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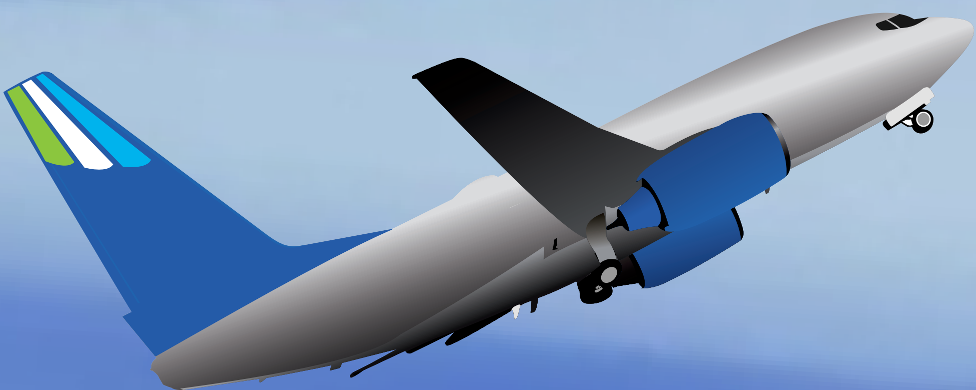

International Journal of Aviation Science and Technology

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International Journal of Aviation Science and Technology

Editorial

Dear Authors,

Aviation is a dynamic and globally developing industry and the problems because of the dizzying speed of the development on aviation technologies and effects ask methodological approaches to the problems. Scientific literature is a base for sustainable development that inspires us to name the journal as "International Journal of Sustainable Aviation Science and Technology" which shortened as IJAST.

As an International Sustainable Aviation and Energy Research Society, (SARES), We are, all aware about the importance of the industrial problems of Aviation, and we are ready to support literature by collecting the information parts of this giant jigsaw. SARES Society and its focused professionals and academicians who are researching on aviation and energy subjects gathered to publish IJAST Journal. Editorial committee has taken a decision to publish the IJAST Journal twice annually as a starter. Journal will focus on below topics.

- Sustainable Aerospace Vehicles
  - Sustainable aircraft, helicopter, missile, launch and satellites design, technological change and innovation, research and development
  - Mathematical modeling, numerical/experimental methods, optimization
  - Green airlines
  - Green airports
  - Green engine
  - Green Aviation Vehicles
  - Electric Planes
    - More Electric Planes
    - All Electric Aircraft

- Renewable Energy Sources
  - Alternative/green aviation fuels
  - Energy recovery systems, alternative/renewable/clean energy technologies
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  - Emission/noise/radiation, global warming/climate change: Environmental effects and measurement techniques
  - Mathematical modeling, numerical/experimental methods, optimization

- Air Conditioning and Cooling Applications in Aircraft
  - Air conditioning and optimization in airports
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- Energy, Exergy, Performance Analysis, Flight Mechanics and Computational Fluid Dynamics
  - Energy analysis
  - Exergy analysis
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  - Flight mechanics
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- Motor Drive Technologies for Aviation Vehicles

- Combustion Technologies
  - Combustion and optimization
  - Combustion instabilities
  - Innovative combustion technologies

- Mathematical Modeling, Numerical/Experimental Methods, Optimization

- Avionics and Auto Control
  - Avionics
  - Automatic control

- Spacecraft Materials, Measurement Techniques and Sensors

- Design, Management, Planning, Development

- Space Vehicle Strategic Planning,

- Aviation Management, Fleet Planning/Scheduling; Air Traffic Management, Future Air Transport

- Airport Design, Management, Planning, Development

- Aircraft Maintenance, Repair and Overhaul; Airworthiness, Reliability/Safety

IJAST journal will join the prominent international databases and indexes to act as a lead role on scientific aviation sustainable technologies. IJAST will stays as free and “Open Access” journal and marks the publications by DOI numbers as prominent journals internationally.

I would like to thank you all who have a contribution to publish this very first issue, Managerial Board of the SARES Society, Editorial Board of the IJAST Journal, Co-Editors, reviewers and authors, who have supported us to build this valuable issue.

Regards.

Prof. Dr. T. Hikmet Karakoç

Editor

International Journal of Aviation Science and Technology

Sizing of a Turboprop Engine Powered High Altitude Unmanned Aerial Vehicle and It`s Propulsion System for an Assumed Mission Profile in Turkey

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Abstract

In this study, preliminary sizing of a turboprop engine powered high altitude unmanned aerial vehicle and it`s propulsion system for an assumed mission profile in Turkey was performed. Aircraft mission profile is one of the most important design inputs in aircraft design. While the aircraft is dimensioned according to the requirements in the specification (useful payload, range, target cost, etc.), parameters such as cruise altitude and speed within the mission profile affect the engine type, power level, fuel quantity, and therefore the overall dimensions and total weight of the aircraft. The unmanned aerial vehicle with turboprop engine investigated in this study, can stay in the air for at least 24 hours at high altitude (40000 ft) and can be used for border surveillance, coast control, forest fires and land exploration.

Keywords

Unmanned aerial vehicle sizing
Turboprop engine
Gas turbine engine
Cycle analysis

Time Scale of Article

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1. Introduction

The aviation industry has made great progress since the Wright brothers made their first controlled, propulsion and heavier than air human flight in 1903. Over the last century, many types of aircraft with complex systems have been designed and built as technology advanced. In parallel to this, unmanned aerial vehicles (UAVs) have been developed by using pioneering technologies in recent years and have increased their prevalence and effectiveness in civil and military applications. UAVs are generally referred to as aircrafts that are pre-programmed to fly autonomously without remote flight crew or which can be controlled from the ground by remote control and can be used multiple times. Today, there are many types of UAVs which are produced for different purposes. Within the scope of this study high altitude unmanned aerial vehicles with turboprop engines were investigated and the following examples can be given in this class: “Predator B” [1] developed by General Atomics (USA), on “Heron TP” [2] of IAI (Israel Aircraft Industries) and “Akıncı” [3] unmanned aerial vehicle which is being developed by Baykar Defense Company in recent years.

In Turkey, there exists many institutions and organizations which conduct studies in the areas of UAV airframe, engines, software, electronics, sensors for both domestic and foreign markets. This study was conducted to support UAV development activities in our country.

2. Sizing of Unmanned Aerial Vehicles

In order to size unmanned aerial vehicles, general aircraft equations can be used by removing the parts related to crew and passengers [4].

$$W_0 = W_e + W_{FL} + W_f + W_{misc} \tag{1}$$

W_0 : gross weight (kg); W_e : empty weight; W_{PL} : payload weight; W_f : fuel weight; W_{misc} : miscellaneous other components weight.

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$$W_e = W_{airframe} + W_{lg} + W_{eng} + W_{sys} \quad (2)$$

$W_{airframe}$: airframe weight; W_{lg} : landing gear weight; W_{eng}: engine weight; W_{sys} : systems weight

$$W_e = W_0 - + \left(W_0 \frac{W_f}{W_0}\right) + \left(W_0 \frac{W_{misc}}{W_0}\right) - W_{PL} \quad (3)$$

$$W_{eng.inst} = W_0 \left(\frac{T_0}{W_0}\right) \left(\frac{\left(\frac{W_{eng.inst}}{W_{eng.uninst}}\right)}{\left(\frac{T_0}{W_{eng.uninst}}\right)} \right) \quad (4)$$

$W_{eng,inst}$: installed engine weight;

$W_{eng,uninst}$: uninstalled engine weight;

T_0 : sea level engine power or thrust;

Fig. 1. Predator B turboprop UAV [1].

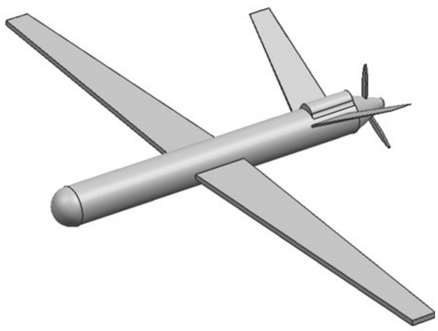

Fig. 2. Assumed UAV geometry [5].

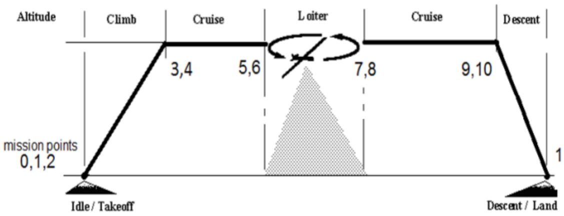

Fig. 3. Typical mission profile of a reconnaissance UAV [5].

The validation of the methodology used in this study was performed on "Predator B" UAV with turboprop engine in a previous study [5]. The deviation rate in the obtained results was determined as ± 1.5% for UAV dimensions and weights. The simplified unmanned aerial vehicle geometry used in the study is given in Figure 2. The mission profile of a typical reconnaissance unmanned aircraft is shown in Fig. 3.

3. Turboprop Engine Cycle Analysis

In this study, cycle analysis of turboprop engine was done for all points during flight and results are given in the next sections. Engine design begins with parametric cycle analysis. The objective of parametric cycle analysis is to calculate performance characteristics (power, thrust, specific fuel consumption etc.) based on design constraints (maximum turbine inlet temperature and achievable component efficiencies etc.), flight conditions (ambient air temperature and pressure, flight Mach number), and design choices (compressor and fan pressure ratio, bypass ratio, etc.) [6].

Cycle analysis is the investigation of thermodynamic behavior of air flowing in the engine. Instead of dealing with components such as inlet, compressor, combustion chamber, turbine, exhaust nozzle, these components are characterized according to the results they produce. In other words, for example, the compressor is defined only by the total pressure ratio and efficiency. In fact, the behavior of a real engine depends on the geometry [7].

In general, the main components of the turboprop engine (Figure 4) can be listed as air intake (A), compressor (B), combustion chamber (C), high pressure turbine (D), low pressure or power turbine (E) followed by exhaust nozzle (F). In this study mathematical formulation of a turboprop engine was adopted from [8] in order to use in the cycle analysis.

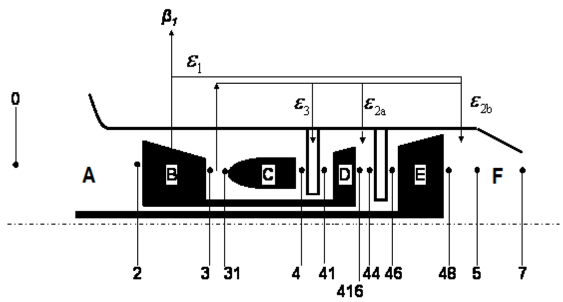

Fig. 4. Schematic representation of a two-shaft turboprop engine [8].

4. Sizing of a UAV for Surveillance Mission in Turkey

In this study, surveillance mission profile for a turboprop UAV was assumed be 24 hours at 40,000 ft altitude in Turkey. In addition, the amount of payload to be carried was assumed to be 1350 kg (450 kg internal and 900 kg external). In this category, Akıncı UAV is an example which is under development in our country [3] and is shown in Figure 5.

Fig. 5. Akıncı UAV [3].

In this study, the UAV for which the calculations were made was named as TURKUAV. The summary results of these calculations are compared with the literature values of Predator-B and Akıncı UAV in Table 1. The Predator-B UAV uses a 944 hp TPE331–10 turboprop engine [9]. The turboprop engine parametric model and computer program were developed in a previous study [5]. This computer code was also used for TURKUAV in this study.

When Table 1 is examined, it is seen that all three UAVs have similar technical characteristics. When the Predator B values are examined, it is understood that some of the values given by the manufacturer are given as maximum values and not all of them can be valid at the same time. For example, 27 hours flight time and 50000 ft flight altitude cannot be provided at the same time. Similarly, it will not be possible to load the payload and fuel weight at the same time as maximum. In this sense, there are 3 different configurations for Predator B [10]:

- Configuration 1: Internal payload (363 kg), internal and external fuel (862 + 907 = 1469 kg) and 1/3 external payload or ammunition (454 kg). Total take-off weight 4763 kg.
- Configuration 2: Clean configuration, internal payload (363 kg) and internal fuel (862 kg), (without external fuel and external ammunition). Total take-off weight is 3454 kg.
- Configuration 3: Internal payload (363 kg), full (100%) external payload or ammunition (1362 kg) (without external fuel). Total take-off weight 4763 kg.

The maximum flight time of 27 hours in Table 1 seems to be possible only with maximum fuel (Configuration 1). Similarly, a maximum altitude of 50000 ft would be possible without external fuel and external load, with reduced total take-off weight (Configuration 2). Operation altitude is specified as 30000 ft in fully loaded cases such as configuration 3 [10].

Table 1. UAV specifications

Technical Specifications	Predator B	Akıncı [3]	TURKUAV
Payload (kg)	1747 [1]	1350	1350
UAV gross weight (kg)	4763 [1]	5500	6304
Fuel weight (kg)	1769 [1]		1110 internal/1110 external
Endurance (h)	27 max [1]	24	26.5
Surveillance time (h)			24
Engine power (hp)	944 [5]	2x750	1572
Surveillance altitude (ft)		40000	40000
Maximum altitude (ft)	50000 [1]		

Table 2. TURKUAV size/performance and engine cycle analysis results

UAV size/performance											
W_0	UAV gross weight	6304	kg								
t_{loi}	Loiter (surveillance) time (constant 40000 ft altitude)	24	h								
t_{tot}	Total mission time (taxi, takeoff, climb, loiter, descent, landing)	26.5	h								
Mission points		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
H (altitude)	km	0	0	12.19	12.19	12.19	12.19	12.19	12.19	12.19	0
M_0 (speed)	mach	0.151	0.188	0.400	0.349	0.349	0.400	0.357	0.349	0.349	0.152
C_L (lift coefficient)		1.354	0.868	1.021	1.337	1.337	1.016	0.868	0.909	0.901	0.868
V_0 (speed)	km/h	185.2	230.6	464.8	370.4	370.4	424.9	379.0	370.4	370.4	186.3
Lift/Drag		22.10	24.31	24.00	22.21	22.21	24.01	24.31	24.28	24.29	24.31
W (weight)	kg	6291	6259	6118	6118	6118	6118	4161	4161	4121	4121
D (drag)	kN	2791	2524	2512	2700	2700	2497	1678	1680	1663	1647
Engine cycle analysis (turboprop)											
PW	kW	1189	1203	418	404	404	418	406	404	404	1189
PWeq	kW	1234	1259	441	425	425	441	427	425	425	1234
PSFC (fuel consumption)	kg/(kW.h)	0.324	0.322	0.254	0.258	0.258	0.254	0.258	0.258	0.258	0.324
PSFC equivalent	kg/(kW.h)	0.312	0.308	0.241	0.246	0.246	0.241	0.245	0.246	0.246	0.312
Total thrust (prop+nozzle)	kN	18.88	15.34	2.83	3.16	3.16	2.83	3.10	3.16	3.16	18.77
TSFC (fuel consumption)	g/(kN.s)	5.67	7.02	10.44	9.17	9.17	10.44	9.37	9.17	9.17	5.71

In this study, the values are given for the TURKUAV calculated by analytical method are valid as full load (450 kg internal and 900 kg external useful load). It is also assumed to be fully loaded at 40000 ft altitude. In addition, a 24-hour net reconnaissance (at 40000 ft) time was provided. A total flight time of more than 26 hours was calculated, including take-off, climb, descent and 1-hour reserve fuel for landing loiter. For these reasons, it was calculated that it would be larger and heavier than the others. Unlike Predator B, the TURKUAV will be able to meet all the maximum values specified for at the same time. In other words, it will be able to operate with full payload (1350 kg), continuously at altitude of 40000 ft and a net of 24-hour surveillance or loiter. The required engine power will be around 1572 hp (single engine). In terms of engine power level, it is similar to Akıncı UAV (750 hp x 2 engine).
Some of the possible uses of such a UAV can be listed as follows:

- Security operations in and out of country.
- Border patrolling (smuggling, illegal trespassing etc.)
- Coastal surveillance (detection of waste from ships etc.).
- Search and rescue operations after accidents and natural disasters etc.
- Monitoring of energy and oil pipelines for security purposes.
- Detection and extinguishing of forest fires, which intensify especially in summer and cause big losses.
- Examination of climate change and its impacts on the vegetation and forests.
- Occupancy rates of agricultural areas, crop yields, planning and monitoring of forests.

Such a UAV with 24 hours of surveillance time can be used for those missions. For example, with an average speed of 400 km/h, UAV can travel al Turkish sea and land borders 10765 km in 27 hours. Similarly, it can scan all the eastern and southern borders (2477 km) from Batum to Antakya in 6.2 hours or all Iraq and Iranian (944 km) borders in 2.4 hours.

5. Conclusion

In the world of today, where unmanned aerial vehicles are becoming more and more important, the development of these vehicles and engines are within the objectives of our country. For this reason, it is of strategic importance that the studies by domestic companies, institutions, and organizations to be carried out. It has been evaluated that studies like this paper will support the development of long endurance and high-altitude turboprop engine powered UAVs which can be used for civilian and military purposes. The domestic computer code which was developed within the scope of this study can be used for preliminary sizing-dimensioning of aircraft and its engine.

