is autocorrelation between the series used in the data set.

Regarding panel data analysis, especially in pooled OLS models, the presence of a high degree of correlation between explanatory independent variables is referred to as multicollinearity. This situation indicates an undesirable situation in regression analysis. The Variance Inflation Factor (VIF) is employed to determine the extent of multicollinearity. The variance inflation factor (VIF) for X_1 is calculated using the following formula: $VIF(X_1) = 1 / (1 - R_1^2)$. This is derived from the regression model, where each independent variable is formed with other independent variables. A VIF value less than 5 for each independent variable indicates that it is not highly correlated with other independent variables.

Three methods can be used to estimate the model using panel regression as the estimation method for both time and cross-sectional data. These methods are the Pooled Panel Data Method (OLS), the Fixed Effects Method and the Random Effects Method. If it can be assumed that the coefficients between time and cross-sections are constant, the model can be constructed with pooled panel data analysis. In this instance, the most straightforward approach is to disregard the cross-sectional and time dimensions of the pooled data and estimate with the classical ordinary least squares method (OLS). Thus, the fixed parameter (α) and the slope parameters (β) of the independent variables do not vary across units or across units and time but remain constant.

The model in which the coefficients are assumed to vary across units or units and time is called the fixed effects model (Pazarlıoğlu & Gürler, 2007, p. 4). To account for the unique characteristics of each cross-section, it is necessary to assume that the constant coefficients (α) are different for each category, whereas the slope coefficients (β) are the same. The constant coefficient is distinct for each categorical unit, yet the constant of each categorical unit remains unchanged over time. In such a case, estimation can be conducted with the fixed effects model.

In the fixed effects model, it is assumed that the independent variable(s) and the error term are related. In contrast, in the random effects model, it is assumed that there is no relationship between the error term and the independent variable(s). Unlike the fixed effects model, it is stated that the effects arising from the categorical units are not fixed, but random. The random effects model assumes that there is no relationship between the independent variables and the unit effect (Nwakuya & Ijomah, 2017). This distinction is the most significant aspect differentiating the random effects model from the fixed effects model.

Appropriate statistical tests help to decide between models. The F-test can be used to decide on the choice of the pooled

OLS model. The test's alternative hypothesis asserts that there is a difference between the squares of the residuals for the two models under comparison, whereas the null hypothesis claims that there is no difference at all. If the null hypothesis is rejected at the end of the test, it is decided that there is an effect between units and therefore the classical model is not valid and cannot be preferred. The Breusch-Pagan LM test establishes a hypothesis like the F-test using the likelihood function estimator. If the H0 hypothesis is rejected, it is decided that there are unit and/or time effects, that is, the classical model is not appropriate (Tatoğlu, 2012). After determining the existence of unit effects, that is, the classical model is not valid, it is necessary to choose between fixed effects and random effects model. The random effects model is stated by hypothesis H0 in Hausman's (1978) test, while the fixed effects model is stated by alternative hypothesis H1. If the H0 hypothesis cannot be rejected, the random effects model is preferred by deciding that the components of the error term are related to the independent variables.

4. Result and Discussion

The initial descriptive statistics of the variables are presented, followed by the application of cross-sectional independent tests, unit root tests, model selection tests, and multicollinearity tests. Finally, the model coefficient and statistical results are reported.

All the variables used in the analysis are transformed into their percentage return values. Table 2 displays the variables' descriptive statistics. Additionally, the level form of the revenue, EBITDA, FDI, openness and GDP data is submitted in billions of USD. Between 2009 and 2022, the average revenues of the 10 flag carriers increase annually. However, the average EBITDA remains low due to the Covid-19 effect. During this period, the trade openness, growth, foreign direct investment and exchange rates of flagged carriers' countries increase on average. Oil prices also increase on average globally, while 1-year short-term interest rates decrease on average for selected countries.

Table 2. Descriptive Statistics of the Model Variables.

Variable	Mean	Std. Deviation	Min	Max
D_Rev	0.0744	0.3359	-0.7611	1.4845
D_EBITDA	-0.1676	3.8272	-38.4942	17.2922
D_FDI	0.4145	1.9655	-1.9839	18.4683
D_Openness	0.0592	0.1284	-0.3163	0.3531
D_GDP	3.0291	3.2048	-7.5405	14.5197
D_Bond	-0.8665	12.2483	-136.76	23.4020
D_EXC	0.0391	0.1204	-0.1433	0.8122
D_WTI	0.0986	0.4067	-0.4619	1.2112
REVENUE (Bln USD)	15.7591	10.2044	0.7820	42.2013
EBITDA (Bln USD)	2.3384	1.5497	-3.3115	6.0971
FDI (Bln USD)	62.5917	69.3566	-39.7998	344.07
Openness (Bln USD)	1701.1603	1327.7246	362.80	6851
GDP (Bln USD)	3127.3578	3448.8685	239.80	17963

The stationarity of the series in econometric modeling is frequently recommended in the literature for the robustness of the models. In order to confide in which, the series is stationary, differences between the series can be taken into account. In this empirical research, the return transformations and growth changes of the series are analyzed to avoid the unit root risk of the variable series in the models created in this study. The employed panel data is balanced, defined as a panel containing the same number of observations for each observation unit within a given period (in this study relatively airline companies and years).

The Breusch-Pagan LM (BPLM) test is used for cross-sectional independence in panel data analysis. The statistics, p-values and parameters obtained as a result of the test are used to assess whether or not cross-sectional independence is rejected. This test used when time scale samples are more than unit samples in panel data, thus our panel data is so it is. According to the results of the BPLM test in the models where both revenue and EBITDA are dependent variables, the null hypothesis (existence of cross-sectional independence) is rejected, and the alternative hypothesis (existence of cross-sectional dependence) is accepted (Table 3). Based on these results, it is deemed necessary to apply the second-generation unit root tests to ascertain whether the data contains unit roots and to evaluate whether the series is stationary.

Table 3. Breusch-Pagan LM Cross-Sectional independence Test.

Model	Statistics	p.value
Revenue Model	129.66	0.00
EBITDA Model	176.27	0.00

Following the results of the Breusch-Pagan LM cross-sectional independence test, the second-generation panel covariate augmented Dickey-Fuller (panel-CADF) unit root tests are applied to the variables in the model (Choi, 2001; Demetrescu et.al, 2006). There is no unit root in the panel data without constant and trend and with constant and trend (Table 4).

Table 4. Second Generation Covariate Augmented Dickey-Fuller (panel-CADF) Test Results.

pCADF unit root	Revenue			EBITDA		
	None	Const.	Trend	None	Const.	Trend
Test statistic	-14.40	-14.70	-14.03	-14.40	-14.96	-14.28
p-value	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***

*** 1% significance, **5% significance, *10% significance. There is no unit root according to 2nd generation pCADF unit root tests

Panel regression offers three methods for estimating the model and is a useful technique for handling both cross-sectional and time series data. These are the Pooled Panel Data Method (OLS), the Fixed Effects Method and the Random Effects Method. The tests performed to determine the most appropriate panel model among them, reveal that the pooled OLS panel model is the most effective for both the revenue model. The F-Test, Breusch-Pagan LM test, and Hausman test are employed relatively (Table 5) to identify the most suitable model for revenue model. The Chow F-test distinguishes between fixed effects (FE) and pooled OLS models. The F-test statistic is 0.91, with a p-value of 0.52. This indicates that the null hypothesis H0 cannot be rejected, and thus that the pooled OLS model should be preferred. The Breusch-Pagan LM test is used to decide between the random effect model and the pooled OLS regression. The resulting test statistic is 0.49, with a p-value of 0.48, indicating that the pooled OLS regression model should be preferred. Hausman is employed to select whether fixed effects (FE) or random effects (RE) models. The Hausman test statistic is 3.54, with a corresponding p-value of 0.83. Thus, the null hypothesis H0 cannot be rejected, and the random effects model should be preferred. The results of the applied model selection tests, in particular the F-test and BPLM test, indicate that the pooled OLS is the most appropriate model for the revenue panel model.

Table 5. Statistical Tests for Revenue Model Selection

Model	Test	Statistic	p-value	Result
Revenue	**F Test**	0.9061	0.52	POOLED OLS
	BPLM Test	0.4928	0.48	POOLED OLS
	Hausman Test	3.5481	0.83	RANDOM EFFECT

The presence of multicollinearity, which reduces the predictive power of an independent variable according to the degree of its relationship with other independent variables, is tested in the pooled OLS model. Since both the Revenue model and the EBITDA model include the same explanatory variables, the variance inflation factors (VIF) yield similar results (Table 7). The VIF values for the variables are lower than the accepted value of 5. As a result, it is reasonable to conclude that the models' multicollinearity is not a significant problem.

Table 6. Correlation table and VIF statistical result for independent variables of the models.

Variable	Rev	Ebitda	Bond	GDP	FDI	Openness	WTI
Ebitda	-0.02						
Bond	0.12	0.08					
GDP	0.47	0.09	0.08				
FDI	0.04	0.06	-0.29	0.04			
Openness	0.59	0.07	0.08	0.60	-0.02		
WTI	0.61	-0.03	0.07	0.44	0.07	0.76	
EXC	0.08	-0.02	0.09	-0.02	0.08	-0.31	-0.19

Variable	VIF
D_FDI	1.1298
D_Openness	3.5409
D_GDP	1.7602
Dummy	1.2887
D_Bond	1.1263
D_EXC	1.1953
D_WTI	2.9439

The last, serial correlation of the panel model residuals should be tested to avoid spurious regression. The Breusch-Godfrey/Wooldridge test is employed to analyze whether the revenue of the pooled OLS panel model residuals exhibit serial correlation. The 0.28 significance result of the test is found to be above the 5% significance level, indicating that the presence of autocorrelation in the residuals is rejected. For testing heteroscedasticity in the panel data, Breusch-Pagan test (1979) is applied. According to test results, presence of heteroscedasticity in the residuals is also rejected (Table 7).

Table 7. Serial Correlation and Heteroscedasticity test in Revenue Panel Model

Test	Model	Statistics	p.value
Serial Correlation	Revenue	15.4843	0.28
Heteroscedasticity	Revenue	7.152	0.41

Table 8 displays the revenue outcomes of the pooled OLS model. The model's R-square is 60%, and it have an adjusted R-square of 58%, these values are relatively high explanatory indicators for the revenue. The model significance probability value of the F statistic is less than 1%. The coefficients of the model variables D_Openness, D_EXC, D_WTI and Dummy are significant at the 10% level. Among the variables measuring and representing trade dynamism, the coefficient of D_Openness is significant at the 10% probability level, whereas the coefficients of D_FDI and D_GDP are not significant in the model. Trade openness is a variable that increases international air mobility. In particular, the coefficient effect of openness in the model is high compared to other variables, suggesting that it is an important indicator that increases airline revenues. A 1% increase in trade openness is associated with a 0.47% increase in airline revenues. These results are similar to literature (Kulendran & Wilson, 2000; Eğilmez, 2020). However, increase or decrease in GDP and direct investment do not yield significant results in the model. It can be concluded that FDI does not have as significant an effect on airline revenues as openness. In contrast to literature that debates domestic production and air traffic volume relationships (Choi, 2023; Hazel et. al., 2014) in this study the GDP coefficient is not found to be significant in the model. One possible explanation for this discrepancy is the influence of other variables, such as openness and oil and exchange rates, which act as control variables and may affect the revenue. Oil prices effected airline revenues and move in the same direction; increasing 1% in oil prices rise revenue for 0.51%. Although fluctuations in oil prices presented a risk factor for companies and affect their profitability, airline companies would adjust ticket prices to mitigate this risk. The revenue model indicated that the Covid-19 dummy variable is significant at the 1% level and negatively correlated. During the period of the Covid-19 pandemic, there is a marked decline in the volume of air travel. These results show that trade openness, as a global economic activities indicator, is a considerable factor to determining flagged airline's revenue.

Table 8. Panel Pooled-OLS Model for Revenue (D_Revenue)

Variable	Estimate	Std.error	Statistic	p.value
(Intercept)	0.0195	0.0314	0.6201	0.54
D_FDI	0.0011	0.0104	0.1092	0.91
D_Openness	0.4706	0.2811	1.6745	0.10*
D_GDP	0.0031	0.0079	0.3876	0.70
Dummy	-0.3565	0.0601	-5.9313	0.00***
D_Bond	0.0013	0.0017	0.7762	0.44
D_EXC	0.5950	0.1742	3.4163	0.00***
D_WTI	0.5071	0.0809	6.2665	0.00***

P-OLS Model Stats:	R2	Adj-R2	F-stat	F-prob
	0.60	0.58	184.68	0.00***

*** 1% significance, **5% significance, *10% significance

To establish the EBITDA model, the same test steps are repeated as the revenue model. Numerous panel models are tested with different combination of control variables. Nevertheless, coefficient results are not significant with low r-squares. As the statistics of the EBITDA model does not give any significant results, it is not considered appropriate to present them here in the form of a table. There is no unanimous view on EBITDA in the literature. Several potential reasons may explain this outcome. EBITDA is a profitability information that assesses the company's degree of financial efficiency. Internal dynamics of the company may be more important than the external macroeconomic variables in determining EBITDA. The impact of internal dynamics of the company such as management processes, input costs, and sales strategies on EBITDA may be more forceful than macroeconomic variables. In conclusion, the macroeconomic variables used in the study are found not to be significantly related to EBITDA.

Kulendran and Wilson (2000), in their research on the economic variables affecting business travel, find that trade openness is a significant factor in explaining business travel. The findings of this study indicate that trade openness plays a significant role among the factors affecting airline revenues similar to the literature. The results of the model demonstrate that trade openness is associated with a notable increase in airline revenues and has a more pronounced impact than other variables. Thus, trade openness enhances international travel mobility in the airline industry, thereby positively affecting revenues. Conversely, GDP and direct investments do not yield significant results in the model. This indicates that the effects of GDP and direct investments on airline revenues are not as significant as that of trade openness. Nevertheless, the impact of oil prices on revenues is considerable, with increases in oil prices resulting in a corresponding rise in airline revenues. This finding indicates that oil prices represent a pivotal factor in airline revenues and that airlines are responsive to these price fluctuations. Furthermore, a significant negative correlation is observed between the Covid-19 era dummies and a significant drop in air travel. This suggests that contingencies, especially pandemic outbreaks, negatively affect the revenues of the airline industry.

5. Conclusion

The global economy is undergoing a period of rapid change, which is significantly impacting the airline industry. As a result of this change and transformation, various factors affecting the performance of airline companies are emerging. Research in the literature shows that factors such as trade openness, direct investments and economic production growth impact the airline industry. This study aims to investigate in further depth the effects of selected macro factors representing global economic mobility and volume on the revenue and EBITDA performance of the flagged carrier airlines.

The findings of the panel model study indicate that international economic mobility and volume have a positive impact on airline revenues. As a result, trade openness leads to an increase in airline revenues, furthermore, control variables like oil and exchange rates positively affect revenues. However, factors such as direct investment and domestic production do not have a significant effect on revenues. In addition, the study reveals that the impact of the COVID-19 pandemic has a detrimental effect on revenue. Although there is no direct relationship between the research variables in the existing literature, a similar relationship is observed between the increase in trade openness and airline revenues due to the connection between trade openness and airline travel volume. Moreover, GDP and FDI do not have a significant impact on revenue, and therefore, this result is not directly supported by the literature.

In the analyses conducted for EBITDA performance, financial indicators do not have the same degree of influence as revenues. The macro variables considered in the model do not have a significant effect on EBITDA. This may be since the internal dynamics of companies may have a more pronounced effect on EBITDA. Further research could investigate the relationship between these variables.

This research primarily provides flagged airline companies with valuable insights that can inform the strategic planning of their budgets and financial forecasts. By closely monitoring the key macroeconomic indicators that have been highlighted, flagged airlines are better positioned to navigate economic fluctuations and sustain financial health. For policymakers, the findings emphasize the importance of considering the effects of trade openness and economic policies that promote global mobility, as these factors directly influence the revenue generation of national airlines. Additionally, investors can leverage the study's results to more accurately assess the financial resilience of airline companies in response to macroeconomic changes, particularly during times of economic uncertainty.

In conclusion, this study sheds light on the effects of global economic factors on revenue and EBITDA performance in the airline industry. The study's novel approach, combining panel models with flagged airlines' financial data and macroeconomic indicators, offers fresh insights that expand upon previous findings in the field. These findings emphasize that global economic factors such as trade openness should be considered when evaluating the revenue performance of airlines.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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An Assessment of an Airline Company within the Scope of Circular Economy Based Waste Management

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Abstract

The rapid growth in the aviation sector has prompted the industry to act and develop new and sustainable business models due to the greenhouse gases and waste generated inherently by the sector. In this context, this study provides an assessment of identifiable areas and determinants of circular economy in an airline company, considering its environmental impacts. As a result of the assessment, it has been observed that the airline company conducts initiatives in reduction, reuse, and recycling, along with the management of cabin materials and waste segregation. Action plans are in place regarding the reduction, substitution, or elimination of single-use plastics in material selection. In order to mitigate both the environmental and economic impacts of paper consumption, the company is undertaking digitalization efforts within its business processes. The weight of aircraft is a crucial factor in the amount of fuel consumed and the quantity of CO2 emissions released. Therefore, airlines prefer to use lightweight materials inside the aircraft to reduce weight. Plastic catering materials are among these lightweight options. Unfortunately, due to the adverse environmental impacts of plastics, reducing their usage and, if possible, phasing them out are essential measures that airlines need to take. Consequently, the airline company under this study has removed the plastic outer packaging of the packaged materials used in the cabin. Furthermore, it continues its efforts to remove plastic materials used during catering services or replace them with biodegradable alternatives.

1. Introduction

Our current economic model is based on the traditional linear economy model, which follows the production, consumption, and disposal of products. However, this unsustainable linear economic model leads to increasing pressure on limited resources and generates significant amounts of waste, pollution, and greenhouse gas (GHG) emissions. The linear economic model, which follows the take-make-consume-dispose approach (Jaeger and Upadhyay, 2020), encourages consumers to continually consume new products. Moreover, this approach yields products with short lifespans, unsustainable outcomes, and residual waste within the system post-consumption, while absolving producers of any responsibility regarding waste management. (Karamustafa et al., 2022).

The traditional production and consumption paradigm poses challenges to the environment, society, and the depletion of finite resources. Globally, consumption rates have increased eightfold over a few decades, and it is projected that global resource use would triple by 2050. The overuse of finite resources has led to environmental degradation reaching unsustainable levels. Cities with dense populations produce 1.3 billion tons of waste annually, and this figure is expected to rise to 2.2 billion tons by 2025 (Jaeger and Upadhyay, 2020).

Estimates suggesting that global consumption has exceeded the planet's capacity for self-renewal by 50% indicate that if unsustainable production and consumption patterns persist, the critical situation would worsen even further in the near future (Veral, 2019). Currently, meeting the needs of the world's population requires 1.75 Earths, and if current consumption and production patterns continue, it is estimated that by 2050, we would need the resources equivalent to three Earths to meet our needs (Global Footprint Network, 2023). As a result of all these negative developments, various driving forces such as customers, investors, regulatory bodies, and other stakeholders are urging companies, governments, and all other organizations to adopt more environmentally friendly practices for solving the problem.

In the circular economy model, which offers an alternative path to the current model, the aim is to maximize the value obtained from the resources used while also striving to keep materials circulating for as long as possible. Moreover, the objective is to minimize environmental and social impacts, reduce economic costs, and generate employment opportunities. In this manner, the circular economy model is building economic, natural and social capital (ICAO, 2024). The circular economy model, is defined as a clean production model where energy and all resources are used efficiently, waste is recycled through an integrated process, and product and raw material reuse is facilitated, leading to almost zero waste formation (Veral, 2019). In the circular economy, the focus is on products re-entering the production line, thus giving producers responsibility for waste management by producing recyclable products (Karamustafa et al., 2022).

The measurement of the social and environmental impacts of companies' activities and how these metrics guide their business strategies and operations, shaping their business models considering these impacts, are among the focal points of today's society, investors, and customers. Companies are now being evaluated not only based on financial data but also on environmental and social metrics by their stakeholders. Impact stakeholders, both internal and external, prioritize understanding which environmental and social contributions lead to companies' economic successes. Sustainability now plays a crucial role in companies' long-term economic success. What is expected from companies is to determine the environmental and social impacts of their business strategies and models at both micro and macro levels and manage their outputs with a sustainable development model (PricewaterhouseCoopers, 2024).

Although the circular economy model proposes a production and management model for the manufacturing sector, there is still a significant lack of development of this model for the service sector. With the increasing momentum in air transportation and the time advantage offered by airlines, they have begun to emerge as one of the most significant players in the service sector in the 21st century. This has led to an increase in passenger capacity, routes, and destinations. However, at the current stage of passenger transportation, the growing number of passengers and destinations place significant responsibilities on airlines regarding the management of both emissions and waste. This encourages airlines to take responsibility for their activities by managing them through sustainable development. Despite the lack of a standardized circular model in the service sector, the circular economy seeks cleaner production and better management of resources. In this context, initiatives such as the adoption of more efficient materials and the reduction of raw materials through 3R (Reduce, Reuse, Recycle) and zero waste initiatives are becoming widespread across Airlines (Salesa et al., 2023). According to Dias et al. (2022), businesses can minimize environmental degradation while maximizing mutually beneficial results, improving brand image, growing market share, and increasing profitability by implementing circular economy concepts like 3R.

Studies on environmentally friendly strategies used in the aviation industry are available in the literature, with a focus on lowering waste's negative environmental effects, meeting legal obligations, minimizing energy consumption and concerning sustainable development. Baxter et al. (2018) investigated Kansai International Airport's waste management from 2002 to 2015 using a comprehensive case study approach. They presented both the annual waste data produced with the empirical data they obtained as a result of the document analysis and presented the changes in the waste amounts in various year intervals statistically with the quantitative data analysis they performed. Baxter and Srisaeng (2022) carried out a similar study for London Gatwick Airport.

Blanca-Alcubilla et al. (2020) performed a case study on Iberia, the Spanish airline's catering service. They concentrated on how reusing packaging and tableware could lower greenhouse gas emissions. Sarbassov et al. (2020) conducted a compositional analysis of the municipal solid waste generated at Astana International Airport with the aim of assessing the greenhouse gas emissions associated with four distinct waste management scenarios. The first scenario outlined the existing state of municipal solid waste management; the second included recycling in 29% of cases and landfilling in 71% of cases; the third scenario called for the complete incineration of municipal solid waste from airports. scenario 4 calls for processing the leftover waste for energy recovery and recycling 29% of it. An analysis of the effects of airport operations on carbon emissions at the macro and micro levels was given by Xiong et al (2023). During the years 1999–2017, 280 prefecture-level cities in China provided a total of 4938 datasets for study. The heterogeneity analysis was examined from several dimensions.

Günerhan et al. (2023) assessed the use of oil from waste tires in aviation gas turbines in terms of fuel properties, emissions, performance and combustion characteristics, considering that the need for alternative fuels in terms of sustainability and renewability. A study focusing on the use of plastic waste-based alternative oil for use in aircraft turbojet engines was also discussed by Lee et al. (2024). By using thermodynamic calculations, they assessed the created high density polyethylene derivative oils' suitability as aircraft fuels and compared them with a range of commercial aviation fuels.

Tjahjono et al. (2023) suggested a novel design approach for managing retail waste at airport terminals dubbed circular airport retail waste management (CAWM). The suggested approach was on the basis of the circular economy 9R framework and could handle waste from airport terminals more effectively and economically. A business process modeling system was created by Sukhorukov et al. (2023) to manage the plan for the collection, transfer, and disposal of municipal solid waste at Moscow Domodedovo Airport. The waste data produced in the cabin in 2019 was used by Guven et al. (2024) to illustrate the potential of Antalya Airport's international in-flight waste to produce valuable products such as fertilizer, energy.

Previous literature has focused on various themes in the aviation sector such as emission reduction, waste management, alternative fuel use, etc. Based on the literature review, further research is needed that evaluates the waste management mechanism of an airline company from many perspectives within the scope of circular economy.

