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The Turreted Gun System Technology Integrated to The Helmet Mounted Display System

Kerem Çalışkan[1] **Ufuk Sakarya**[2]

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Abstract

This research aims to emphasize the operational importance of avionics subsystems integrated into helicopters, primarily used for assault purposes, such as the Helmet Mounted Display System (HMDS) and Turreted Gun Systems. It addresses the functional capabilities of HMDS in target detection and aiming and the defense and engagement capabilities of Turreted Gun Systems against various threats. The focus of the research is on evaluating the parametric data, such as the dispersion of the Turreted Gun Systems and the targeting performance values of the HMDS, during their use together. It also assesses the transmission of this data through a Kalman filter before sending it to the Turreted Gun Systems to mitigate platform-induced disruptive factors. The findings help us understand the profound impact of technological advancements in helicopter avionics systems on operational effectiveness. Additionally, this study sheds light on the impact of dispersion values on hit performance during usage. It is assessed that the proposed method in this study will result in more stable data and that controlling the Turreted Gun Systems with this stable data can enhance hit performance. The study can be further developed by examining subsystems with different performance characteristics and filtering methods.

Key Words: The Turreted Gun System Technology, The Helmet Mounted Display System, The Estimation Theory.

JEL Classification: M10, M19.

Kaska Monteli Görüntüleme Sistemine Entegre Taretli Silah Sistemi Teknolojisi

Öz

Bu araştırma, yaygınlıkla taarruz amaçlı kullanılan helikopterlere entegre edilen aviyonik alt sistemlerden Kask Üzeri Gösterim Sistemi (HMDS) ve Taretli Top Sistemleri'nin operasyonel önemini vurgulamayı amaçlamıştır. HMDS'nin hedef tespiti ve nişan alma gibi fonksiyonel yetenekleri ile Taretli Top Sistemleri'nin çeşitli tehditlere karşı savunma, angaje olma kabiliyetlerini ele almaktadır. Araştırmanın odak noktası, Taretli Top Sistemleri'nin, HMDS ile birlikte kullanımı sırasında platform kaynaklı bozucu etkenler, Taretli Top Sistemleri'nin dispersiyon ve HMDS'nin hedefleme performans değerleri gibi parametrik verilerin elde edilmesi ve Taretli Top Sistemine iletilmeden önce Kalman filtresinden geçirilerek iletimini değerlendirmektir. Bulgular, helikopter aviyonik sistemlerindeki teknolojik gelişmelerin operasyonel etkinlik üzerindeki derin etkilerini anlamamıza yardımcı olurken, bu çalışma aynı zamanda dispersiyon değerlerinin kullanım sırasındaki vuruş başarım performansı üzerindeki etkilerini de aydınlatmaktadır. Bu çalışmanın önerdiği yöntem ışığında çıkan sonuçların daha stabil hale geleceği ve bu stabil verilerle Taretli Top Sistemleri'nin kontrol edilmesi sonrasında hedef vuruş başarım performansının artabileceği değerlendirilmektedir. Birbirinden farklı performans karakteristiğine sahip alt sistemlerin ve filtreleme metotlarının incelenmesi ile çalışma geliştirebilir.

Anahtar Kelimeler: Taretli Top Sistem Teknolojisi, Kaska Monteli Görüntüleme Sistemi, Tahmin Teorisi.

JEL Sınıflandırma: M10, M19.

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INTRODUCTION

Helicopter technology plays a pivotal role in diverse military and civilian domains. The integration of advanced technologies, such as the Turreted Gun System (TGS) and the Head Mounted Display System (HMDS), can enhance the operational capabilities of these aircraft, particularly in attack helicopters. The TGS facilitates various operations, while the HMDS significantly augments mission success by enabling pilots to precisely target objectives.

This study particularly underscores the crucial significance of the HMDS in platforms with limited technological resources, such as the AH-1S Cobra. The AH-1S Cobra's effective utilization of its 7.62mm Turreted Gun, facilitated by the HMDS, exemplifies the strategic value of this technology.