Nomenclature

W_0	:	Gross weight (kg)
t_{loi}	:	Loiter time (h)
t_{tot}	:	Total mission time (h)
H	:	Altitude (km)
M_0	:	Speed (Mach)
C_L	:	Lift coefficient
V_0	:	Speed (km/h)
W	:	Weight (kg)
D	:	Drag (kN)
PW	:	Engine power (kW)
PWeq	:	Equivalent engine power (kW)
PSFC	:	Fuel consumption (kg/kW.h)
PSFC	:	Equivalent fuel consumption (kg/kW.h)
TSFC	:	Thrust specific fuel consumption (g/kN.s)

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Journal of Aviation

Design of a Pesticide Spraying Quadcopter

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Abstract

Today, coupled with technological development, UAV (Unmanned Aerial Vehicle) systems show an important improvement in civil area applications. UAV systems have active tasks with cost-effective solutions in several areas like defense, logistics, engineering, and agriculture. Especially in agricultural applications, UAV system usage contributes to improvement of the critical parameters of this sector as efficiency and sustainability. Thus, in agricultural areas, improvement and usage of unmanned systems are of importance. In this study, a remote-control rotary wing UAV system that can perform irrigation and spraying and its design, production and application processes are discussed. The designed, verified and all test operations completed UAV system is planned to be used in remote control liquid rejection in the agricultural area.

Keywords

Unmanned aerial vehicle (UAV)
Rotary Wing UAV
Spraying, Remote Control UAV
Sustainability

Time Scale of Article

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1. Introduction

The entirety of system elements that are differ from each other and required for flight such as an unmanned aerial vehicle (UAV), control station, command and control data connection and takeoff and landing systems is called a UAV system. UAV is the most critical part of this entirety of systems, while it is defined as an aerial vehicle that is operated remotely by a UAV pilot or autonomously planning by a UAV pilot without having a pilot onboard [1]. Although UAV systems have started to be used for military purposes, especially with the prevalence of commercial off the shelf products and technological developments, they have found their place in several civilian areas such as environmental applications, land mapping, forest fire detection, search and rescue and sensitive agriculture practices. In particular, UAV systems have been used since the beginning of the 20th century in tasks that are monotonous, long-term, where human focus would be lost, that require excessive attention, in dangerous and risky environments [2].

In comparison to manned aerial vehicles, UAV systems have different sizes, weights, endurance and performance (slow flight velocity, angle of climb, etc.) characteristics. For this reason, it is complicated and difficult to compare UAV system to today's manned aerial vehicles. Some UAV systems are designed as small size and weight so that they could not be detected by other manned aerial vehicles, and they can be managed from any location. Some of them, on the other hand, operate at very high altitudes and can stay in the air for a very long time. This is why UAVs are categorized based on criteria like size, range, altitude, velocity and endurance. The National Aviation Authority name as Directorate General of Civil Aviation (DGCA) categorizes UAV systems based on maximum take-off weights as in Table 1 [1].

Table 1. Classification of UAV systems [1]

Category	Maximum Takeoff Weight
UAV 0	500 g (including) – 4kg
UAV 1	4 kg (including) – 25 kg
UAV 2	25 kg (including) – 150 kg
UAV 3	150 kg (including) or more

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UAV systems are designed as fixed wing and rotary wing systems for requirements in different platforms. Among these, rotary wing UAV systems are designed as UAVs that can take-off and land vertically, hover and fly with a lover range and altitude in comparison to fixed wing ones [3]. Rotary wing UAV systems that have more effective design, production and operation capacity in comparison to others are named based on the number of rotors on them. Nowadays, UAV systems with rotary wings and four rotors (quadrotor, quadcopter, etc.), with their capacity of maneuvering, effective load carrying capacity, simple mechanical structure and design, are used in different civilian applications such as airborne imaging, monitoring of electricity transmission lines and following of agricultural products.

It is estimated that several civilian applications made with manned systems today will be made with UAV systems in the future based on the development of technology. It is expected for the future flight operations of UAV systems to be included at all stages of the airspace where manned aerial vehicles' flight operations are conducted. According to the Annex 11 document, the International Civil Aviation Organization (ICAO) divided airspaces into 7 classes from A to G. In this approach, air traffic service and flight requirements vary for each airspace [4]. On the other hand, the European Organization for the Safety of Air Navigation, or EUROCONTROL, defines airspaces for UAV systems in three parts [5]. Figure 1 shows these parts.

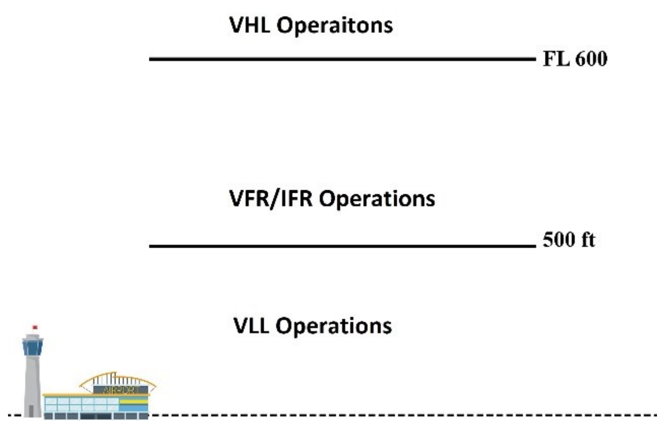

Fig. 1. Definition of airspace for UAV systems [5]

UAV systems are expected to conduct their flight operations in a mixed space within the air traffic control where the flight operations of existing manned aerial vehicles are carried out depending on the requirements of the relevant airspace. These are [6]:

- VHL (Very High Level) Operations: Include above FL600 and under orbit IFR (Instrument Flight Rules) operations.
- IFR (Instrument Flight Rules) or VFR (Visual Flight Rules) Operations: Include similar rules applied in manned aviation.
- VLL (Very Low Level) Operations: Include operations below 500 ft.

UAV systems to be used in agricultural activities are usually expected to have capacities to conduct flight operations below 500 ft and closer to the ground. It is seen that UAV systems that would conduct flight operations below 500 ft have more advantages in terms of minimum equipment requirements, accessibility and usage variation in comparison to UAV systems to be used in other airspaces. In addition to this, for the purpose of using UAV systems for increasing efficiency and sustainability of agricultural products, several research and development studies are carried out [7-9].

Logan et al. stated that if UAV systems to be used in agricultural activities helped only 1% of improvement in product quality, there would be an increase of 1.43 million dollars in product sales (assuming that only 10% of 310 million decare of agricultural land in the US would be used by UAV systems) [10]. Torres-Rua et al. used a UAV system with the capacity of image processing for the purpose of monitoring the development of agricultural products to examine several factors such as soil humidity, evaporation rates, chlorophyll and nitrogen rates in a certain area, and they reported that this had a positive contribution on production [11].

Additionally, in comparison to high-resolution satellite and airborne sensors, usage of UAV systems in such applications provides a substantial advantage [12]. Some of the benefits of agricultural activities conducted by using UAV systems include increased production, improved productivity, reduction of environmental effects and having measurable data [13-14] . On the other hand, in cases where meteorological conditions are inadequate, and human access is difficult during pesticide application on some agricultural products, usage of UAV systems is one of the solutions that are cost-effective which increase productivity.

Therefore, technological developments to be achieved in UAV systems to be used in the agricultural field are important in terms of production, monitoring, analysis and sustainability of agricultural products. This study designs a quadrotor UAV that can be used in pesticide application and irrigation when needed in the field of agriculture and showed that the UAV system structure successfully served its function by flight and implementation trials.

2. Design, Production, and Implementation Process

The developed UAV has a rotary wing structure. Additionally, the developed quadrotor UAV has the ability to manually and autonomously fly with the autopilot system on it. The autopilot system used in the study is the naza model produced by DJI company. It contains inner damping, controllers, 3-axis gyroscope, 3-axis accelerometer and barometer in its light and small Main Controller. It can measure flying altitude, attitude and therefore can be used for autopilot/automatic control.

In the rotary wing UAV system, there are hardware components as brushless direct current (DC) motors, electronic speed controllers (ESC), propellers, a battery, global positioning system (GPS), telemetry system and autopilot system. The relationship among the hardware components of the produced UAV system is shown in Figure 2. To increase the stability of the UAV, the fans of the propellers fixed on the DC motors are made out of hard plastic material.

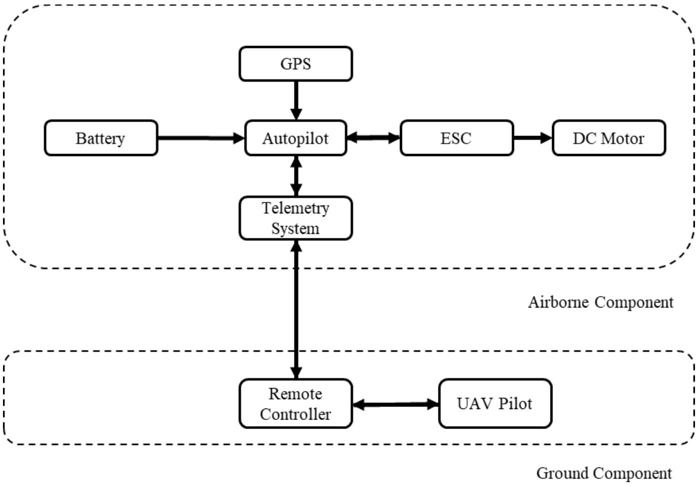

Fig 2. System component structure of the quadrotor UAV system

Onto the UAV system that is developed to be used in the field of agriculture to release liquid material from the air in a remote-controlled way, a liquid container was added as seen in Figure 3. By this way, the UAV system with the liquid container is equipped with pesticide spraying capacity, and its necessary test and validation processes are completed with success. For using the pesticide spraying system, the input and output terminals of the autopilot system are defined as shown in Figure 4. By means of this, the pilot is able to use the pesticide spraying system remotely and safely in a manual or autonomous mode at a desired phase of the flight. Furthermore, the UAV system finds its position based on its GPS sensor successfully during the flight tests.

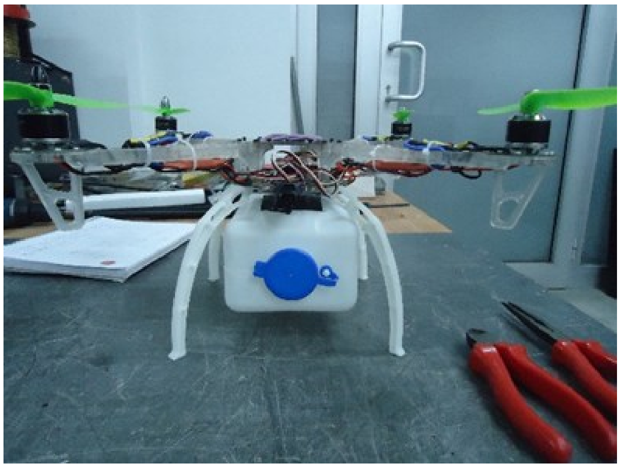

Fig 3. The Developed UAV system

2.1 System Components and Properties

Brushless Direct Current Motor:

In production of rotary wing UAV systems, brushless direct current (DC) motors are among the frequently used motors. Brushless DC motors have several advantages such as high efficiency, easiness of maintenance, long lifespan and silent operation. Technical information about the brushless motor that is used in the design is given in Table 2.

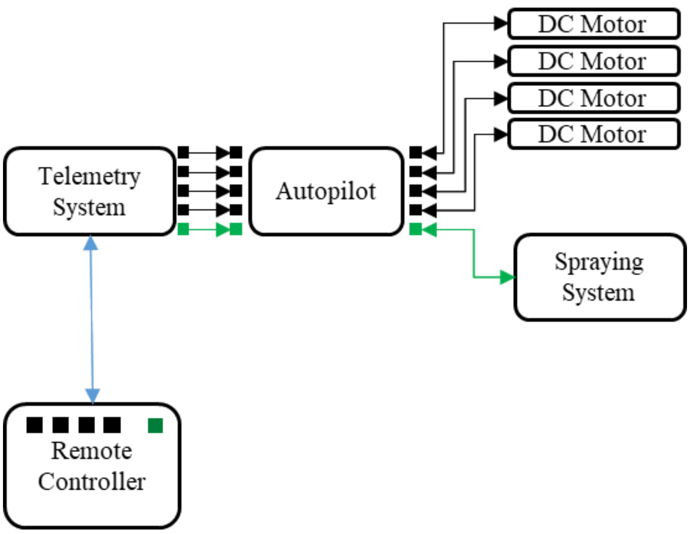

Fig 4. Spraying system positioning structure

Table 2. Technical properties of the brushless motor

	Unloaded		With Load		
Voltage (V)	Current (A)	Speed (RPM)	Current (A)	Carrying Capacity (g)	Power (W)
11.1	0.3	10200	8.5	600	94.4
14.8	0.3	13610	13	940	192.4
18.5	0.4	17000	17.2	1270	318.2

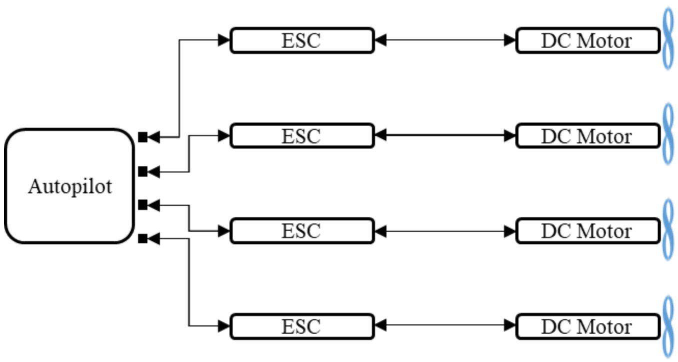

Fig. 5. ESC and motor positioning structure

Propeller

In rotary wing platforms, there are two types of propellers that create lift with the effect of speed. These are:

- Clockwise (cw)
- Counterclockwise (ccw)

Based on the structure of the rotary wing platform and the motor that is used, propeller selection and positioning are carried out. The properties of the carbon fiber propeller used in the project are shown in Table 3.

Table 3. Technical properties of the propeller

Fan Length	Torsion Angle
9 inch	4.5 inch

Battery

Lithium-polymer (Li-po) batteries consist of various numbers of cell structures. Each cell has an average voltage. Different voltage values can also be obtained by connecting the cells in series (S) or parallel (P). The symbol C on the battery provides information about the discharge rate. The properties of the li-po battery with a form of 3S1P that is used in the produced UAV system are given in Table 4.

Table 4. Technical properties of the battery

Property	Value
Minimum Capacity	7000 mAh
Configuration	3S1P
Discharge Rate	40 C
Max. Discharge Rate	80 C

Pesticide Spraying System

For the pesticide spraying system, a system consisting of a motor, motor controller, intermediate switching element, centrifuge, pesticide container and spraying nozzle is designed and used. The intermediate switching element sends a signal to the motor, therefore the spraying element. As the switching element, a BC307 PNP type transistor is preferred. The base of the transistor was connected to the pin of the microcontroller that provided an output of 3.3V. As this output value satisfies the threshold voltage of the base of the transistor, based on the incoming command, the microcontroller will provide the 3.3V to the base of the transistor, and depending on the working principle of the transistor, when the threshold voltage is exceeded, it will pass the battery voltage over itself and start to drive respectively the motor and pump systems. The spraying nozzle on the liquid container attached to the rotary wind UAV system has the capacity to serve its function manually or autonomously. The general structure is seen in Figure 6. It was supported with an external battery so that it would not affect the flight duration. Against vibrations that would occur during the movement of the spraying nozzle on the liquid container, the container is supported with anti-vibration materials.

2.2 The Weight and Endurance of the UAV System

As seen in Table 5, the total weight of the hardware components of the rotary wing UAV system developed for the purpose of pesticide application and irrigation, the frame and the payload is approximately 3 kg. This way, the endurance of the aerial vehicle in a full state of its 500-ml liquid container is theoretically calculated to be 24 minutes. Theoretical calculations are found in accordance with the equation as shown below:

$$Flight\ Time = \frac{\text{Battery Capacity (ah)}}{\text{Total Current (a)}}\ x\ 60 \quad (1)$$

With the testing and validation operations, it is seen that the UAV system stayed airborne by approximately these levels. The distance between the aerial vehicle and the UAV pilot covers an area of 1 km in diameter based on the transponder and receiver of the telemetry system. Approximately, 14.17 m^2 agricultural area can be sprayed with the proposed system.