This study focuses on a global airline company's waste management system and its incorporation of circular economy practices into the daily operations. The airline is operating international flights and covering a wide range of geographical areas due to the extensive network of its flight routes. The study examines the circular economy practices implemented by an airline using a framework based on the literature The methods employed by the airline to achieve better environmental performance are derived from responses obtained from relevant departments within the airline, sustainability reports of the airline, and publicly available sources. Based on the information gathered, the airline's performance in seven different categories was calculated and presented through a radar chart.

This study has given airlines operating in the Turkish aviation sector a framework to assess themselves and has added to the literature with the application carried out. The study calculates the airline's score for recycling, upcycling, or handling of various forms of waste and reveals its shortcomings. Therefore, in this respect, it is important as an example of waste management within the scope of the circular economy, which has been given importance by all businesses in recent years.

The structure of this paper is as follows: the next section presents general information about the circular economy. The third section highlights the importance of waste management in a circular economy. In the fourth section, waste management is discussed specifically in the aviation industry. The fifth section explains the basic structure of the methodology in order to assess airline's performance. Finally, results and discussion are presented.

2. What Is Circular Economy?

Circularity has been the guiding principle of nature since the very beginning. The first humans lived in a circular society of scarcity and lack, driven by necessity, in many regions of the world that are still industrially less developed today. This was a non-monetary circular society. With the changing way of living, working and communicating in recent years, society, business world and governments realized that the "linear economy" that emerged in the early industrial revolutions was not financially, socially or ecologically sustainable, and instead, a new approach, the circular economy, emerged. Rather than producing value loss by discarding products and materials after use, the circular economy redesigns products, processes, supply networks, and business models to create, protect, and circulate value Reuse, repair, remanufacturing, and recycling are made possible by the creation of durable items and the recovery of products and resources after use. The "take-make-use-dispose" paradigm is changed into "value cycles" by circular economy strategies, which also replenish ecosystems and resources to produce more with less. (Weetman, 2020).

Preserving and managing the values of assets, such as natural, cultural, human, manufactured, and financial stocks, is the goal of the circular economy. The circular economy is considered the most sustainable post-industrial economy business model available (Stahel and MacArthur, 2019).

The definition of a circular economy is an economic model that seeks to limit the adverse effects of specific raw materials, goods, and assets on the environment while utilizing rational, effective, and efficient resources. Innovation, environmental protection and stewardship, competitiveness vis-à-vis the linear economy, sustainability and regenerative nature of products, raw material supply security, cost savings, improved quality of life, and stable economic growth based on sustainable development are the factors that define a circular economy (Rutkowski, 2022).

The "take-make-use-dispose" model of the linear economy is turning into a circular model at various levels; micro, meso (medium) and macro. At the micro level, environmental management systems are integrated with the reduction of resource use and emissions in a specific process or production facility. At the meso level, a group of manufacturing facilities or sectors may be included in an industrial park or industrial ecology-type system where unusable output from one can feed into another. The macro level includes the development of eco-cities. Unlike the micro and meso level, there are both production and consumption concerns at the macro level and the transformation is expressed at the level of the entire economy (Gheewala and Silalertruksa, 2021). In light of all this information, the circular economy substitutes material reduction, reuse, recycling, and recovery for the idea of "end-of-life" in production, distribution, and consumption processes. The circular economy, then, is an economic framework that operates at three different levels: micro (products, companies, and consumers), meso (eco-industrial parks), and macro (city, region, country, and beyond). Its goals are to create social equality, economic prosperity, and environmental quality for both present and future generations in order to achieve sustainable development. (Kirchherr et al., 2017).

Circulation of materials back into the system ensures that the value of the products is preserved, thus being a better alternative to the widespread linear economic model. The shift from a linear model to a circular model reduces the demand for both raw resource inputs and waste disposal. Natural resource use and waste disposal are two carbon-intensive activities that are closely linked to global warming. Therefore, the circular economy is considered a suitable mitigation strategy to address the issues of resource scarcity, waste management, and climate change. Moreover, the circular economy is seen not only as a viable climate change mitigation strategy but also as an enabler for achieving the Sustainable Development Goals - SDGs (Tuladhar et al., 2022).

Korhonen et al. (2018) demonstrated the win-win-win potential of the circular economy. They argued that the economic, environmental, and social facets of sustainable development are all enhanced by a flourishing circular economy. Additionally, they stated that, by honoring reproduction rates, the circular economy should employ natural ecosystem cycles as a model for economic cycles.

Circular economy type regulations of physical flows of materials and energy will reduce natural inputs to the system and waste and emissions from the system. Costs associated with resources, energy, waste, and emissions—such as additional expenses brought on by environmental laws, taxes, or trash and landfill management—will be decreased. There will be new market, business, and job prospects. Because the value contained in the materials will be used many times, and not just once, as is usually the case in the modern global economic system, the circular economy extends existing business or corporate environmental management systems by promoting cross-sectoral, cross-organizational and cross-life cycle material and energy cascades to achieve the highest possible economic value in resources. Therefore, circular economy is defined as an inter-organizational environmental and sustainability management (Korhonen et al., 2018).

3. Waste Management in Circular Economy

A significant percentage of the world's population is concentrated in urban areas. The large number of people living in urban areas has brought with it various problems such as inadequate water supply and sanitation, air pollution, traffic problems and increasing amounts of solid waste. Most of the population growth occurs in economically developing countries. Although many industrialized countries in Europe, North America and Asia have developed policies to reduce the amount of waste produced, there are still many countries that do not properly manage their solid waste and rely on open dumps for disposal (Diaz, 2017).

Emphasizing that there are some problems that need to be solved regarding solid waste management in developing countries, Diaz (2017) also stated some of the most critical needs as follows: A political will to deal with the problem (waste), a national policy, rules and regulations on solid waste management, adequate resource allocation to solve the problem, educational programs at all levels and, lastly but the most important, implementation of policies regarding the establishment of a circular economy model. Although the "circular economy concept" was formulated relatively recently, the concept is being discussed and tried to be put into practice by public and private sector actors in developing countries. However, most, if not all, developing countries are applying some principles of the circular economy in waste management through "resource recovery efforts".

Circular economy is defined as a closed-loop value chain. In this value chain, it is essential to collect waste through appropriate channels and send it to production units for reuse. Thus, the model ensures sustainability in production and environmental practices by preventing and reducing waste (Gedik, 2020). Aiming to close supply chain loops as much as possible, the circular economy aims to create a sustainable and zero-waste environment, and for this it focuses specifically on the waste hierarchy, from waste prevention at the top to disposal at the bottom. An appropriate waste management system ensures that discarded, worn and/or old products are collected so that they are not left in nature and do not pollute the environment. In addition, such a waste management system ensures that waste is handled appropriately to facilitate re-intake into the system, thus avoiding the extraction of primary materials. Therefore, supporting environmental sustainability, human health, and the shift from a linear to a circular economy all depend on effective waste management. (Ranjbari et al., 2021).

Circular economy is defined as the most sustainable business model for the post-production process. It uses natural, human, cultural and produced stocks to improve the ecological, social and economic factors that create sustainability. “Greening Industry” concepts such as Industrial Ecology and Industrial Common Lives involve the reuse of waste from production processes within a linear industrial economy. These concepts reduce environmental degradation and increase the economic efficiency of production while managing production waste. While waste prevention is part of optimizing the use of objects in the circular industrial economy, waste management is the final stage of the linear industrial economy (Stahel and MacArthur, 2019).

4. Waste Management in Aviation Industry

The airline industry is one of the industries, that is noisy in nature, contributes to climate change with its waste, carbon dioxide (CO_2), NOx and other GHG emissions and causes many environmental problems. In addition to GHG, which are the most important factor in climate change, one of the main problems for the airline industry is the large amounts of waste produced during its operations (Alkhatib and Migdadi, 2021).

According to the research conducted by the Intergovernmental Panel on Climate Change (IPCC), the global airline industry is responsible for 12% of CO_2 emissions from all transportation sectors and produces approximately 2.1 % of human-induced GHG emissions that cause climate change (ATAG, 2024).

Considering the climate crisis and the effects of the airline industry, with increasing environmental awareness in recent years, the airline industry been forced intensify its efforts associated with all aviation activities and operations on consumption, waste and emissions towards a greener, cleaner and more sustainable aviation by reducing the environmental impacts. The aviation industry’s potentially large environmental impact in terms of handling hazardous and non-hazardous waste needs to be addressed by developing and subsequently managing more sustainable environmental practices. Airlines are striving to modernize their outdated waste management systems and recovery processes and are rapidly implementing a wide range of measures to keep environmental impacts to a minimum (Migdadi, 2018).

The airline industry carries out various environmental practices and policies in order to minimize its negative environmental impacts. Alkhatib and Migdadi (2021) divided the environmental actions and indicators carried out by airlines into three main areas. These are operational, environmental and corporate actions.

1. Operational category/area: This includes actions such as route optimization, flight procedure optimization, air traffic management, weight reduction, reduction of use of auxiliary power units (APU), reduction of fuel management, ground operations, waste prevention, CO_2 offset programs, online check-in, reducing flight delays, engine flushing and reducing aircraft weight.
2. Environmental category/area (GHG emissions actions): It includes energy saving in facilities and buildings, sustainable energy use, improvement and replacement of facilities, vehicle and engine operation, maintenance management, recycling, upcycling and recycling of industrial and hazardous waste in aircraft and on the ground, waste management practices such as reuse and water management studies, maintenance, recycling, saving and recovery of facility and building water.
3. Corporate policies and strategies category/area: It includes applications related to the design of vehicles and engines such as aircraft designs, fleet modernization, use of winglets and sharklets, engine modifications and alternative biofuels, electric vehicles in land operations and renewable energy fueled equipment.

Although the circular economy is a developing concept for the aviation sector, the implementation of many circular economy practices in the sector already provides the sector with valuable environmental, social and economic opportunities. Stating that aviation is a sector that expects significant growth, ICAO (International Civil Aviation Organization) expects annual world air traffic to double by 2035 and the sector to grow at an average annual rate of 4.4 percent. According to Boeing and Airbus, the estimate of new aircraft delivered by 2034 will be 38,050 and 32,585 respectively. While all these predictions point to a potential increase in resource consumption, waste and emission production in global aviation, they underline how important the transition from a linear economy to a circular economy is for the sector in terms of contributing to the reduction of negative environmental impacts and associated economic costs (ICAO, 2023). Circular economy principles would enable the transition to circular aviation by creating a framework for re-evaluating the life cycle of every aspect of aviation with a complete, cradle to cradle understanding.

The application of circular economy principles to the aviation sector focuses on three elements: aircraft, flights and airports. The circular economy strategies adopted by airlines in their flight operations include four components of the circular economy as follows (ICAO, 2023):

- Redesign: Redesigning food services to properly separate waste;
- Reduce: Reducing the mass of food packaging and switching guidelines from hard copy to digital;
- Reuse: Reuse of seats and in-car entertainment systems in other systems;
- Recycle: Recycling reusable equipment such as trays, carrier drawers, blankets and serving carts.

In addition to managing GHG emissions for airlines, another top priority issue is waste management. Waste management in airlines is addressed by directly assessing the content of the airlines’ activities. Considering the direct fields of activity, airlines generate waste such as in-flight packaging, paper, textiles, etc. as well as food waste and waste resulting from regular maintenance and use of aircraft.

Concretely, the types of waste resulting from the regular maintenance and use of aircraft are managed by airports or maintenance companies. Therefore, two types of waste are addressed directly in connection with the activities of airlines, which are food waste and other waste (from cabin and ground operations). Other waste includes many different products such as packaging, paper, textile and plastic, and hygienic waste types. It is stated by some researchers that in-cabin waste is the most common type waste for airlines worldwide and 70% of such waste is generated by passengers. On the other hand, food waste resulting from the feeding of passengers and cabin crew is defined as a priority problem by an increasing number of associations and governments due to food waste and the high pollution level it brings (Salesa et al., 2023).

National waste management regulations that reduce pollution apply to all in-flight waste, including newspapers, paper towels, plastic packaging from headphones and blankets, and residual food and drink packaging. (Aviationbenefits, 2023). The International Catering Waste (ICW) regulations, which have been enacted by numerous nations, are the main barrier to airlines' efforts to reuse and recycle more cabin waste. These regulations require international catering trash to follow certain procedures in an effort to lower the danger of plant and animal disease transmission (IATA, 2020).

Many country regulations impose strict controls on food waste from international flights based on animal welfare concerns. Rules formulated to prevent international transmission of certain diseases require airlines to treat food waste as high risk or burn it or bury it in deep landfills, preventing reuse and recycling (Aviationbenefits, 2023). On overseas flights, these stringent regulations prohibit airline food and cabin supplies from being reused or recycled. Cabin waste inspections carried out by IATA and airlines have shown that 20-25% of cabin waste consists of food and beverages not consumed by passengers or cabin crew. Although the volume of in-flight catering decreased during the pandemic, the industry burned or threw away 2-3 billion dollars of resources. While rules limit the industry's capacity to support the Sustainable Development Goals (SDGs), which seek to halve global food waste by 2030, and assist create a circular economy, airlines and catering providers can still reduce cabin waste via improved planning and logistics. (IATA, 2022).

Due to relevant regulations, estimating the approximate amount of food needed to satisfy each passenger's needs and cut down on extra stock is the greatest strategy to improve the efficiency of food products. In order to estimate the amount of food supply needed to meet passenger needs, airlines have started to develop new forecasting algorithms based on artificial intelligence and passenger behavior. Airlines would have precise knowledge of the required amount of meals if meal reservation systems were in place, greatly minimizing wastage. (Salesa et al., 2023).

5. Material and Method

Despite the fact that airlines adopt a variety of steps to carry out the circular economy assumptions (Asmatulu et al., 2013; Blanca-Alcubilla et al., 2020; Sarbassov et al., 2020; Domone et al., 2021; Baxter & Srisaeng, 2022; Dolganova et al., 2022; Markatos & Pantelakis, 2022; Tjahjono et al., 2023; Sukhorukov et al., 2023; Guven et al., 2024; Yang et al, 2024), studies are not yet considered sufficiently the implementation of effective and sustainable practices in flight and ground operations. Therefore, the practices carried out by airlines in order to transition to a circular economy are still open to evaluation. Based on this foresight, in this study, a single case study method was employed by incorporating survey form to collect and analyze empirical data to examine the waste management performance of an airline within the scope of circular economy.

The airline operates international flights, and has operations in many different geographies thanks to the wide flight network. The circular economy practices adopted by the airline to improve waste and material management were examined based on the analysis and classification of specific sustainable practices developed by Salesa et al (2023). The waste and material management practices developed by Salesa et al (2023) and which form the basis of this study, consist of 7 global categories and 23 general initiatives that serve as a reference to focus only on activities related to the circular economy. Table 1 provides descriptions of these 7 categories and 23 general initiatives. Under general initiatives, there are a total of 58 identifiable, circular economy-oriented sub-headings. These were shown in Appendix.

Table 1. Hierarchy of Initiatives

C1. Onboard and ground waste recycling
1. Recycling tracking system
2. Internal auditing in recycling
3. In-cabin waste management system
4. In-cabin material recycling
5. Recycling paper
6. Recycling plastic
7. Recycling cans
C2. Onboard and ground waste upcycling
8. Outdated uniforms to manufacture in-flight products
9. Stuff clothing repurposed
10. Eco-friendly materials
11. Plans to remove plastic
12. New product design reusability
13. New product design reparability
C3. Reducing the use of paper
14. Electronic airway bills
15. Using electronic boarding passes
16. Providing iPads/tablets to reduce paper
C4. Upcycling industrial waste
17. Burning waste to recover energy
C5. Processing hazardous waste
18. Recycling hazardous waste
19. Tracking systems
C6. Upcycling hazardous waste
20. Burning hazardous waste
C7. Food waste management
21. Food stock prediction and eco-friendly packaging
22. Food waste management
23. Food eco-friendly packaging

The information about the airline's circular economy practices based on Table 1 was obtained directly from the relevant respondents in the airline, from the Sustainability Reports published by the airline between 2022-2023, and from information published in public sources. Table 2 includes information about the 4 respondents, who work at the airline company and whose information was consulted. We made sure that the respondents were chosen based on their extensive work background with the airline.

While collecting information from the relevant respondents, a survey form was presented, which included 58 sub-headings of the 7 global categories content prepared by

Table 2. Profiles of the respondents

Respondent #	Department	Position	Experience (Years)
Respondent 1	Sustainability Department	Sustainability Specialist	>10
Respondent 2	Sustainability Department	Corporate Sustainability Specialist	>5
Respondent 3	Waste Management Department	Department Chief	>10
Respondent 4	Catering Department	Specialist	>5

Salesa et al. (2023). Then the participants' response to the implementation status of each subheading were obtained in the following categories:

- Implemented: The initiative is implemented by the airline in all operations and processes.
- Partially Implemented: The initiative has started to be implemented in the airline, but its scope does not yet cover all activities/locations/processes.
- Not implemented: The initiative is not implemented by the airline.
- To be implemented: The initiative has been approved by airline management but has not yet been implemented.

Although many subheadings were answered directly by respondents, the answers were also confirmed with secondary data obtained from sustainability reports shared with the public or other published sources.

6. Result and Discussion

The level of adoption of the applications in the framework in Table 1 by the airline considered in this study is calculated and shown with a radar chart presented in Figure 1. If the subheadings under each category are implemented, they are scored equally, totaling 100 points; in partial implementations, half of this score is taken; in cases of non-implementation or to be implementation, no score is assigned to the subheading. For example, there are 20 subheadings under category C1, and if the implementation of these headings is in question, each one received 5 points. “No plastic bags for in cabin purchases”, “Using the mobile devices and tablets to the cabin crew to make whole snacks and meals sells processes”, “Receipts from in-flight purchases are send through the app not requiring a ticket printing” were excluded from the evaluation, because there are no in-flight sales in the airline.

The airline focuses heavily on initiatives such as recycling plastic, paper and cans, integrates an internal recycling tracking system into its business models to track how waste is managed and uses new environmentally friendly materials to replace these “hard to recycle” elements. Regarding to “C1: Onboard and ground waste recycling”, it has been found that the airline has developed systems to monitor waste management and is working to promote the 3Rs (Reduce, Reuse, Recycle) within the organization. With its regular monitoring systems and regular inspections arising from legal regulations, the airline not only monitors the regular functioning of waste separation practices but also ensures the control of storage areas and inspections of sites. Another notable practice in the airlines is the management and recycling of waste in the cabin. In this context, waste in the cabin is separated and recycled during the flight, and training is given to the cabin crew on how to manage these wastes correctly.

Rather than recycling paper, the airline also prevents the use of paper with the new products and systems it develops. In particular, the development of electronic document correspondence systems prevents the use of paper. At the same time, for plastics, it offers products without plastic outer packaging within the scope of plastic prevention and takes initiatives to replace plastic products with substitute products. In line with all this information, the score the airline received for the “C1: Onboard and ground waste recycling” category was calculated as 90.

“C2: Onboard and ground waste upcycling” shows the airline’s key practices for recycling waste. Focusing on using ecological materials, the airline uses biodegradable materials instead of materials that cannot be easily recycled. On the other hand, there appears to be a high movement focusing on reducing and eliminating the use of plastic in flights and ground operations. In the airline, practices are carried out to avoid the use of products that may harm the environment and to reduce plastics. At the same time, introducing bamboo and other plant materials for some daily-used materials, especially on flights, is among the airline’s upcoming projects. In general, the airline reduces the amount of plastic used, but also implements some special practices. These practices include presenting plastic-free packaging in order to eliminate single-use plastics, replacing products made of plastic materials with biodegradable products among the products distributed in the cabin, replacing plastic cutlery with products made of different materials, reducing resource use by ensuring that materials are used more than once and outdated products, applications reusing uniforms to produce different products and ensuring that the materials inside the aircraft are made of easily repairable materials to increase the life cycle of the products.

“Introducing vegetal alternatives to pollutant materials”, “inclusion of materials like bamboo and others replace plastic single-use elements”, “reduction of the plastic present in packaging by eco-designing it” and “removing any plastic cup by compostable cups made with bio elements” were evaluated under the C2 category. However, these were considered to be implemented by the airline company and therefore no points were given during the evaluation phase. Accordingly, the airline's evaluation score was low in this category, at 40.93.

The airline is implementing many of the nine key practices that contribute to three different initiatives within the “C3: Reducing the use of paper” category. Applications related to in-flight product sales under the category were excluded from evaluation since they do not fall within the scope of the airline’s activities. Works are being carried out to digitalize the normal workflow in order to reduce paper use in the airline. As part of the complete digitalization of mandatory flight documents, the use of printed documents has been terminated. In this context, tablets are provided to flight crews so that they can both make reports and access flight documents. Another application implemented to reduce paper use is the digital boarding process. Airline applications are being developed to fully digitize boarding passes. At the same time, magazines offered to passengers on the plane have been moved to digital media, the contents have been enriched and airline magazines have been removed. The score the airline received in this category was calculated as 71.44.

The “C5: Processing hazardous waste” category shows the key practices implemented by the airline to recycle and upcycle hazardous waste. There are not many specific practices for managing hazardous waste. However, the airline company sends all hazardous waste to expert processors and ensures that the waste is disposed of in accordance with all

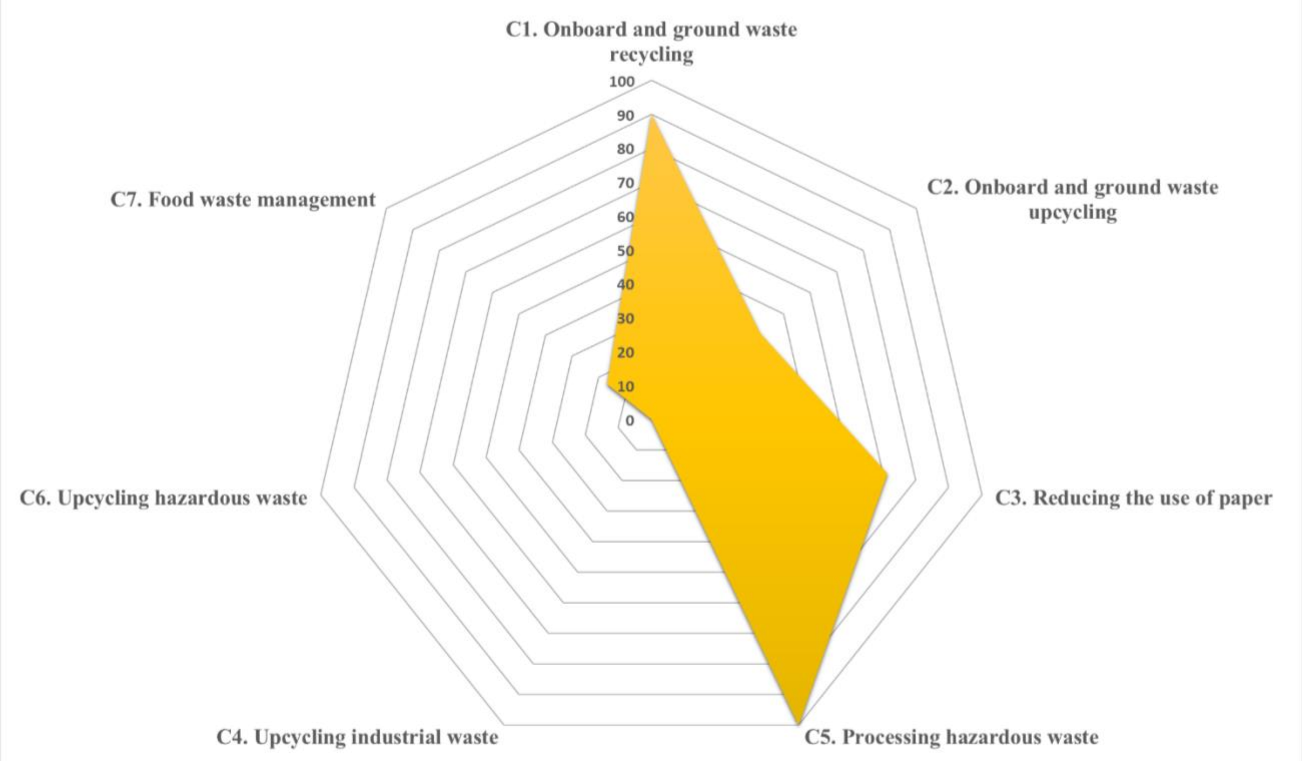

Figure 2. If authors want to put the figures as above, please do as above.

legal regulations. In line with all these practices, the airline received a full score (100) in this category.