Concurrently, the research delves into the noteworthy applications of the Kalman filter in target tracking and prediction and provides valuable insights to defense and civil aviation experts by highlighting the operational advantages of integrating these technologies into helicopter avionic systems and exploring the potential future applications of filtering techniques. Briefly, in this research article, the features of HMDS and TGS systems that can be used in attack helicopters are examined and their capabilities are presented. Estimation and fusion were examined by considering that data could be transmitted to each other with the help of a filter.

1. THE TURRETED GUN SYSTEM INTEGRATED TO THE HMDS

1.1. An Overview of the HMDS

HMDS (HMDS) represents a pinnacle in aviation technology, seamlessly integrating various components to enhance pilot capabilities. This section delves into the fundamental aspects of HMDS, starting with the indispensable role of the Helmet itself.

The utilization of the TGS, a notable and distinctive feature integrated within HMDS commonly employed in attack helicopters, will be thoroughly scrutinized and analyzed in great depth within the subsequent sections of this research.

1.1.1. Basic Helmet Functions

HMDS (HMDS) is a sophisticated and multifaceted system comprised of various components, with the Helmet being one of its crucial elements. Acting as a vital link between the pilot and the system, the Helmet facilitates direct communication and interaction. Meticulously designed and crafted, this highly important component has been tailored to meet the specific demands and requirements of the aircraft and its unique platform. It is important to acknowledge that these requirements may vary significantly across different installations and contexts.

Over time, the Helmet has evolved into more than just a carrier; it has become a mounting platform for the various subsystems that need to be affixed onto it (Rash et al., 1998) This evolution has greatly enhanced the Helmet's functionality and versatility, enabled seamless integration of these subsystems and ensured optimal performance. Thus, the Helmet plays a pivotal role in the overall efficacy and success of the HMDS, serving as a vital connection between the pilot and the various subsystems that constitute the system. Its meticulous design and craftsmanship ensure it meets the specific requirements of the aircraft and its platform. Furthermore, the helmet's evolution into a mounting platform enhances its functionality and versatility, allowing for seamless integration of subsystems.

The main purpose of the Helmet is to ensure the safety and protection of the pilot or crew member wearing it. By safeguarding their cranium, the Helmet serves the crucial purpose of defending against potential collisions, fragments, and other conceivable dangers that may arise within the confined space of the cockpit or the operational environment. In the case of airplanes, it is worth noting that the Helmet also absorbs the physical loads imposed on the pilot. These loads can manifest in various ways, such as when the pilot comes into contact with the canopy during seat ejection or when subjected to loads during maneuvering (Carter and Cameron, 2000)

Integrating microphones and headphones into the Helmet, which has a direct physical interface with the pilot, emerges as a very suitable alternative to ensure seamless interoperability between these components. The inclusion of a microphone allows audio signals generated by the pilot to be transmitted to receivers located both inside and outside the platform. The purpose of the headset goes beyond transmitting the sound signals coming from the microphone to the pilot, but also includes the vital task of cleaning these signals from any unwanted environmental noise they may contain. Following these complex integration processes, the main goal is not only to minimize the potential losses incurred but also to reduce possible amplification effects on the platform, thus optimizing the overall audio experience.

Circumoral headphones, a type of headphones that are specifically designed to fully enclose the ears of the pilot, possess the remarkable capability to produce sound of exceptional quality, characterized by its high fidelity and clarity, thus greatly enhancing the overall experience of listening for individuals who utilize them. Furthermore, these headphones offer an additional advantage, namely the ability to shield the user's auditory system to a certain extent from any unwanted noises that may emanate from the surrounding environment. This auditory shielding function is of utmost importance as it serves to protect the listener's hearing, by effectively minimizing the exposure to potentially harmful levels of noise pollution that may have detrimental effects on their auditory system (Rash et al., 2009).

1.1.2. Display Functions

The main objective of HMDS is to project a diverse array of artificially generated images and videos onto its viewfinder. This advanced technology serves to enhance the user's visual experience by providing a wide range of visual content directly within their field of view. These images and videos can be produced by the Forward-Looking Infrared (FLIR) system, which is responsible for detecting and identifying targets within the operational platform. HMDS serves as a crucial interface between the operator and the FLIR system, enabling seamless integration and real-time visualization of the detected targets (Seidel et al., 2006).