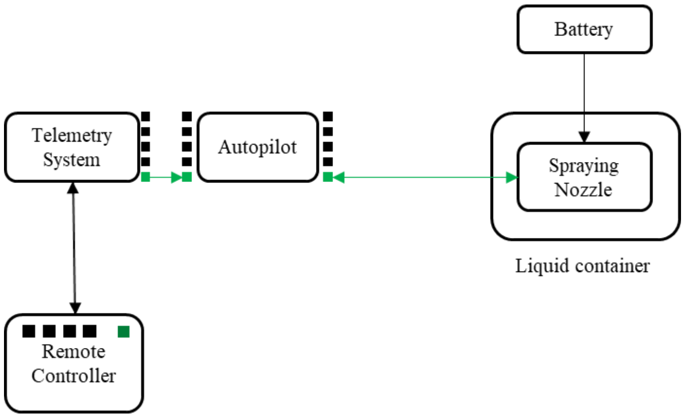

Fig. 6. Structure of the spraying system

Table 5. The total weight of the hardware components of the rotary wing UAV system

Hardware	Total Weight
DC Motor (x4)	320 g
ESC (x4)	64 g
Autopilot (x1)	50 g
Propeller (x4)	40 g
Battery (x2)	1106 g
Liquid Container and Spraying Nozzle	450 g
Frame, Arms and Other Components of the Aerial Vehicle	1050 g
Total Weight	**3080 g**

3. Conclusion and Future Studies

This study discusses a quadrotor UAV system that is developed for pesticide application and irrigation. Testing and validation activities are successfully completed for this UAV system that can stay airborne for approximately 20 min with a full liquid container and serve its functions manually or autonomously. As the next stage in the project, it is planning to increase the endurance and make improvements on the pesticide carrying capacity and spraying mechanism.

Acknowledgements

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Aeroelastic Analysis of a Flapping Blow Fly Wing

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Abstract

In this study, a 3D model of the bio-inspired blowfly wing Callphere Erytrocephala is created and aeroelastic analysis is performed to calculate its aerodynamical characteristics by use of numerical methods. To perform the flapping motion, a sinusoidal input function is created. The scope of this study is to perform aeroelastic analysis by synchronizing computational fluid dynamics (CFD) and structural dynamic analysis models and to investigate the unsteady lift formation on the aeroelastic flapping wing for different angles of attack.

Keywords

Micro air vehicle
Fluid-structure interaction analysis
Computational Fluid Dynamics
Structural dynamic analysis
Finite element analysis

Time Scale of Article

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1. Introduction

In recent times, flapping-wing micro air vehicles (FWMAVs) which are a subset of micro air vehicles have attracted great attention [1-5]. Compared to fixed-wing and rotary-wing micro air vehicles, FWMAVs are preferred since they offer great numbers of functionalities such as suitability for in-door applications, high maneuver capability, low acoustic characteristics. Lately, with the development of light-weight structures and small-scale electronic devices such as actuators, sensors, there have been proposed micro air vehicles [6].

There are two major aspects distinguish FWMAVs from other conventional MAVs which are:

- Method of producing lift and thrust forces,
- Operational flight regimes.

FWMAVs show more complex lift and thrust generating mechanisms compared to the fixed-wing micro air vehicles. Fixed-wing aircraft convert relative airstream velocity in to lift force and utilizing a mounted engine on the wing for propelling their body. Bio-inspired flying robots generate lift and thrust force with airfoils in plunging and pitching motion. The second difference between fixed and flapping wing MAVs is the operational flight regime. Since the bio-inspired flapping systems are unable to fly fast as much as fixed-wing aircraft, they have to deal with the low Reynolds regime and produce sufficient lift and thrust force.

Even though the leading-edge vortex (LEV) associated studies dates back to the first era of aviation history, understanding the important role of the vortex structures for enhancing lift and thrust capabilities of the flapping wing systems have been attracting a great deal of attention for nearly 20 years [7]. Investigated the effect of LEV structures by performing an experimental study. The proposed study shows that LEV structures occur on the upper surface on an up-scaled blowfly wing and creates a low-pressure region. This behavior leads to the occurrence of stall delay and enhances the lift capacity of the proposed wing [8]. Investigated the blowfly wing and hawkmoth wing in different Reynolds number regimes by performing computational fluid dynamics (CFD) study and, researchers showed that the

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generated lift is directly proportional to the Reynolds number. Besides, it is shown that as the Reynolds number decreases the formation of the LEV structures changes its shape from the conical section to the cylindrical section [8].

There are numerous numerical studies that have been proposed to characterize FWMAV structures from the aerodynamical standpoint. Essentially, the performed by the researchers in this field assume the flapping wing as rigid [9]. However, making rigid-wing assumptions underestimates the aeroelastic effects that occurred on the wing. During the flapping motion, two types of motion exert on the wing structure as inertial and aerodynamic loads. Inertial loads maximize its value at the end of up-stroke and down-stroke motion since the acceleration reaches its maximum value. Aerodynamic forces relatively change depending on the velocity of the surrounds wing. The studies have been put forward in this field shows that the contribution of the inertial loads to the elastic deformation on the hawkmoth wing is more than the contribution is done by aerodynamic loads [10]. Researches performed fluid-structure interaction analysis to investigate how aeroelasticity contributes to the wing deformation [11].

Fluid-structure interaction (FSI) analyses combine the structural dynamic and fluid dynamic equations and solve both formulations simultaneously. Nakata et al. [9] report that the lift capacity of hawkmoth increases with the flexibility of the proposed wing. In the first step of the FSI, the pressure distribution is obtained for the proposed structure in the CFD domain. Then the pressure distribution is transferred to the structural dynamics domain and the imposed on the body of the corresponding structure and deformed body is obtained. Utilizing the deformed body of the structure, a dynamic analysis is solved for one increment and inertial loads are imposed on the structure. Lastly, the final position of the nodal coordinates of the deformed body is transferred to the CFD domain and, a CFD analysis is performed based on the updated elastically deformed body. The schematic view of how employing the incremental-iterative solution in fluid-structure interaction analysis is given in Figure 1.

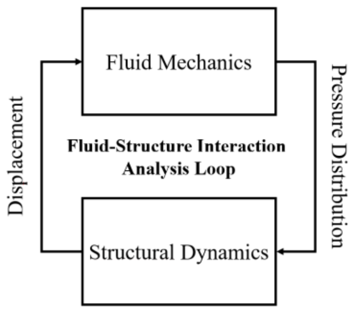


Fig. 1. Fluid-structure interaction analysis

In this study, how the aerodynamic characteristic of the Calliphora Erytrocephala wing varies with the angle of attack is investigated by flapping at a constant frequency.

2. Method

2.1. Wing Model

In this study, a blowfly wing designed by Konkuk University is used as a reference model [12,13]. The chord length and the half-span of the utilized wing are 29.15 mm and 58.47 mm respectively. The schematic view of the proposed wing is given in Figure 2.

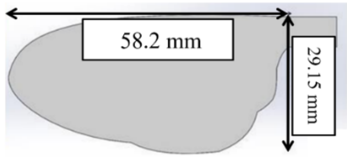


Fig. 2. Wing Model

The flapping angle of the proposed system is 41.5° and the flapping frequency is set as 11.2 Hz as given in Figure 3 [13].

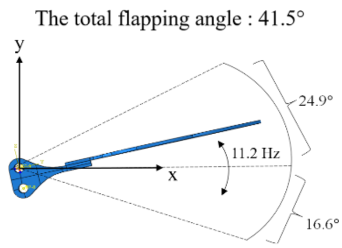


Fig. 3. The total flapping angle and flapping frequency

2.2. Fluid-Structure Interaction Model

Structural Dynamics Model

In the presented study, a dynamic-implicit model is defined for solving the structural-dynamics model with $5x10^{-4}$ seconds increment. The linear-elastic material properties of plexiglass material are defined to wing part in the model. Linear-elastic material properties of the plexiglass are given in Table-1.

Table1. Material properties of the plexi-glass

Material	Elastic Modulus (MPa)	Density (gr/cm^3)	Poisson's Ratio
Plexi-glass	3100	1.04	0.35

The C3D8 linear-hexagonal cell grids are designated for the structural dynamics model. The total number of nodes and cells are given in Table 2.

Table 2. Mesh properties

Mesh type	Number of Cell	Number of Nodes
C3D8	2474	3816

A rotational periodic boundary condition is defined as sinusoidal input (Eq. 1) with 12 Hz from the pivot point of the proposed analysis model. In the Eq. 1, the θ and f define the flapping angle and the flapping frequency as 41.5° and 11.2 Hz respectively. The illustration of the defined boundary conditions of the proposed structural dynamics model is given in Figure 4.

$$A = \frac{\theta}{2}\sin(2\pi f t) \quad (1)$$

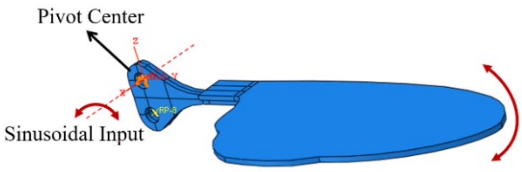


Fig. 4. Boundary conditions

2.3. Computational Fluid Dynamics Model

For the proposed study the Reynolds number is 6000. In this framework, a laminar, implicit analysis step with $5x10^{-4}$ seconds increment is defined for the CFD model. The fluid domain created for the CFD model is given in Figure 5. The proposed study is employed for hover mode The air density is defined for the fluid domain as 1.21 kg/m^3.

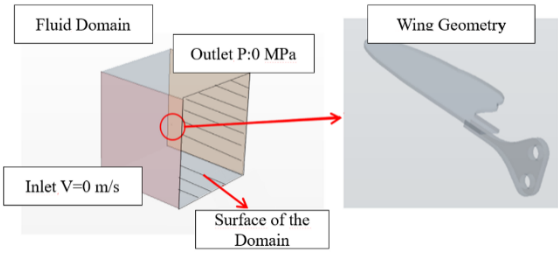
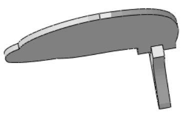
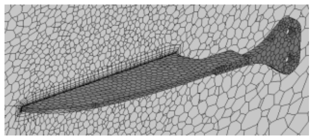
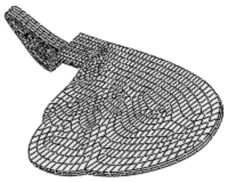
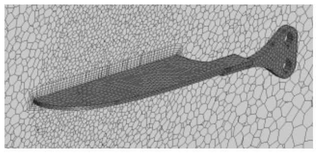
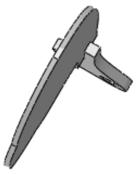
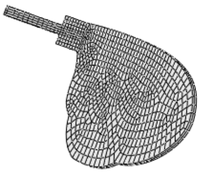
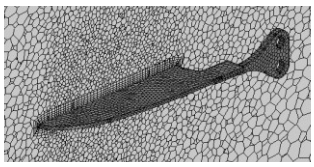
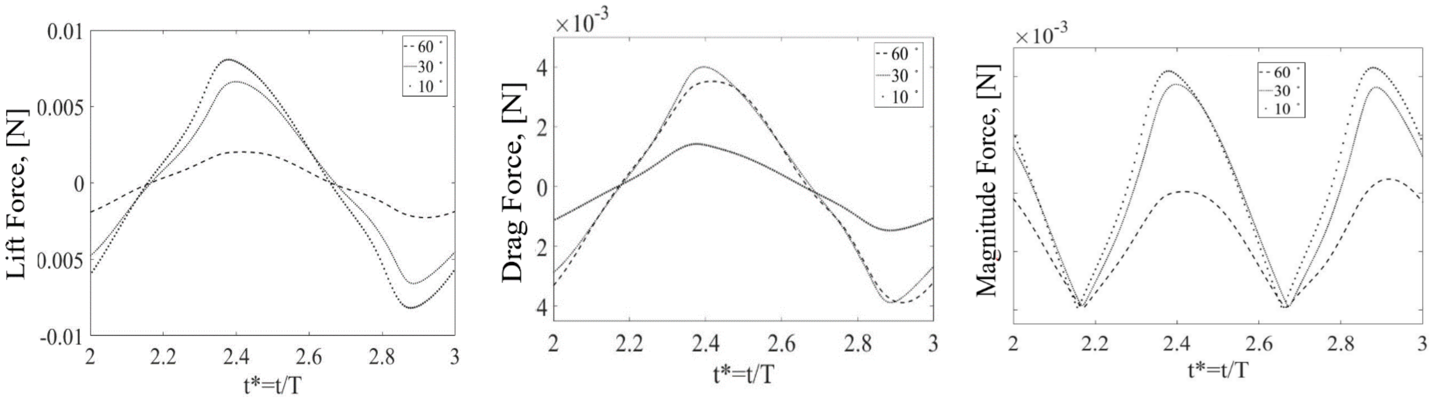


Fig. 5. CFD model

Table 3. CAD, FEA and CFD model cases for varying angle of attack

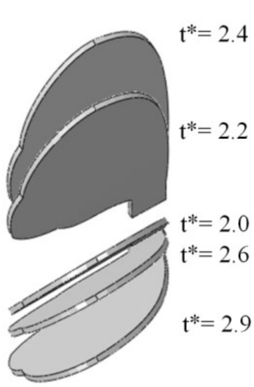
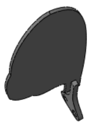
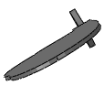
Angle of attack	CAD Model	Structural Dynamics Model	CFD Model
10°			
30°			
60°			



(a) (b) (c)

Fig. 6. Force results (a) Lift force (b) Drag force (c) Magnitude force

Table 4. CAD, FEA and CFD model cases for different mean angles of attack

Non-dimensional Time (t*=t ∗ f)	Wing Position	
2.0		
2.2		
2.4		
2.6		
2.9		

In this study, the aerodynamic forces created by flapping motion for different mean angles of attack are investigated. Within this scope, models are created for 10°, 30° and 60° angles of attack and results are presented. The FEA models for the presented study is given in Table 3.

3. Results

The drag, lift and total forces obtained from FSI solutions for different mean angles of attack are given in Figure 6. It is observed that the resultant aerodynamic forces deviate from sinusoidal flapping motion input. The direction of the magnitude force results achieved for models with distinct angle of attacks are given in Table 5.

Even if the drag force for the models with 30° ve 60° angles of attack are quite similar, the difference between two models for lift force. The vortex and pressure contour results at t*=2.4 are investigated for the four different sections for the proposed wing and given in Table 6 and Table 7 respectively.

The time-dependent elastic tip deflection of the proposed wing is investigated in comparison with the rigid case. The investigated point of the proposed wing is pinpointed and given in Figure 7. The comparison of of the deflections between the rigid and elastic wings are given in Figure 8.

Table 5. Time dependent magnitude force and its direction

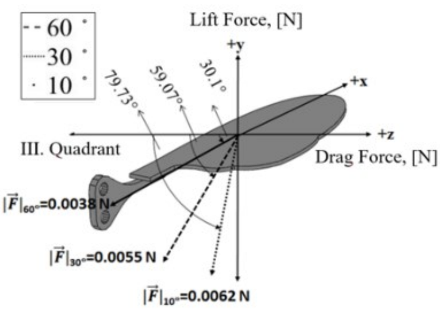
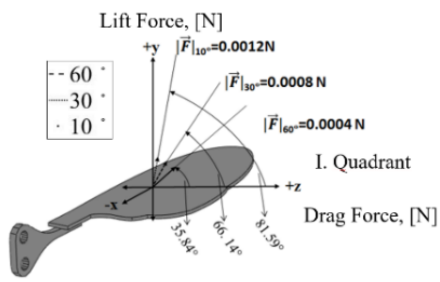
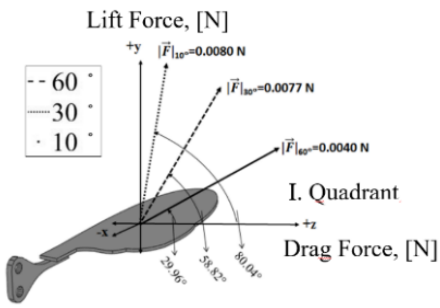
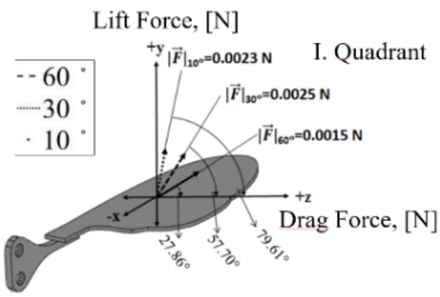
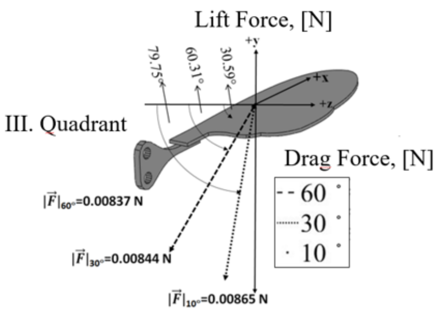
Force magnitudes and directions for distinct non-dimensional times				
t=2.0	t=2.2	t=2.4	t=2.6	t=2.9
				