Since incineration of waste for energy gain, which is in the categories "C4: Upcycling industrial waste" and "C6: Upcycling hazardous wastes", has not yet been implemented in the airline, these categories received the lowest value with 0 points in the chart.

Finally, regarding the management of food waste, the "C7: Food waste management" category summarizes the key practices adopted by the airline. The applications discussed in this category consist of applications that focus on reducing the amount of food carried on each flight and reducing the negative impact of its packaging. When the applications are evaluated, the applications that will be implemented by the airline in the near future to reduce food waste are stated. However, since these applications have not been implemented yet, no points were given, and under this category, the airline received 16.67 points, which was evaluated lower than other categories, as can be seen from the radar chart. Increasing food waste as a result of the airline's general practices have caused the airline to change its strategy. The airline is working to improve the flight meal reservation system in order to prevent increasing food waste. The airline also develops collaborations with the aim of reducing menu cards and switching to sustainable alternatives in food packages. On the other hand, the issues of ensuring the reusability of cutlery sets used in airline flights by making them from biomaterials and changing the traditional presentation of refreshments with ecological packaging have not yet been addressed by the airline.

In general, in order to accelerate its transition to a circular economy, the airline primarily adopts the reduction of waste where it cannot prevent its generation. Thus, the airline states that it acts on the principle of bringing waste back into the economy through recycling processes. Despite the implemented practices and measures taken, unavoidable waste is sent for disposal by the airline through licensed companies in accordance with environmental legislation.

7. Conclusion

The airlines have been developing sustainability strategies for a long time and taking precautions in this context in order to reduce their negative impact on the environment. With these measures, which they call cleaner and greener, they implement various circular economy practices in order to reduce both natural resource consumption and waste. These practices increase the sustainability performance of airlines and facilitate their transition to a circular economy.

There is still a need for improvement in this regard in the airline industry due to the lack of a specific model for all companies in the service sector, the high investment levels for the transformation of systems, and the limitations of the circular economy model in the service sector. Although there are studies in the literature that statistically analyze various types of waste in airlines (Baxter et al., 2018; Baxter and Srisaeng, 2022), evaluate carbon emission levels with different waste management practices (Blanca-Alcubilla et al., 2020; Sarbassov et al., 2020; Xiong et al., 2023), examine the use of alternative fuels in aviation gas turbines (Günerhan et al., 2023; Lee et al., 2024), and ensure that waste generated in airline terminals is managed effectively and economically within the scope of the circular economy (Tjahjono et al., 2023; Sukhorukov et al., 2023; Guven et al., 2024), a study has not been conducted in which an airline company would score and evaluate itself in terms of different types of waste within the perspective of the circular economy.

In this regard, within the scope of this study, through a case analysis conducted in an airline company, points open to improvement within the scope of circular economy based waste management were tried to be identified. In the study, the practices carried out by the airline for recycling, upcycling or processing of various forms of waste are evaluated according to whether they are implemented, partially implemented, not implemented or to be implemented, and the shortcomings are revealed in line with the calculated scores.

It is clear that the airline has many practices in waste recycling, reducing paper usage, and handling hazardous waste. However, there is currently no application for upcycling industrial and hazardous wastes to generate energy. Significant advancements in these aspects of aviation are necessary.

The issue of food waste is already a controversial issue in the airline industry, but it is a difficult area to manage. Given that food waste is organic waste, many nations have put in place stringent regulations to safeguard national wildlife or public health. Managing food waste requires extra effort as restrictions vary from country to country and often requires further transfer to processing and incineration. Due to these issues, businesses are starting to develop substitutes that would cut down on food waste and food packaging waste at the source. For this reason, meal reservation systems are often used in airlines (IATA, 2022). In the airline company under study, while recycling of cooking oils into biodiesel and provision of napkins made from recycled materials upon request are implemented, there exist numerous other practices that could be undertaken within the framework of the circular economy.

This study is well-suited to support efforts in the service industries aimed at implementing circular economy practices. Through this structured narrative, the study aspires to make a substantial contribution to the field of aviation, providing airlines with a robust approach for waste management. Undertaking similar initiatives in other service sectors will establish the foundation for future studies and enable the framework under consideration to be generalized. The research also aims to bridge the gap between theoretical models specific to the circular economy and real-world applicability.

Appendix

Table 1. Hierarchy of Initiatives

C1. Onboard and ground waste recycling

1. Recycling tracking system
   - Waste management tracking system
   - 3Rs diffusion through the organization
   - Identification of types and sources of waste
   - Frequent monitoring
2. Internal auditing in recycling
   - Landfills periodically checked
   - Waste storage sites' inspections
   - Records of waste managed
3. In-cabin waste management system
   - Teaching cabin crew to properly manage waste
   - Amenities on demand
   - Redesign of daily elements the use less quantity of raw materials
   - Reduce the number of basic products to reduce waste
   - Separate hazardous waste from non-hazardous to facilitate sorting
4. In-cabin material recycling
   - Waste sorting in-cabin segregating during the flight
   - Promotion of recycling to passengers and cabin crew
   - Full recovery of reusable in-cabin items
5. Recycling paper
   - "Expired magazines" are fully recycled
   - Specific spaces for paper and cardboard storage
6. Recycling plastic
   - Collection and transfer of PET Waste to further disposal
   - Implementing new recycling methods to foster plastic recovery
7. Recycling cans
   - Collection of every aluminum can from in-flight services

C2. Onboard and ground waste upcycling

8. Outdated uniforms to manufacture in-flight products
   - Old-fashioned, deprecated and highly used uniforms clothing use to apparel amenities
9. Stuff clothing repurposed
   - Napkins and table clothes from old uniforms
10. Eco-friendly materials
    - Biodegradable products to replace the materials difficult to recycle
    - Introducing vegetal alternatives to pollutant materials
    - Removing some elements that can be harmful for the environment
    - Fostering programs like bring your own cup and bottle by a discount
    - Collaborating with several institutions to design effective and efficient materials with specific conditions
11. Plans to remove plastic
    - Inclusion of materials like Bamboo and others to replace plastic single –use elements
    - Single use plastic reduction programs
    - Cutlery and food complements are removing the single use plastics
    - Designing in-flight strategies to reduce plastic
    - Reduction of the plastic present in packaging by eco-designing it
    - Removing any plastic cup by compostable cups made with bio elements
    - Reuse of plastic elements commonly used by the cabin crew (plastic rollers on IDs and paper tickers)
    - Unavoidable plastic used is used un plants to produce synthetic crude oil
    - No plastic bags for in cabin purchases
12. New product design reusability
    - Initiatives to invest in reusable a disposable new product instead
    - Removable parts on single use elements to divide hazardous from non-hazardous waste and easier the recycling process
    - Some plastic elements are used to produce synthetic crude oil
    - Items made with biodegradable materials are transformed into compost after the lifetime
13. New product design reparability
    - Whenever it is possible giving the elements more than one use to reduce the amount of items required
    - New eco cups easily removable and stackable to easier the management capacities
    - Furniture is made with easily repairable design to facilitate the reparability and increasing elements lifecycle

C3. Reducing the use of paper

14. Electronic airway bills
    - Total digitalization of mandatory flight documentation to reduce the use of paper and the weight
    - App-based reporting platform for cabin crew
    - Used of platforms to fully digitalize and automate the regular workflow
15. Using electronic boarding passes
    - Development of airlines apps to fully include the digital boarding process
    - Using only electronic boarding passes and charging an additional cost to people who wants printed passes
16. Providing tablets to reduce paper

- Pilots are provided with tablets to have all the information centralized and reducing the amount of paper required
- Replacing airlines magazines by tablets, reducing the paper use and making the content dynamic and more attractive
- Using the mobile devices and tablets to the cabin crew to make whole snacks and meals sells processes
- Receipts from in-flight purchases are send through the app not requiring a ticket printing

C4. Upcycling industrial waste

17. Burning waste to recover energy
    - Burning waste according to regulations whenever is not possible to be recycled to produce energy

C5. Processing hazardous waste

18. Recycling hazardous waste
    - Hazardous waste is properly dispose to comply all regulatory requirements
    - Hazardous waste is sent to specific and specialized handers to be properly processed
19. Tracking systems
    - Hazardous waste is sent to special plants to be managed according to countries regulation
    - Long-term collection plants to securely process potentially dangerous resources

C6. Upcycling hazardous waste

20. Burning hazardous waste
    - Generate energy from burning hazardous waste. According to international regulations whenever is not possible to be recycled or securely disposed

C7. Food waste management

21. Food stock prediction and eco-friendly packaging
    - Incorporation of a meal booking system to reduce food waste
    - Continuous food stock adaption using a prediction system to forecast the required amount of food
    - Reduction of the amount of "easy cooking" meals available to demand on flights
    - Reduction of the snacks and beverage catalogue
22. Food waste management
    - Agreements with suppliers to produce meals packaging in a sustainable manner
    - Recycling cooking oil to produce biodiesel
23. Food eco-friendly packaging
    - Reusable dishes and cutlery made with biomaterials
    - Napkins and amenities made from recycled materials and given on demand
    - Removing the traditional presentation of snacks for alternative ecological packaging made specifically for flight travels

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Reflection of Crew Resource Management (CRM) Trainings to Real-Life Field Practice in Air Passenger Transportation: A Qualitative Research

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Abstract

In the air transportation sector, flight safety stands as one of the foremost values. To ensure safety, airlines rely on Crew Resource Management (CRM) training. These training programs aim to foster coordination, communication, and awareness among all personnel involved in flight operations, encouraging rational responses to potential issues as a unified team. Naturally, as is the case with any training process, the practical applicability of CRM training alongside its theoretical structure is of paramount importance. Hence, this study, conducted within the framework of qualitative research, delves into the perspectives of cabin crew members regarding CRM training by evaluating its content, benefits, and real-life field applications. Employing interview-based methodology, qualitative data were gathered from 19 cabin crew participants through purposive sampling. The collected data underwent descriptive analysis, leading to certain conclusions. The findings illustrate that CRM training has a positive impact on emotional and knowledge management, communication skills, team collaboration, and a proactive approach in matters of safety. It underscores that CRM training significantly permeates into the realm of real-world applications—namely, flight operations. However, participants highlighted certain issues and emphasized the need for more practical, interactive, and participant-centered training methods for the enhancement of CRM training, aiming to address those concerns.

1. Introduction

With the rapid development of the civil aviation industry, the reliability of aircraft and equipment has become very high. Today, the cause of accidents and incidents during flights is no longer solely attributed to aircraft, technical hardware, or equipment issues. The attitudes and behaviours of flight crews have become one of the main factors leading to accidents, alongside their technical knowledge and skills.

Human factors, including errors made by crew members, have long been identified as a major cause of aviation accidents.

Past analyses have reported that 60% of fatal accidents occurring in scheduled passenger transport in the civil aviation sector are human-caused and more than 70% are directly caused by human error (İnan, 2018: 45). These data have been confirmed by official reports of aviation authorities. The International Civil Aviation Organization (ICAO) and the Federal Aviation Administration (FAA) consistently report that human error is a predominant cause of aviation incidents. The FAA's annual data indicate that human factors contribute to approximately 70-80% of aviation accidents (FAA, 2021). n its 2018-2022 accident analysis, the European Union Aviation Safety Agency (EASA) found that procedural violations and failure to adhere to safety protocols contributed to over 60% of accidents caused by human error (EASA, 2022). Many flight accidents arise from human factors such as lack of situational awareness, negligence, miscommunication, and lack of coordination (Du & Zhu, 2022: 18). All of these elements pose significant risks to flight safety.

Flight safety encompasses all necessary efforts to identify, define, manage, and prevent hazards and risks arising from incorrect or faulty practices, leading to aircraft accidents or losses. These efforts involve a comprehensive approach that includes safety-related hardware, software, and human factors (Terzioğlu, 2018: 7).

It is necessary to acknowledge that the civil aviation industry is always associated with high risks, and flight and ground safety is critical in all its operations. Therefore, flight safety ranks among the most crucial factors for civil aviation organisations. These organisations place significant importance on Crew Resource Management (CRM) training to ensure the highest level of flight safety while maintaining the quality of the provided flight services without compromising their ability to respond to changing demands (Erdem, 2018: 1).

The concept of CRM was initially introduced by NASA (National Aeronautics and Space Administration) in 1979 to enhance flight safety by initially addressing communication principles among flight crews. Over time, this concept has been further developed and has become a significant part of civil aviation training (İnan, 2018: 45). CRM has since been integrated into civilian and military aviation. It is designed to reduce aviation incidents caused by pilot errors by identifying observable behaviours that enhance team performance (Helmreich and Wilhelm, 1991). The initial inclusive goal of CRM was to manage social and cognitive skills during flight operations to ensure the safe functioning of the aircraft (Bruemmer, 2008; Kreischer et al., 2022: 2011). Today, CRM has been implemented into the civil aviation training curriculum for over forty years to optimise flight management, enhance safety, and improve flight crews' non-technical skills and performance (Jimenez et al., 2015: 946).

In its current sense, CRM is defined as the proper utilisation of available information, equipment, procedures, and human factors to carry out safe, efficient, and effective flight operations (İnan, 2019: 359). CRM focuses on the "human factors" considered non-technical skills in ensuring flight safety. It primarily involves managing hardware, software, and especially human resources through training to enable the safe and efficient execution of all flight operations (Jensen, 1997: 265). CRM recognises that besides technical knowledge and skills, the effective management of human factors is essential in achieving safe and effective flight operations.

CRM training is a team training strategy that focuses on improving team coordination, performance, and the expected attitudes and behaviours related to safety (Salas et al., 2006: 393-393). It is a series of instructional strategies designed to enhance teamwork (i.e., team knowledge, skills, and attitudes) by employing well-tested training tools and appropriate training methods (including theoretical lectures as well as simulators, videos, performance measurements, statistical data, role-playing, case studies, exercises, and simulations). The aim is to develop effective teamwork by applying these methods and tools in CRM training (Salas et al., 1999: 163).

CRM training is more field-specific, realistic, and applied than purely theoretical and generic (Hunt and Callaghan, 2008: 690). CRM training primarily encompasses two scopes: initial training and recurrent training. An initial CRM training is typically conducted in a classroom over 2 or 3 days (though this can vary from country to country and airline to airline). Following the completion of the initial course, recurrent training is conducted at regular intervals. Recurrent training typically consists of a half or full-day course focusing on a specific CRM topic and is also mandated by major civil aviation regulators (O'Connor et al., 2008: 356). The training is provided to all personnel related to flight operations, such as pilots, cabin crew, pursers, dispatchers, and air traffic controllers, in the form of basic training and recurrent training at specific intervals.

The training programs, with a particular emphasis on pilots and cabin crew, are designed within the framework of regulations set by the General Directorate of Civil Aviation (SHGM) at the national level, in line with the standards established by international authorities such as the International Civil Aviation Organization (ICAO) and the European Union Aviation Safety Agency (EASA) (IATA, 2016: 45). These training programs are conducted based on the Part-D documents, which are the training manuals of airline operators, by the standards identified by these authorities. Flying personnel who do not undergo annual CRM training or fail to refresh their CRM qualifications may have their flight licenses suspended (Bükeç & Başdemir, 2021: 1060).

CRM training provides essential guidance on effective communication, task sharing, workload management, teamwork, situational awareness, power distance, decision-making, leadership, and other related topics (Wagener & Ison, 2014: 4). The human skills imparted to personnel through CRM training aim to enable employees with different perspectives to work effectively as a team by efficiently utilising all available resources for a safe flight operation (Chute and Weiner, 1996; Karaarslan & Erkmen, 2021: 476). The training is theoretical, generic, field-specific, realistic, and applied (Hunt and Callaghan, 2008: 690). However, the knowledge and skills provided through CRM training can only be beneficial if they are effectively used in flight operations. Therefore, it is essential to assess CRM training programs' outcomes, effectiveness, content, and results and evaluate their alignment with real-world applications (Klampfer et al., 2011: 135; Baykın, 2021: 34-35). Assessing the aspects and various dimensions the training aims to instil, examining their reflections on actual field practices based on firsthand information, and reporting systems are crucial for gaining deeper insights.

It is possible to mention studies focusing on CRM training outcomes in the literature. One early study by Helmreich and Wilhelm (1991) examined the effects of CRM training on participants' self-reports and attitude measurements regarding cabin safety. The findings demonstrated that CRM training was positively received and led to significant and positive changes in attitudes and behaviours related to team coordination and personal skills. However, some participants reacted adversely to the training and observed negative attitude changes. The study highlighted that research on the reasons for this effect could reveal personality factors and group dynamics as critical determinants of responses to training and attitude changes.

Freeman (2005) demonstrated that participants perceived CRM training as beneficial and believed all aviation crew members should receive this training. Salas et al. (2006) showed that CRM training elicited positive participant responses and impacted learning and behaviour changes. The study conducted by O'Connor et al. (2012), which aimed to evaluate the effectiveness and outcomes of CRM training programs, revealed that maritime aviators found CRM helpful training, had an excellent overall understanding of the concepts covered in training, and displayed positive attitudes towards the concepts addressed. Bennett (2019) conducted a study to improve the pedagogy of CRM training. Based on survey results, it was suggested that the target audience of CRM training should be expanded to include operational personnel other than flight and cabin crew, and experiential/action learning exercises, such as spending time in a fully functional three-axis flight simulator, should be added. Bükeç & Başdemir (2021) aimed to propose a CRM training model to enhance its contribution to flight safety by identifying deficiencies that arise during training and obtaining solution suggestions and recommendations from CRM experts. Data were collected through surveys from pilots and cabin crew members, and semi-structured interviews were conducted with 6 CRM instructors to identify identifiable shortcomings during CRM training and determine the areas that need improvement. The results revealed that CRM training generally supports flight safety; however, there is a need for improvement in program content, teaching techniques, training tools, and instructor qualifications. Karaarslan & Erkmen (2021) examined the impact of Covid-

19 on the CRM attitudes of aviation sector employees and investigated whether there were any differences in CRM attitudes of cabin crews before and during the Covid-19 period. The research found no statistically significant difference in CRM attitudes. In one of the recent studies by Du and Zhu (2022), the authors aimed to discuss the common problems pilots face due to the lack of CRM training. The study proposed targeted programs to address issues such as pre-flight information acquisition, technical flight ability, crew communication, increasing situational awareness, and improving CRM skills. However, this study focused only on pilots and did not involve field application.

It is worth mentioning that there are studies focused on CRM training in civil aviation, aiming to provide insights into these training outcomes. However, it should be noted that these studies predominantly approach the topic through quantitative research. Furthermore, when evaluated from a holistic perspective, these studies have limited quantity, which enhances the importance of conducting further research in this area and increases the value of the findings and evaluations that will be obtained.

Under these circumstances, the main objective of this research is to examine the real-life implications of CRM training, which focuses on human factors in ensuring cabin safety in civil aviation passenger transportation operations, to guide cabin crew members' awareness, attitudes, and behaviours related to safety. Within this scope, the study aims to identify the practical application of CRM training in the cabin under the main topics of situational awareness, power distance, stress and workload management, intra-team communication and coordination, as well as to examine the consistency and inconsistency between the training content and its implementation in the field. The foundation of the research is based on making certain inferences and evaluations by obtaining responses from cabin crew members through a qualitative research method to contribute to the literature and field practice.

2. Materials and Methods

2.1. Research Design

This study is based on a qualitative research method. Qualitative research aims to explore the nature of phenomena, such as different manifestations of facts, their contexts, or perspectives in which they can be perceived. Qualitative designs are necessary to explore the reasons behind observed patterns, especially those that are unseen or surprising (Busetto et al., 2020: 1). "Qualitative" methods are often used to determine the participant's perspective to answer questions about experience, opinion, belief, meaning, and perspective. This is because data of this kind is generally not amenable to quantitative measurement. Qualitative research techniques typically involve interviews to investigate beliefs, attitudes, and concepts related to normative behaviour. "Semi-structured interviews" are used to obtain opinions on a focused topic or essential sources of information for background knowledge or institutional perspectives. In contrast, in-depth interviews are employed to understand a situation, experience, or event from a personal perspective (Hammarberg et al., 2016: 498).

2.2. Data Collection Method

The qualitative research method relies extensively on the data collection process. This study employed a semi-structured interview technique as a qualitative method. The semi-structured interview technique has a predetermined structural form before data collection. However, the questions included in this form are primarily open-ended and depend on the research topic. These comprehensive questions allow the researcher to guide and encourage the participant towards the necessary points to obtain more data when their interest is high. This semi-structured format provides an opportunity for a detailed discussion within the boundaries of the research topic. It enables the researcher to freely guide the interview based on the content of the interviewee's responses (Oun & Bach, 2014: 254). In this context, voluntary interviewees participating in the research were guided through a previously prepared interview questionnaire, following a systematic structural approach, to sequentially address the questions and encourage them to provide evaluations as openly as possible.

The interview form for the research consists of two main sections. The first section includes descriptive questions such as gender, age, education level, position in the cabin crew, and professional experience. The second section contains the main questions. The formulation of these questions drew inspiration from studies conducted by Halbesleben et al. (2011), Kemper et al. (2014) and Van Den Berg et al. (2020). The questions were adapted, added, and organised under themes, undergoing supervision by expert academics to reach their final form.

These questions were sequentially directed to the participants to obtain data. During the interviews, the responses were recorded with the permission of the interviewees in the form of audio recordings. These audio recordings were analysed, transcribed into text format using computer software, and further investigated.

The themes addressed in the resulting structure of the research are as follows:

- Situational awareness (2 questions)
- Power distance (2 questions)
- Stress and workload management (2 questions)
- Team communication and coordination (2 questions)
- Implementation of CRM training in the field (4 questions)

In creating these themes, the responses from the participants were taken into account, along with the CRM literature and training content. The first four themes represent the main focus areas in literature and training, forming the thematic framework. The last theme aim to evaluate the reflection of training in the field.

2.3. Population and Sample

The study population consists of active cabin crew members in the civil aviation industry. In this research, purposive sampling, a non-probability sampling method, is planned to reach cabin crew members with characteristics that can represent this population. In qualitative studies, a relatively small and purposefully selected sample can be used to enhance the depth of understanding (as opposed to breadth) (Palinkas et al., 2015; Miles & Huberman, 1994).

Purposive sampling is a method used to select participants who are likely to provide relevant and helpful information (Kelly, 2010: 317) and is a way to identify and choose cases that effectively utilise limited research resources (Palinkas et al., 2015; Campbell et al., 2020: 2-3). Purposive sampling is the selection of sampling units within the population segment that possesses the most information about the variable of interest. It involves purposefully selecting from a specific portion of the population, believed in providing the best examples to estimate the population parameter of interest (Guarte & Barrios, 2006: 278).

Determining the exact sample size for qualitative research can be challenging due to the nature of such studies, and it may not be appropriate to pre-determine it. One fundamental criterion for an ideal sample size is the formation of a saturation point, where the obtained information becomes saturated. After a certain point, new interviewees will provide data that is similar to or the same as the data provided by previous interviewees (Morgan & Morgan, 2008). During this saturation stage, the data collection process should be halted, and the sample size should be fixed where saturation begins (Onwuegbuzie & Collins, 2007; Baltacı, 2018: 262). Based on this information, in the data collection phase of the research, the aim is to gather data by enriching it with different perspectives within the purposive sampling framework. This is achieved by diversifying the participants among cabin crew members in terms of characteristics such as gender, age, and experience to represent different groups. As a result, the responses obtained from 19 participants constituted the research data set. As part of the research, informed consent was obtained from the cabin crew members who were reached by providing them with information about the purpose and subject of the study. Within this framework, data could be obtained from willing participants following the structure of the interview questionnaire.

2.4. Data Analysis Method

The responses obtained from the participants were taken as they were without any intervention from the researcher. However, to ethical considerations in qualitative research, pseudonyms were used instead of participants' real names. The data obtained from the interviews, converted into text format, were subjected to descriptive analysis.

Descriptive analysis is a qualitative research method used to analyse the content and context of the variables under study. This method aims to obtain systematic data using inductive techniques, where information is sought within the social reality. This approach's fundamental data analysis includes description, classification, and correlation. The findings obtained from the data are summarised and compared. The researcher examines the developed themes concerning each other, explores relationships and differences, and tries to conclude by making various connections (Özdemir, 2010: 330). In this context, the data obtained from the participants in the research were examined based on descriptive analysis, and certain inferences and evaluations were made in line with the identified themes.