This advanced technology greatly enhances situational awareness and provides the operator with a comprehensive and detailed understanding of the operational environment. By projecting these synthetically produced images and FLIR videos onto the viewfinder, HMDS offers a comprehensive and immersive visual experience. This empowers the operator to make informed decisions and take appropriate actions based on the detected targets.

FLIR, a system that enables the platform to function in both diurnal and nocturnal circumstances, constitutes one of the fundamental target detection systems in conjunction with the Helmet Mounted Display (Mulholland, 2000). The presence of an infrared camera within FLIR enables the pilot to discern targets based on temperature, thereby facilitating the visual exploration of the corresponding camera image through Helmet Mounted Display (HMD) viewfinder, which remains accessible at all times (Böhm and Erismann, 1997).

Moreover, HMDS plays a vital role in reducing cognitive load on the operator by providing a consolidated and streamlined display of relevant information. This ensures that the operator can focus on the task at hand without being overwhelmed by excessive data or visual clutter.

The symbology display is an indispensable tool in aviation, providing pilots with the necessary information to operate the aircraft and its weaponry effectively. It’s combined with the use of various signs and symbols, allows for clear and concise communication of critical flight and weapon usage indicators, ensuring enhanced situation awareness and effectiveness. This presentation is achieved through a strategic placement of a variety of signs and symbols on the viewfinder. It is important to emphasize that the symbology display aims to convey this information in a clear, concise, and easily interpretable manner, enabling the pilot to understand the data quickly and accurately being presented.

To accomplish this objective, the symbology display utilizes a range of visual cues that are specifically designed to provide the pilot with the necessary information to effectively operate the aircraft and its weaponry (Rash et al., 1998). These cues are displayed within the pilot's line of sight (LOS), ensuring easy and quick access during flight operations. By employing a two-dimensional approach, the symbology display effectively communicates information that is easily understood by the pilot, resulting in a more efficient and effective flight experience.

Overall, HMDS significantly enhances the operational effectiveness and efficiency of the platform. It seamlessly integrates the FLIR system and provides the operator with a comprehensive and detailed visual representation of the operational environment. This empowers the operator to effectively carry out their duties and achieve mission success (Heinecke, 2006).

1.1.3. Tracking Function

The Tracker System is an advanced function that tracks the position and movement of the pilot's or copilot's head, which is of utmost importance for effectively aligning the symbology and aiming systems with the pilot's LOS, ensuring accurate and efficient operations within the aircraft (Brindle, 1996). By constantly tracking the head, the system can determine the exact location of their LOS, which is crucial for aligning the symbology and aiming systems within the aircraft (So ve Griffin, 2000). This alignment is paramount for the pilot to have a clear and accurate view of the information displayed on the HMD.

Various methods have been employed to obtain line of sight information thus far. Presently, optical and magnetic trackers are the preferred options. The Tracker System, a constituent of HMDS, may comprise multiple subunits depending on the prevailing conditions. The sensors on the helmet, responsible for indicating the line of sight, along with the position-detecting sensors, transmit the gathered data to the Mission Computer (Vuong Anh et al., 2022).

As evident from, the operation of HMDS, which encompasses multiple subunits, may necessitate the use of more than one signal type or communication protocol. For instance, while transmitting information related to sensors and symbology, a distinct communication protocol might be required, which could differ from the communication protocol employed by the platform's avionics system. To address this, it becomes imperative to possess a computer specific to HMDS, serving as a bridge between the subsystems and the platform (Böhm et al., 1998).

Once the data regarding the pilot's head movements is captured, the Helmet Mounted Sight (HMS) then analyzes this information and calculates the appropriate adjustments required to align the symbology and aiming systems with the pilot's LOS. These adjustments are crucial to ensure that the pilot's view is optimized, allowing them to easily and effectively interpret the information displayed on the HMD (Cameron et al., 1995).