Table 6. Vortex contours about x axis for different angles of attacks at t*=2.4

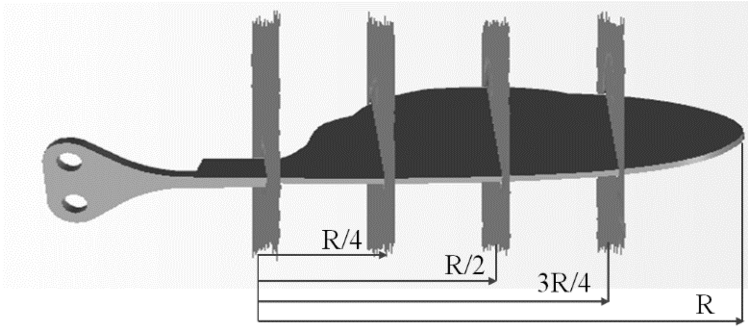
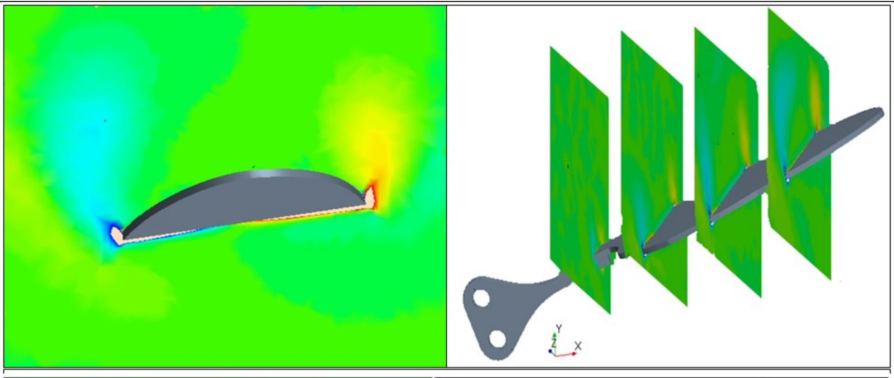
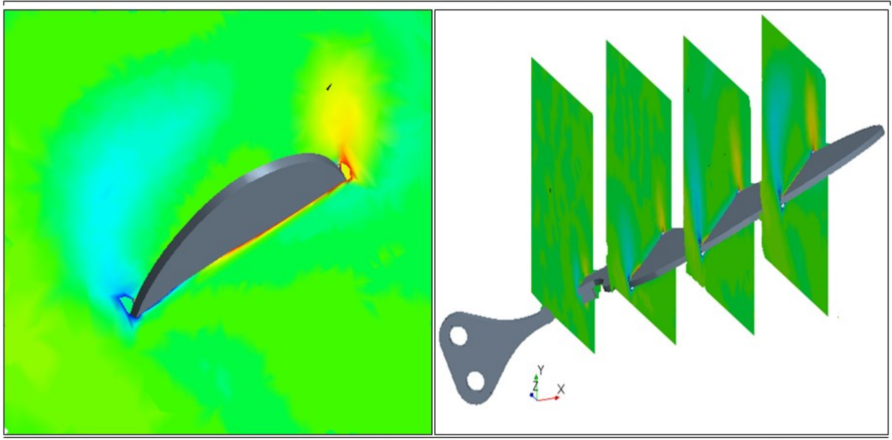
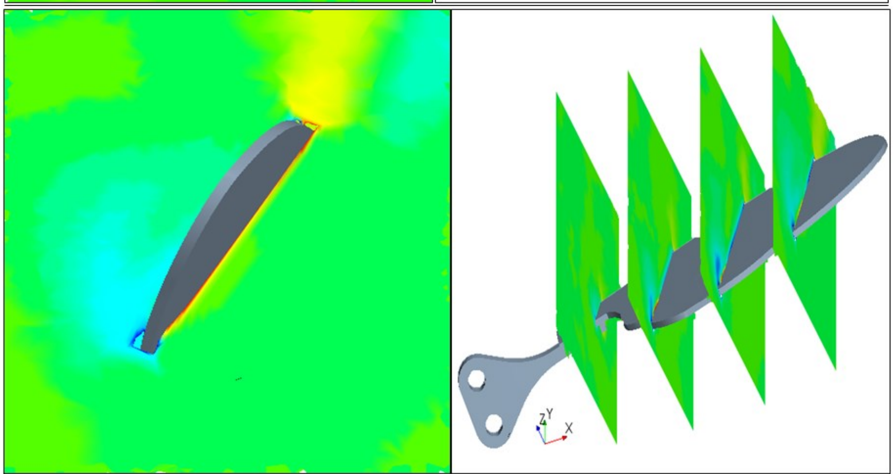
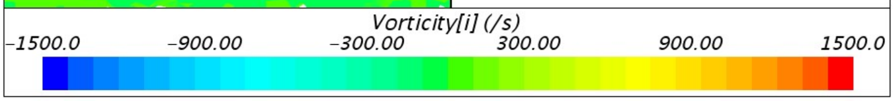
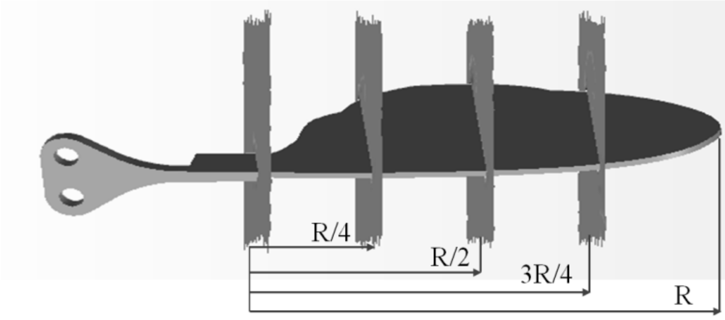
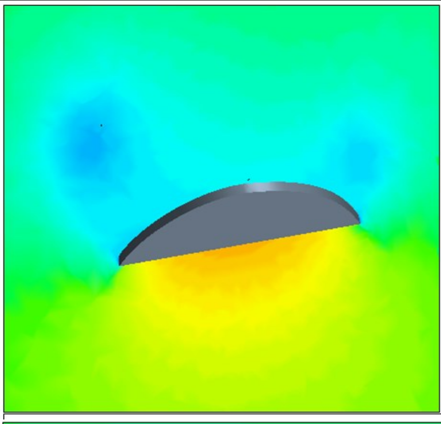
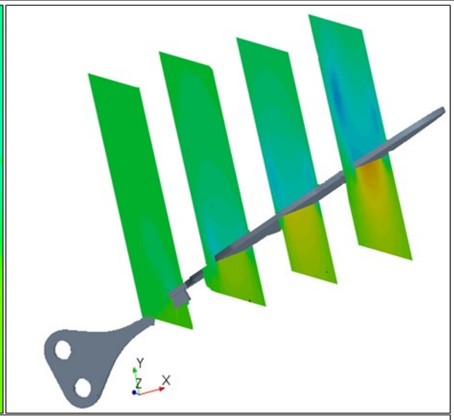
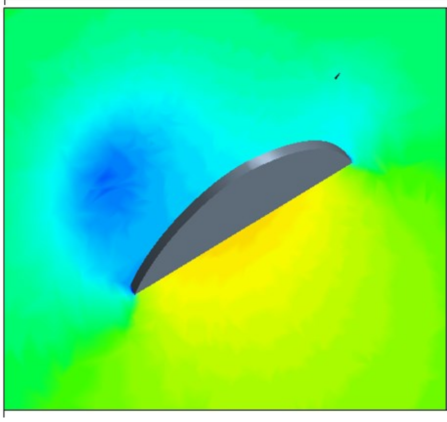
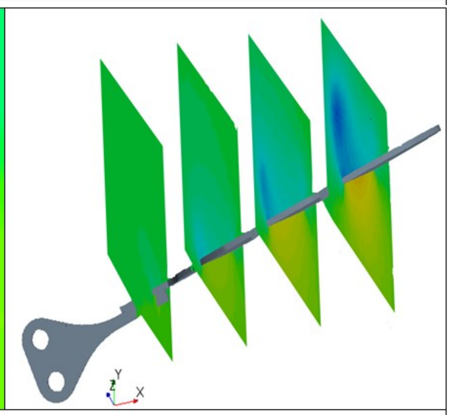
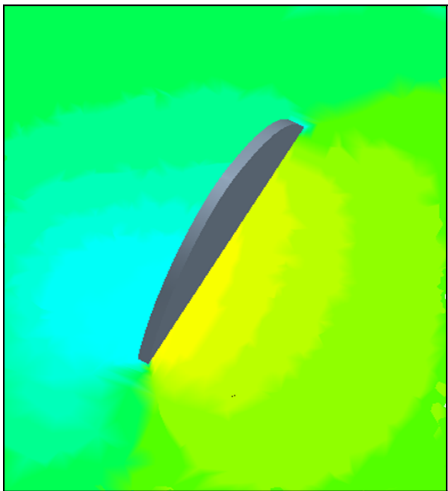
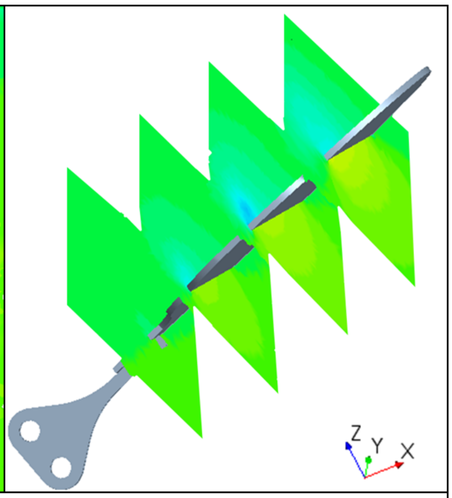
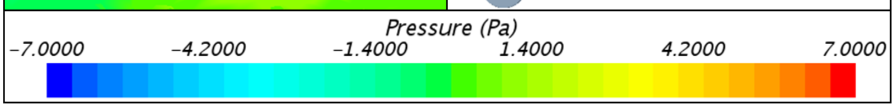
Investigated wing section	
Angle of attack	t*=2.4
10°	
30°	
60°	
	

Table 7. Pressure contours for different angles of attack at t*=2.4

Investigated wing section		
Angle of attack	t*=2.4	
10°		
30°		
60°		
		

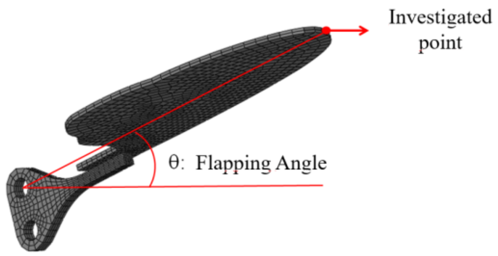


Fig. 7. The Investigated point

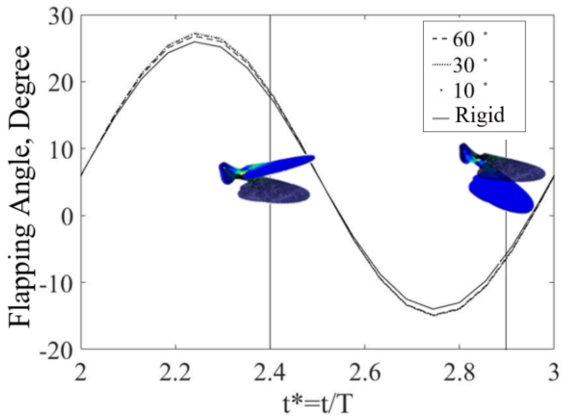


Fig. 8. Instantaneous aeroelastic effect to the tip deflection of the proposed wing

The time-dependent force results given in Figure 6, show that as the angle of attack increases the peak lift force value decreases concordantly. On the other hand, finding the mean force values using equation (2) gives significant evidence that the mean lift force is directly proportional to the angle of attack. In (2) T, t* and F refer to period, non-dimensional time and force value (lift or drag) belong to corresponding time interval respectively.

$$t^* = \frac{1}{T}\int_{t^*=2}^{t^*=3} F dt \qquad (2)$$

The mean lift force results varying with the angle of attacks are given in Table 8. Negative lift force is obtained for the models with 10° and 60° angles of attack, on the flip side positive lift force is obtained for the model with 30°. Based on the given vortex results in Table 6, as the angle of attack increases the LEV (leading-edge vortex) decreases and nearly disappears at the 60° angle of attack analysis case. The time-dependent lift force results are given in Figure 6a presents that the 10° angle of attack model exhibits greater lift force amplitude compared to the analysis cases with 30° and 60° angle of attack. The minimum drag force amplitude is attained for the 10° angle of attack model. The 10° angle of attack model shows the greatest magnitude force characteristic among the proposed flapping case models as given in Figure 6c. As it is seen from Table 6, even though the LEV structures for each model don't show a significant difference visually, the 10° angle of attack model shows greater and positive mean lift force as it is given in Table 8.

Table 8. Lift force statistics

Angle of attack [°]	Maximum Lift Force [N]	Minimum Lift Force [N]	Mean Lift Force [N]
10	0.00807	-0.00818	-0.00004
30	0.00662	-0.00659	0.000091
60	0.002	-0.00226	-0.000042

Drag forces varying with different angles of attack models show negative drag force in −z-direction (Figure 6b). This situation leads to the occurrence of positive thrust caused by flapping motion (Figure 6b). Drag forces for different mean angles of attack are given in Table 9. Based on Table 9, it is seen that the net negative drag forces (thrust) are achieved for the 10° and 60° angles of attack models. Also, maximum drag forces are attained from analysis models with the 10° and 60° angles of attack.

Table 9. Drag force statistics

Angle of attack [°]	Maximum Drag Force [N]	Maximum Drag Force [N]	Mean Lift Force [N]
10	0.00143	-0.00146	-0.000024
30	0.004	-0.00387	0.000055
60	0.00352	-0.00387	-0.000051

The magnitude of lift and drag forces and their quadrants are given in Table 5 (Figure 6c). The aerodynamic force magnitudes for the t*= 2.2 and t*= 2.6 appear at first quadrant, for the t*= 2.0 and t*= 2.9, the force magnitudes take negative values and results within quadrant III.

The instantaneous wing tip displacement varying with the proposed angle of attack analysis cases is given in Figure 8. Compared to the rigid case, the 60° angle of attack model shows the least elastic angular displacement. The 10° and 30° angle of attack models exhibit the greatest and least angular displacement at the end of the up-stroke of the defined flapping motion respectively. Since the proposed system performs non-symmetric flapping motion around the x-axis (Figure 3), different inertial body forces exert on the system at the end of up and downstroke motion.

The pressure contours given in Table 7 clearly show that the analysis models with the 10° and 60° angle of attacks show homogenous high and low-pressure distribution on the upper and lower wing surfaces.

4. Conclusion

In this study, the 3D model of the blowfly wing (Calliphora Wing) is modelled and analysed at different angles of attack. Instantaneous tip deflections of the modelled wing are obtained and the effects aeroelasticity are investigated on the aerodynamic forces. It is concluded that the flexibility of the wing increases the lift force amplitude compared to the rigid configuration.

Thanks

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Symbols

f	:	Frequency [Hz]
θ	:	Flapping angle [°]
T	:	Period [s]
F	:	Force [N]
t	:	Time [s]
t*	:	Non-dimensional time

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An Assessment of Aircraft Maintenance Technician Competency

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Abstract

Aircraft maintenance activities are one of the most important criteria for the safe and effective execution of aviation operations., In aircraft accidents and incidents, maintenance factor is vital for the development of safety for organizations, authorities, and countries in the aviation field. Effective maintenance activities will also contribute to the costs of organizations by ensuring the safe operations of aircraft with people. Maintenance activities are carried out by maintenance technicians in areas such as hangars or aprons. Aircraft maintenance technicians' performance in performing maintenance activities directly impacts flight safety and technician safety, which in turn has a positive or negative impact on organizations. Improving technician competency assessment processes can reduce maintenance errors, improve technician performance, create positive impacts on safe and efficient flight operations, reduce maintenance costs and benefit of the entire aviation industry. Technician competency should be considered in performance evaluations and assignments by assessing at all levels with the compatibility of widely used human resources management methods. In this study, technician competency assessment processes are mentioned, the effects of these processes on aviation safety are explained and solutions are proposed to develop and apply the assessment processes.

Keywords

Aircraft maintenance
Aircraft maintenance technician competency
Competency assessment
Human factors

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1. Introduction

Aircraft maintenance activities are one of the direct operational and primary operational activities of air transport, which is the most effective transportation method today, safely, effective and sustainable manner. Performing aviation operations safely and effectively depends on the performance of human resources. Human has an important role in aviation incidents and crashes compared to aircraft and flight-related systems [1].

Pilots, air traffic controllers, and aircraft maintenance technicians are critical human resources in terms of flight safety. These qualified resources are the leading actors in maintaining operations as intended in terms of flight safety and effectiveness. The physical and cognitive processes of these operators may affect their behavior and thus flight efficiency in a good or bad way (Turhan, 2019). In other words, aircraft maintenance technicians are the human resources that create significant added value in the realization of flights as planned.

The competence and performance of aircraft maintenance organizations and maintenance technicians are effective in terms of safety and cost in the environment in which aviation and airline organizations operate. While the performances of the work perform as expected, they provide positive added value in all operations, while the consequences of the negativities may be very destructive.

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The purpose of aircraft maintenance activities is to maintain flight operations safely and to ensure the reliability of components and systems at the lowest possible cost. To achieve these goals, it is one of the most important criteria for maintenance technicians to perform the maintenance activities properly [2]. Although it is known that air transportation is one of the safest methods of transportation, an accident or incident that may occur have serious consequences both in terms of its impact and cost.

Although it is known that maintenance activities are vital for aviation safety, the supply of qualified technicians, recruitment and selection practices may be insufficient to supply the ever-increasing demand for qualified human resources in the operational aviation environment. There are problems at the international level regarding aircraft maintenance technician training, and there is a shortage of certified technicians (technicians who approve maintenance tasks) in organizations. Despite knowing the importance of aircraft maintenance, unfortunately, present technology used in the field of maintenance and also the existing structure of the aircraft maintenance documentation, which is the main ground of maintenance operations, remains insufficient [3].