3. Result and Discussion

In the first section of the questions addressed to the participants of the study, gender, age, education level, role in cabin crew, and professional experience (years) are included. In light of the obtained data, the sample characteristics reflecting the participants' attributes are presented in Table 1.

Table 1. Distribution of Characteristics of the Participants

Parti-cipant	Gender	Age	Educat-ion Level	Role	Expe-rience (years)
P1	Female	36	Bachelor's	Instructor	13
P2	Male	38	Master's	Supervisor	16
P3	Male	48	Master's	Instructor	26
P4	Female	38	Bachelor's	Supervisor	17
P5	Female	45	Master's	Supervisor	25
P6	Female	45	Bachelor's	Supervisor	23
P7	Female	43	Bachelor's	Instructor	16
P8	Female	44	Bachelor's	Purser	21
P9	Female	38	Bachelor's	Instructor	13
P10	Female	36	Bachelor's	Instructor	7
P11	Female	36	Bachelor's	Instructor	18
P12	Female	40	Bachelor's	Instructor	18
P13	Female	43	Master's	Instructor	22
P14	Male	49	Bachelor's	Supervisor	27
P15	Male	44	Bachelor's	Supervisor	26
P16	Male	40	Master's	Supervisor	19
P17	Female	40	Master's	Instructor	10
P18	Female	50	Master's	Instructor	30
P19	Female	49	Bachelor's	Supervisor	26

The findings obtained under five themes, derived from the participants' responses and the evaluations made within this framework, are presented below.

Situational Awareness

SA1. Do you believe that you possess the personal knowledge and skills required for safety-related requirements?

Many of the participants expressed that, following the completed CRM (Crew Resource Management) trainings, they believe they possess the knowledge and skills necessary to meet the requirements for flight safety. The participants' responses acknowledge the importance of knowledge and skills for safety-related requirements.

"Mostly yes. But if there is a change related to the requirements, I try to take action quickly." (P3)

"In addition to the trainings, I believe I have this knowledge and skills because I carefully follow safety-related announcements and bulletins." (P4)

"Yes, the required standard procedures already make it mandatory." (P9)

"I think I am at a sufficient level, but I am open to improvement within the framework of daily conditions." (P12)

"Yes, receiving competency-based training from the organization I work for has an impact on acquiring these knowledge and skills." (P13)

"Through the training I have received and my flight experience, I believe I possess this knowledge and skills." (P15)

"Thanks to the training I have received and my experiences, I believe I can meet the relevant requirements." (P19)

SA2. When an unusual situation arises that goes beyond routine non-standard SOPs or written rules and materials related to cabin safety, what actions should be taken to manage this situation?

The responses received highlighted the significance of CRM safety knowledge in managing unusual situations related to cabin safety. Participants emphasized the importance of being prepared for potential scenarios and the value of adhering to acquired information and Standard Operating Procedures (SOPs).

"At that moment, having accurate information is important to make the right decision. This way, more precise actions can be taken." (P2)

"I try to compile cumulative knowledge and seek verification beyond acquired information." (P3)

"I believe in always having situational awareness. The 'what if' game gains importance here. Mental preparedness is a must." (P4)

"It's necessary to engage in mental simulations about possible scenarios and play the 'what if' game to be ready." (P5)

"Based on the known information, an assessment of the situation should be made." (P6)

"Taking into consideration all aspects of the situation within the framework of existing knowledge and rules, the most suitable solution should be generated." (P7)

"Decisions should be made by leveraging existing SOPs. Any perceived gaps should be reported." (P10)

"Situations should be managed without deviating from SOPs." (P11)

"I act in accordance with the available documents and CRM knowledge and skills." (P15)

"The person who possesses comprehensive safety-related knowledge can call upon the most appropriate information, assess the situation, and make the best possible decision." (P17)

Power Distance

PD1. During the flight, assume you encounter a situation related to cabin safety that you perceive as unusual and serious. Suppose you are the first one to notice it. How would you communicate about this situation with your supervisor at that moment?

In response to the question aimed at assessing how participants would handle cabin safety-related issues during a flight and how they would communicate, the respondents demonstrated their appreciation for essential elements such as clarity, speed, collaboration, effective body language, honesty, and seriousness in communication. Alongside communication skills, a focus on situational analysis and solution-oriented approaches also becomes evident in these responses. Almost all participants are aware of the need to report the situation as quickly, accurately, and objectively as possible.

"I convey all information quickly with a clear statement; it should be open and straightforward." (P1)

"I would inform the cabin manager and other team members that I need assistance related to the matter." (P2)

"Firstly, I make an effort to communicate and report the relevant violation or issue." (P3)

"I immediately convey the situation to the cabin manager without adding any personal interpretation. If they are not nearby, I use the interphone to inform them and save time." (P4)

"If I'm close to the interphone, I use it, or if I'm close to another cabin crew member, I communicate with them and take action accordingly." (P5)

"I convey the situation to the team using clear and concise words along with appropriate body language and tone of voice." (P9)

"It's necessary to report the situation as it is and, if there is a mistake, admit it honestly." (P12)

"As quickly as possible, I need to objectively communicate the severity of the incident to my manager." (P16)

PD2. You notice that your supervisor does not take a danger risking safety seriously based on their personal experience. However, in your opinion, this situation could worsen and compromise safety. What would you do in this situation?

Participants indicated that they demonstrated determined persistence in convincing their supervisors when faced with situations where their supervisors did not take safety-threatening issues seriously. The overall inference from these responses is that participants emphasize the importance of assertiveness, effective communication, and persistently conveying safety concerns to their superiors. Many candidates seem to be focused on finding ways to address the situation without undermining the authority of their supervisors. Participants frequently mention the importance of emphasizing the significance of the situation and displaying unwavering perseverance. Their focus on highlighting the severity of safety hazards and their willingness to explore different communication strategies reflect a solid commitment to safety protocols and a proactive problem-solving attitude.

"I insist on carrying out the required task. I exhibit assertive behavior." (P1)

"I would share the situation with them. If the attitude persists, I would report through the appropriate reporting system." (P3)

"I emphasize the importance of the situation by displaying determined persistence." (P5)

"I ensure that the captain is informed. I make every effort possible concerning the situation." (P7)

"I utilize my skill of determined persistence." (P9)

"I would explain to them assertively why this situation could violate safety regulations." (P11)

"I mention the potential consequences." (P12)

"I describe the situation in an explanatory manner. If they insist, I try to convey it using different approaches. If I am confident in my knowledge, I would persist." (P16)

Stress and Workload Management

SWM1. Do you review physical fatigue or stress issues before or during the flight? How do you manage this situation?

This question revolves around how candidates manage and address physical fatigue and stress issues before and during flights. The responses collectively underscore a strong awareness of the importance of managing personal well-being to ensure safety and performance. The candidates' answers consistently highlight self-awareness and preparedness. Many participants exhibit a proactive approach by taking pre-flight measures such as adequate rest, healthy eating, and proper sleep. Several candidates mention understanding their personal limits and taking precautions accordingly. This demonstrates a high level of responsibility and understanding regarding the potential impact of physical fatigue and stress on performance. Participants are conscious of the potential risks associated with fatigue and stress and prioritize managing these factors to uphold both their well-being and their responsibilities as part of the flight crew.

"I try to become aware of my own limits." (P1)

"I pay attention to my rest before the flight. I focus on healthy eating and sleep." (P2)

"I know my body's limits. I take precautions knowing that sleep deprivation can greatly affect me and lower my performance." (P4)

"I apply the checklist for this issue before every flight." (P5)

"I observe my own condition at every stage." (P7)

"I live in accordance with adequate rest hours." (P9)

"I make sure to get enough rest before flights." (P13)

"I rest myself physically and mentally." (P15)

SWM2. In your opinion, what kind of risks can stress and workload pose while performing your duties? Are there safety-related tasks in your work environment that could be affected by your fatigue, negative mood, or stressful situations?

In response to this question that focuses on the potential risks of stress and workload in the work environment concerning the fulfillment of tasks and safety-related responsibilities, the answers provided insights into participants' understanding of the negative impact of stress, fatigue, and negative mood on ensuring safety and performing effectively. The responses indicate a clear awareness of the risks associated with stress, workload, and negative mood. Participants acknowledge that these factors can lead to errors, reduced situational awareness, lack of attention, hinder the use of standard skills and competencies, and ultimately jeopardize safety. Many participants have emphasized the potential for making mistakes and errors under stress and high workload conditions.

"It can make us prone to errors. We can lose situational awareness." (P1)

"Stress and workload can push us towards making mistakes. That's why managing them is important." (P2)

"Increased stress and workload can make it harder to use regular abilities and competencies. They can lead to safety violations." (P3)

"The stages of the flight can be negatively affected by this. It can create an unsafe environment." (P7)

"It reduces situational awareness, leads to violations." (P8)

"It can prevent us from noticing the mistakes made. It can lead to complacency and a decrease in situational awareness." (P12)

"It can prevent us from recognizing threats, leading to incomplete controls." (P13)

"It can lead to incomplete or incorrect procedures and information sharing." (P17)

"It makes us prone to errors, disrupts concentration." (P19)

Team Communication and Coordination

TCC1. How does a negative situation within the team, such as a communication issue (e.g., a minor dispute with a team member or supervisor), affect you during the flight?

In response to this question that examines how participants react to adverse events, especially communication issues within the crew, during a flight, the answers reveal that participants generally fall into two different perspectives. Some participants reflect professionalism, safety, and a commitment to effective communication. The answers highlight the importance of sustaining professionalism and self-regulation. Candidates emphasize that they should not allow personal emotions to influence their behavior and decisions during a flight. There is a tendency to focus on constructive and vocational approaches to finding solutions. Participants intended to remain focused on their tasks and not allow negative events to impact their performance adversely.

"I think about and investigate the root cause. I consider that the problem might be from both the other side and from me, and decide accordingly. I exhibit appropriate behavior so that it doesn't negatively affect safety." (P2)

"I try not to take it to a point where I lose control. I experience this situation positively and constructively." (P3)

"Emotions have no place in professionalism. Objective decisions cannot be made if emotions are involved." (P4)

"I try to remain unaffected and concentrate on my duties with a professional attitude." (P7)

"I don't allow it to affect me with a professional attitude." (P11)

"I don't perceive the issue personally and prevent the situation from escalating." (P12)

On the other hand, some participants acknowledge that situations of this kind can have a range of emotional and psychological effects on themselves. While the responses use different phrasings, there is a consistent acceptance of the negative impact of adverse events.

"It can lead to a decrease in my motivation." (P1)

"I may be negatively affected, but I make an effort not to reflect it onto other team members." (P13)

"It has a negative effect, increases stress, and physical fatigue." (P14)

"It has a negative impact." (P15)

"It affects negatively, but I resolve it within the framework of rules without personalizing it." (P18)

"It has a negative effect." (P19)

TCC2. When a safety-related situation arises in your unit, who takes on the leadership role in decision-making? Are responsibilities shared collectively as a team, or is there a hierarchy in place?

In response to this question investigating how participants approach decision-making when a safety-related situation arises in their units, the answers overwhelmingly indicate an acceptance of a hierarchical structure for decision-making. The responses consistently demonstrate that there is a hierarchical structure in place for making decisions related to safety situations. Participants state that reporting and decision-making responsibilities are clearly defined within their units.

"The relevant department supervisor takes responsibility, hierarchy is in place." (P9)

"The hierarchy includes the captain, chief, manager; each officer has a separate role. Reporting is the responsibility of the supervisor." (P10)

"A higher-level supervisor takes on the responsibility, and there is a hierarchical order in decision-making." (P11)

On the other hand, there is an explicit acknowledgment of the existence of a hierarchy. However, in addition to this, a specific subset of responses has revealed a combination of teamwork and shared responsibility. The answers consistently emphasize the importance of teamwork and shared responsibility in making decisions related to safety and security. Some participants highlight that safety is a collective effort involving the entire team, and all team members share a common goal of ensuring safety.

"There is only one right thing when it comes to safety. We need to make the right decision as a team without forgetting that we are a team." (P2)

"Matters related to safety are the responsibility of every employee. The responsibility for decision-making lies with upper management, and the responsibility for reporting lies

with subordinates. However, any employee can intervene in a safety-related matter if necessary." (P5)

"The process is carried out through sharing as a team." (P14)

"It's shared collectively." (P15)

"Although there are levels, solving a problem is everyone's responsibility." (P18)

Implementation of CRM Training in the Field

IMP1. What are the most significant aspects that have stuck in your mind from the CRM training you received? Regarding flight operations, what benefits does CRM training bring to cabin safety?

In response to this question, focusing on the essential takeaways from CRM training and the benefits of CRM training for cabin safety in flight operations, a significant portion of the answers emphasize the importance of CRM training in improving communication, teamwork, safety awareness, and effective resource management. The responses indicate that CRM training is crucial in increasing safety awareness and promoting a sense of teamwork between cabin and cockpit crews.

"CRM is essential for a safe flight." (P4)

"As cabin and cockpit crews, we embrace the concept of empathy and teamwork more with these training sessions." (P5)

"CRM is crucial for managing communication skills related to safety." (P6)

"It enables harmonious teamwork within the team. By acting together and sharing responsibilities, it contributes to achieving safety goals most easily." (P7)

"Our attitudes in situations affect safety. The knowledge and skills to manage all resources are directly related to how safety is ensured." (P9)

"Sometimes, especially in situations where SOPs are not enough, the awareness created by CRM is indispensable." (P12)

"The most effective aspect of CRM training is its ability to provide the skills to understand the other party and manage communication appropriately." (P16)

In addition to these responses, many participants mentioned using interactive methods during CRM training, such as real-world scenario-based applications, games, discussions, case studies, and accident videos. This shows that various engaging training techniques contribute to effective learning and retention.

"The Swiss Cheese Model is memorable. CRM training has an impact on increasing knowledge, skills, and forming specific attitudes." (P2)

"What is most memorable are past accidents and incidents. This awareness helps us stay safer." (P10)

"Examinations of past aircraft accidents are most memorable. The mistakes made in these accidents help us learn lessons." (P13)

"The applications, games, and discussions we had in CRM training stick in mind. They change our perspectives on events and help us look at them more safely." (P14)

"Interactive games and case analyses provide significant benefits." (P15)

"The support of incident case studies, accident videos, and group work emphasizes the importance of communication and teamwork." (P19)

IMP2. How is the CRM approach implemented in your unit? Could you provide an example of how you use CRM training concepts during your work?

In response to this question focusing on how CRM concepts are applied in participants' units and how they are practically implemented in daily operations, a significant portion of the answers reflect a range of ways in which CRM principles are integrated into various stages of flight operations. The responses indicate that CRM principles are integrated into unit team dynamics and are used to ensure flight safety. Participants emphasize applying CRM concepts from pre-flight checks to in-flight activities throughout flight operations. This illustrates that CRM principles are not limited to specific stages but are seamlessly integrated into the entire operational process.

"In our unit, assertive behaviors are applied. Especially proactive thinking and behavior models are implemented." (P5)

"It enables harmonious teamwork within the team. We move together and apply CRM principles through task sharing." (P7)

"The knowledge gained in CRM training is practically applied during flight operations." (P9)

"Leadership, decision-making, and taking initiatives are concepts that are attempted to be consolidated on a common ground." (P11)

"CRM principles are effectively used throughout all stages of flight operations, especially during pre-flight checks and in-flight, even extending to the ground crew." (P16)

"Especially, CRM methods are included in checklist items during flights." (P17)

"They are used to ensure flight safety during flights." (P18)

IMP3. Have you observed any obstacles, shortcomings, or gaps while applying the information provided in training (i.e., during flight operations)?

In response to this question investigating whether obstacles, deficiencies, or gaps are observed while applying CRM training information in flight operations, specific prominent themes emerge from the answers. Some participants focus on issues related to document usage and procedures. Some responses emphasize concerns about the practicality of using documents during flight operations. Participants suggest that document usage might be perceived as time-consuming and that they might not always refer to documents due to impracticality.

"Document usage is seen as a time-consuming activity, and sometimes, due to impracticality, we don't refer to documents." (P13)

"There are deficiencies in tracking documents." (P14)

"The problem lies in the impracticality of document usage." (P15)

Some responses highlight challenges related to time pressure, workload management, and attention to detail. The common theme in these responses is the negative impact of time pressure and excessive workload on implementing CRM training concepts. Participants stress that these factors can hinder the proper execution of safety procedures and practices.

"For instance, security checks conducted in the cabin are sometimes not done properly due to time pressure, unlike what is taught in classes." (P4)

"Areas like time and attention management, excessive workload, can lead to gaps." (P9)

"Time pressure is an obstacle. There can be very little time between schedules, and it can be challenging to catch up." (P18)

"Time pressure and excessive workload can create certain gaps." (P19)

In addition to these responses, some answers highlight challenges related to timely action, knowledge management, individual dynamics, psychological factors, empathy, and self-assessment. These responses demonstrate that the difficulties in implementing CRM training are multidimensional and beyond simple procedural matters.

"Delayed action, correct information arriving late, clinging to old information, mixing old and new information can be mentioned." (P3)

"Depending on the flight dynamics, there can be obstacles in prioritizing or implementing information. Especially, individuals staying in the blind spot, an area where skills are not applied, is one of the gaps we encounter." (P5)

"Obstacles arise due to individuals' varying psychological capacities." (P11)

"Different perspectives, inability to empathize, prejudice, lack of self-assessment." (P12)

IMP4. What changes would you suggest for CRM training? In your opinion, how could it be conducted to be more effective?

The responses to the question investigating recommendations for improving and making CRM training more effective overwhelmingly emphasize a recurring theme: the importance of practical application. Participants suggest that CRM training would be more effective if it included practical scenarios, case studies, and live examples from daily flight operations.

"Increasing practical applications and enabling individuals to self-realize through their participation could be important." (P1)

"I believe that employees at every level should conduct case studies." (P2)

"Being more hands-on and having a longer duration would be more effective." (P3)

"I think it would be more appropriate to share a larger number of case studies." (P4)

"There should be an increase in hands-on training." (P6)

"I think concrete examples from actual flight operations are much more effective than textbook definitions. Providing real-life examples of all concepts in daily life and flight operations can be more effective for the targeted groups of participants." (P7)

"Practical scenarios will be more effective." (P9)

"Applications, group work, and aligning them with the purpose they serve can be important." (P10)

"Being more interactive and focused on case studies could be beneficial." (P13)

"More case study analyses can make the training more effective." (P15)

"Hands-on training should be increased, and more case studies should be included." (P17)

"Group work should be done, supported by scenarios, and the practical emphasis should be on which information serves which purpose." (P18)

"The number of lessons should be increased. It should be supported with more hands-on, scenario-based training." (P19)

As evident from these responses, many participants emphasized the desire for CRM training to be more practical, interactive, and application-oriented.

4. Conclusion

Aviation industry's CRM training offers fundamental guidance in effective communication, task sharing, workload management, teamwork, situational awareness, power distance, decision-making, leadership, and related areas (Wagener & Ison, 2014: 4). The human skills imparted through CRM training aim to enable personnel with diverse perspectives to efficiently collaborate as a team, utilizing all available resources for safe flight operations (Chute and Weiner, 1996; Karaarslan & Erkmen, 2021: 476). However, the knowledge and skills from CRM training can be beneficial only when effectively applied in flight operations. This study explores the real-life effects of CRM training, which focuses on human factors in ensuring cabin safety within civil aviation passenger transportation operations. It examines cabin crew members' awareness, attitudes, and behaviors related to safety. Employing a qualitative research method, data were obtained from 19 cabin crew participants through interviews, and findings were evaluated under five themes.

Under the "Situational Awareness" theme, responses indicated that many participants believe they possess the necessary personal knowledge and skills for safety requirements following CRM training. Addressing how to manage unusual situations beyond routine standard procedures, participants emphasized the importance of CRM safety knowledge. The need for accurate, up-to-date information, situational awareness, and mental preparedness was noted. Furthermore, the importance of adhering to Standard Operating Procedures (SOPs) and utilizing existing knowledge and rules was evident in their responses. These results illustrate that CRM training plays a significant role in enhancing situational awareness and decision-making abilities in the context of flight safety.

Responses under the "Power Distance" theme clearly show participants' value for practical communication skills, transparency, and urgency regarding safety matters. Participants highlighted the significance of open and concise communication and objective reporting of situations. They expressed determination to convey the seriousness of situations and emphasize potential outcomes. Their focus on collaborating with team members and conveying the seriousness of situations without personal interpretation underscores their commitment to ensuring safety. Their willingness to employ various communication strategies and explore different approaches while respecting authorities signifies a proactive problem-solving attitude.

Key insights emerged regarding the "Stress and Workload Management" theme. Overall, responses demonstrate participants' priority for personal awareness, proactive well-being measures, and understanding the impact of stress and workload on performance and safety. While addressing the risks of stress and workload, participants comprehended the potential adverse effects of these factors. Emphasis on adequate rest, healthy nutrition, sleep, and self-awareness suggests a proactive approach to managing stress and workload to ensure health and flight safety. Participants reflected a safety-conscious and responsible attitude, committing to managing these factors to achieve optimal task performance and safety.

Responses within the “Team Communication and Coordination” theme reveal that some participants possess high professionalism, safety commitment, and effective emotional management. They highlight the importance of maintaining professionalism, preventing personal emotions from influencing behavior, focusing on constructive solutions, and prioritizing safety and effective performance by demonstrating a solid commitment to their roles and responsibilities. Conversely, another group of participants acknowledged potential negative impacts from adverse situations. This highlight specific difficulties in CRM implementation. While responses vary, consistent acceptance of the adverse effects of negative events is notable. This points to a lack of awareness in maintaining cabin safety, emphasizing the need for improvement. Examining the decision-making process regarding safety situations in their units, responses reveal an explicit acceptance of hierarchical decision-making structures. However, a subset of responses within this theme emphasizes the significance of teamwork and shared responsibility even within a hierarchical framework. Participants acknowledge that safety is a collective effort despite hierarchy, and all team members are responsible for ensuring safety.

Findings under the “Implementation of CRM Training in the Field” theme reveal a belief in CRM training’s positive impact on enhancing empathy, communication skills, teamwork, safety awareness, and resource management. CRM principles are considered a predominant element throughout the pre-flight and flight stages. Many participants emphasized the effectiveness of interactive training methods like real-world scenarios, discussions, case studies, and accident videos in facilitating impactful learning. On the other hand, the use of documents during flights has been perceived as time-consuming and impractical, and attention has been drawn to the potential for time pressure and excessive workload, leading to gaps in safety procedures.

As a general evaluation, these findings demonstrate that participants perceive CRM training to positively impact emotion and knowledge management, communication skills, teamwork, and a proactive approach to safety matters. CRM training significantly permeates into the real-world application field, namely flight operations. It can be said that all individuals within the flight crew feel a high level of responsibility for safety within this scope, which is attributed to CRM training.

In line with these research findings, the relevant literature supports the positive impact of CRM (Crew Resource Management) training on various aspects of aviation safety. For instance, Helmreich et al. (1999) revealed that CRM training fosters a safety-focused mindset among crew members and ensures a higher level of shared responsibility for safety. The study highlights that crew members who have received CRM training are more likely to identify potential safety threats and take proactive measures to mitigate them. These findings are consistent with our findings, suggesting that CRM training leads to a heightened sense of responsibility for safety among flight crew members. A comprehensive review of CRM training in aviation conducted by Salas et al. (2001) found that CRM training significantly improves flight crews’ communication, teamwork, and decision-making skills. The study concluded that practical CRM training reduces human error, is critical in aviation operations, and enhances safety outcomes. Similarly, a study by O’Connor et al. (2008) examined the effects of CRM training on airline crew members and found that CRM training significantly improved communication and teamwork among flight crews. The study reported a noticeable increase in standardized communication procedures following CRM training, emphasizing collaborative decision-making, which is crucial for safe flight operations. The authors concluded that these improvements in communication and teamwork directly contribute to enhanced safety and efficiency in flight operations. Flin and O’Connor (2017) emphasized that CRM training makes crew members feel better equipped to handle stressful situations and communicate effectively, contributing to a safer flight environment. Another related study by Kanki et al. (2010) addressed the broader impacts of CRM training on crew members’ abilities to manage their emotions and information under stress, noting that CRM training provides flight crews with tools to manage stress and emotions more effectively, thereby helping to maintain cognitive function and decision-making quality in high-pressure situations. According to a study by Mulyanto et al. (2021), CRM training enhances communication and coordination among flight crews, leading to improved teamwork and operational efficiency. Meta-analyses and evaluation studies have shown that CRM training is generally well-received by participants and leads to positive changes in attitudes, knowledge, and behaviors related to teamwork and safety. All these findings align with the results obtained in this specific research. However, the limitations in the literature concerning concrete data on the practical application of CRM training in daily life, particularly in the actual cabin environment, are inspiring for future research.