This alignment is paramount for the pilot to have a clear and accurate view of the information displayed on HMD. In order to achieve this alignment, HMS utilizes advanced sensors and algorithms that are capable of capturing and processing real-time data regarding the pilot's head movements (Smith, 2001). These sensors are strategically placed within the helmet or headgear, ensuring that they can accurately detect even the slightest changes in the pilot's head position and orientation (Nguyen et al., 2021).

Furthermore, HMS also plays a vital role in enhancing situational awareness for the pilot. By accurately aligning the symbology and aiming systems with the pilot's LOS, the system enables the pilot to access critical information quickly and effortlessly, such as navigation data, flight parameters, and targeting information. This enhanced situational awareness greatly improves the pilot's ability to make informed decisions and react promptly to any changes or threats encountered during flight operations (Heinecke, 2006).

In conclusion, HMS is a cutting-edge technology that revolutionizes the aviation industry by effectively tracking and analyzing the position and movement of the pilot's or copilot's head. Through its advanced sensors and algorithms, it aligns the symbology and aiming systems with the pilot's LOS, ensuring accurate and efficient operations within the aircraft. Additionally, it enhances situational awareness for the pilot, enabling them to access critical information effortlessly. This technology truly plays a crucial role in the safe and successful execution of flight operations.

2. Usage Of Turreted Gun Systems on Helicopters

Turreted Gun Systems, an integral part of attack helicopters, present an immensely formidable array of offensive capabilities. These cutting-edge weapon systems are equipped with advanced technology that enables their motors to target specific locations with utmost precision. This is made possible through the utilization of target acquisition systems, which heavily rely on LOS data (Williams, 1987). The acquisition systems provide invaluable information, including crucial azimuth and elevation angles, which play a pivotal role in directing the weapons towards the intended target.

The turrets, possessing the remarkable ability to rotate both horizontally and vertically, equip the attack helicopter with the necessary means to effectively counter threats originating from various directions and altitudes. This exceptional feature undoubtedly enhances the overall combat effectiveness of the attack helicopter, empowering it to neutralize enemy forces with great efficiency. As a result, turreted gun systems undeniably represent a vital asset within the extensive inventory of attack helicopters, endowing them with the remarkable capacity to deliver precise and devastating firepower on the battlefield (Osder, 1991).

The performance characteristics of the gun itself play a crucial role in ensuring the effective functioning of Turreted Gun Systems. These characteristics encompass various aspects that significantly impact the overall performance of the system. One such aspect is the dispersion values, which provide valuable insights into the accuracy and precision of the Turreted Gun Systems. It is highly imperative to carefully analyze the dispersion values as they serve as a reliable indicator of the system's capability to consistently hit the target with precision. It has been observed that certain types of Turreted Gun Systems exhibit a dispersion of approximately 3 milliradians, signifying a relatively accurate performance. On the other hand, there are other variants of Turreted Gun Systems that demonstrate a dispersion of up to eight milliradians, indicating a relatively higher level of inaccuracy. The variance in dispersion values among different types of Turreted Gun Systems underscores the need for a comprehensive understanding of the performance characteristics of the gun, as it directly influences the operational efficiency and effectiveness of the entire system. Therefore, meticulous evaluation of these performance characteristics is crucial for the successful deployment and utilization of Turret Gun Systems (Strahl and Center, 1990).

3. Relation Between Turreted Gun System and Head Mounted Display System on Helicopters

The utilization of HMDS (HMDS) for the purpose of aiming is an essential function that is integrated into rotary-wing attack platforms. This groundbreaking capability allows pilots to effortlessly engage their designated targets, without the need for any additional exertion, thereby significantly augmenting the likelihood of accomplishing a successful mission (Böhm et al., 1998).

On a global scale, the AH-1S Cobra Helicopter occupies the first position among all helicopters that are equipped with the highly advanced HMDS. The AH-1S Cobra Helicopter indispensably relies on the HMDS to effectively engage its 7.62mm Turreted Gun with precision and accuracy. Due to the inherent technological limitations of this particular helicopter, it does not deploy any other supplementary fire support systems such as FLIR or Radar, as these technologies were not available during the era when the helicopter was initially conceived in the 1970s (Foote et al., 2015).