The current structure of the maintenance documents used during maintenance tasks does not provide sufficient benefits for the efficient maintenance of technician competence assessment procedures. Preparing and using maintenance documents with interactive technologies will provide a significant improvement in the more objective and effective maintenance of technician competency assessment processes.

The competence of aircraft maintenance technicians can be defined as all of the knowledge, skills, behaviors, and attitudes used to perform their tasks within the scope of aircraft maintenance and repair activities. Task performances depend on the level of these basic knowledge, skills, and behaviors. The level of knowledge and experience of maintenance technicians is an important factor that closely affects the cost of direct maintenance for organizations. If there is a lack of technician training, it will lead to the unnecessary dismantling of available components and ordering spare parts and will reduce efficiency in troubleshooting. Because more time is needed to complete maintenance activities, more manpower will be needed for the planned maintenance tasks.

This will also cause problems in the use of test equipment and the use of technical documentation, and all these adversities will increase the maintenance cost (Mercan, 1999). Despite this information, it is generally assumed that technicians are not involved in the airworthiness process. The technician is the last link in the airworthiness chain. The owner of the last signature of the aircraft before the flight [4]. Therefore, important roles such as assessment of technician competence and flight availability approval should be assigned to qualified and competent aircraft maintenance technicians.

In this study, it is aimed to examine the factors that affect their competence and thus their performance and to contribute to the field literature and operational processes for competency assessment.

Factors affecting the performance of technicians can be listed as cognitive factors, physical factors, organizational factors, and procedural factors. Accurately measuring, analyzing and evaluating these factors will help improve technician performance, have positive impacts on safe and efficient flight operations, reduce maintenance costs and benefit the entire aviation industry.

2. Aircraft Maintenance and Maintenance Technicians

Aircraft maintenance activities are required to perform safe flights that meet the requirements for airworthiness. An aircraft is delivered from the manufacturer to the operator under conditions in which the systems are fully operational and airworthiness requirements are met [5]. Maintenance activities are carried out to maintain and improve the performance and robustness of the aircraft. Maintenance activities include visual inspection, repair, repair, replacement and replacement of parts [5]. The maintenance activities are carried out by authorized technicians by the standards, methods, techniques, and instructions specified in the regulations, in the use of appropriate tools and materials and appropriate facilities or areas under all environmental conditions.

The main purpose of aircraft maintenance; to keep the aircraft within the design limits in terms of performance and reliability [7]. Aircraft maintenance is an important process where safety, security and quality requirements are strictly applied. Maintenance procedures are determined by the manufacturer and controlled by the competent authorities throughout the operation. Aircraft maintenance is therefore carried out by regulations such as EASA-145 (European Aviation Safety Agency) and MSG-3 (Maintenance Guidance Guide) [8]. Aircraft operators are obliged to keep the airplane they operate in an airworthy condition, to establish the necessary organization to perform maintenance activities or to purchase them. In general, maintenance services require appropriate maintenance workshops or hangars, appropriate and sufficient equipment, tools, equipment, infrastructure systems, maintenance technicians and certified technicians [9]. The responsibility of aircraft maintenance, which is the most basic part of the airworthiness, lies with all employees of the organization, especially the aircraft operators.

Maintenance activities are the key factors in achieving the goals that the airline organizations plan at the foundation stage and succeeding in this direction, increasing the reliability of the aircraft, using the aircraft efficiently, performing the operations within the safety framework, and increasing the respectability of the organization and aviation sector [10].

Human factors play an effective role in aviation accidents or fractures that have occurred. Human factors can also be cited as the cause of maintenance errors. Individual-based errors can be caused by education deficiencies, planning deficiencies, human factors such as attention, perception, stress, workload and situational awareness. Although organizations take several measures to prevent these situations, which cause serious cost and dignity loss for them, the increasing number of flights and airplanes in the sector, the spread of automation systems and the increase in competition make the maintenance technicians capable of making mistakes from time to time.

As shown in previous studies, the maintenance factor is very effective in all aviation accidents. 28.6% of the fatal aviation accidents between 1999 and 2008 were responsible for the maintenance factor (Froslee, 2011). Although technological advances in the aviation sector have positively affected air traffic safety and caused a decrease in aviation accidents, there has not been a satisfactory decrease in the rate of maintenance-related accidents and incidents. Although the rate of maintenance errors in aviation accidents gives different results in the researches, it can be said that this rate is approximately 12-20% [11].

In the aviation area, approximately 12 man-hours of maintenance are performed per flight hour. Considering these periods, it is not surprising that 12-15% of aviation accidents occurred due to maintenance. (Rashid et al, 2014). The studies emphasize that proactive methods should be developed to reduce these rates and their necessity is vital for the safety of aviation operations. [12].

Although maintenance errors can be prevented without causing accidents, situations such as flight cancellation and delays create serious costs for organizations. According to the researches, 20-30% of the engine stopping events occurred during the flight as a result of maintenance errors, while approximately 50% of the engine-induced flight cancellations or delays are due to maintenance errors. Even the lowest level of maintenance failure can somehow threaten operational safety.

An efficient maintenance system is an important factor in the airline's goal of achieving its cost objectives. Reducing flight cancellations, delays and air returns will be beneficial for the operator with the efficient maintenance required [13].

The main purpose of all airlines is to transport their passengers and / or cargo from one point to another for profit. Maintenance activities enable aircraft to perform operations within the framework of the planned flight schedule. Maintenance activities are carried out through maintenance programs determined for these purposes.

The appropriately planned and established aircraft maintenance organization will be successful in the safety, component and aircraft reliability and cost issues that are the main objectives of aircraft maintenance and will contribute to the achievement of the objectives of the organization.

For this reason, the objectives of maintenance activities should be considered and planned during the establishment phase of the organizations [14]. The objectives of maintenance activities can be grouped under three main headings. These; safety, availability and, cost.

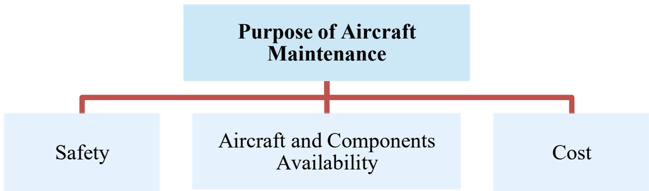

Fig. 1. Purpose of aircraft maintenance

It is aimed to perform maintenance activities at the highest level of safety, optimum aircraft and component reliability at the lowest possible costs. However, these objectives may not always be possible in the aviation industry, where flights and maintenance activities are carried out at all times of the day, in all weather conditions.

Maintenance activities are the key factors in increasing aircraft reliability, efficient use of aircraft, carrying out operations within the framework of safety, and increasing the reputation of the organization and the sector [9]. The objectives of aircraft maintenance are directly related to each other and all three objectives need to be considered and realized together. When the required levels of safety are reached, maintenance errors will be reduced, maintenance-related accidents, incidents, delays, and cancellations will be reduced and thus, significant contributions will be made to organizations in terms of cost. On the other hand, organizations' efforts to reduce costs in an unplanned manner may have negative impacts on safety.

Failure to keep sufficient material in stocks, reducing the number of employees, avoiding the necessary investments in maintenance areas may also increase maintenance errors. This may directly affect the reliability of aircraft and components.

Proper maintenance activities in aprons, hangars, and workshops have an important place in aviation safety. In addition to accidents and incidents caused by maintenance failure, maintenance activities may also indirectly affect other causes of the accident, such as pilotage and material factors.

2.1. Aircraft Maintenance Technician

The main factor in the successful maintenance of aircraft maintenance and repair activities is "human". For the organization to operate profitably, it is necessary to employ technicians who can provide timely and safe service.

The technician following the requirements of the aircraft maintenance job descriptions must be recruited and trained. Information on job descriptions and requirements can be collected through business analyzes within the organization itself, as well as the work of international organizations [15].

The aircraft maintenance system is a complex structure with human and machine components as one of the critical elements ensuring the reliability and safety of the transportation system. The aircraft maintenance technician who performs aircraft maintenance for operational efficiency and safe flight is one of the cornerstones of this system.

An aircraft maintenance technician is a person who performs scheduled or unplanned maintenance for aircraft units [16]. Technicians can think analytically as required by the profession, have a strong perception and are well educated. They continue their education in technical education, business, and management after vocational education.

Maintenance technician concept; aircraft technician, assistant technician, and service worker class. The technician's job descriptions may be inspection, repair, revision, maintenance or aircraft ground handling activities. The concept of maintenance personnel also includes support personnel (administrative staff, programmers, planners, supervisors, and managers) responsible for decision-making, analysis or record-keeping during planning or maintenance execution due to their tasks [17].

Aircraft maintenance technicians can be mainly divided into mechanical maintenance technicians and avionics maintenance technicians. It is also possible to subdivide them into subheadings. Aircraft mechanical maintenance technicians are technicians who perform operations such as inspection, repair, and service of aircraft structure and power units. Aircraft maintenance technicians have an important position in the aviation field. Generally, they perform maintenance activities in a hangar environment or in areas such as apron which can be considered as noisy and dangerous. Their work is very tiring and requires enough physical activity to adversely affect their performance [18].

The duties and responsibilities of the technicians include the safety of the passengers and crew and the airworthiness of the aircraft. The responsibility of the maintenance technician also continues in the service, maintenance and inspection operations of the aircraft [19]. At every stage of maintenance, technicians must interact with the equipment, the work area, the maintenance books, and the information in electronic or hard copy sources required by maintenance activities.

Since its inception, the International Civil Aviation Organization (ICAO) has been involved in operational procedures and competencies of the aircraft technician. The aircraft maintenance technician is licensed by a civil aviation authority approved by ICAO to ensure appropriate safety standards. In this process, ICAO specifies countries' licensing standards with international validity, sets out the differences between these standards, uses a common text and terminology, provides a common platform for the recognition of licenses, and allows countries to audit regulatory systems.

According to ICAO, licensing is a means or method that authorizes the technician to perform specific activities by the authority. Licensing of aircraft maintenance technicians under the Chicago Convention is a responsibility for each country. In the European Union countries, maintenance technicians are licensed under EASA Part 66. In this way, a common license definition was created for all EASA affiliated technicians. According to EASA Part 66, maintenance technician license categories are divided into three categories: A, B, and C. These categories are known as authorized technician classifications in the aircraft maintenance system [20]. To use the competencies that these categories have recognized, there are certain requirements that the technician should provide.

For the licensing of technicians, they must meet the requirements of the civil aviation authority to which they belong. Successful completion of written, oral and test exams is required for the licenses to be applicable. This license is not required to work as an assistant technician in the aircraft maintenance task, but the license required to be able to service the aircraft, ie to become a certifying technician, must be obtained (SHGM, 2013). Licensed technicians often charge more and are preferred by employers.

Maintenance activities carried out on an aircraft are regularly checked by national and international authorities. Aircraft maintenance technicians can be classified according to their certification. A valid aircraft maintenance technician license following the provisions of these instructions is required to perform repair, maintenance, revision, inspection, and service operations to ensure the airworthiness of aircraft or components [21].

2.2. Become an Aircraft Maintenance Technician

Currently, there is no licensing requirement to work as a technician or mechanic in aircraft maintenance activities, while licensed or confirmatory maintenance techniques.

The aircraft maintenance technician must first fulfill the requirements and obtain a license according to a license category he/she has chosen to become a certifying technician. License categories are divided into three categories: A, B, and C. The maintenance technician must provide some basic knowledge, experience, and foreign language requirements to be licensed in the relevant categories.

After passing the relevant module exams for A license, one year is required if the technician has completed Part 147 training, two years for a qualified technician, and three years if he/she has not received basic technical training. After passing the relevant module exams for B license, the technician is required to have two years of experience in Part 147, three years for a qualified technician, and five years if he/she has not received basic technical training. Three or five years of experience are required depending on the authorization to use the C license. The validity period of the licenses is five years and renewal is required at the end of this period (Fig.2, 3.) [21].

The certifying technician refers to the technician responsible for the maintenance output of the component or aircraft to certify that the maintenance activity has been completed following the requirements of the relevant authority [21]. To become a certified technician, it is necessary to have the appropriate aircraft maintenance license and to have the type training certificate according to the duty of the aircraft concerned [6].

To become an approved technician, the organization in which the technician works must also be authorized. This authority is renewed once every two years and the technician is required to spend at least six months of two years working in aircraft maintenance. The age limit for becoming a licensed technician is 18, while this is 21 for the certifying technician. This means that even if the licensee fulfills all the requirements, he/she cannot become an approved technician before she/he is 21 years of age.

Technological advances in the aviation industry have also affected aircraft maintenance technicians and have made it imperative that they become compatible with complex aircraft systems with advancing technology. For maintenance technicians to achieve this compliance, it has become inevitable that technician training should be adapted to today's conditions in organizations and schools providing maintenance training [22]. Well-trained and qualified aircraft technicians with expertise in specialized equipment have a significant impact on preventing maintenance-induced delays. The shortage of qualified technicians is becoming an increasingly large problem for the industry.

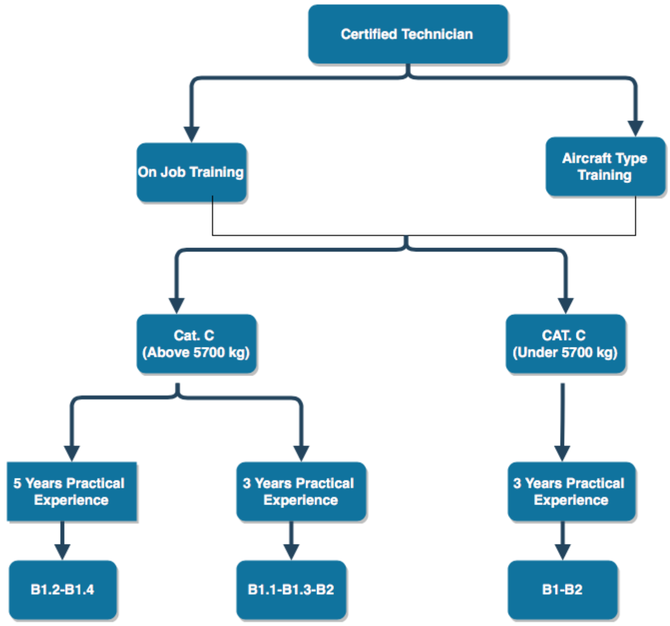

Fig. 2. Become an aircraft maintenance technician (a)

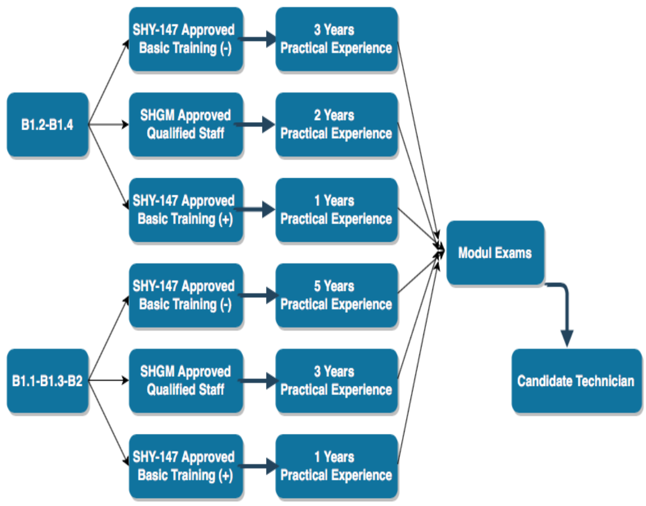

Fig. 3. Become an aircraft maintenance technician (b)

The aviation industry needs well-trained, qualified and professionally qualified maintenance technicians. Graduates of schools providing care education cannot adequately meet this demand. The training received from graduates of educational institutions could not keep up with the changing technology in the aircraft maintenance environment [23]. Students do not have sufficient job training experience and as a result, are not sufficiently prepared to move to work. After receiving the basic training required for the profession, the aircraft technician should keep himself up to date, develop his skills, acquire new processes and be able to master the procedures.

To summarize the training, licensing and promotion processes of the aircraft maintenance technician; the candidate technician must first receive basic and practical training from a maintenance training organization approved by the relevant authorities.

Afterward, they have to pass the module exams required for licensing determined by international authorities and as a result, they must be authorized by the organization they work for. The licensed technician can be sent to type training if required by her/his organization and work as an approving technician in any type of aircraft. These include theoretical and on-the-job training (OJT). A technician working as an approving technician may also work in the aircraft maintenance field by taking update training, human factors training and organization procedures training, if deemed appropriate by his organization.

3. Evaluatıon of Aırcraft Maintenance Technıcian's Competency

The concept of competence for aircraft maintenance can be defined as all of the knowledge, skills, and behaviors that technicians use to perform their duties in aircraft maintenance and repair. Assessing the competencies of maintenance technicians can be described as defining, measuring, and using competency assessment results of technicians performing aircraft maintenance and repair activities. Competence assessment activities should be implemented throughout the process of selecting and placing the maintenance technician, assisting technician and becoming a certified technician.

Determination of recruitment criteria, selection of recruitment and assignment to work units, determination of transition criteria between career levels and application of competency assessment criteria in the determination of transition criteria to the certified technician will provide important benefits in aviation safety. They will also be able to use task-specific training, identify performance problems and prevent frustration.