These results indicate that training effectiveness can be enhanced by incorporating more practical, interactive, and participant-centered approaches. Therefore, linking what participants learn during CRM training with real-life scenarios can contribute to more lasting knowledge retention and practical skill application. Organizing feedback sessions with team members at specific intervals can provide an opportunity to identify areas for improvement and encourage intra-team communication, coordination, and continuous learning. In this regard, both airlines need to consider feedback from flight crews and future research to determine how employees within the flight crew approach the subject, as seen in this study, regarding ensuring safety.

Besides all, this research has revealed the benefits of CRM training and its correspondences in real-world field practices. All findings and evaluations based on these findings are grounded in qualitative research and are limited to the research sample. In future research, considering different samples may provide further insights. On the other hand, qualitative research allows participants to express their opinions freely. It enables in-depth evaluations, yet it is essential to emphasize that due to its subjective nature based on personal experiences and views of participants, it may not be entirely objective. Therefore, using quantitative methods in this field can also contribute to the literature and field by providing a more balanced perspective.

Ethical approval

The necessary permission for the ethical aspect of the research was obtained through document no. E-88083623-020-125736 With the decision numbered 2023/07 dated 03.08.2023 of İstanbul Aydın University Social and Human Sciences Ethics Committee, stating that the research is deemed ethically appropriate.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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The Lessons from Sanctions on Iran and Their Impacts on the Development of Civil Aviation Understanding and Iranian Airlines

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Abstract

After the Islamic Revolution, Iran lived through many hard times not only because of its economic and financial resources such as oil and petroleum but also because of its historical, social, supremacy and leadership of some other Islamic countries and communities. Essentially, it has tried to defend its position for many years without sacrificing its Idiosyncratic Islamic governance structure within the world context or other Islamic countries, for these reasons, it has witnessed a lot of economic and financial sanctions or bans. Although Iran has a lot of highly qualified academicians and a workforce in the science of aviation, its civil aviation management structure and related activities, such as airline management, are very far from the average of the world depending on these financial and economic sanctions and bans by international orders. This situation is subjected to this research as a gap. This paper will analyse the civil aviation and air carrier industry of Iran under the impacts of these economic and financial bans and sanctions regarding four dimensions: Maintenance, Training and licensing, corporal development, and relationships with manufacturers. Essentially, at the beginning of the new age, in terms of international politics and conflicts in every continent of the world, new sanctions and bans are on the trouble agenda of world civil aviation agencies and institutions because of their highly political structure, and these bans and sanctions carry generally economic and financial identities, although they have international policy claims. There are a lot of possibilities on the desks of the civil aviation authorities for the burdens of these sanctions and bans and their sustainability impacts on civil aviation. Moving from the situation of Iran, the correct courses and necessary economic and financial policies will be suggested in this new world context and understanding

1. Introduction

Economic sanctions have become the most relevant instrument of foreign policy designed to respond to a wrongful act of policy of a state, such as aggression, support of terrorism, involvement in internal wars and the violation of human rights. Sanctions are primarily imposed to change the behaviour of the wrongdoer state. However, they have been widely used as an instrument to induce regime change or even as a complement to war (Razavi and Zeynodini, 2020). And, the purposes and means of a sanctioning act can change from the focus point of the power to another. According to Karacasulu and Karakir (2014), the European Union's main objectives in applying sanctions are: i) To safeguard the common values, fundamental interests, independence and integrity of the Union in conformity with the principles of the United Nations Charter; ii) to strengthen the security of the Union in all ways; iii) to promote international peace and strengthen international security; iv) to promote international cooperation. On the other side, the sanctions and bans of the United States are under strict investigation by different authorities depending on the 1955 Treaty of Amity which removes any impediments to the free exportation to Iran of medicines and medical devices, foodstuffs and agricultural commodities, and spare parts, equipment, and associated services necessary for the safety of civil aviation (Akhtar, 2019)

Since the Islamic Revolution of 1987, Iran has been affected by economic sanctions imposed by Western countries, especially the United States Since 2006 and with the development of the Iranian nuclear conflict, the United Nations has frequently imposed economic and financial sanctions against Iran (Shirazi et al, 2016). Essentially, the region suffers from these kinds of events such as the Syrian civil war, increased sectarian strife in Iraq, Afghanistan, Lebanon, and Libya, escalating violence in Israel and Palestinian territories, and rising security threats in Egypt, Turkey and Pakistan (Bell et al, 2016). For this cause, the existence of civil aviation and the utilization of airspace in the region always have some sustainability dilemmas with ambiguities regarding international politics. For example, according to Bucala and Hawrey (2016), the supportive attitude of Iran toward Syria (the Assad Regime) in the Syrian civil war including the activities of cargo and passenger transportation subjected to sanctions and bans from Europe and the United States. The results are devastating for Iran Civil Aviation and Iran Airlines.

Table 1. Sanctions on Iran

Sectors	Sanctions by the US (1995 -)	Sanctions by the European Union (2007 -)	Sanctions by the United Nations (2006- 2016)
Missile/arms industry	Restricted	Restricted	Removed
Islamic Revolutionary Guard Corps	Restricted	Restricted	Removed
Nuclear industry	Restricted	Restricted	Removed
Energy/petroleum industry	Restricted	Restricted	Removed
Banking	Restricted	Restricted	Removed
Central Bank of Iran	Restricted	Restricted	Removed
Shipping industry	Restricted	Restricted	Removed
International trade	Restricted	Restricted	Removed
Insurance	Restricted	Restricted	Removed
Foreign firms dealing with Iran	Restricted	Restricted	Removed

Iran is beyond being a Middle Eastern and developing country in world conjuncture. It has witnessed a lot of in-border and off-border negativities during the last 75 years politically and economically. Although it has redundant oil and natural gas resources, effective and efficient utilization of these resources is problematic not only by country but also by world economics. If it is coded the sanction and ban crisis in the context of Iran correctly, it seems that there is not only one state's sanctions or bans, but there is a global sanction against Iran under the leadership of several big countries such as the European Union and the United States (Rahimi et al, 2014) and the attitude of the United Nations toward Iran becomes always negative in this equation or processes (Suzuki, 2019). Besides these, the lesson of Iran is such a clear example that the cost of protecting a regime is to remain distant from reaching the world economic community. If a list is formed of the critical sanctions in Iran, they can be counted in Table 1. Although there is a sharp decreasing trend in sanctions and bans at the United Nations level, the country and region felt the destructive impacts of the United States and European Union's sanctions in 2016 (Jay, 2015). At the same time, If it is realized a comparison of the power of the sanctions, Torbat (2005) clearly explains that financial sanctions have a more powerful impact than trade sanctions.

Iran's civil aviation industry is also a sorrowful victim of these sanctions with other industries such as defence, oil and shipping industries (Amir, 2018). This paper aims to analyze the impacts of the sanctions on critical and vital pillars of civil aviation and airline management: Maintenance, training and licensing, corporal development, and relationships with manufacturers as a method. The importance of these four variables is examined in detail in the related titles of the literature and findings section. At the same time, the work will complete a sustainability gap and examine the development an airline and civil aviation understanding under the hard and harsh conditions of the sanctioned economy and financial context. In this way, the research offers some policies for the international civil aviation and airline order in the world where there are living conflicts and wars.

2. Method Development

The development of civil aviation shows similar characteristics in different countries. As it is understood from the work of Taneja (1994), civil aviation has three pillars which can be called the technological, political and economic dimensions of civil aviation. Safety, which is an important variable in the middle of this triangle, is nourished and flourished by their development and interaction of them. For example, the Paris Conference of 1919 was an important step in the political dimension toward internationalism that should be aimed to protect by authorities (Sucharitkul, 1994) on the other side, the creation of the "Airbus Idea" in the middle of the 1970s meant a great leap for European Aviation Comprehension which competed with the United States regarding three dimensions. At the same time, these two events are safety, economic, political and technological challenges for international civil aviation. Therefore, these three dimensions have complementary impacts on each other as it can be observed in the Iranian Case.

The focus point of the governance structure of civil aviation business segments has become also another important argument throughout history. Engineering, marketing, financial, and branding understandings of the civil aviation system, their positions and conformities with the aviation system are other important arguments since the beginning of civil aviation activities (Clark, 2017). Safety is another element that should be argued well. Ben-Saed and Pilbeam (2022) argue that embargos and sanctions have dramatic impacts on the development of safety climate regarding safety training, lack of safety resources, and poor safety communication. On the other side, maintenance activities have great importance for safety and countries should develop maintenance activities (Zimmermann and Mendonca, 2021). These acts should be compulsory matters (Fidanoğlu, 2017) of the elaboration of the Iranian Civil Aviation Case.

Civil aviation has an idiosyncratic legal basis under the roof of the International Civil Aviation Organization (ICAO) supplying other legal and law institutions that take their roots from bilateral and multilateral agreements and conventions and state codes such as the Turkish Civil Aviation Code of No.2920 nationally and internationally under the emphasize of a complete state freedom (Rhyne, 1946: 459). The administrative impacts of the ICAO draw a framework for countries and states for their national safety comprehension. The decisions of the ICAO are locally binding and final in front of the international legal courts (Dempsey, 1987). Nevertheless, the political positioning of ICAO has been restricted by unpeaceful considerations and states, although it develops security enhancement programs against the violence against civil aviation (Sochor, 1988). Moreover, international civil aviation activities and their governance structure show differences in the dimension of regions and states under the impact of technological and communicational infrastructures, this situation causes fragmentation, disorder and lesser integration (Sanggiovanni, 2022).

The civil aviation sanctions show their dramatic impacts on the development of airline activities in almost every dimension. Davidson (1993) counts these negative impacts as contracts and contract-depended relationships, long-term planning and future orientation, and the defects in internationalism. Katzman (2015) adds that the trade of aviation fuels, maintenance, education and training of civil aviators, and international and industrial development are in trouble agenda of the Iranian regime because of the sanctions and bans.

In light of the arguments above, contemporary civil aviation activities are grouped by four different and important points in this work. Firstly, it concentrates on the development of maintenance activities that are responsible for the great majority of civil aviational accidents and incidents. These activities are framed and formed with dense international, national and regional or continental contractual activities, certifications and licences depending on, for example, Annex 1 (Personal Licencing) and Annex 8 (Airworthiness) of ICAO. In the absence of these activities, the situation of Iran or any sanctioned state is in question. Secondly, training and licensing are another important aim of these bans. Unless a country is a member of the international licence and train programs and creates a uniform structure complying with international civil aviation order, its civil aviation suffers deeply from all of the negativities in the industry. Thirdly, the research welcomes a corporate approach to civil aviation, especially airlines which have a business entity. While other international airlines give the last shape to their business-making styles in the light of industrial partnerships and alliances, the state of Iranian Air Carries has a great ambiguity. And the future is a paradox for them because of the impediments of the international order. For this reason, the corporal structure of Iranian Air Carriers is in elaborate trouble and this process should be examined. Fourthly and lastly, it develops a solid framework for the Iranian civil aviation industry regarding the most effective and efficient economic duopoly of the world between Boeing and Airbus. This duopoly gives a last shape to all of the airline activities with suppliers. Iran's situation should be evaluated in this regard, although it has other aircraft manufacturers' vehicles.

3. Literature Review and Findings

The sanctions on civil aviation in Iran

Every state tries to have nuclear power depending on its effective and efficient utilization as an energy resource for civil purposes and depending on its frustrating force for military purposes. For these reasons, states manage a nuclear policy. Nevertheless, Iran's situation is a little bit different because it elaborates an aggressive nuclear policy against international order claiming to protect a civil regime and its independence regarding energy production (Intaek and Jang, 2013). But, the distance between nuclear energy and a nuclear weapon is so short in the science of physics. The second important cause of the Iranian sanctions is the violation of human rights which are delineated as the main feature of oppressive regimes by international order. The third cause can be considered as Iran's support to Hezbollah, Hamas and Palestine Islamic Jihad (Katzman, 2001). On the other side, the sanctioning states and international order argue the current situation under the name of Iranian terrorism. Iran sustains its existence in a complex Middle Eastern region regarding political, economic, and social frameworks. Therefore, finding an optimal and comprehensive solution is not easy for the states and Iranian elite politicians in world politics (Draca et al., 2019). In this context, a rational state should consider that there are critical industries such as civil aviation, maritime, energy, finance, and technological infrastructure but, it should know that if it makes aggressive moves, the response of international order shows its impacts on these industries of the country. Iran sustains its existence in this situation. The relationship between Iranian civil aviation and sanctions can be examined in Table 2 (IRAM).

Table 2. The sanctions on civil aviation in Iran

Claims	Sanctions
Transportation of weapons and military personnel with civil airlines in conflicting times in the Middle East.	Various international and regional airport restrictions. Political, economic and financial sanctions against Iranian Civil Aviation.
Unfair and illegal nuclear weapon programme	Restrictions on Aircraft Cargo in Iran Air, flag carrier and state-owned air carrier of Iran, in UN Security Council Resolutions 1803 (2008) and 1929 (2010).
Political and safety reasons	Restrictions on European Union (EU) airports in cargo transportation in July 2010.
Aims to isolate financial proliferators of weapons of mass destruction and their supporters	Restrictions on Iranian airlines US Executive Orders 13382.
As a response to the 9/11 attacks to curb terrorist financing and activities.	Restrictions on Iranian airlines US Executive Orders 13224.
Supporting support to the Islamic Revolutionary Guard Corps's (IRGC)	Restrictions on Iranian airlines such as Mahan Air, Caspian Air, Meraj Air and Pouya Air regarding spare parts.
*To comply with the Joint Comprehensive Plan of Action (JCPOA)	*Iran was permitted to purchase only finished commercial aircraft. Iran Air was taken off the US sanctions.
USA's exit from JCPOA	Iran Air and some people were blacklisted.
Depending on the hardships in the US export-control lists. Illegal utilization of sanction-evasion channels and Iran-bound cargo.	Mahan Air was blacklisted regarding spare parts. Dubai free zones (Blue Sky Aviation Co and Avia Trust) were sanctioned regarding aircraft parts and equipment.
The measures of the Office of Foreign Assets Control (OFAC)	Ukrainian Bukovyna Airlines is sanctioned due to relationships with Mahan Air.
The measures of the Office of Foreign Assets Control (OFAC)	Ukrainian-Mediterranean Airlines (Um Air) and its director and owner were also blacklisted due to relationships with Mahan Air.
The measures of the Office of Foreign Assets Control (OFAC)	Kyrgyz Trans Avia (KTA) was also blacklisted due to relationships with Mahan Air.
The measures of the Office of Foreign Assets Control (OFAC)	Pouya Air was blacklisted from the complex services.

*It is a well-intended, dialogue-depended and creative process for Iran and world order. So, positivity is felt in the international policies of Iran and other parties. In this process, Boeing and Airbus also decided to sell aircraft to Iran.

Maintenance

The aviational activities need a systematic approach in which the main items can be counted as availability, maintainability, safety, durability and reliability of these items (Zio et al., 2019) because maintenance-dependent accidents and incidents are fatal (Wild, 2023). Maintenance is not only a cost of airline companies, but it is also a subject of large and important titles according to international and continental legislation and monitoring (Herrera, 2009) bodies such as the International Civil Aviation Organization (ICAO), European Union Aviation Safety Agency (EASA) and Federal Aviation Administration (FAA) regarding contracts, licencing, BOT (Build, Operate and Transfer), OEM (Original Equipment Manufacturer) and outsourcing because of its importance in incident-accident prevention nature (Bogdanov et al., 2011). Therefore, civil aviation maintenance activities are in the hands of states and governments (Liangrokapart and Sittiwatethanasiri, 2023) under the name of airworthiness. Reporting, standardization, licenses and certifications are of great importance in airworthiness actions and need extra efforts in the international, national and regional context (Latorella and Prabhu, 2000). In the case of Iran's civil aviation, all of these matters are problematic because they depend not only on international sanctions but also on the depletion of Research and Development activities which are the main veins in the development of civil aviation in the international arena under these economic and financial sanctions (Miremadi and Baharloo, 2020). Besides these, Dadpay (2019) underlines the importance of maintenance in safety and security one more time and proves the negativity of the economic and financial sanctions regarding maintenance services and spare parts in some incidents and accidents examples. Besides, it is an unforgettable reality that an accident or an incident at regional and state levels is an international problem for civil aviators who are observing civil aviation accidents and incidents closely. According to the reasoning of Jalali (2011: 87), technical and technological sanctions against Iran can cause a collapse in international safety and security understanding of civil aviation for this reason, international civil aviation authorities and states should find a way to dialogue. By the way, the importance and position of international civil authorities in the Iran case are explained economically, and politically by (Carney and Farashahi, 2005). According to them, transnational policies and understandings are so important to develop a global understanding of civil aviation.

Training and Licencing

Training and Licensing are important parts of civil aviation. If it is concentrated on corporal education and licencing matters and institutions in the world civil aviation order, it can be understood that the reality of civil aviation develops a dependence on international licencing and reporting (Avers et al., 2012). Even, the civil aviation language is designed and controlled by a proficiency program developed by ICAO (Kraniscka, 2016). Besides, Shi (2024) argues that civil aviation activities are an important part of Urban Air Mobility (UAM), so civil aviation is subjected to continual development regarding certifications. Ateş and Kafalı (2020) maintain that civil aviation human resources suffer from the necessary qualifications. With restrictions on reaching the maintenance and manufacturer resources, Iran's capabilities and abilities are restricted regarding licencing, therefore training. Pilots, cabin crew, maintenance technicians and engineers, and airport and ramp services, air traffic services can not gain an international identity with the lack of international certificates, licences and training which should be given and controlled by international manufacturers and industrial suppliers qualitatively (Galisanskis, 2004) and quantitively. The civil aviation activities of the states are managed and controlled with these certificates and licences (Brushnikin et al., 2020; Bennett, 1984). Besides these, Gov and Paksoy (2021) emphasize the importance of licences, certificates and education and training which grant them. This reasoning is confirmed also in the works of Todd and Thomas (2013: 1) regarding pilotage education and training underlying the importance of competence, regulatory minimums and syllabus. For Mendonca et al. (2019) and MoghimiEsfandabadi et al. (2023), one of the main causes of high-profile accidents is the education and training system which includes decision-making, poor leadership and ineffective communication. According to the findings of Gauci et al. (2021: 1), education and training are visionary and future tools in the hands of the civil aviation authorities. Also, civil aviation has education and training mechanisms that nourish a great job opportunity for younger generations (Watkins et al, 2016: 2) and managerial job demand with high degrees (Newcomer et al., 2014: 23). Besides this information, the licences and licences dependent training activities are the main targets of sanctions and bans against Iran (Rennack, 2016). Airports and commercial aircraft operators should ensure some licences and certifications (Yadav and Nikraz, 2014). When considering this situation in the Iranian civil aviation context, the sanctions and bans hit not only the current state of civil aviation but also its future since the first sanctions made by both the public and private institutions.

Corporal Development

Corporal development of airlines is the third important pillar of this research. When it concentrated on the development of airlines, especially after the Airline Deregulation Act of 1978, it can be observed micro, macro and international-level corporal structures. For example, marketing and promotion-based managers began to overcome engineering-oriented managers. On the other side, budget planning, cost-effectiveness, dynamic pricing, and hybrid airlines have been the most important and contemporary managerial and theoretical subjects and activities. The development of alliances, code-sharing activities and slot programs gain new forms at the micro level considerations. Technology-based programs such as NEXTGEN (Strohmeier, 2014; Fleming et al, 2013) in the United States, activities of EUROCONTROL (MacInally, 2010; Pedroche, 2024) in European countries, development of new vision in the African and Asia continents, and regionalism such as Asia Pacific are examples which became macro and international subjects of civil aviation. So, under the impacts of internationalization and professionalism, the industry of civil aviation redefines its identity and existence year by year. Ethical and deontological philosophical movements regarding fairness, accountability, social responsibility and transparency transformed into important corporal subjects of the airlines near the safety, security, and elimination of environmental pollutants and noise. The definition of new human capital and intangible assets are the key issues in this context (Lopez, 2007; Warn 2005). Mustilli and Izzo (2009) also underline these factors as they define the global civil aviation industry. For Fardnia et al. (2022: 1), there is a negative correlation between the quality of the governance practices and safety mistakes, errors and faults in aviation. According to Sangiovanni (2021), international civil aviation overcomes obstacles such as duplication, inconsistency and conflicts through cooperation and common sense. In the case of Iran, i) there are a lot of huge barriers and obstacles between international civil aviation understanding and corporal mechanisms and Iran, ii) As it can be seen in Table 2, every airline development and step toward internationalisation was oppressed by a sanction.

Relationships with aircraft manufacturers

The last explanation or pillar is about the relationship between aircraft manufacturers and Iran. There are two aircraft manufacturers in the world, Boeing of the United States and Airbus of the European Union. They are not only the projections of historical competition between two continents on both sides of the Atlantic Ocean but also are technological and innovative giants of the aviation industry. Without their contributions, it is impossible to draw a future framework in every segment of civil aviation regarding engine and component production, airport and air traffic development, and economic, social and environmental sustainability. Their effectiveness and efficiency in international civil aviation politics, rules and regulations are a known reality depending on the power of the US and European countries. Iran's aggressive or positive attitudes against its dissidents inside and outside of the country are general subjects of bans and sanctions by these two giants. Wolber (2017) takes attention to this situation in the nuclear agreement process emphasizing the importance of Airbus and Boeing's financial gains regarding the USA and EU. It is so important and open reality that these two giants and their suppliers are so important for developing countries such as Turkiye desiring to build solid aviation partnerships and aeronautical governance structures with the US and European countries. So, sanctions toward accessing to resources of Boeing-Airbus duopoly is another problem for Iran Civil Aviation and Iran Airlines. And findings of Adesnik and Ghasseminejad (2018) affirm the relationship between Boeing and Airbus and the sanctions by emphasizing the priorities of these companies in their region and state policies. The countries, which understand the importance of aircraft manufacturing and maintenance, develop strategies and investments in parallel with this duopoly such as Brazil (Junqueira et al., 2018) and Oman (Rawahi et al., 2020).

Under the strict, strong, harsh and comprehensive sanctions and bans and their impacts that can be counted as four pillars -and there can be more- Iran Civil Aviation and Iran Airlines try to survive. The next section of the analysis will focus on the fleets, their technology and the network structures and airports, and then it will realize a comprehensive financial analysis of airlines in Iran. The total Airline fleet of Iran can be summarized in the following Table 3(Planetspotter, 2023). Although it is observed the existence of other air manufacturers such as ATR (Aerei da Trasporto Regionale or Avions de Transport Régional), the density of Boeing and Airbus aircraft is overwhelming regarding Iran's civil aviation fleet like the other parts of the world.

Table 3. Some details on Airline Fleets of Iran

Airlines	Boeing	Airbus	ATR	Other	Average year*
Iran Air	28	58	13	27	18.0 years
Iran Airtour Airlines	2	16		18	36.0 years
Iran Aseman Airlines	4	7	9	23	30.0 years
Iran Naft Airlines	1			10	
Mahan Air	5	62		31	27.0 years

As stated in the table, the Iran Civil Aviation force does not suffer only from the negativies regarding aircraft models, but also their needs of maintenance (Average age). But, depending on the sanctions on spare parts and maintenance-related Research and Development, most aircraft stay on the ground. This reality has been corrected by also media and social media. The cost of an unflying aircraft to the airlines is more expensive than maintenance costs. One of the main aims of the Iran Civil Aviation Organization is to lessen the average age of civil aircraft (Tehran Times, 2024). Besides these, there are 319 airports in Iran. Their development strategies and internationalization processes are very important for regions and state(Pishdar et al.,2019; Oflat and Pishdar, 2017).