The prime focus of HMDS is to optimize the aiming performance, particularly in the context of firing the turreted gun system. This sophisticated system actively transmits crucial LOS information to the pilot, enabling them to seamlessly align their target and weapon systems

(Newman and Greeley, 1997). The criticality of this functionality cannot be overstated, as it plays a pivotal role in ensuring the successful execution of operational tasks.

3.1.Avionic Architecture of Platform

When conducting an examination of avionics architectures, it becomes evident that the overall operating logic encompasses a multitude of subsystems that are meticulously crafted around the central core of the Mission Computer (Flint, 2016). In a similar vein, HMDS dutifully heeds the commands emanating from the platform's Mission Computer, thereby facilitating a seamless and synchronized operation. The vital communication link between the commands generated and the Mission Computer is deftly established through meticulously specified communication protocols.

There are instances in which the Mission Computer software manager has successfully accomplished the harmonious amalgamation and authoritative supervision of avionics functionalities within a stringent 50-millisecond timeframe through the utilization of the dual-redundant MIL-STD-1553 bus for the purpose of communication (Flint, 2016).

Systems that are anticipated to operate in conjunction on the platform must utilize the identical bus and the pertinent administration must be executed by the Mission Computer. A tangible instance of this procedure is the conscientious transmission of LOS information, which has been meticulously generated by HMDS, to the turreted gun system.

3.2.Turreted Gun Aiming with HMDS

In the context of weapons cueing, it is customary for pilots to position a fixed targeting reticle at the central region of HMD, directly above a designated adversary target. This action signifies the target as a potential threat. However, this process of weapons cueing requires careful consideration of tracker errors, which encompass all aiming errors, including those caused by the optical properties of the HMD and the refraction phenomenon through the aircraft's canopy.

Maintaining precise tracker and aiming accuracy is crucial, as these errors must be kept at an exceedingly small fraction of a degree. Therefore, the requirements for helmet tracker accuracy are meticulously defined, with the specified range typically varying between 6-8 milliradians (Mulholland, 2002). On the other hand, there is acceptance in Hewlett studies that the targeting accuracy is around 4 milliradians (Hewlett and Cameron, 2000).

In addition to these considerations, it has been evaluated that performance enhancement and stabilization can be achieved through filtering methods. The next section explores various filtering techniques to further examine their potential in refining and stabilizing the targeting process.

4. Filtering

In the dynamic realm of motion tracking and target prediction, engineers and computer scientists grapple with fundamental challenges. This section focuses on the Kalman filter, a venerable technique, to unravel its applications and recent advancements in target tracking and motion prediction. Developed in the 1960s, the Kalman filter addresses uncertainties in dynamic systems, making it particularly adept for target tracking applications.

4.1.Kalman Filter Applications in Target Tracking

Motion tracking and target prediction are two of the most fundamental challenges faced by engineers and computer scientists in a wide range of fields. These challenges require careful consideration and exploration of various filtering techniques in order to improve predictions and optimize the tracking of targets. This literature review aims to delve into the applications of the Kalman filter, a widely utilized technique, and examine the recent advancements made in the field of target tracking and motion prediction (Li et al., 2020).

The Kalman filter, which was developed in the 1960s, is a sophisticated technique that focuses on reducing uncertainty within a dynamic system. Its main objective is to accurately predict the future state of a system by utilizing the current state and previous predictions. These distinctive characteristics make the Kalman filter particularly well-suited for applications such as target tracking (Welch and Bishop, 2006).

In the domain of radar and satellite systems, the Kalman Filter stands as a cornerstone in the arena of target prediction and tracking, playing an indispensable role. Its significance is rooted in its ability to navigate the intricacies of dynamic systems, providing a robust framework for predicting and tracking targets. The mathematical underpinning of the Kalman Filter, as articulated in Equations 1 to 6, orchestrates both the prediction and update stages of the tracking process (Kim and Bang, 2018).