3.1. Aircraft Maintenance Technician Competency Levels

Candidates wishing to become an aircraft maintenance technician may apply for the job if the institutions providing maintenance services meet the criteria stated in the job advertisements. As the first stage of competence assessment, the selection and placement stage is accepted. At this stage, organizations determine occupational, physical and cognitive competencies for the care technician profession and thus create a recruitment announcement and the first qualifications are performed at this stage. Candidates who pass the pre-evaluation stage are invited to the selection exams under the conditions determined by the organizations. In the selection exams, candidates can be asked verbal and written questions about the field. The candidates who are successful in the selection process can work as assistant technicians. In line with the criteria and needs determined by the organizations, assistant technicians are assigned to the units where they will work. The technicians who pass the required module exams and complete the experience period can be appointed as a certified technician if the organization deems appropriate.

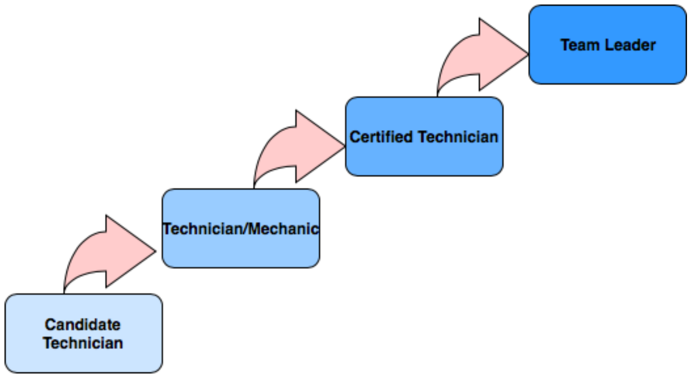

Fig. 4. Aircraft maintenance technician competency levels

The effectiveness of the criteria and methods identified and applied in all of these stages will directly affect the efficiency and efficiency of the aircraft maintenance technician and will be a decisive criterion for aviation safety.
The selection of a candidate who is not suitable for the profession or does not have sufficient competence during the recruitment and selection phase may adversely affect the efficiency of all subsequent stages.

3.2. Evaluation of Aircraft Maintenance Technician's Competency

Effective evaluation of the competence of maintenance technicians is crucial. In this way, it will be possible to carry out value-added studies in terms of efficiency of technicians, job satisfaction and career development. In general, maintenance technicians' methods of performing their tasks are standard, which may facilitate convenience evaluation.

The task cards used by the maintenance technicians during the maintenance activities are the work orders prepared by the maintenance organizations according to the rules of the international authorities.

On these task cards, maintenance technicians write maintenance tasks assigned to them, for example, the technician makes part changes and completes the job as well as the status of the maintenance planning units by writing them to the maintenance planning units. The task cards also include man-hour information related to the defined job.

These cards, which are stored in the archives by the maintenance planning units, contain information about who or by whom the task was performed, whether the task was completed, whether or not changes were made. Based on this information, it is possible to implement an evaluation mechanism for maintenance technicians effectively.

In this context, organizational issues such as whether the work is performed, how unplanned failures occur, increases in maintenance costs are considered as performance indicators and individual factors may remain in the background.

It can also provide benefits in maintenance organizations such as maintaining appropriate data about technicians and providing a return system, effectively planning the tasks assigned to them, and the functioning of reward, punishment, and promotion systems.

In such cases, the efficiency of maintenance technicians may have positive effects on the operation of the planning system, flight operations that need to be carried out safely and effectively, and reduction of maintenance costs.

The competency assessment methods that can be applied to maintenance technicians can be listed as follows.

Direct Observation: Maintenance technicians may be observed during their duties by chief technicians, team chiefs or other technicians who are more senior. During this observation process, it will be possible to have information about whether the technician performs the maintenance task effectively, the effectiveness of the use of documents and tools, whether he/she uses personal protective equipment and safety perception.

Tracking Records: In this method, records such as maintenance documents used by technicians, training received, and evaluation results will be examined and data will be provided on the competence of the technician.

Review and Analysis of Quality Control Records: The quality assessment records maintained by the quality units of the maintenance organizations will be periodically reviewed to provide an assessment of the competencies of maintenance technicians.

Safety Management System (SMS) Records Review and Analysis: By examining the records kept by the Safety Management System units of maintenance organizations, technicians will be able to learn about the errors, safety perceptions, and causes of errors during the maintenance tasks.

Comparison of Technician Performance: While evaluating the results to be obtained by direct observation, monitoring of records, and examination of quality and safety management system records, the performances of employees can be compared. This will provide information on the competence and efficiency of performance evaluation criteria.

The methods given above can be used as competence assessment methods in aircraft maintenance companies, and the implementation of these practices will directly contribute to aviation safety and maintenance activities and thus have a positive impact on cost.

After an appropriate competency assessment process to be carried out during the selection process, it is necessary to make systematic observations and maintenance records of technicians working in maintenance environments within certain programs.

These data will be able to conclude how effectively the maintenance technician performs the maintenance tasks and whether they comply with the safety directives.

The extent to which the technician correctly performs the use of documents and materials during his or her duty, whether he uses personal protective equipment or not, will provide data on both professional competence topics and human factors and safety issues.

In addition to these, quality control records and SMS records can be examined and potential errors that the technician has made or will be able to make can be identified and the aspects that need to be improved in terms of human factors and professional competence will be identified.

In this way, a more effective maintenance environment can be provided, and maintenance errors can be reduced.

In all of these evaluations, a feedback system for technicians should be established and the technicians should be informed about the evaluations and solution suggestions with the applications such as the case study method.

4. Conclusion

One of the most important steps in safe and effective flight operations is aircraft maintenance activities. Considering the difficult working conditions of maintenance technicians who will perform maintenance activities, it is necessary to analyze the technician competency assessment processes and apply the necessary arrangements from the selection and placement process to the approval technician process. Apart from the assessment of competencies such as professional knowledge, foreign language knowledge, document usage knowledge, the application of human factors evaluations such as the ability to work under time pressure, adaptation to shift work system, situational awareness, attention and perception measurement is very important in terms of aviation safety.

In the basic training of aircraft maintenance technicians and the future work environments, the authorities and all relevant stakeholders should act with the support of culture to develop competency assessment.

In the recruitment process of technicians, professional competencies should be evaluated as applied and professional competencies should be applied in terms of appointment to operational units and promotion to approving technicians.

Likewise, language proficiency should be applied as a measure and assessment of reading, listening, writing, and speaking skills both in recruitment and subsequent processes.

In addition to these assessments, it is necessary to evaluate the compliance of the candidate technicians to the profession, especially during the selection process.

During the selection process, the subjects such as attention, perception measurement, working under time pressure and stress, and safety culture measurement should also be evaluated.

Unless appropriate criteria are applied and evaluated during the selection process, adversities may be experienced in all of the technician's next career development stages.

Maintenance faults, which directly or indirectly have an important place in aircraft accidents, crashes, and incidents, will be significantly reduced if these assessments are made appropriately. In this way, flight operations will be performed in a safer manner, costs resulting from maintenance errors will be reduced and a safer maintenance site will be created. Together with all these features and in this way it will make positive contributions to the whole aviation sector.

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A Review on Applications and Effects of Morphing Wing Technology on UAVs

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Abstract

Unmanned aerial vehicles (UAVs) have excelled with their ability to perform the intended task on or without personnel. In recent years, UAVs have been designed for civilian purposes as well as military applications. Morphing wings are changeable wing applications developed as a result of the need for a different lift and drag forces in various phases of the flight of aircraft. It is an application that enables altering the wing aspect ratio, wing airfoil, wing airfoil camber ratio, wing reference area and even different angles of attack are obtained in different parts of the wing. Although morphing wing application has just begun on today's UAVs, modern airliners already have morphing wingtip devices such as Boeing 777-X's. The benefits of the use of morphing wings for UAVs make this technology important. UAVs with morphing wing technology; may increase its payload ratio, may achieve a shorter take-off distance, may land and stop in shorter distance, may take-off where runway clearance is limited, has more efficient altitude change at lower engine RPMs, can obtain higher cruise speeds, may decrease its stall speed, may lower its drag if necessary, thus; saving energy and time. This study concludes a review of literature over morphing wing technology.

Keywords

Morphing wing
UAV
Lift
Drag
Efficiency

Time Scale of Article

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1. Introduction

The purpose of the morphing wing is to increase aircraft performance in different flight phases. Performance parameters that can be developed with the morphing wing concept; are important parameters such as maximum speed, fuel consumption, maneuverability, carrying capacity, range, durability, stability. Improving some or all of these parameterrs will increase flight efficiency and expand the possible mission profiles that the aircraft can perform. Improvement of performance parameters can be achieved especially by changing the wing section and air net shapes.

Changing the wing planform; while it means changing the wingspan, chord length, arrow angle, dihedral angle and some geometric parameters such as wing camber, the airfoil change can be achieved with morphing parameters such as maximum thickness and camber line curvature. Many studies have been conducted on small-scale models that allow changes in one or more of these geometric parameters and the wing morphing concepts.

Abdulrahim and Cocquyt [1], have conducted studies on flexible wings on micro aircraft that allow complex wing shapes at the University of Florida. With these wing surfaces, active flight control was attempted to be made possible without the control surface during the flight (Fig. 1).

After the complex wing study at the University of Florida, seagull wing studies were carried out to increase flight stability [2]. With a mechanical system, the wing dihedral angles were changed and their effects on flight stability were examined (Fig. 2).

Abduldrahim [3] designed, produced and tested partitioned wings in order to increase the aerodynamic efficiency by performing the lift-drag ratio optimization

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in the unmanned aerial vehicle. The movement of the partitioned wings is provided with the help of servomotors (Fig. 3).

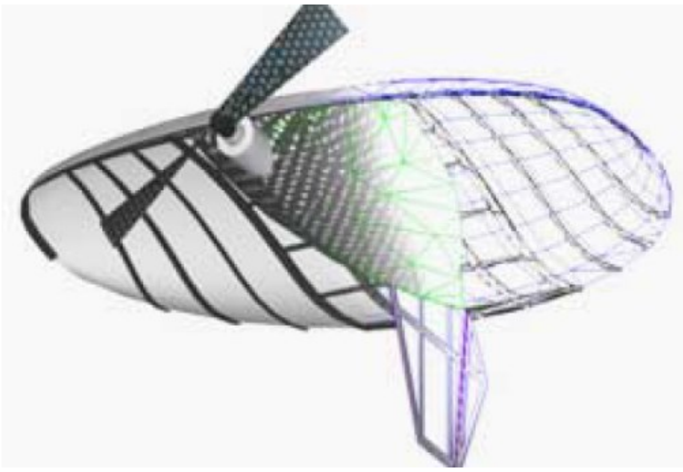


Fig. 1. Complex wing [1]

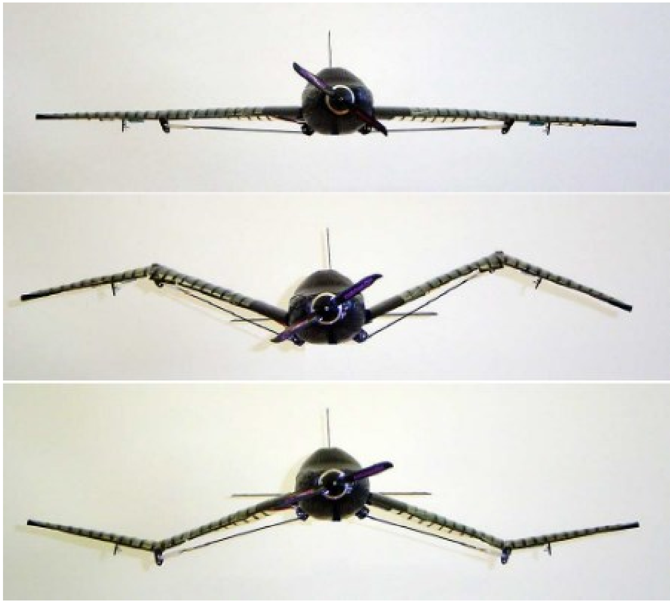


Fig. 2. Gull-Wing that changes shape [2]

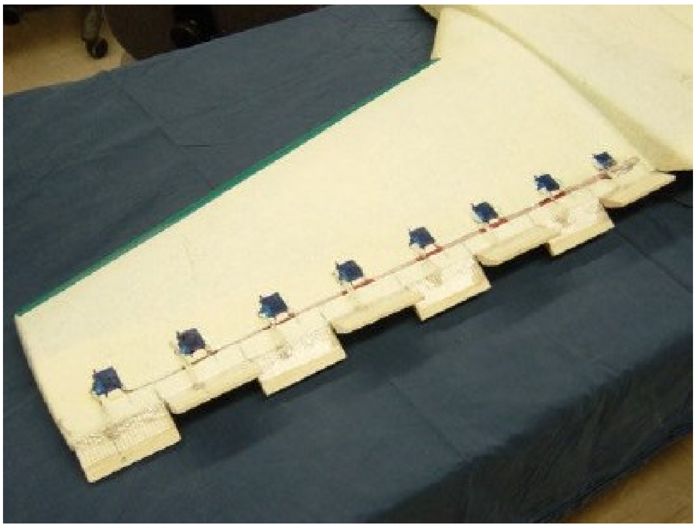


Fig. 3. Partitioned wing [3]

Another wing oriented project, aimed to reduce the weight of the wing by producing inflatable wings activated by piezoelectric actuators and to change the lift and drag coefficients of the wing by changing the camber line during flight [4] (Fig. 4).

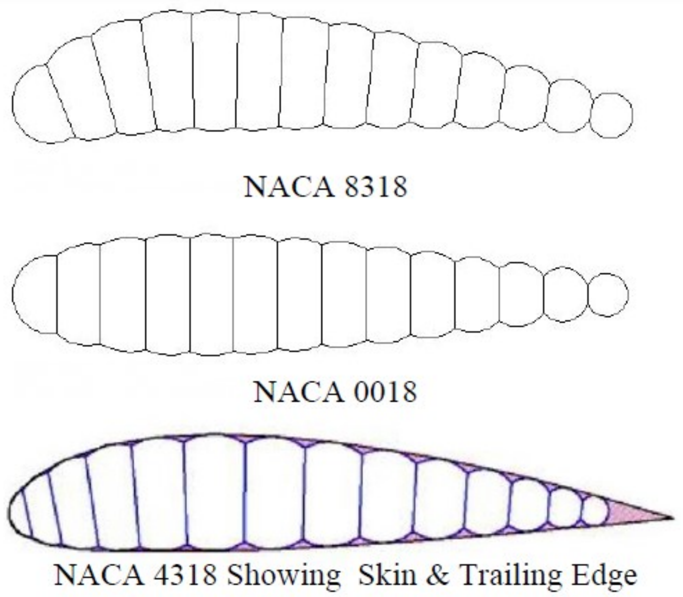


Fig. 4. Inflatable wing application [4]

In the study, it has been suggested that the inflatable wings can be nested with a telescopic system over the spars, thereby increasing and decreasing the wing area at different stages of the flight. It was also mentioned that this kind of wing design will contribute to the placement of the plane in a way that it can take up less space (Fig. 5).

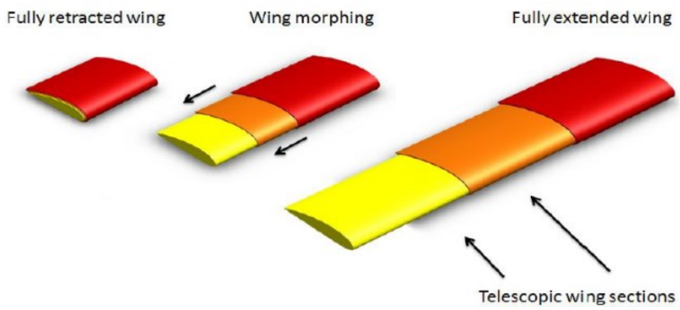


Fig. 5. Telescopic wing application with the use of inflatable spar [4]

With the inflatable wing application, Bat type wing modeling of Next Generation Aeronautics manufacturer in Fig. 6 and 7, respectively, and Z type wing modeling of Lockheed Martin manufacturer company are mentioned in the study. It is not possible to produce such wings with conventional wing design and production methods. However, these morphing surfaces can be obtained with the inflatable wing.

In a morphing winglet study researchers aimed to reduce the induced drag in various phases of the flight and to control the wing tip losses more clearly with the morphing angle winglet application they designed by designing in their study [5]. (Fig. 8).