As it concentrates on developing civil aviation, the civil aviation industry is nourished by two main resources. One of them is the tourism industry and the other is the export and import power of the countries. Especially the balance between export and import goods economically, their diversity gains importance regarding work balance, variability of work and experience.

Shirazi et al. (2016: 11) state that the sanctions imposed against Iran have had a significant and negative effect on the amount of exports in Iran and all the countries considered in all the given years. As well, the intensity and the extent of this effectiveness over time compared to 2012 have increased which could be due to the exacerbation of the economic sanctions over time, as well as the joining of more countries to the sanctions. According to the results, the sanctions imposed each year have decreased about 33 per cent of Iran's exports annually and have imposed a loss of 104 billion dollars on Iran's trade. Given the reduction of 1 million barrels in Iranian exports, these results were not unexpected. It is a historical lecture and course that the sanctions have long-term and future-oriented results regarding international trade (Askari et al., 2001)

International efforts to isolate Iran and force it to stop its nuclear agenda and schedule have a lot of negative impacts on the country's economy: all of the industries have been paralyzed, the nutritive materials prices and fuel prices are skyrocketing, and the local currency is collapsing. But by causing a plunge of the rial, the sanctions have had an unintended and, for Iran, very welcome consequence: a jump in tourism (Butler, 1993). According to some sources, three million tourists visited the country by the end of 2011, contributing more than $2 billion to the local economy. Also according to the UN World Tourism Organization, from 2004 to 2010 international tourism in Iran grew four times faster than the global average, which posted an annual gain of 3.2% (Mirani, 2013) with some negativities, for example, psychological impacts such as fear, economical investments, absences of necessary transportation and technological infrastructure and sophisticated financial services, mobility and visa restrictions, gender disempowerment and less purchasing power (Seyfi et al., 2022).

In this context, the cargo and passenger numbers show volatility structures which gain importance depending on sanctions as in Graph 1 (World Bank database, 2024) and Graph 2 (World Bank database, 2024).

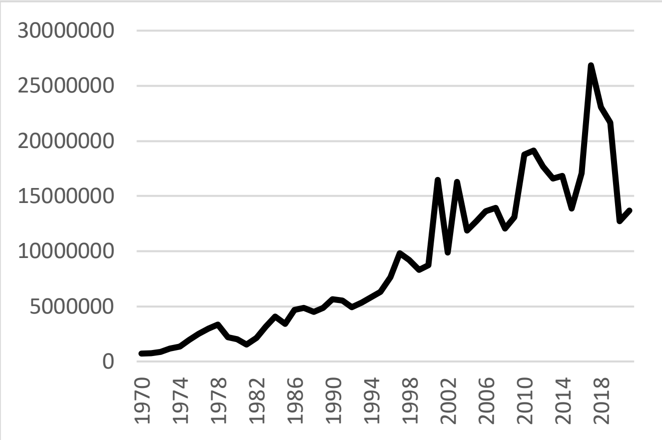

Figure 1. Iran Air Republic Passenger Numbers.

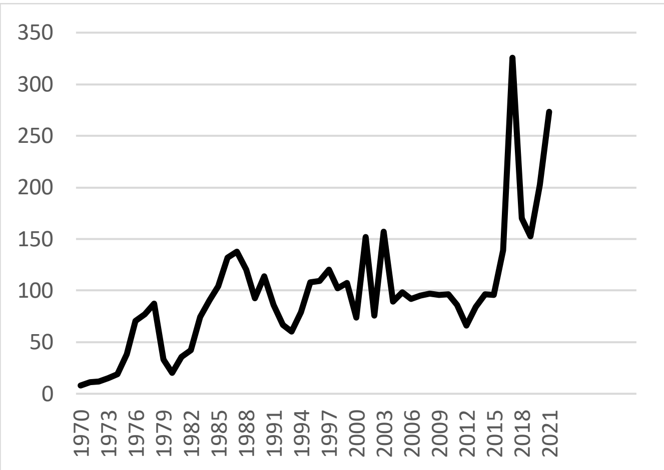

Figure 2. Iran Air Republic Cargo Numbers.

4. Conclusions

With the words of Carney and Farashahi (2005: 1) emphasizing the globalities of sanctions and bans, the case of Iranian civil aviation depicts a more volatile scenario of frictionless and uncontested institutionalization of civil aviation, followed by gradual erosion of isomorphism with international norms. In this regard, the pathways to globalization are not straightforward. However, they also emphasize that adherence to transnational norms is of material concern to the economic prospects of developing countries. On the other hand, As Iran's nuclear programme edges closer to weapons capability, the nations concerned about this prospect have centred on sanctions as their favoured policy tool. Critics find this foolhardy because they see no obvious signs that sanctions are working, other than to impose hardships on ordinary Iranians (Esfandiary and Fitzpatrick, 2011:1). From the findings of this research, more clear words, it can be easily concluded that the civil aviation industry of a country has a great dependence on internationalization. Technical and operational variables such as safety, security, environmental consciousness and noise management are formed in a continual international regulation process. Therefore, to yield profit from the activities, the technical and operational base is a necessity.

Secondly, the financial and economic impacts of the sanctions on airlines and civil aviation can be examined in short, middle and long periods. In a short time, the sanctions hit the financial and economic fiscal and financial table balance of Iran regarding airlines and the civil aviation industry. The competitive force of the airline companies and other segments of civil aviation is measured by indicators such as EBITDA (Earnings Before Interests, Taxes, Depreciation and Amortization), ROI (Return on Investments), ROA (Return on Assets) and ROE (Return on Equity) without effective, efficient and internationalized management practices, utilization and calculation of assets, debts, revenues, costs and inventories (Liu et al, 2023; Renold et al, 2023; Tsikriktsis, 2007) it is open that Iranian Air Carriers lost their financial and economic competitive force on an international scale under the impacts of the sanctioned economy in a short time. On the other side, the loss of qualified human force hitches in marketing policies, and devastation in corporate governance structure were the main results in the middle term. Moreover, Iran's civil aviation and Air Carriers lost the main triggering forces that belong to the civil aviation world such as airline reputation (Cocis et al, 2021; Jehn and Scott, 2015) in the eyes of the passenger and cargo consumers with a collapse in safety and security policies, routing and network strategies and research and development power in technical fields. Iran suffers also from the nullities of these activities which can be counted as the maintenance of aircraft, training, certification and licencing of human forces in the long term. At the same time, branding policies (Wong and Musa, 2011; Lin and Ryan, 2016) lost their impact after incidents and accidents which formed under the impacts of the large sanctions on spare parts and maintenance and the absence of new aircraft systems.

Another important detail that should be considered here is the size of Iran's Economy and the importance of the place of SMEs in this equation and the civil aviation supply chain, it is interesting to say that Cheratian et al. (2022) find that reducing research and development (R&D) expenditures, marketing costs fixed/overhead costs and investing in information technology (IT) are positively related to small and medium-sized firms' persistence. Conversely, managerial decisions to reduce production and cut or freeze staff pay have negative and significant impacts on a firm's ability to persist during sanctions. Moreover, micro-firms are more resilient than their small and medium counterparts and they confirmed that the age of the firm has a significant and positive impact on firm persistence. Finally, the results show that having a business plan, access to finance and technology, owner education, export orientation, business networking and consulting services are the key drivers of withstanding pressure from sanctions. Regarding stock markets, within increasing the sanctions case, if the institutional quality has been also enhanced; an increase in the number of sanctions causes a long-term improvement in the bullish market. Also, in the bearish market, an increase in the sanctions and the depreciation of the rial, along with increasing institutional quality, leads to long-term growth in the stock market (Roudari et al., 2023). Considering these arguments, the financial structure of Iran was dramatically affected by sanctions disregarding financial markets and company size. For these reasons, sanctions have also direct impacts on the financial development of Iran where civil aviation and airlines can be directly affected.

The causes of the sanctions and bans are subjects of international politics. On the other side, Iran's existence in the civil aviation and airlines world is so important not only for the country but also for a region, continent and world civil aviation activities such as airspace utilization, airline partnership and alliances, route and network arrangements and activities. The well-intended efforts toward normalization and dialogue in the Iran-World relationships and also world conjuncture gave their fruits every time, like the Joint Comprehensive Plan of Action (JCPOA) of 2016 which aimed to alleviate the economic and political burdens of Iran in return for constructive policies of Iran (Ranjbar, 2020). As observed, in the findings of Donoghue et al. (2014), one of the first aims of the JCPOA was to realize an arrangement in the transactions of Iran regarding civil aviation due to increasing impacts of internationalism in the activities of civil aviation. So, policymakers in the international arena can focus on and develop soft communication skills to develop a total solution in Iran's case. Otherwise, the region is subjected to conflicts and even wars and will continue to suffer from these negativies regarding civil aviation, airlines and air space utilization financially and economically, because of aggressiveness in sanctions and bans. The Iranian case should be an instance of the Russian-Ukrainian conflict (Prakasa et al., 2022; Akbarlı et al., 2022), the tensions between the African States and the situation of Southeastern Asian Countries such as North Korea, China and Taiwan to international civil aviation order.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Assessing the Impact of Hybrid Propulsion Systems on the Range and Efficiency of Aircraft

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Abstract

The demand for aviation continues to grow, posing issues in terms of fuel consumption, environmental effect, and operational efficiency. In addition, the COVID-19 pandemic has also highlighted the need for sustainable solutions in the aviation sector. To address these issues, hybrid electric propulsion systems have emerged as a potential option. Hybrid electric propulsion systems have the potential to improve airplane performance while reducing environmental impact. This article looks into the effects of hybrid electric propulsion technologies on optimal aircraft range. The study looks at aviation's environmental impact, several hybrid aircraft prototypes, and battery capacity and density challenges. Fuel usage increases in proportion to the weight of the aircraft. As a result, the range is shorter. In modern technology, along with to the added weight of batteries used as energy storage in hybrid propulsion systems, there are low battery densities and capacities. When the researches were reviewed, it was discovered that overcoming these limitations was easier for small aircraft and more difficult for large aircraft. As a consequence of the studies and research conducted, the development of light and reliable batteries with high energy density and capacity would expand the range of hybrid aircraft and allow them to be used more efficiently over long distances.

1. Introduction

Due to the increasing consumption of fossil fuels, their high cost and their negative effects on the environment, the search for new energy sources continues. In order to use fuel more efficiently in the aviation field, studies are being carried out such as improvements in existing engines and lighter aircraft materials. Recently, studies have mainly focused on hybrid propulsion systems in aircraft to reduce fossil fuel use.

The adoption of hybrid electric propulsion systems in the aerospace industry represents a paradigm shift towards more sustainable and environmentally friendly aviation. The aviation industry faces challenges such as carbon emissions, fuel consumption, and the search for efficient propulsion technologies. In response to these challenges, hybrid electric propulsion systems offer a significant benefit by reducing environmental impact through decreased fossil fuel consumption and harmful emissions.

By combining the power of conventional fuel-powered engines with the efficiency and versatility of electric motors, hybrid electric propulsion systems not only reduce fuel consumption but also diminish the environmental carbon footprint of the aviation industry. Hybrid electric propulsion is seen as a testament to the commitment to a greener future for air travel.

The advantages of hybrid electric drive are not limited to reducing environmental impact; they also have the potential to reduce noise pollution and advance aircraft performance with features such as improved power distribution, high reliability, and operational flexibility. These systems can enhance the capability of aircraft and optimize their range by utilizing both conventional and electric propulsion.

One of the most important performance indicators for aircraft is range. The range of an aircraft directly affects the accessibility and versatility of air travel. This study evaluated the effects of hybrid electric propulsion on aircraft range.

2. Literature Review

Hybrid electric propulsion systems offer advantages over conventional propulsion systems, such as reduced emissions and noise, increased global aircraft efficiency, increased aircraft power distribution/quality and flight range, and the capacity to expand the market to smaller airports (Sliwinski et al. 2017).

The development of hybrid-electric propulsion systems for aircraft has been a subject of interest in recent years due to its potential to reduce fuel consumption and emissions. In the following studies found in the open literature, it has been observed that the effects of these systems on optimum aircraft range have been investigated.

High-weight batteries have a significant influence on designs, as the study by Voskuijl et al. emphasizes when measuring the design space depending on hybridization level and duty range. It also highlights how important it is to take into account other system elements during the design phase, like cabling and battery cooling. By using a parallel hybrid electric propulsion system architecture, making assumptions about future developments in battery technology, and comparing the results with traditional turboprop aircraft, the study shows that hybrid electric propulsion produces significant emissions savings. According to the study, a design that needs 34% electric shaft power, for example, reduces mission fuel consumption by 28%. This, in turn, lowers local emissions and noise levels during takeoff and landing (Voskuijl et al., 2018).

Vries et al. conducted a dimensioning study a passenger aircraft with on-wing distributed hybrid electric drive and evaluated the impact of this configuration on energy efficiency. The comparative analysis revealed that the hybrid electric aircraft is 2.5% heavier and consumes 2.5% more energy compared to the reference aircraft (Vries et al., 2019).

The study by He and his team evaluated the performance of a hybrid passenger aircraft using turbofans and electric fans at different degrees of hybridization, examined the effects of hybridization on the main performance characteristics, and developed an optimization method that allows hybrid electric propulsion systems to quickly enhance the design requirements for series hybrid electric systems. (He et al., 2020).

The research conducted by Xie et al. underscores that although hybrid electric systems exhibit a balance of emission reduction, fuel savings, and performance for small-scale aircraft, the adaptation of these systems to larger aircraft is a subject of skepticism among some researchers. Progress in this field depends on advancements in electric storage technologies (Xie et al., 2021).

The research by Bravo et al. compares all-electric and hybrid propulsion systems in the context of efforts to reduce emissions in the aviation industry. They found that all-electric propulsion tends to have more battery weight, while piston engines are both more efficient and cost-effective. Another study by the same team looks at the aerodynamic efficiency of a distributed hybrid propulsion system. It mentions that although drag is reduced, there's also a decrease in lift, emphasizing the need for thoughtful design (Bravo et al., 2021).

Palaia and Abu Salem investigated hybrid-electric regional aircraft mission systems, assessing their operational performance across diverse conditions through simulation software. They emphasized the distinct operational methods of hybrid electric aircraft compared to traditional fuel-driven ones, particularly regarding load-range diagrams and optimizing power supply techniques for enhanced fuel efficiency and extended flight range (Palaia and Abu Salem, 2023).

Zaghari et al. conducted a study on the aerodynamic and acoustic performance of electric motor and propeller designs. They concluded that aerodynamics significantly influences energy consumption reduction and noise mitigation during flight. Wide engine views were found to enhance both acoustic and aerodynamic performance. This research underscores the importance of noise reduction and increased aerodynamic efficiency in developing sustainable hybrid electric aircraft technology (Zaghari et al., 2023).

3. Changes in Air Transportation and the Impact of Covid-19

Increasing demand for products supplied from different parts of the world necessitates rapid transportation. For example, the global e-commerce industry relies heavily on cargo transportation by air to provide fast deliveries to consumers. Pharmaceutical and perishable goods industries have also become dependent on air-transportation for timely transportation of their sensitive products. As a result, air transport is becoming an integral part of the global trade network and contributes significantly to economic development and prosperity.

The number of airline passengers has been increasing steadily over the last few decades. According to the International Air Transport Association, the global airline industry carries a steadily increasing number of passengers each year, carrying approximately 4.5 billion passengers in 2019 (hhtp-2). Airlines around the world are expanding their fleets to meet increasing demand. Data from Boeing and Airbus, two of the world's largest aircraft manufacturers, show that the global commercial aircraft fleet is expected to double over the next two decades. Airlines ordered thousands of new aircraft in 2019 to meet this increasing demand (http-1; http-2).

Nevertheless, the aviation industry has been hit hard by the COVID-19 pandemic, experiencing an unprecedented decline. The pandemic caused a dramatic decrease in air travel, leading to significant financial losses for airlines. Travel restrictions, lockdowns, and quarantine measures imposed by countries to curb the virus spread resulted in a sharp drop in passenger numbers. Both international and domestic travel almost came to a standstill, leaving airports deserted. In 2020, global passenger demand plummeted by around 65.9% compared to the previous year, as reported by the International Air Transport Association (IATA, 2020).

Thanks to widespread vaccination campaigns, people are feeling more confident about flying again. Many countries have rolled out vaccination programs, and airlines and airports have stepped up their health and safety measures. These include requirements for masks, stricter cleaning routines, and better ventilation systems. These efforts have helped reassure travelers that flying is safe.

As the pandemic situation improved and precautions were put in place, many countries started easing travel restrictions and border closures. This has allowed international travel to slowly resume, which is crucial for the industry's recovery. Bilateral agreements and agreed-upon health protocols have made cross-border movement easier.

The demand for air transportation is increasing steadily under the influence of several key factors. One of the main catalysts is the expansion of the global middle class. As more people reach higher income levels and better standards of living, the desire and capacity for air travel is increasing significantly. The International Air Transport Association estimates that the number of passengers traveling by air will double to 8.2 billion by 2037 (http-3).

Air transportation has a larger share than the land and sea transportation market. Aircraft are becoming the preferred method of long-distance travel, often replacing slower alternatives such as trains or buses. In some regions, such as North America and Europe, air travel holds a significant share of the market, with more than half of all travel being made by air (Caputo et al., 2023).

4. Environmental Impacts of Aviation

The rising demand for air travel presents challenges in terms of environmental impact and sustainability. The aviation industry is actively striving to develop technologies that are more fuel-efficient and eco-friendlier to reduce its environmental footprint. It aims to balance the benefits of air travel with its environmental responsibilities, driving ongoing research and improvement efforts.

To tackle environmental issues in aviation, significant investments are being made in alternative fuel sources like biofuels and renewable energy to minimize greenhouse gas emissions.

In 2022, the aviation sector accounted for 2% of global CO_2 emissions, driven largely by energy use, surpassing emissions from road and sea transportation due to recent growth. With international travel demand rebounding post-COVID-19, emissions in 2022 nearly reached 800 million metric tons of CO_2, about 80% of pre-pandemic levels. Various technical measures, including low-emission fuels and advancements in engine design, are being employed to curb emission growth and work towards reducing emissions to net zero by 2050 (http-4).

5. Methodology

Hybrid propulsion systems ingeniously combine conventional fuel-powered engines with electric motors, significantly reducing focus impact while simply maximizing efficiency and creating an energy-efficient synergy. Such advances are promising efforts towards creating a greener future for air travel through profound technological advances and cutting-edge research in detail technology. In the field of aviation, efforts have intensified to use hybrid drive systems during the transition phase to the use of fully electric propulsion systems.

5.1. Series hybrid propulsion systems

In aircraft, one popular hybrid electric propulsion setup is the series hybrid configuration (Figure 1). Here, the propeller isn't directly linked to the gas turbine; instead, it's solely powered by an electric motor (Rendón et al., 2021). This setup resembles the turboelectric architecture but adds a battery for energy storage and propulsion assistance. In this setup, a generator converts the gas turbine's mechanical energy into electrical power. This electricity can directly run electric motors or be stored in a battery. Since the gas turbine's main job is generating electricity, this setup works well for planes with distributed propulsion (Gogolák et al., 2019).

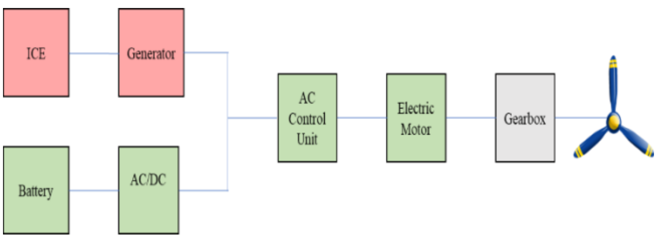

Figure 1. Series Hybrid Propulsion Configuration

In the series hybrid propulsion system, the propeller isn't directly linked to the gas turbine, allowing the turbine to operate optimally throughout the flight, cutting fuel use significantly compared to other setups (Capata and Coccia, 2010). While offering simplicity and flexibility in engine placement, this setup adds weight due to the generator and battery, and it's less efficient due to power losses in conversion (Economou et al., 2019). Moreover, it lacks redundancy in case of engine failure.

In 2011, Siemens, Diamond Aircraft, Austro Engine, and Airbus showcased the first manned serial hybrid electric aircraft at the Paris Air Show. This DA36 E-Star aircraft achieved a 25% decrease in emissions and fuel consumption using a Siemens electric motor and an Austro Engine (http-5; Alvarez et al., 2022). Manufacturers suggest the aircraft's scalability for 100 passengers, but no technical evidence supports this claim.

5.2. Parallel hybrid propulsion systems

Another hybrid electric aircraft setup is the parallel hybrid architecture, showcased in Boeing's SUGAR Volt and SUGAR Freeze concepts (NASA, December 12, 2023). This design utilizes both internal combustion and electric motors to propel the aircraft. The internal combustion engine and electric motor are linked to a gearbox that moves the propeller in parallel. Unlike the series hybrid, this setup offers greater reliability and redundancy by allowing independent operation of both systems (Capata and Corcia, 2010). Additionally, it enables the use of smaller engines to achieve similar power levels as larger ones, thus cutting fuel use and emissions.

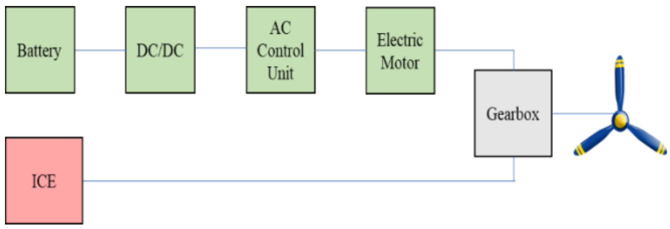

Figure 2. Parallel Hybrid Propulsion Configuration.

In the parallel hybrid architecture, depicted in Figure 6.2, two parallel drive shafts are mechanically connected. One shaft is powered by combustion, while the other by electricity (Rendon et al., 2021). Both electric motor and internal combustion engine shafts are connected to a common shaft driving a fan or propeller, allowing either or both to contribute to propulsion. Moreover, batteries can recharge as the internal combustion engine drives the propeller and the electric motor acts as a generator. Unlike other architectures, there's no electrical generator attached to the internal combustion engine's shaft, reducing component size and weight.

However, this configuration has drawbacks. The mechanical connection between drive shafts adds extra mass (Gogolak et al., 2019), requiring a more sophisticated control system. Additionally, the internal combustion engine's optimal operation may be compromised at different flight phases compared to the series setup, as it contributes to thrust generation (Barelli et al., 2018).

5.3. Series-Parallel Hybrid Propulsion Systems

Another hybrid electric aircraft configuration is the series-parallel hybrid propulsion system, as illustrated in Figure 3, combining elements of both series and parallel setups. This hybrid design incorporates two power sources: an internal combustion engine paired with an electric generator, along with a battery-powered electric motor. These components are connected in series, delivering thrust power to the aircraft (Xie et al., 2021). The series-parallel hybrid system offers benefits from both configurations, allowing flexibility in power source selection for various flight phases and enabling energy recovery through regenerative braking (Jain and Kumar, 2018). While the series part ensures efficient low-speed operations, the parallel section is advantageous for high-power demands like takeoff and climb. However, this system requires an advanced control setup to optimize performance and is more intricate compared to parallel or series architectures (Hong et al., 2018).

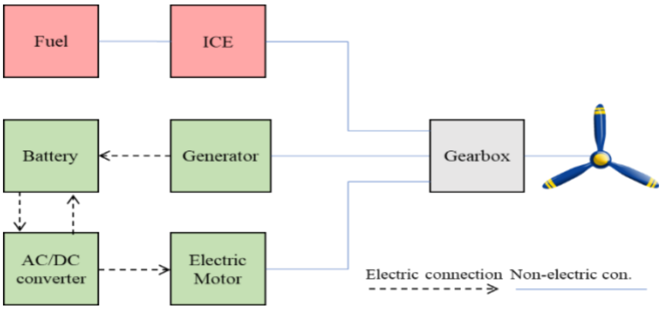

Figure 3. Series-Parallel Hybrid Propulsion Configuration.

5.4. Degree of hybridization

Parallel and combined hybrid vehicles can be classified based on their level of hybridization, determined by the balance of power from the internal combustion (IC) engine and electric motor. In some cases, the IC engine is primary, with the electric motor activating only for extra power. In others, both the IC engine and electric motor share the workload equally. Some vehicles can operate solely on the electric motor system. The degree of hybridization is measured by the ratio of power generated by the electric motor to the total power used by the vehicle. Three main types of hybridization are mild, full and plug-in hybridization.