Equation 1 describes the prediction stage, where the anticipated state of the system ($\hat{x}$) is computed based on the previous state, external control inputs, and their respective predictions. Here, F is the state transition matrix, B is the control input matrix, $\hat{u}$ is external control inputs, and $k-1$ denotes the previous time step.

$$\hat{x} = F\hat{x}^{k-1} + B\hat{u}^{k-1} + \hat{u}^{k-1} \quad (1)$$

Simultaneously, Equation 2 formulates the prediction error covariance matrix (P_k), reflecting the uncertainty associated with the predicted state, incorporating the process noise covariance matrix, Q.

$$P_k = FP_{k-1}F^T + Q \quad (2)$$

The Kalman Filter's prowess extends beyond prediction, as detailed in Equations 3 to 6. In this update stage, real-time measurements z_k refine predictions, dynamically adjusting estimates based on observed data. Equation 3 expresses the measurement residual $\tilde{y}$, signifying the disparity between predicted and observed measurements, with H as the measurement matrix.

$$\tilde{y} = z_k - H\hat{x}^k \quad (3)$$

Leveraging this information, Equations 4 to 6 compute the Kalman Gain K_k, update the state estimate $\hat{x}^+$, and refine the error covariance matrix ${P_k}^+$. This meticulous process enables the Kalman Filter to mitigate uncertainty, enhancing the accuracy of target predictions, rendering unparalleled capabilities to radar and satellite systems in dynamic scenarios.

Equation 4 involves the Kalman Gain, where I is the identity matrix R is the measurement noise covariance matrix (Kim and Bang, 2018).

$$K_k = P_k H^T (H P_k H^T + R)^{-1} \tag{4}$$

$$\hat{x}^+ = \hat{x}^k + K_k \tilde{y} \tag{5}$$

$$P_k{}^+ = (I - K_k H) P_k \tag{6}$$

In the domain of video and image processing, the Kalman Filter extends its influence, playing a pivotal role in tracking and predicting object movements. This adaptability is mathematically expressed in the update stage through Equations 3 to 6, where the Kalman Filter effectively tracks targets amidst changing environmental conditions. By incorporating these equations, the Kalman Filter responds promptly and accurately to changes or fluctuations in dynamic scenarios (Litvin et al., 2003).

4.2.Innovative Studies in Kalman Filter Applications

The adaptive Kalman filters, discussed in this section, aim to reinforce the versatility of the Kalman Filter in scenarios marked by sudden changes in velocity. Through this observation model, the Kalman Filter intelligently combines prior knowledge with incoming measurements, iteratively updating its estimate of the true state while accommodating inherent uncertainties and noise (Huang et al., 2019).

In the pursuit of enhancing the adaptability of the Kalman Filter, researchers explore adaptive Kalman filters, introducing Equation 7 to encapsulate the intricate filtering process. This observation model serves as the foundation for the entire filtering process. Here, $\tilde{y}$ is the measurement residual, representing the disparity between predicted and observed measurements, H is the measurement matrix, x_k signifies the system state, and v_k accounts for noise (Anderson and Moore, 2012).

$$\tilde{y} = H x_k + v_k \tag{7}$$

In parallel with the exploration and advancement of adaptive Kalman filters, diligent researchers have also delved into two other prominent variants, namely the Unscented Kalman Filters (UKF) and the Extended Kalman Filters (EKF). These highly sophisticated adaptations represent significant breakthroughs in the field of filtering and have been specifically designed to address the unique challenges and intricacies that arise in diverse real-world applications. While the adaptive Kalman filters excel at handling sudden changes in velocity, the UKF and EKF variants excel at handling other types of challenging scenarios, such as non-linear dynamics and non-Gaussian measurement noise (Sorenson and Alspach, 1971). By leveraging innovative and ingenious techniques, these variants further enhance the adaptability and performance of the Kalman Filter, allowing it to effectively tackle a broader range of real-world problems with remarkable accuracy and precision.