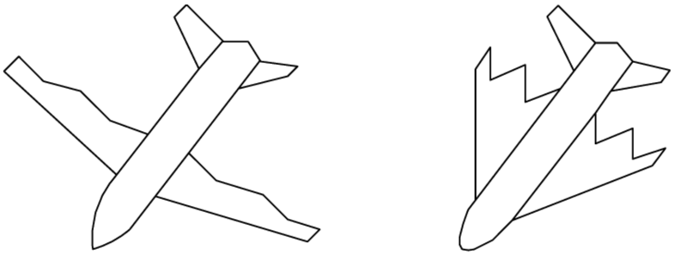


Fig. 6. Bat-type wing modeling of Next Generation Aeronautics [4]

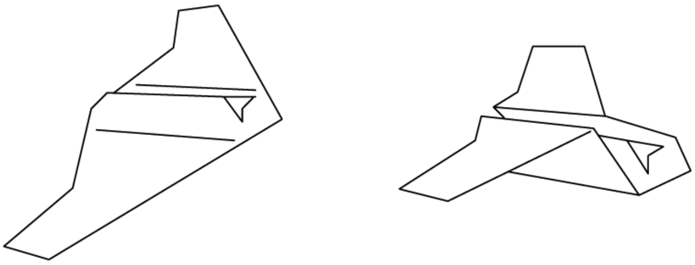


Fig. 7. Z-type wing model of Lockheed Martin company [4]

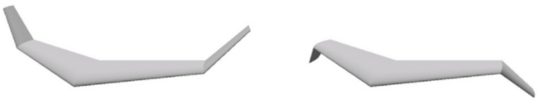


Fig. 8. Morphing angle winglet application [5]

Fig. 9. Flexible winged albatross water bird [6]

The morphing surface concept is used with the materials that can change shape and return to their original state after this change. The main benefit of the morphing wing concept is its high energy efficiency. The first starting point of the concept is inspired by large-winged animals, such as albatross, which can glide for miles over long distances, using only the flexibility of its wing, with a minimum drag of miles (Fig. 9).

The application of the morphing wing to the aircraft can result in the removal of many handicaps by achieving long gliding distances and durations, low drag force and high lifting force, just as the Albatross bird does.

Morphing wing that changes the aerodynamics of the plane according to the different phases of the flight; In the T / O, G / A, APR and LND phases of the flight, it can provide more efficient and safer flight phase time by increasing the airfoil performance. More efficient engine designs, lower engine noise levels, lower fuel consumption and greatly reduced runway area required, as well as the increase in the achieved thrust efficiency, both make the morphing wing concept more attractive and play a role in guiding the sustainable aviation of the future.

2. Wing Morphing Methods

The morphing wing does not only mean wing-shape change but also covers the characteristics of wing characteristics and performance changes, so we can say that it is a whole of scientific studies and research that sheds light on the progress of both military and civil aviation sectors. Unfortunately, the morphing wing structural application, which has not yet taken its place in mass production benches and aircraft factories, is only subject to research for now, and if it is considered as a production stage, it is produced only as a prototype. The reason for not being able to take its place in serial production benches is that it is necessary to work with high precision and meticulousness during the production phases, as well as the materials to be used in the production of more morphing wings can not be of the desired properties and the desired structural strength and wing stiffness can not be provided when necessary.

Research on morphing wing concept and application shows us that this wing design and production, which is very advantageous, is generally not preferred due to its production difficulties. According to the information obtained from the researches, if a morphing wing of mass production is desired, a great number of people from various disciplines should come together and conduct sensitive research and reveal a design and engineering wonder that the entrepreneurs can undertake with peace of mind.

If we classify the researches on the subject of morphing wing, we have focused on two different subjects. Although a small part of the researches on this subject is encountered in the study of the materials and materials that will be used in morphing wing production, we often encounter various design studies on the morphing wing.

2.1. Morphing Wing Studies Using Material Technology

Kuder et. al. [7] conducted research on shape memory alloys, shape memory polymers, elastic memory composites, shape memory composites, fluid filled flexible composites in flexible material research at the

Zurich Structural Technologies Center, which conducts morphing wing production material research. In this study, the results of the use of sandwich composites in morphing wing production have been investigated. Although pneumatic force-operated air balloons are used to make the honeycomb structure to be used in the sandwich composite structure, a test image quoted in Fig. 10, has been used, a material that will cover the honeycomb structure and will not lose its strength despite reaching great flexibility has not been found.

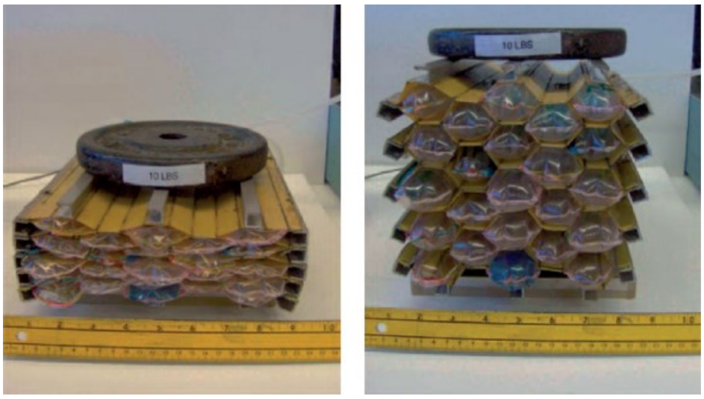


Fig. 10. Honeycomb that changes shape by balloons inflated with the help of pneumatic force [7]

Lee et. al. [8], at the Nanyang University of Technology in Singapore, a UAV was made using a flexible membrane with a tendon structure similar to the skeleton-muscle system in anatomy (Fig. 11). In this prototype, which has no contribution to increase flight performance, it is aimed to produce only a modularity and a portable platform, and researches on material technology have been made on it.

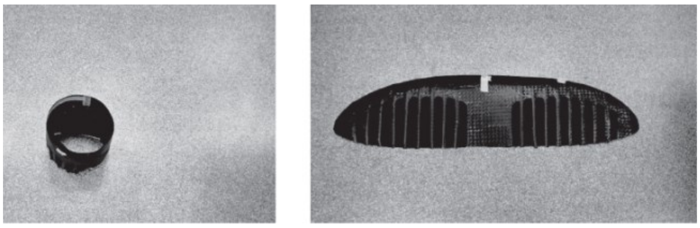


Fig. 11. Foldable wing designed as a tendon structure [8]

Dayyani et. al. [9], in their study, they produced a wing structure which was obtained by using honeycomb and only the wing trailing edge has a shape-changing structure. The trailing edge of the deformed wing applied in this wing has acted as the basic flight control surfaces, increasing its mobility to a certain extent.

Diaconu et. al.[10], performed research that investigates the potential of using bi-stable laminated composite structures for morphing an airfoil section. In the project, the researchers identified geometry and lay-ups for a candidate configuration. Thermal curing has been applied to achieve bi-stability. It has been discussed that the bistable flap-like structure at the trailing edge of the airfoil found the most adequate from a manufacturing point of view.

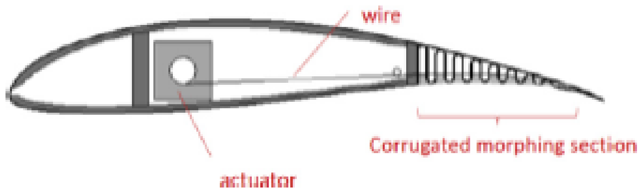


Fig. 12. A semi-deforming wing obtained using a corrugated structure [9]

Tong et. al., [11], studied a topology optimization for adaptive leading edge using composite materials. The researchers used glass fiber reinforced epoxy composite plates based on the symmetric laminated plate theory. An optimization has been performed to achieve the desired curve and aerodynamical shape on the airfoil. A prototype was manufactured during the research for testing purposes which verified the morphing capability of topology structure and illustrated the feasibility of the technique.

A poly-morphing winglet development based on material technology was carried out by Ursache et. al., [12]. The morphing winglet demonstrator that was designed in the project established the feasibility of scalable technology integration for product development, material compliance, mechanism kinematics, and experimentation. Potential composite materials for flexible skins were assessed which were Hexweb, Kevlar49, and Hexply. An aluminum mold for the corrugated skin was manufactured during the project. A Kevlar corrugated skin was manufactured and its performance was investigated both numerical FEM methods and function tests. The paper presented a demonstration of the final prototype that can achieve 30 degrees of dihedral angle and 5 degrees of twist angle.

Digital Morphing Wing concept was presented by Jenett et. al., [13] which uses composite lattice based cellular structures for active wing shaping. The researchers described an approach for the discrete and reversible assebly of tunavle and actively changeable structures by employing modular block parts. The approach presented by researchers offers a number of potential benefits over conventional methods. The discrete assembly provided a reduce in the manufacturing complexity. The case study in the paper presents a modular and reversibly assembled wing that can perform continious span-wise twist deformation. The presented design was reported as lightweight and easy to repair. The design for the airfoil was based on the NACA 0012. Waterjet cut carbon fiber lattices were used as wing ribs with a flexible wing skin. Tip twist of the wing was actuated via a flexure arm. The resulting design had ability to +10 and -10 degrees of twist along the span. Wind tunnel tests performed during the research have been suggested that the digital morphing wing has the ability to increase the roll efficiency compared to a conventional rigid aileron system.

2.2. Morphing Wing Studies Using Mechanism Design

The "Zigzag" wing box design for a span morphing wing has been introduced as a mechanism design by Ajaj et. al.[14]. The Zigzag wing box concept enables wingspan to be changed by 44%. The design allows wingspan to extract and retract 22%. The right part has been kept as a fuel tank housing and used to transfer the morphing loads t the fuselage. The morphing partitions have been designed with two spars each have two beams hinged together. The morphing partitions have been covered using flexible skin and bounded by two wing ribs. The Zigzag wing box design was incorporated in the rectangular wing of a MALE UAV to enhance its operational performance and increase the roll control. The research presented feasible results on using Zigzag wing box design to increase UAV performance capabilities.

One of the design ideas found in the literature was the usage of the "belt-rib" concept to varying the camber of the airfoil which was based in a paper published by Campanile and Sachau, [15]. The belt rib idea used structural flexibility instead of mechatronic solutions which includes hinges or linear bearings. The resulting system was both structurally reliable and lighter. Although, the system was easier to maintain due to the absence of a joint wearing problem. The belt rib project was accompanied by experimental tests on different prototypes. Then a prototype was selected to further developments which were manufacturing, weight optimization, and strength aspects. The researchers used a hybrid glass fiber-carbon fiber-reinforced composite structure and the model was actuated by cables. The paper provided valuable data for further researches by presenting the major advantages of a structronic approach.

A project with a novel design was presented by Di Luca et. al., [16], which includes the design, testing, and flight validation of a UAV that has a featherlike partitional morphing wing like the birds have. The design in the study is composed of artificial feathers that can rapidly modify its geometry to fulfill different aerodynamic requirements. The paper presented that a fully deployed configuration increases maneuverability while a folded configuration offers lower drag force at high speeds. Also, the asymmetrical folding of the wings has been shown as a method that can be used for roll control. The aerodynamic performance of the wing was assessed in simulations and wind tunnel measurements. A comparison between CFD and wind tunnel results were performed. The flight-testing data was also provided which includes inertial measurement unit provided data on maneuverability of the mini UAV.

Gamboa et. al. [17], in their study, designed a morphing wing design that changed the shape and therefore the characteristic of both the wingspan and the wing when viewed from above.

In this design, each wing consists of three parts. These; The rotary shaft charge edge is the rotary shaft charge edge and the rib expansion mechanism that provides the connection of these shafts (Fig. 13).

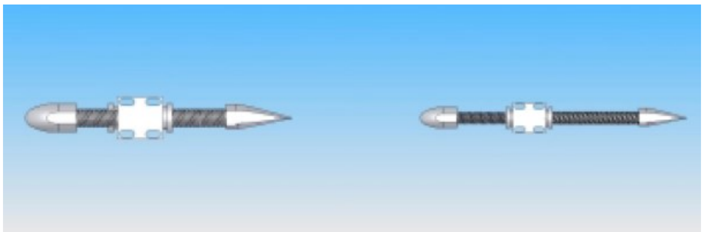


Fig. 13. Morphing wing application that can be changed wing area [17]

During the production of the parts, it was produced from both acrylic material with the help of 3D printer and aluminum material on CNC machine. Although the weight of the pieces obtained is almost the same, the material chosen in the prototype production is aluminum because aluminum can withstand a pulling force of 160 MPa. Thanks to these parts, a trapezoidal, rectangular or elliptical wing can be obtained by changing the wing shape, while at the same time, the wing area can be changed by increasing the distance between the edge of attack and trailing with the help of rotary shafts.

Wang et. al., [18], performed a modeling study on multisegmented folding wings. The study included a general aeroelastic model that predicts flutter speed and flutter frequency of a folding wing with simple geometry. The structural model derived from Component modal analysis that used to derive the structural equations of the folding wing system. Experiments have also been applied after the theoretical study, three configurations were manufactured to study the behavior of two segments, three-segment, and four-segment folding wings. The experimental setup consisted of an accelerometer, an amplifier, an acquisition device, and Labview software for analysis. One of the several trends in the test cases was the flutter frequency. The flutter frequency typically decreased as the fold angle becomes more positive. From the tests, it was observed that from the zero outboard fold angle to either positive or negative 75 deg outboard angle the four-segment wing flutter speed increases 30%. This result suggests that a folded wing can increase the aeroelastic stability and extend the flutter boundary.

The wing section, which is of great importance with this morphing wing study, cannot be changed. As a disadvantage of this, it can be shown that the wing section, which has to be permanently fixed, in addition to the wing area and the changeable wing shape, cannot change to more cambered airfoils.

Jankee and Ajaj, (2018), In the study they carried out at Southampton University, researchers made an application that can only change the wingspan in a wing morphing study. In this application, a material application requiring surface flexibility is not required.

In practice, it is based on the logic of pushing an additional small wing hidden in the main wing to the end of the wing and locking it in the desired position with the help of servo motor power.

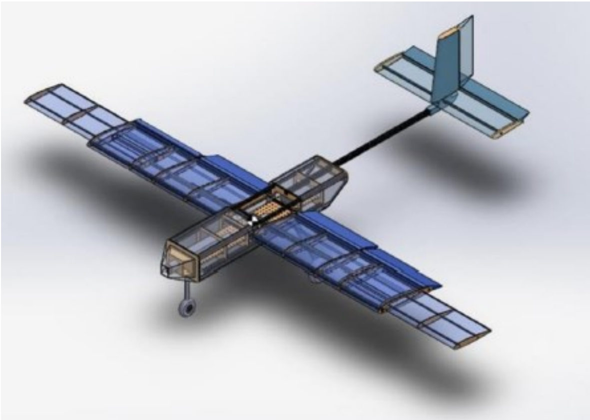


Fig. 14. Morphing wingspan with adjustable wingspan [19]

While it can be shown as the wingspan and wing area as the advantage of the application, the disadvantage is again that the camber cannot be changed and the aircraft has to complete the flight with the same wing section in all phases of its flight. The technical drawing of the design is given in Fig. 15.

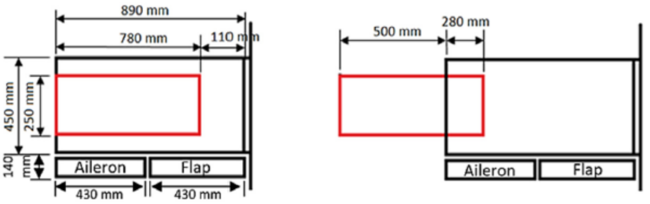


Fig. 15. Technical drawings of the wingspan changeable wing [19]

Hui, Zhang and Chen [20], in their study, examined the aerodynamic performance of the deformable winged drone aircraft used in nature emulation. They designed a deformation mechanism similar to the large deformations achieved by the bones and cartilage on the wings of birds. In the study, a pigeon wing was chosen for simulation. A structure similar to the pigeon wing was obtained by using rigid and flexible structures together (Fig. 16).

The wing created in the study was placed on the outer wing of an unmanned aerial vehicle. Two different states of the tip of the wing are defined as fully open and fully backward angle. With the computational fluid dynamics analysis and wind tunnel tests performed on these two conditions, the change in the coefficient of lift and drag in two states was tried to be revealed. In Fig. 17, the graph of the coefficient of lift with the angle of attack and the graph of the drag coefficient with the angle of attack are given. In the graphics given in the Fig., the difference between the discrete form of the wing and its continuous form is shown with curves.