In a mild hybrid system, the electric motor offers partial assistance to the internal combustion engine. It helps during acceleration or high-power needs but can't propel the vehicle independently. The internal combustion engine remains the main power source, while the electric motor acts as a power booster or energy recovery system. Mild hybrid systems have a low degree of hybridization, with the electric motor contributing only a fraction of the total drive power (Cardoso et al., 2020).

In a full hybrid system, the internal combustion engine and electric motor share power more evenly (Boschert, 2006). Both can propel the vehicle alone or together. This setup utilizes regenerative braking and battery-stored energy to supply electricity during low-speed operations or to assist the internal combustion engine during high-demand situations. Full hybrid systems have a moderate degree of hybridization, with both power sources playing a significant role in propulsion.

A plug-in hybrid system achieves the highest level of hybridization (Maddumage et al., 2021). It features a larger battery that can be charged from an external power source, usually the mains. The electric motor is crucial for vehicle propulsion, with the internal combustion engine serving as a backup or for extended range. Plug-in hybrids can run solely on electricity for short distances, relying on the electric motor (Boschert, 2006). The internal combustion engine is used mainly for longer trips or when the battery charge is low. Plug-in hybrids have the highest degree of hybridization, with the electric motor providing a significant portion of the power.

The degree of hybridization directly impacts overall efficiency, fuel economy, and environmental impact. Higher degrees, like those in full or plug-in hybrid systems, offer better opportunities for energy recovery, regenerative braking, and lower emissions compared to mild hybrids. However, increased hybridization usually means higher complexity, cost, and weight. The choice of hybridization level depends on specific needs, performance requirements, and the desired balance between fuel efficiency and system complexity.

5.5. Energy Management

The aim of energy management in hybrid electric aircraft is to enhance efficiency and performance while reducing environmental impact (He et al., 2020). One of the main hurdles in hybrid electric aircraft is effectively managing energy flow between different power sources. This involves smartly distributing power between the gas turbine engine and electric motor based on flight phase, altitude, speed, and mission needs.

During takeoff and climb, when higher power is needed, the gas turbine engine provides primary thrust. As the aircraft reaches cruise altitude, it shifts to a more electrically-intensive mode where the electric motor takes over, allowing the gas turbine to operate at its most efficient power range. Regenerative braking is another vital aspect of energy management, where the electric motor acts as a generator during descent, converting kinetic energy into electrical energy for storage or powering auxiliary systems (Morishita et al., 2023).

To ensure seamless switching between power sources and optimize energy efficiency, advanced power distribution and management systems are essential in hybrid electric aircraft (He et al., 2020). These systems rely on sophisticated control algorithms and flight management systems to monitor flight parameters and adjust power settings autonomously for efficient operation and enhanced safety.

In the realm of hybrid electric vehicles, power sharing is a crucial aspect of energy management. It involves distributing power between the electric motor and internal combustion engine within the vehicle's powertrain. The power sharing ratio, denoted as S, indicates the proportion of shaft power provided by the electric motor (P_{el}) to the total shaft power (P_{total}) from the internal combustion engine and electric motor. This $S = P_{el}/P_{total}$ ratio helps determine the optimal allocation of power resources for different flight conditions (Voskuijl et al., 2018).

5.6. Analysis of Current Hybrid Electrical Aircraft Prototypes

Investigation of hybrid electrical aircraft, engaged with current research, and examination of multitude of characteristics gave us valuable insights. Each of the researched hybrid aircraft exhibits different capabilities and innovations. Hypstair stands out with its six-fold increase in power/weight ratio and operating range of up to 1000 km, underlining its efficiency and environmental friendliness. In contrast, the E-Genius is impressive with its focus on sustainability, 400 km range and ability to operate at altitudes of up to 6,000 m. Although Zunum Aero promises efficient regional air travel, its current status remains uncertain due to financial difficulties. Combining efficiency and practicality, the Diamond DA36 E-Star has a range of 1,094 km and a significant reduction in fuel consumption and emissions. Meanwhile, the N3-X aims to revolutionize long-haul air travel with the ambitious goal of reducing fuel consumption by 70%. Airlander 10 and Airlander 50 offer solutions for both cargo and passenger transportation with their durability, load carrying capacity and environmental friendliness. The Panthera Hybrid and Ampaire Electric EEL demonstrate the potential of hybrid-electric propulsion in a variety of flight regimes. Finally, the ENFICA-FC Project exemplifies the use of fuel cell-based power systems for light aircraft, emphasizing both environmental friendliness and operational robustness. Collectively, these hybrid aircraft represent the industry's quest for greener and more efficient aviation solutions (Correa et al., 2015), (Ratner, 2018) (Bradley and Droney, 2015), (Doll et al., 2022), (Arabul et al., 2021).

5.7. Range

An aircraft's range, which determines how far it can travel without refueling, is a crucial performance metric. Calculating range involves considering factors like fuel efficiency, weight, aerodynamics, and operating conditions.

The Breguet equation, named after French engineer Louis Charles Breguet, is a fundamental formula used to estimate aircraft range. It relates range to fuel efficiency and other pertinent parameters. The equation computes range by accounting for the change in aircraft weight from start to finish, along with the fuel consumed during this interval. Various flight parameters are also included in the formula to refine the calculation (http-6).

$$R = Vt_f = V\frac{L}{D}I_{sp}\ln\left(\frac{W_i}{W_f}\right) \quad (1)$$

The general range formula is shown in equation (1). Here it can be observed that range equals flight time multiplied by the velocity of the aircraft. Additionally, $\frac{L}{D}$ the aerodynamic design, I_{sp} the propulsion system and $\ln\left(\frac{W_i}{W_f}\right)$ weight ratio are interconnected.

The range formula is also written as shown in equation (2).

$$R = \frac{V}{g}\frac{1}{SFC}\frac{L}{D}\ln\left(\frac{W_i}{W_f}\right) \quad (2)$$

Here:
R= aircraft range, km
V=flight speed, km/h
g= acceleration of gravity
L/D=lift to drag ratio
SFC=specific fuel consumption
W_i=initial weight, kg
W_f=final weight, kg

5.8. Optimum Range

The word optimum is defined as "The most suitable, most convenient, suitable value" (http-7). The term optimum flight range in aviation refers to the planned distance that an aircraft must travel. This distance may vary depending on factors such as the aircraft's engine efficiency, aerodynamic properties and fuel consumption. Pilots and flight engineers use performance graphs, flight tables and calculations to determine the flight range of a particular aircraft. This value is determined to obtain the least fuel consumption and the most favorable range. The optimum flight range may vary for different aircraft types, and this value is important for flight planning and fuel or energy economy.

Optimum flight range is also considered an important performance criterion for hybrid aircraft. Because these aircraft use electric propulsion systems in addition to conventional fuel engines, they can be optimized to provide the most efficient energy use at certain speeds and altitudes. This optimization plays an important role in achieving optimum flight range. In addition, energy management, that is, the energy source and engine type to be used at certain speeds and altitudes, is also taken into account.

5.9. Factors Affecting Range

The main factors affecting the range of conventionally fueled aircraft and hybrid electric aircraft are shown in Table 1.

Table 1. Factors Affecting Range

Traditional ICE Aircraft	Hybrid Electrical Aircraft
Internal combustion engine efficiency	Internal combustion engine efficiency
Fuel capacity	Fuel capacity
Fuel efficiency	Fuel efficiency
Aircraft weight	Aircraft weight
Freight and passenger load	Freight and passenger load
Weather conditions	Weather conditions
Altitude and flight profile	Altitude and flight profile
Air traffic and flight operations	Air traffic and flight operations
Technology and engine efficiency	Technology and engine efficiency
Aircraft type and mission profile	Aircraft type and mission profile
	Battery capacity
	Electric motor efficiency
	Energy management
	Regenerative energy

Aircraft weight, which is directly linked to fuel consumption and range, plays an important role in aviation. Aircraft weight is divided into different categories:

- Maximum Takeoff Weight (MTOW) is a very important parameter determined by the aircraft manufacturer and represents the maximum weight that an aircraft is allowed to take off.
- Complementing the MTOW, Zero Fuel Weight (ZFW) covers the total weight of the aircraft without usable fuel, including all items other than fuel.
- Maximum Landing Weight (MLW) refers to the maximum weight allowed for a safe landing; This value is usually determined by aircraft manufacturers or regulatory authorities.
- Empty operating weight (OEW) includes the weight of the aircraft including the crew and all operationally necessary fluids such as engine oil (excluding fuel used and cargo).
- Payload, a critical measurement, describes the maximum weight available for passengers, cargo or freight, expressing the difference between MTOW and OEW.
- Maximum Taxi Weight (MTW) or Maximum Ramp Weight (MRW) means the maximum weight allowed for ground maneuvers, including taxiing onto the runway.

5.10. Range Formula for Hybrid Propulsion Aircraft

In an analysis article by Mark Voskuijl et al., the range equation of an aircraft powered by a parallel hybrid electric propulsion system is defined as shown below (See (3)) (Voskuijl et al., 2018).

$$R_{\text{hybr}=}\frac{\eta_{\text{prop}}}{g\left(c_{\text{P}}\frac{H_{\text{fuel}}}{g}(1-S)+\frac{S}{\eta_{\text{elec}}}\right)}\frac{C_{\text{L}}}{C_{\text{D}}}\frac{H_{\text{bat}}H_{\text{fuel}}}{(\psi H_{\text{fuel}}+(1-\psi)H_{\text{bat}})}$$
$$\ln\left(\frac{\frac{(\psi H_{\text{fuel}}+(1-\psi)H_{\text{bat}})}{H_{\text{bat}}H_{\text{fuel}}}gE_{\text{start}}+W_{\text{empty}}+W_{\text{payload}}}{W_{\text{empty}}+W_{\text{payload}}}\right) \quad (3)$$

The range equation for series propulsion system aircraft is given below (See (4)).

$$R_{series}=\eta_{gt}\eta_{eg}\eta_{em}\eta_{gb}\eta_{p}\frac{c_L}{c_D}\left(1+\frac{\varphi}{1-\varphi}\right)\left(\frac{e_f}{g}\right)$$
$$\ln\left(\frac{W_{OE}+W_{PL}+\left(\frac{E_{o,tot}g}{e_{bat}}\right)\left(\varphi+\frac{e_{bat}(1-\varphi)}{e_f\eta_{gt}\eta_{eg}}\right)}{W_{OE}+W_{PL}+\frac{g\varphi E_{o,tot}}{e_{bat}}}\right) \quad (4)$$

Each parameter in the formulas plays a very important role in affecting the overall range performance of the aircraft. Gas turbine efficiency (η_{gt}), gearbox efficiency (η_{gb}), and propeller efficiency (η_p) collectively represent the efficiency of the propulsion system. The lift-to-drag ratio $\left(\frac{c_L}{c_D}\right)$ reflects aerodynamic efficiency by emphasizing the balance between lift and drag forces during flight. The hybridization factor (φ) determines the power allocation between electric and gas turbine components, affecting the overall system efficiency. Fuel energy density (e_f) highlights its role in taking into account the energy contribution from the fuel. Additionally, empty operating weight (W_{OE}), payload weight (W_{PL}), and total stored energy are important factors that directly affect the weight of the aircraft and the energy available for propulsion. Essentially, the formula provides a comprehensive perspective on how each parameter affects the range of an aircraft using a parallel hybrid electric propulsion system, providing valuable information for optimizing and understanding the performance of such advanced propulsion technologies.

5.11. Effect of Battery Capacity and Energy Density on Range

The integration of batteries in hybrid aircraft significantly influences their performance. Factors such as weight, energy density, capacity, and other battery characteristics are crucial for determining the optimal range and overall performance of the aircraft.

When considering how batteries impact hybrid electric aircraft and their optimal range, it's important to look at the current battery technology, capacity, energy density, and how these factors affect the aircraft's total weight.

Battery capacity for electric aircraft is typically measured in kilowatt hours (kWh). Recent advancements in battery capacity technology, particularly with high energy density lithium-ion batteries, have been notable. Currently, lithium-ion batteries used in aviation have capacities ranging between 200-260 Wh/kg (http-8).

Understanding the energy density of batteries is crucial, especially for large commercial aircraft aiming to maximize their range. Battery energy density refers to the amount of energy stored in a given volume or mass of the battery. Higher energy density means more energy can be stored in a smaller, lighter package, enabling the aircraft to fly longer distances. While battery chemistry and materials advancements are improving energy density, current battery technology falls short of meeting the requirements for widespread commercial hybrid electric aircraft operations. Lithium sulfur and solid-state batteries show promise for higher energy density compared to traditional lithium-ion batteries (Pomerantseva et al., 2019).

As battery capacity and energy density increase, battery weight decreases for the same amount of stored energy. Lighter batteries contribute to reducing the overall weight of the aircraft, which is crucial for extending the range of hybrid electric aircraft (Huang, 2023).

A reduction in the overall aircraft weight positively impacts its range. Lighter batteries mean more payload capacity or longer range for the aircraft, which influences the practicality and feasibility of using hybrid electric propulsion systems (Ward, 2023).

However, it's essential to note the current limitations regarding battery density and weight. Due to technology constraints, as battery capacity increases, so does the total weight of batteries. This increase in battery weight affects the weight of the hybrid electric aircraft, impacting its range negatively. Despite progress in increasing battery capacity, the trade-off is often increased battery weight. This additional weight demands more energy consumption for propulsion, hindering the range of the hybrid electric aircraft. Therefore, developing lithium-ion batteries with higher energy density and lower weight is critical for the advancement and viability of hybrid electric aircraft (Rendon et al., 2021).

6. Result and Discussion

This study examines the potential of hybrid propulsion systems in aviation and their impact on optimal range. It's clear that air travel demand is rising, but like other sectors, aviation has environmental drawbacks. As long as current technologies are used, environmental impacts will worsen with increased demand. Thus, there's a push for new aviation technologies, with hybrid propulsion systems emerging as a key for a more sustainable future.

Hybrid propulsion systems, which are a combination of conventional engines and electric motors, are promising in improving performance, especially in short-range flights. However, they come with drawbacks like added weight, cost, and complexity. Also, the limited capacity and energy density of current lithium-ion batteries constrain the optimal range of hybrid aircraft, especially for long-distance travel. Today, battery technology limitations hinder hybrid aircraft from efficiently reaching optimal range on long-haul flights.

Developing lightweight, reliable batteries with high energy density enhance the efficiency of hybrid aircraft for long-range travel. Innovations like nanotechnology and solid-state batteries hold promise for advancing battery technologies. Hybrid propulsion systems significantly contribute to achieving environmental sustainability in aviation. However, overcoming battery technology limitations is essential to unleash their full potential. Technological advancements in battery design, such as the development of solid-state batteries and the application of nanotechnology, are essential to overcoming these limitations. Lighter, more energy-dense batteries will be key to unlocking the full range capabilities of hybrid aircraft, making them viable for long-haul flights.

Moving forward, focused research and development in battery technology will be critical in extending the operational range of hybrid aircraft, enabling them to play a significant role in making aviation more sustainable.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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The Role of Organizational Trust in Shaping Commitment and Reducing Turnover Intention in Aviation

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Abstract

In the contemporary business landscape, advancements in artificial intelligence and robotics are rapidly transforming industries, including air transportation. Although the demand for human resources may diminish with technological progress, the necessity for skilled personnel remains critical. The air transportation sector, in particular, relies heavily on qualified professionals, whose contribution to sustainable business practices is substantial. However, despite their importance, these trained professionals may occasionally exhibit a turnover intention their positions. Such turnover in an industry where technology plays a pivotal role represents a significant loss for organizations. Mitigating turnover intentions may depend on the application of effective organizational behavior models, one of which is fostering an environment of trust within the organization. Increased trust in the organization can enhance employees' commitment and job satisfaction, thereby reducing their turnover intention. The primary aim of this study is to identify the factors influencing turnover intention, with a specific focus on whether organizational trust affects this intention. Furthermore, the study seeks to determine whether organizational commitment mediates the relationship between organizational trust and turnover intention. To explore these dynamics, a survey was conducted with 404 ground and flight personnel employed in both public and private aviation sectors in Türkiye. The research findings show that trust has important implications in an organizational setting. As a result of the analysis conducted within the scope of the research, it was determined that organizational trust has no effect on turnover intention. The reason for the different result from the literature may be the sensitivity of the aviation industry and the high staff turnover rate. Due to these characteristics of the sector, employees of the aviation industry may show turnover intention even if they trust their organizations.

1. Introduction

In today's rapidly evolving environment, organizations rely heavily on a skilled workforce to sustain their operations, generate profit, and achieve long-term development goals. Despite advancements in technology, the value contributed by skilled human resources often surpasses that of other factors. As a result, organizations are increasingly investing in the recruitment of new talent and offering enhanced opportunities to retain existing employees, thereby mitigating turnover. The process of training new employees is time-consuming, challenging, and costly. During this period, ensuring that skilled employees remain committed to the organization presents a significant challenge. This challenge is closely linked to the organizational behavior models adopted within the organization. The success of these models, and the benefits they yield, are largely dependent on the level of trust established within the organization. Trust has emerged as a pivotal element influencing communication, leadership effectiveness, management by objectives, negotiation strategies, game theory applications, performance appraisal processes, labor-management relations, and the implementation of self-managed work teams. This review synthesizes existing literature to elucidate the multifaceted role of trust in enhancing organizational performance and cohesion (Mayer et al,1995:709). Organizational trust is a multifaceted concept that includes trust in management, colleagues, the organization's mission and vision, as well as its culture and values. When organizational trust is effectively nurtured, it leads to several positive outcomes, such as increased employee satisfaction, job satisfaction, enhanced organizational commitment, the promotion of organizational justice, and a reduction in turnover intention. The interrelationship between organizational trust, commitment, and turnover intention is well-documented in the literature as an interconnected network. High levels of organizational trust can bolster employees' commitment to the organization, which, in turn, strengthens job satisfaction and reduces the turnover intention. Organizational commitment itself is a key factor in lowering turnover intention, as it is closely associated with job satisfaction and perceived job security. According to Allen and Meyer (1990), organizational commitment is related to the individual's emotional attachment to the organization, the commitment due to the costs of leaving the organization, and the individual's sense of obligation to the organization (Allen & Meyer,1990). Additionally, organizational trust can indirectly impact turnover intention by fostering greater organizational commitment. In essence, higher levels of organizational trust can decrease the turnover intention by enhancing employees' commitment. These relationships are frequently examined within the fields of industrial psychology and human resource management, with contextual factors such as job conditions and organizational culture playing a significant role.

This study investigates the impact of organizational trust and commitment on turnover intention within the aviation sector. The analysis begins with an exploration of the concept of organizational trust, followed by a detailed examination of organizational commitment and the turnover intention.

2. Materials and Methods

2.1. Theoretical Background and Research Hypotheses

Trust plays a critical role in establishing and maintaining communication and collaboration among individuals. In environments where trust is present, individuals are generally more peaceful and happier. Each individual seeks trust in various social environments; in this context, organizational trust is of primary importance. Organizational trust is grounded in various theoretical frameworks, among which social exchange theory is prominent. Social exchange theory is considered a fundamental theoretical perspective for understanding the processes underlying trust at the individual, group, and organizational levels. In this context, the extent to which human resource management practices provide commitment and support is seen as a significant factor in increasing employees' trust in the organization (Cohen, 2015, p. 51). For organizational trust to develop, it is necessary to meet individuals' basic needs. In particular, it has been observed that meeting basic needs such as autonomy, relatedness, and competence positively affect motivation and performance (Ho & Wu, 2019, p. 18). Thus, it will contribute to creating a sustainable trust environment within the organization.

Organizational trust has become an increasingly important topic in organizational theory and research in recent years. Kramer (2006) defines this concept as the willingness of a trusting person to be vulnerable to actions they deem significant, regardless of the ability of the other party to monitor or control them. Social scientists have shown great interest in defining the concept of trust; researchers such as Barber (1983), Luhmann (1988), and Mayer, Davis, & Schoorman (1995) have made significant contributions in this field. However, due to the many factors influencing organizational trust and its numerous outcomes, a universally accepted definition has yet to be established. Organizational trust is a crucial component for an organization's long-term profitability and the well-being of its members (Tüzün, 2007). Establishing a trustful environment allows organizational trust to become prominent and helps achieve the desired performance (Reyhanoğlu & Yılmaz, 2017). This trustful environment is defined as a psychological setting created through the contributions of all organization members, and it involves a willingness to accept vulnerability based on the organization's positive expectations (Koca Ballı & Üstün, 2017; Cohen, 2015).

As managers learn which behaviors are rewarded or punished in their organizations, it becomes evident that personal and organizational trust influence each other. Additionally, organizational culture, coordination, communication, and decision-making processes can either encourage or deter managerial trustworthy behaviors (Vanhala, Puumalainen & Blomqvist, 2011). Anderson and colleagues (2012) have addressed organizational trust in five dimensions: individual psychological states, perceived experiences, the other party's positive expectations, risk-taking, and changes according to general conditions (Jiang & Chen, 2017). In this context, organizational trust plays a critical role in the success of both individuals and the organization, and ensuring this trust is a factor that directly affects the organization's performance.

Establishing trust-based relationships within organizations can reinforce employees' feelings of trust towards their leaders and organizations. This sense of trust can enhance employees' emotional commitment to their organizations, thereby reducing their tendency to leave the organization (Demircan & Ceylan, 2003, p. 140).

The concept of organizational commitment has become a focal point for managers and many human resources departments within organizations, as it is considered a key determinant for retaining employees (Al-Jabari & Ghazzawi, 2019). The foundation of organizational commitment theory is the economic exchange behavior contract between the employee and the organization, based on a personal investment valued by the employee (Becker, 1960). The level of organizational commitment reflects the employee's relationship and bond with the organization; in this context, it mirrors organizational behavior elements such as employee participation, satisfaction, performance, and leadership qualities. Various scales have been developed to measure organizational commitment, which is also defined as the psychological attachment of an individual to the organization. Organizational commitment plays a decisive role in determining how long an employee will stay with the organization and the extent of their enthusiasm in working towards the organization's goals.

Research on organizational commitment has shown that this concept develops spontaneously and is an organic process related to an individual's connection with the organization (Allen & Meyer, 1990). Studies in the literature indicate that organizational commitment has positive effects on various factors, such as reducing employees' turnover intention the organization (Clugston, 2000; Wasti, 2002; Uyguç & Çımrın, 2004), decreasing absenteeism and lateness behaviors (Mathieu & Zajac, 1990), improving performance (Altaş & Çekmecelioğlu, 2007), and increasing productivity (Çekmecelioğlu, 2006) (Çubukçu & Tarakçıoğlu, 2010, p. 59).

Turnover intention is a concept that reflects employees' thoughts and tendencies to leave their current jobs based on various organizational and individual factors. This term indicates the tendency of individuals to assess the likelihood of leaving their job within a specific time frame. In the literature, turnover intention is often associated with factors such as employee dissatisfaction, lack of organizational commitment, workload, job satisfaction, and leadership quality. Employees' intentions to leave can have significant impacts on the overall performance of the organization and are considered a critical determinant in terms of human resource management strategies (Tett & Meyer, 1993; Mobley, 1977). In organizations with high turnover intention, the potential negative outcomes include increased recruitment, selection, and placement costs; rising costs for training and development, as well as audit and compliance expenses; decreased efficiency in new employees' learning of job processes; disruptions in organizational efficiency and planning; lowered morale among remaining employees; reduced organizational memory; and the negative impact on sustainable competitive advantage due to the loss of talented workforce (Tekingündüz et al, 2015, p. 5). In this context, individual and organizational factors affecting the turnover intention should be carefully assessed, and strategic measures should be taken to prevent turnover intentions. Studies have shown that organizational trust and organizational commitment variables have an impact on the turnover intention. In this context, the proposed model of the study is as follows:

Reducing employee turnover, ensuring that employees act effectively in alignment with organizational goals, and enhancing their performance depend on managers' ability to build a sense of trust towards the organization. However, the lack of dimensional breakdown of the concept of organizational trust according to theoretical typologies (Chathoth et al., 2011) and the consideration of this concept as a unidimensional structure have led to issues of validity and reliability. As noted by Reyhanoğlu & Yılmaz (2017), the theoretical validity of this scale, which was applied for the first time in different cultures, may not have been established, possibly due to the scale's lack of cultural appropriateness (Reyhanoğlu & Yılmaz, 2017:p. 313). It has been observed that when employees have the turnover intention the organization and their jobs, their levels of trust towards the organization and its managers are low. In this context, various studies have been conducted on the relationship between organizational trust and issues such as employee turnover and absenteeism, and these studies have yielded results (Demircan & Ceylan, 2003, p. 145). In Yazıcıoğlu's (2009) study, an indirect relationship between organizational trust and the turnover intention was found. It was observed that employees with high levels of organizational trust and job satisfaction have lower intentions to leave (Yazıcıoğlu, 2009, p. 238). In light of these findings, the first hypothesis suggesting that organizational trust is related to the turnover intention is proposed:

Hypothesis 1. There is a significant relationship between organizational trust and the turnover intention.