The Unscented Kalman Filter (UKF) is an extremely noteworthy extension that has been meticulously designed with the purpose of overcoming the inherent limitations of the standard Kalman Filter, particularly when dealing with nonlinear systems. The UKF achieves this by employing a set of carefully selected sigma points that are able to effectively capture the statistical properties of the system under consideration. This unique feature of the UKF enables it to provide significantly more accurate estimates, particularly in scenarios where the system dynamics deviate from linearity. As a result, this innovative approach significantly enhances the adaptability of the Kalman Filter to a much broader range of dynamic systems, thereby establishing it as an exceptionally valuable tool in various fields of study (Kim, 2011).

Another highly pivotal adaptation that has proven to be of utmost importance is the Extended Kalman Filter (EKF), which addresses the challenges posed by nonlinearities by employing a linearization technique. Specifically, the EKF linearizes the system at each time step, thereby allowing it to approximate the nonlinear functions using first-order Taylor expansions. Although the EKF is not as computationally intensive as the UKF, it has demonstrated its effectiveness in numerous nonlinear scenarios and has found widespread applications in diverse fields such as robotics, navigation, and signal processing. This speaks volumes about the immense utility and versatility of the EKF, further highlighting its significance in the realm of nonlinear system estimation and control. In conclusion, both the UKF and the EKF represent remarkable advancements in the field of Kalman Filters, each possessing their own unique set of strengths and applications. Consequently, these extensions have significantly expanded the capabilities and potential applications of the traditional Kalman Filter, opening up new avenues for research and advancement in various domains of science and engineering (Ribeiro, 2004).

In summary, the exploration of advanced variations, such as Adaptive Kalman Filters, Unscented Kalman Filters, and Extended Kalman Filters, underscores continuous efforts to enhance the adaptability, versatility, and robustness of the Kalman Filter across a spectrum of challenging real-world scenarios.

In the relentless pursuit of enhancing the adaptability of the renowned Kalman Filter across a wide range of target movement patterns, diligent researchers have extensively delved into advanced variations, including the ingenious and highly innovative adaptive Kalman filters and particle filters. Particle filters, also known as Sequential Monte Carlo methods, offer a unique approach to Bayesian filtering by representing the probability density function with discrete particles (Herranz et al., 2011). These filters have shown promising results, especially in scenarios with highly nonlinear dynamics and complex uncertainties.

The observation model, elegantly expressed in Equation 7, encapsulates the intricate filtering process. This observation model serves as the foundation upon which the entire filtering process is built, combining prior knowledge about the system's dynamics and incoming measurements. While the adaptive Kalman filters excel at handling sudden changes in velocity, particle filters provide an alternative perspective, particularly beneficial in situations where the assumptions of Gaussian distributions may not hold.

In parallel with the exploration and advancement of adaptive Kalman filters, diligent researchers have also delved into two other prominent variants, namely the Unscented Kalman Filters (UKF) and the Extended Kalman Filters (EKF). These highly sophisticated adaptations represent significant breakthroughs in the field of filtering and have been specifically designed to address the unique challenges and intricacies that arise in diverse real-world applications.

Particle filters, with their ability to handle nonlinearities and complex uncertainties, complement the Kalman filter family and offer a valuable tool in scenarios where traditional methods may face limitations. As research in this field progresses, the integration of particle filters alongside Kalman filters opens new avenues for tackling challenging real-world problems with remarkable accuracy and precision (Herranz et al., 2011).

In applications prioritizing high precision, the literature highlights the Kalman filter's effectiveness in target prediction. Equation 8, where z_k represents measurements, H is the measurement matrix, x_k signifies the system state, and v_k accounts for noise, captures the essence of precise target prediction. Minimizing noise and errors generated by the system is crucial for obtaining accurate predictions, underscoring the importance of implementing the Kalman filter in precision-demanding scenarios (Grewal and Andrews, 2008).

$$z_k = Hx_k + v_k \tag{8}$$

Although the Kalman filter has achieved significant acknowledgment for its remarkable usefulness in linear systems, the complexities associated with nonlinear systems pose inherent difficulties. Acknowledging this disparity, it is crucial to establish the foundation for future research efforts that delve into alternative forms of the Kalman filter (Garcia et al., 2019). This investigation aims to enhance the filter's practicality and efficacy in managing nonlinear scenarios, thus broadening its potential scope of applications.