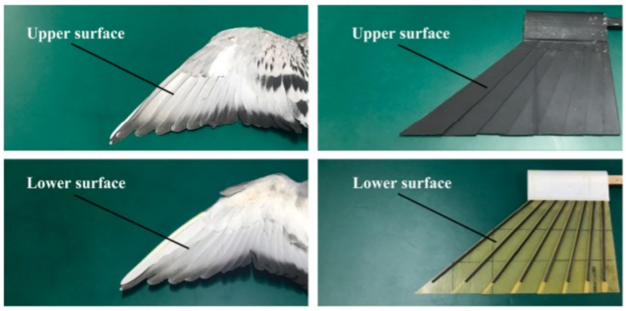


Fig. 16. Pigeon wing and nature simulated wing structure [20]

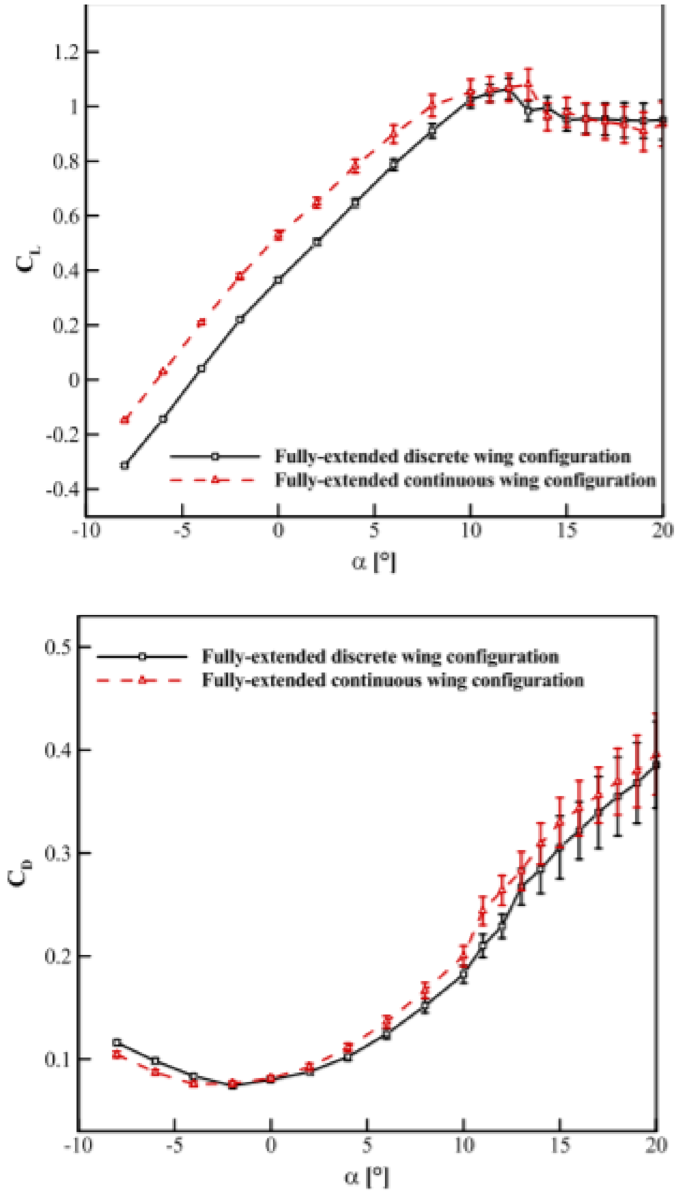


Fig. 17. Variation of Lift Coefficient and Drag Coefficient with Angle of Attack [20]

In the graphics given in Fig. 17, it is seen that the wing form with continuous structure provides an increase in the lift coefficient and does not cause an increase in drag in a low angle of attack. In other words, the aerodynamic efficiency of the aircraft has increased in flight phases performed at low attack angles such as cruise flight.

Kan et. al. [21], in their study, made it possible to delay the stall state and change the critical stall angle by rotating the trailing edge in a wing section. In the study, a NACA 0012 symmetrical wing section was modeled with a flexible trailing edge. On this flexible trailing-edge wing section, the portion of the chord up to 60% from the edge of the is fixed and the rest is modeled as in Fig. 18.

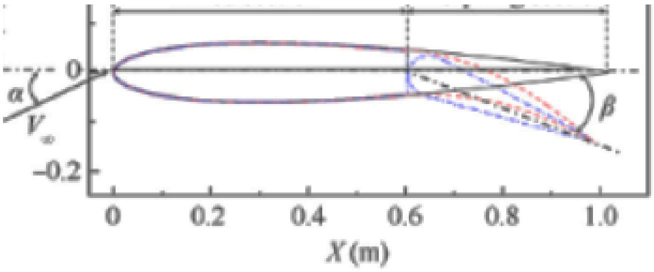
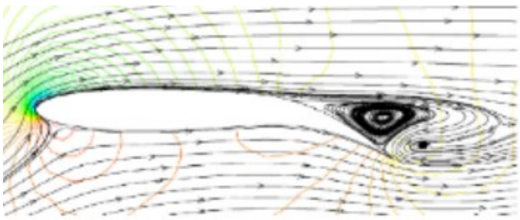
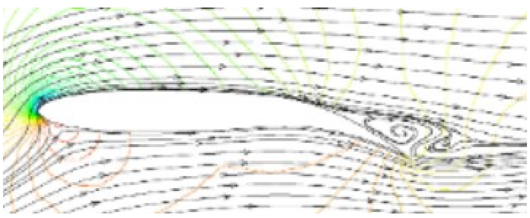


Fig. 18. NACA 0012 wing section model [21]

On the model created in the continuation of the study, the flexible part will remain static and 1.33 Hz. Two models were subjected to computational fluid dynamics analysis, moving at a frequency between the normal state and the flexed state. As a result of the CFD analysis, the eddy formations given in Fig. 19 were seen.



(a) Static



(b) Dynamic

Fig. 19. CFD Analysis results [21]

As a result of the study, it was observed that the stall state of the wing section can be delayed by performing periodic shape changes on the trailing edge. In addition to this result, the information that the coefficient of lift increased with periodic shape change is given in the results section.

Wu et. al. [22], in their study, investigated the effect of changing the surface of a solar powered unmanned aerial vehicle with Z-shaped wings on energy optimization. Solar powered unmanned aerial vehicles produce electrical energy during the flight with solar panels on their wings. The positioning of these panels in such a way that the sun's rays are perpendicular is important in terms of energy efficiency.

In the concept design that they carried out, the researchers revealed that, with a wing that can take the form Z in Fig. 20 according to the angle of arrival of the sun, more electrical energy can be obtained than the planar wings.

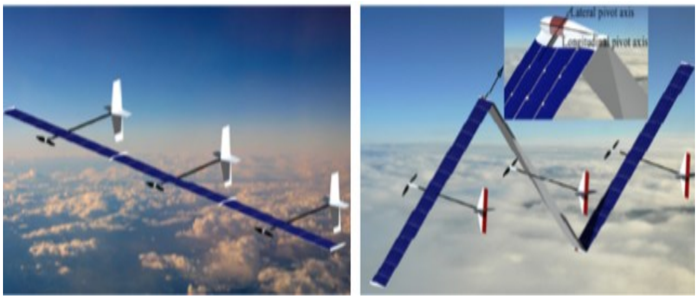


Figure 20: Planar and Z wing designs [22]

With the model they created, the researchers calculated different amounts of electrical energy generated by the beam angles coming to the solar panels. The results obtained are given in Fig. 21.

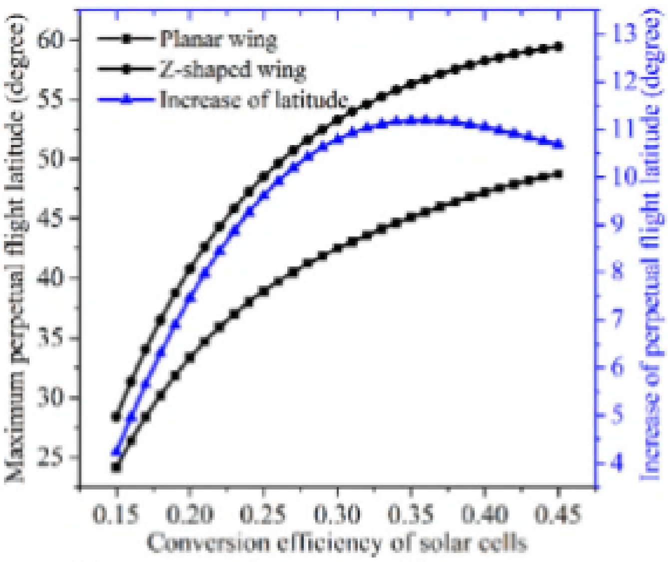


Fig. 21. Planar wing and Z wing solar panel efficiencies [22]

From the graphic in the Fig., it is seen that Z wing provides higher efficiency than solar panels in continuous flight compared to planar wings. In addition, the angle variations experienced during the flight between latitudes around the world make it difficult to travel with solar energy in certain latitudes due to the elliptical orbit around the sun. In the latitudes and in winter days close to the polar regions, the results of the study are given that the flight with the Z wing will provide a more efficient energy conversion performance than the planar flight.

Ajaj et. al. [23], presented a paper that develops a novel span morphing wing concept, the gear-driven autonomous twin-spar (GNATSpar) mini UAV. GnatSpar has proven the ability to increase span extensions up to 100%. For demonstration purposes, it kept in 20% in the study and provided a reduction in induced drag and increased the flight endurance. The GNATSpar wings were designed as overlapping structures and bearings which is in a telescopic form. A physical prototype was also developed and the test results on 7'x5' wind tunnel of the University of Southampton were also presented in the study. The graphs provided in the results of the paper were indicated that at all three different speed regimes that tests were applied, L/D ratio increases with the span increment.

Woods and Friswell [24], have introduced a new surface change concept that will increase the span ratio of the aircraft wing. The concept they designed includes a telescopic wing beam structure and wing ribs that open in the form of an accordion. A driver motor aid is pushed out of the outer part of the spar inside the wing. Thus, the wing takes its form seen in Fig. 22. With this deformation process, the wingspan and span ratio are increased.

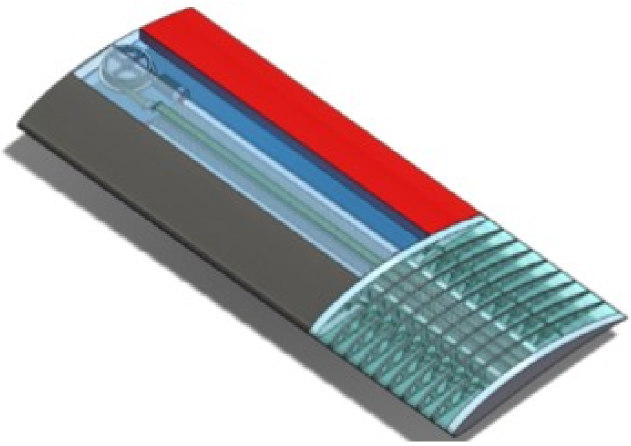


Fig. 22. Wingspan increment mechanism design [20]

Apart from the fixed-wing aircraft surface designs that utilize morphing technology, the rotary-wing aircraft also provide a field to improve the performance within the usage of morphing surfaces. Vocke III et. al. [25], have performed a study that presents the design and validation results for a quasi-static morphing helicopter rotor blade with an adaptive tip. The adaptive tip had the ability to increase its local span by 100% with the constant chord. The design of the morphing airfoil structure consisted of polyurethane sheets and unidirectional carbon fiber layers. The EMC skin was analyzed using linear and nonlinear Finite Element Method analysis to ensure the in-plane stiffness. A genetic algorithm was applied to search the entire design space for minimum mass designs. As a result of the project, a light final design was presented that matches the stiffness design goals.

3. Parameters That Coulds Change Using Morphing Wing

There are original designs as discussed in the literature with the concept of morphing wing. Each design was developed with a focus on a different performance parameter or parameters. While some morphing wing designs focused on changing only one parameter, some morphing wing designs tried to develop more effective designs by focusing on multiple parameter changes. In this section, which purpose these changing parameters serve and which parameters are made for changing designs are examined.

3.1. Changing the Wingspan and Aspect Ratio

The concept, called the wingspan, is the distance between the two ends of the wing. The wingspan ratio is the ratio of the span of an airplane wing to the average chord length. If the chord length is not constant across the span, it is the ratio of the square of the wing span to the wing top-view area.

Changing the wingspan, which is one of the wing characteristics, is considered as an important characteristic feature for a UAV in flight phases where high lift force is required. Due to the increasing air traffic in today's aviation, aircraft with high wingspan are not preferred by companies and squares, and smaller planes are thought to have more returns.

Although the low wingspan is seen as an advantage by companies and squares in terms of occupying space in the hangar, aircraft with low wingspan lose their advantages in the phases of the flight, where the lifting force per m2 is desired. This can be achieved only if the wingspan values varying in the air and on the ground can only be achieved with the application of morphing wings.

3.2. Changing the Wing Area

It is only possible to provide the high lifting force needed during the take-off and landing phases of the flights, but it is only possible to achieve as high lift force as possible by using it in certain parts of the wing. Increasing the wing area means increasing the surface from which direct lift force is obtained.

Increasing the wing area will allow for the increase of carrying force and naturally to pass the landing and take-off phases more easily. Nowadays, only the flap strength and flow characteristic allow the wing area to increase, while this handicap can be eliminated with the use of morphing wings. The increase of the wing area obtained by using the morphing wing can be supported by the increase in the camber, and the lift coefficients in the wing can also be increased. If the deformed surfaces can be achieved by using conventional high conveying devices, a more efficient flight can be realized. In addition, both cost and time can be saved in the maintenance of these control surfaces, hinges and other sub-parts.

3.3. Changing the Airfoil and Wing Camber

The ability to change the wing section allows different performance values to be obtained in different phases of the flight. A wing's profile can directly change flight performance, efficiency, savings and comfort. With the profile change, desired flight speed, desired drag amount and desired cambered can be achieved. With the morphing wing, the desired profile shape can be obtained in the desired phase of the flight. This is one of the features that make the use of the morphing wing perhaps the most attractive. Fig. 23 shows two profiles obtained from the same wing by the blow molding method.

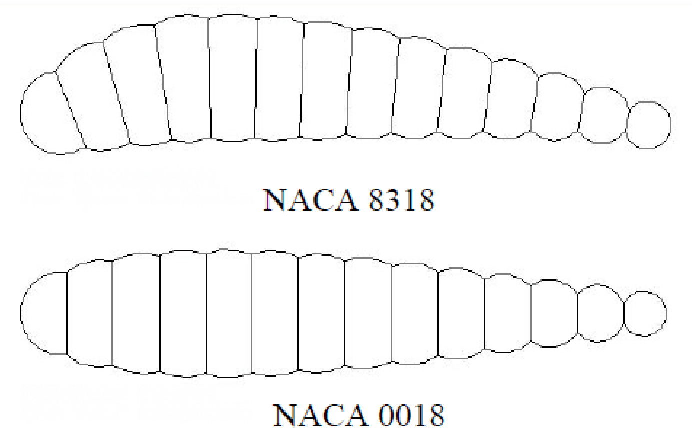


Fig. 23. Profile change with inflatable corrugated structure [4]

Communier et. al., [26], studied a design and validation for a new morphing camber system. The project included both design phase and the testing process of the final aerodynamic shape on wind tunnel. The morphing camber system that designed in the project consisted of a combination of two subsystem which were the morphing trailing edge, and the morphing leading edge. Results in the study provided the effect of each subsystems combined without interference with each other. The results of the study indicated a drag reduction on UAVs. In the case study which was carried out during the research, the morphing camber system was found to allow a reduction of the drag when the lift coefficient was higher than 0.48.

For example, a UAV can switch to a more cambered profile, the NACA 8318 profile, to carry out its take-off easily and with shorter distances with the help of high lifting forces. When it comes to flat flight altitude, it can switch to NACA 0018 profile, which is a symmetrical profile that can reach higher speeds, produces lower pitching moment and less drag force. When the UAV, which completes the cruise flight, switches to the landing phase, it can again switch to a more cambered profile, the NACA 8318 profile, and regain high lifting force. Within this scenario, the aerodynamic efficiency increase that can be achieved by changing the wing section and cambered can be understood.

4. Conclusions

The use of a morphing wing allows the aircraft to have more than one characteristic, regardless of a single characteristic. It is a very important application for achieving future developments and popularity both in the UAV sector, civil aviation sector and military aviation sector, by performing the desired characteristic changes in the desired phase of the flight, by switching to the desired characteristic features. Researches show us that even though morphing wing production is not easy, as it starts to take its place in mass production benches, the needs of human beings in terms of aviation will be met at a higher level and if so to speak, sustainable aviation will continue to put bricks on its wall.

Considering the harmfulness of the raw material and fossil fuel market, which decreases day by day, to the economy and the environment, the use of morphing wing designs in both passenger and military fighter jets and UAVs helps to reduce the consumption of raw materials and fossil fuels to a lesser extent, Thanks to the increased flight comfort, it will both increase the interest in the aviation industry and lead to a decrease in the casualties caused by traffic accidents as the rate of travel by plane, which is the safest form of lift in the world, will increase.

The use of morphing wings will undoubtedly bring great advantages with its use in the future. With the advancement of production techniques with technology and the most accurate design in the use of morphing wings, morphing wing application will take its place in mass production machines in the short-term future. The shape-changing construction that has just been tested on the wing will perhaps be tried for all aircraft components in the future and will lead to a useful technology for everyone with a more advanced production.

We can try the steps of contacting the entrepreneurs and the manufacturer companies to make a morphing wing design that changes more performance parameters using the materials and production techniques used in the researches conducted so far, and if the prototype of this design is tested, if positive results are obtained, to proceed with mass production.

The production of skeleton parts can be tried with the help of parts obtained from 3D printer in terms of ease of production and variety in the material production stage. Since flexible composite production is difficult in the wing outer surface coating, a different surface coating model may be considered. In addition, all the advantageous aspects of different shape changes that have been tried in different studies so far can be collected and applied in a single wing and the effects can be investigated. The most suitable of all methods that can be used in multiple surface changes.

The production of the parts that provide mobility with less cost and less weight can be applied in future studies.

Abbreviations

UAV	:	Unmanned Aerial Vehicle
RPM	:	Number of Spins per Minute
RC	:	Radio Control
CG	:	Center of Gravity
CT	:	Central Tank
TT	:	Trim Tank
T / O	:	Takeoff
G / A	:	Go Around
APR	:	Approach
LND	:	Landing
3D	:	Three Dimensional

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