Organizational commitment reflects employees' beliefs in the organization's values and goals, their effort to achieve these goals, and their desire to remain a member of the organization (Seyrek & İnal, 2017, p. 65). Organizational commitment is a significant factor that directly affects the turnover intention. Individuals who have worked in the same job for many years often perceive leaving the job as an injustice towards the organization, while for new employees, the turnover intention is considered to be associated with social factors and environmental responses (Bozkurt & Yurt, 2013, p. 136).

It has been found that employees with high organizational commitment exhibit positive effects such as higher performance, lower turnover intention, and more organizational citizenship behaviors (Bozkurt & Yurt, 2013, p. 122). Analyses have revealed that the organizational commitment variable has a negative and statistically significant effect on the turnover intention; in other words, as an employee's commitment to the workplace increases, their turnover intention decreases (Seyrek & İnal, 2017, p. 70).

A survey conducted among employees at Ankara Esenboğa Airport found that each dimension of organizational commitment—emotional, continuance, and normative—has a negative impact on the turnover intention (Dalmış, 2019, p. 1415). To prevent performance and productivity losses in the aviation sector, it has been emphasized that strategies aimed at positively developing employees' organizational commitment are important (Dalmış, 2019, p. 1414). Additionally, it has been revealed that organizational commitment is a more effective reason for leaving than job satisfaction and is highly associated with withdrawal behaviors such as low performance, increased absenteeism, and tardiness (Bilgiç, 2017, p. 39; Doğan & Kılıç, 2007, p. 52). In this context, it has been concluded that the organizational commitment variable creates a significant relationship with the turnover intention (Yenihan et al, 2014, p. 40). In this context, as it is emerging that organizational commitment is related to the turnover intention, the first hypothesis of this study is that "there is a relationship between organizational commitment and the turnover intention.

Hypothesis 2. There is a significant relationship between organizational commitment and the turnover intention.

Studies and literature reviews indicate that employees with high levels of organizational commitment also have high levels of trust towards their organization and managers. Çubukçu & Tarakçıoğlu's (2010) research has shown that the four sub-dimensions of organizational trust—sensitivity to employees, trust in management, openness to innovation, and communication environment—have a significant positive relationship with emotional and normative commitment (Çubukçu & Tarakçıoğlu, 2010, p. 71).

A strong relationship was found between organizational trust and emotional commitment, while a weaker relationship was found between organizational trust and normative commitment; no significant relationship was detected between organizational trust and continuance commitment (Taşkın & Dilek, 2010, p. 44). Additionally, Demircan and Ceylan's (2003) research revealed that high levels of trust are associated with organizational commitment and job satisfaction, and are closely related to effective communication of the organization's mission and the development of collaboration (Demircan & Ceylan, 2003, p. 144). In this context, it has been concluded that organizational trust is related to organizational commitment.

Hypothesis 3. There is a significant relationship between organizational trust and organizational commitment.

When employees have a strong sense of trust in their organization, they are more likely to develop a higher level of organizational commitment. This trust fosters an emotional bond (affective commitment), reinforces the perception of the organization's value (normative commitment), and influences their view of the costs associated with leaving (continuance commitment). In turn, employees with greater organizational commitment are less likely to consider leaving the organization. They feel more connected and aligned with the organization's values, making them more inclined to stay. In essence, the relationship works like this: Organizational trust boosts employees' commitment to the organization. This increased commitment then reduces their intention to leave. Thus, organizational commitment serves as a mediator, explaining how trust impacts employees' decisions regarding their tenure with the organization. A meta-analysis examining the relationship between organizational trust, commitment, and turnover intention provides an average effect size value as a quantitative research method. This helps in reaching a general conclusion about the topic, but it also has some limitations (Tanğ & Çakır,2023, p.225).

Hypothesis 4. Organizational commitment mediates the effect of organizational trust on turnover intention.

Figure 1. Research Model

2.2. Method

In this study, the relationships between the concepts of organizational trust, organizational commitment, and turnover intention were examined among personnel working in the Turkish civil aviation sector. Data for the research were obtained using quantitative research techniques, including surveys and scales. A closed-ended 5-point Likert scale was used for the survey. The study also assessed the strength and direction of the relationships between the variables.

2.3. Sample and procedures

This study aims to reveal the impact of organizational trust and organizational commitment variables on the turnover intention among employees working in all aviation organizations. To prevent social desirability bias or common method bias (Podsakoff & Organ, 1986), company managers informed participants that the research results were intended solely for academic purposes and that personal information would be kept strictly confidential. The reliability results of the surveys used in the scales in the research were found to be high. The Cronbach Alpha value for the organizational trust scale was measured at 0.96, for the organizational commitment scale at 0.92, and for the turnover intention scale at 0.93.

2.4. Measures

A fully structured questionnaire was used for this study, and in measuring the research variables, scales that had previously been tested for reliability and validity were utilized based on a literature review. During the creation of the questionnaire, care was taken to ensure that the questions were brief and clear. The organizational trust scale used in the study is the three-dimensional organizational trust scale developed by Chathoth, Mak, Sim, Jauhari, and Manaktola (2011), which was translated into Turkish and used in the study by Reyhanoğlu and Yılmaz. The scale consists of a total of 19 items: 7 items for the integrity dimension, 7 items for the commitment dimension, and 5 items for the trustworthiness dimension. To measure organizational commitment, the Organizational Commitment Scale (OCS) developed by Meyer and Allen (1991) was used. This scale, which is widely used and generally accepted, consists of three dimensions: emotional commitment (6 items), continuance commitment (6 items), and normative commitment (6 items), totaling 18 items. To measure the turnover intention, the Turnover Intention Scale (TIS) consisting of 4 items, used in the study by Jackson and Turner (1987), was employed. The reliability values of the scales indicate that the responses are consistent and the questions are clear. For all three scales, a 5-point Likert type scale was used as the measurement technique, ranging from "strongly disagree" to "strongly agree."

3. Result and Discussion

3.1. Demographic characteristics

The data for the study were obtained from 404 personnel working in the growing and developing Turkish civil aviation sector.

Table 1. Demographic Characteristics

	Category	Frequency (*N*=404)	%
Gender	Women	91	22.5
	Men	313	77.5
Marital Status	Married	227	56.2
	Single	177	43.8
Age	20 and under	7	1.7
	21-30	180	44.6
	31-40	124	30.7
	41-50	80	19.8
	50 over	13	3.2
Education	High	17	4.2
	Vocational	35	8.7
	Undergraduate	268	66.3
	Graduate	84	20.8
Place of Employment	Government	122	30.2
	Private	282	69.8
Field of Work	Flight Operation	80	19.8
	Ground Operation	324	80.2
Category of Organization	Airline	117	29.0
	Airport/Terminal	92	22.8
	Ground Handling	87	21.5
	Maintenance	49	12.1
	Air Taxi	4	1.0
	Training	55	13.6
Total Professional Experience (Years)	0 - 5	143	35.4
	6 - 10	99	24.5
	11 - 15	47	11.6
	16 - 20	59	14.6
	21 -25	34	8.4
	26 - 30	13	3.2
	30 over	9	2.2
Current Organizational Experience (Years)	0 - 5	231	57.2
	6 - 10	76	18.8
	11 - 15	45	11.1
	16 - 20	21	5.2
	21 -25	24	5.9
	26 - 30	5	1.2
	30 over	2	0.5

The 404 personnel consist of both flight and ground staff from the public and private sectors. Of these employees, 77.5% are male and 22.5% are female. The proportion of married individuals is 56.2%, while the proportion of single individuals is 43.8%. The majority of the participants in the study are employees aged 21-30. In the aviation sector, which has a high level of education, there is always a need for qualified personnel. In recruitment, candidates with aviation training and undergraduate degrees are preferred. Consequently, 66.3% of the participants are bachelor degree, 20.8% graduate degree, 8.7% Vocational Schools and 4.2% high school. There are many areas of activity in the civil aviation sector. Among the participants in the study, 29% work in airline operations, 22.8% in airport terminal operations, 21.5% in ground services operations, 13% in training organizations, 12.1% in maintenance operations, and 1% in air taxi operations.

3.2. Exploratory factor analysis

Main constructs or broad categories being measured are in factor analysis. Specific aspects or components within each dimension have been examined. Values indicating the strength of the relationship between each item and the underlying factor have been obtained. The specific statements or questions used to assess the dimensions have been utilized. Factor analysis was applied to a 41-item structure consisting of scales for organizational commitment, organizational trust, and turnover intention. According to Tabachnick and Fidell (1996), it is recommended that factor loadings be above 0.32. In this study, a factor loading of 0.4 or above was applied to facilitate the interpretation of items and to meet the requirements of the Structural Equation Modeling (SEM) (Table 2). Consequently, items 8, 13, and 14 of the organizational trust scale, as well as items 3, 4, 6, 7, 10, 11, 12, 13, and 14 of the organizational commitment scale, were excluded. The factor analysis resulted in a four-factor structure that explained 67.15% of the total variance. These factors were defined as organizational commitment, organizational trust 1, organizational trust 2, and turnover intention. The Kaiser–Meyer–Olkin (KMO) value was 96.9 (p<0.001). The sub-dimensions of organizational trust were identified as 'integrity' and 'dependability', taking into account previous studies (Chathoth et al., 2011).

3.3. Validity and reliability

In this study, validity and reliability and analyses were conducted to see the stability of the measurement values and the degree of correct measurement of the data obtained in. Reliability, one of the features that a scale must have, is an indicator of the stability of the measurement values obtained in repeated measurements under the same conditions with a measurement tool. Validity is the degree to which a measurement tool can accurately measure the feature it aims to measure without confusing it with any other feature (Ercan & Kan,2004:212-214).

Table 2. Correlation Analysis for Variables

	M	SD	1	2	3	4
Integrity	3.28	1.06	(.96)			
Dependability	3.79	.94	.76**	(.87)		
Organizational Commitment	3.34	1.07	.76**	.61**	(.92)	
Turnover Intention	2.63	1.36	-.56**	-.41**	-.69**	(.93)

*p<0.05, **p<0.01

There are moderate to high positive and significant relationships between the variables. The Cronbach's Alpha values of the scales indicate that they have high levels of reliability.

Table 3. Correlation Analysis for Demographic Variables

	Gov/Priv	Flg/Gr	Tot. Exp.	Op. Exp.	Age	Com
OT	-	-	-	-	-	-.151**
OC	-.181**	-	.144**	.099*	.120*	-.176**
TI	.193**	.106*	-.098*	-	-	.139**

*p<0.05, **p<0.01
Note: OT (Organizational Trust), OC (Organizational Commitment), TI (Turnover Intention).

There is a low and significant relationship between organizational trust and category of business (r = -0.151; p < 0.01). There are low but significant relationships between organizational commitment and public/private (r = 0.118; p <0.01), total experience (r = 0.144; p <0.01), operational experience (r = 0.099; p <0.05), age (r = 0.120; p < 0.05), and type of operation (r = -0.176; p < 0.01). There are low but significant relationships between the turnover intention and public/private (r = 0.193; p < 0.01), flight/ground (r = 0.106; p < 0.05), total experience (r = 0.098; p < 0.05), and type of operation (r = 0.139; p < 0.01).

Table 4. Standardized Factor Loadings and AVE-CR Values

Factors	Dimensions	Path Coefficients	AVE	CR
OT4	OT-D1	.825	.68	.96
OT5	OT-D1	.840		
OT7	OT-D1	.844		
OT6	OT-D1	.854		
OT1	OT-D1	.824		
OT2	OT-D1	.840		
OT3	OT-D1	.779		
OT15	OT-D1	.823		
OT16	OT-D1	.750		
OT17	OT-D1	.875		
OT18	OT-D1	.862		
OT19	OT-D1	.794		
OT12	OT-D2	.888	.63	.87
OT11	OT-D2	.774		
OT10	OT-D2	.711		
OT9	OT-D2	.805		
OC1	OC	.865	.57	.92
OC2	OC	.777		
OC5	OC	.848		
OC8	OC	.525		
OC9	OC	.709		
OC15	OC	.669		
OC16	OC	.853		
OC17	OC	.736		
OC18	OC	.784		
TI1	TI	.845	.78	.93
TI2	TI	.922		
TI3	TI	.905		
TI4	TI	.868		

The CR value greater than 0.7 indicates that the scales for organizational trust, organizational commitment, and turnover intention have discriminant validity. Additionally, the AVE value greater than 0.5 demonstrates that the scales possess convergent validity.

3.4. Confirmatory factor analysis

The measurement model used in the study was tested through confirmatory factor analysis using the AMOS 20 program. The analysis, conducted using the Maximum Likelihood method, examined whether the proposed structures of the scales were supported by the collected data, employing an alternative models strategy. The first and second-level alternatives of the 29-factor model (12 for integrity, 4 for dependability, 9 for organizational commitment, and 4 for turnover intention) were compared (see Table 6). The second-level, Model 2, provided the best fit according to model fit indices. Additionally, these findings indicate that the scales used in the study have discriminant validity.

Table 5. Confirmatory Factor Analysis

Level	Model	X²	df	P	Cmin	RMR	NFI	CFI	RMSEA
1.Level	1	1025.05	371	.00	2.763	.073	.90	.93	.066
1.Level	2	905.496	367	.00	2.467	.069	.91	.94	.060
2.Level	1	908.097	368	.00	2.468	.069	.91	.94	.060
2.Level	2	835.444	367	.00	2.276	.069	.92	.95	.056

3.5. Path and mediation analysis with latent variables

The hypotheses of the study were tested using IBM AMOS 20 software. Due to the normal distribution of the data, the covariance matrix was constructed using the Maximum Likelihood estimation method. Initially, the measurement model consisting of organizational trust, organizational commitment, and turnover intention variables was tested. The fit indices indicate that the measurement model is validated ($X^2/df = 2.246$; CFI = 0.956; RMSEA = 0.056; RMR = 0.069).

To validate the measurement model, a structural model analysis with latent variables was conducted. Organizational trust and organizational commitment were considered as external variables, while turnover intention was assessed as an internal variable ($X^2/df = 2.360$; CFI = 0.952; RMSEA = 0.058; RMR = 0.070). The results of the analysis showed that organizational trust predicts turnover intention ($p < 0.001$; $\beta = -0.86$), whereas organizational commitment does not predict turnover intention ($p > 0.05$; $\beta = 0.14$). Additionally, another structural model analysis with latent variables was performed where organizational trust was evaluated as an external variable, and organizational commitment and turnover intention were assessed as internal variables ($X^2/df = 2.360$; CFI = 0.952; RMSEA = 0.058; RMR = 0.070). This analysis indicated that organizational trust predicts organizational commitment ($p < 0.001$; $\beta = 0.821$) but does not predict turnover intention ($p > 0.05$; $\beta = 0.137$). Organizational commitment, however, does predict turnover intention ($p < 0.001$; $\beta = -0.865$).

Mediation analysis was conducted to determine whether organizational commitment acts as a mediator between organizational trust and turnover intention in the model. The analysis followed the steps outlined in Baron and Kenny's (1986) model, examining the effects between the independent variable, the mediator, and the dependent variable. It was found that organizational trust has a significant effect on organizational commitment ($\beta = 0.82$; $p < 0.01$), with an explanatory power of ($R^2 = 0.674$). Similarly, organizational trust significantly affects turnover intention ($\beta = -0.55$; $p < 0.01$), with an explanatory power of ($R^2 = 0.303$). When examining the effect of the mediator variable, organizational commitment, on the dependent variable, turnover intention, a significant and strong relationship was observed ($\beta = -0.752$; $p < 0.01$). The explanatory power in this analysis was determined to be $R^2 = 0.565$. Therefore, it is evident that the independent variable significantly affects both the mediator and the dependent variable, and the mediator significantly affects the dependent variable.

In the mediation analysis with latent variables, it was found that the effect of organizational trust on turnover intention became non-significant ($\beta = 0.137$; $p > 0.05$), while the effect of organizational commitment on turnover intention remained significant and increased ($\beta = -0.865$; $p < 0.01$). This indicates that organizational commitment fully mediates the effect of organizational trust on turnover intention. To test the significance of this change in mediation, the Bootstrap method was employed. At a 95% confidence interval (N = 3000; $p < 0.01$; [-0.845, -0.594]), it demonstrates that organizational commitment has an indirect effect in the relationship between organizational trust and turnover intention. So, hypotheses H4 are accepted.

3.6. Path analysis with observed variables

After validating the measurement model, research hypotheses were tested using the latent variable structural model. The results of the structural model analysis are provided in Figure (3). The results of Structural Equation Modeling indicate that organizational trust has a significant effect on organizational commitment ($\beta=0.76$; $p<0.01$), while its effect on turnover intention is not significant ($\beta=-0.480$; $p<0.38$). It is observed that organizational commitment has a significant effect on the turnover intention ($\beta=-0.66$; $p<0.01$) (Figure 3 Model 1). As a result of factor analysis, the organizational trust variable was divided into two sub-dimensions. The results of the structural model analysis using these dimensions are presented in Figure 3 as Model 2 and Model 3. The SEM results show that "integrity" significantly affects organizational commitment ($\beta=0.76$; $p<0.01$) but has an insignificant effect on turnover intention ($\beta=-0.072$; $p<0.19$). In this model, it is observed that organizational commitment significantly affects the turnover intention ($\beta=0.76$; $p<0.01$). When examining Model 2, it is noted that "dependability", like integrity, has an insignificant effect on turnover intention ($\beta=0.027$; $p<0.53$). Based on these results, hypotheses H2 and H3 are accepted, while hypothesis H1 is rejected.

Table 6. Relationships between variables

	Direct Effects		*P score*	Standart Error	*β*	T Scores	.95 CI Low	.95 Cı High
	Independent	Dependent						
Model 3	Integrity	Organizational Commitment	p<0.01	0.032	0.767	23.965	0.721	0.810
	Dependability	Turnover Intention	p>0.05 (0.19)	0.056	-0.072	-1.299	-0.186	0.035
	Organizational Commitment	Turnover Intention	p<0.01	0.056	-0.641	-11.535	-0.737	-0.535
Model 2	Dependability	Organizational Commitment	p<0.01	0.039	0.614	15.596	0.550	0.674
	Dependability	Turnover Intention	p>0.05 (0.53)	0.045	0.027	0.607	-0.058	0.113
	Organizational Commitment	Turnover Intention	p<0.01	0.045	-0.713	-15.756	-0.787	-0.624
Model 1	Organizational Trust	Organizational Commitment	p<0.01	0.032	0.764	23.770	0.708	0.820
	Organizational Trust	Turnover Intention	p>0.05 (0.38)	0.055	-0.480	-0.861	-0.155	0.062
	Organizational Commitment	Turnover Intention	p<0.01	0.055	-0.660	-11.918	-0.754	-0.555

Table 7. Indirect Effects

Indirect (Mediated) Effects			*P score*	*β*	.95 CI	.95 CI
Independent	**Mediated**	**Dependent**			**Low**	**High**
Integrity	Organizational Commitment	Turnover Intention	p<0.01	-0.491	-0.580	-0.401
Dependability	Organizational Commitment	Turnover Intention	p<0.01	-0.437	-0.504	-0.373
Organizational Trust	Organizational Commitment	Turnover Intention	p<0.01	-0.504	-0.592	-0.418

4. Conclusion

In the aviation sector, licensed and certified personnel are employed. These licensed and certified individuals are considered qualified professionals. The need for qualified personnel is a constant requirement in the aviation industry, and training such professionals involves significant costs. Additionally, training a new qualified employee to replace one who has left is also a costly process. The departing qualified employee will have taken with them valuable information about the organization. In this context, understanding the reasons behind the intention of trained personnel to leave has become an important issue. One of the factors could be related to organizational trust and organizational commitment. Further research in this area is needed.

In this study, which was conducted to determine the factors affecting the turnover intention of the personnel working in the aviation sector, it was determined that the majority of the participants were male, married, between the ages of 21 and 30 and had a bachelor's degree. It was also determined that a significant number of the participants worked in the private sector, ground operations and airline companies.

Employees who trust their organization are more likely to exhibit higher levels of effort and maintain more positive job attitudes. Mishra (1996) argued that trust is a central factor in enhancing an organization's long-term success and survival, particularly due to the inherent uncertainties and competitive pressures of the contemporary global business environment. Trust is crucial as it facilitates adaptation to new processes and work methods (Cohen, 2015: 51). High organizational trust is generally associated with increased employee commitment and a greater tendency to remain within the organization. Organizational trust can enhance employees' job satisfaction and commitment, thereby reducing their intention to leave. Conversely, a lack of organizational trust may lead to feelings of dissatisfaction among employees and an increased intention to resign. This relationship is frequently examined in organizational behavior research and typically reveals a negative association. However, it is important to note that this relationship may not be universally applicable and can vary across different contexts. As a result of the analysis conducted within the scope of the research, it was determined that organizational trust has no effect on turnover intention. This result is different from the results of Abubakar et al. (2014); Ng (2015); Ensari & Karabay (2016); Özgeldi & Hamitoğlu (2019); Alharbi & Abuelhassan (2020) and Zhao et al. (2022). The reason for the different result from the literature may be the sensitivity of the aviation industry and the high staff turnover rate (Siddiqui & Bisaria, 2018). Due to these characteristics of the sector, employees of the aviation industry may show turnover intention even if they trust their organizations.

High organizational commitment generally reduces the intention to leave (Beck & Wilson, 2000). When employees are highly committed to their organization, they are more likely to continue their employment. This commitment can lower their intention to leave by increasing their job satisfaction and strengthening their alignment with the organization's goals. This relationship is supported by various studies (Hussain & Asif, 2012; Ng, 2015; Guzeller & Celiker, 2020 etc.) and is typically examined in the fields of industrial psychology and organizational behavior. In this study, similar to Ausar et al. (2016); Ensari & Karabay (2016) and Alharbi & Abuelhassan (2020), a relationship was found between organizational commitment and turnover intention. However, this relationship can vary depending on the context (Carbery et al., 2003; Uludag et al., 2011) and may not be universally applicable. For example, even in situations of high organizational commitment, job conditions or personal factors can still influence the intention to leave.

It is important to create an atmosphere in which employees can trust the organizations they work for. In such a situation, employees can develop positive feelings towards their jobs and feel satisfied. Employees with a high sense of satisfaction towards their jobs may also have a high level of organizational commitment (Top et al., 2015; Brien et al., 2015). In this study, the effect of organizational trust on organizational commitment was found to be statistically significant. This result is similar to the studies of Nyhan (1999); Vanhala et al. (2016) and Alharbi & Abuelhassan (2020). In this context, aviation companies should take the necessary actions to build trust among their employees. Establishing strong professional relationships, promotions, financial compensation can be considered as useful practices for building organizational trust. Finally, the mediating effect of organizational commitment on the relationship between organizational trust and turnover intention was examined. In this regard, similar to the study of Alharbi & Abuelhassan (2020), it was concluded that organizational commitment fully mediates the relationship between organizational trust and turnover intention. Therefore, if aviation companies can develop a good relationship with their employees, employees will be able to identify with the company. Thus, employees may feel commitment to the aviation company and as a result, turnover intention may not occur.

Ethical approval

The necessary permission for the ethical aspect of the research was obtained through document no. E-22398675-050.04-149553 With the decision numbered 2024/09 dated 03.09.2024 of Iskenderun Technical University Scientific Research and Publication Ethics Committee, stating that the research is deemed ethically appropriate.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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