The significance of this research is underscored by Equation 9, which captures a fundamental aspect of the Kalman filter's adaptive capacity in the face of nonlinear dynamics. In this equation, $\hat{x}^{+}$represents the updated or predicted state of the system at the current time step k, while F is the state transition matrix, B is the control input matrix, and w_{k-1} is the process noise. The term Bu_{k-1} accounts for external control inputs at the previous time step, providing a comprehensive prediction of the system's state evolution. This adaptability is crucial in addressing the intricacies introduced by nonlinear dynamics, showcasing the Kalman filter's versatility across a spectrum of dynamic systems.

$$\hat{x}^{+} = Fx_{k-1} + Bu_{k-1} + w_{k-1} \tag{9}$$

Beyond nonlinear systems, the Kalman filter plays a pivotal role in multiple target tracking, unveiling a myriad of intricate challenges that necessitate careful consideration and resolution. The optimization of the Kalman filter's performance, particularly in scenarios involving the simultaneous tracking of multiple targets, calls for focused research attention. Researchers must grapple with challenges such as target occlusion, appearance and disappearance, and data association ambiguities. Future investigations should be devoted to comprehending and addressing these complexities, thereby contributing significantly to the advancement of this field and enhancing the capabilities of the Kalman filter in demanding scenarios (Li et al., 2010).

Equations 10 and 11 play a pivotal role in the update stage of the Kalman filter, refining predictions based on real-time measurements and minimizing the disparity between predicted and observed data. In Equation 10, $\hat{x}^{+}$is updated by the Kalman gain K_k, times the measurement residual $\tilde{y}$ ensuring a more accurate estimate of the system's true state. Simultaneously, Equation 11 refines the error covariance matrix P_k adjusting for the influence of the measurement through the Kalman gain. Here, $I - K_k H$ acts as a correction factor, contributing to the continuous improvement of the filter's accuracy. These equations collectively demonstrate the Kalman filter's ability to dynamically adapt to incoming measurements, providing a robust mechanism for tracking targets and predicting their future states in real-world scenarios.

$$\hat{x}^{+} = \hat{x}^{k} + K_k \tilde{y} \tag{10}$$

$$P_k{}^{+} = (I - K_k H) P_k \tag{11}$$

5. CONCLUSION

In conclusion, this exhaustive review of the literature has furnished a profound comprehension of HMDS, Turreted Gun Systems on helicopters, and the multifaceted applications of the Kalman filter in target tracking and prediction. The amalgamation of these subjects underscores their collective importance in advancing the capabilities of contemporary assault helicopters.

The HMDS emerges as a pivotal constituent, augmenting the operational efficacy of assault helicopters by facilitating seamless interaction with Turreted Gun Systems and other avionic functionalities. Its integration optimizes aiming performance, transmitting crucial LOS information for the efficient alignment of target and weapon systems.

Turreted Gun Systems, with their versatile horizontal and vertical rotation capabilities, make a significant contribution to the combat capabilities of assault helicopters. The precision of these systems relies on factors such as dispersion values, highlighting the necessity for a comprehensive understanding of performance characteristics in order to achieve successful deployment.

The collaboration potential of advanced technologies is exemplified by the AH-1S Cobra Helicopter, which showcases the synergy achieved through the integration of HMDS and Turreted Gun Systems. This integration is crucial for the success of missions, particularly in situations where there may be limitations on additional fire support systems.

Moreover, the versatility of the Kalman filter in radar and satellite target tracking, image processing, and motion tracking is highlighted through the exploration of its applications and adaptive variants. The adaptations, such as the Adaptive Kalman Filters, Unscented Kalman Filters, Extended Kalman Filters, and Particle Filters, address the challenges encountered in nonlinear systems, resulting in improved precision and performance.

Despite the progress that has been made, there are still challenges that need to be addressed, especially when it comes to the practical implementation of the Kalman filter in nonlinear systems and the complexities of simultaneously tracking multiple targets. Future research should focus on the development of alternative modifications to enhance the effectiveness of the filter in nonlinear scenarios and to tackle the challenges associated with tracking multiple targets.

The present literature review provides a concise overview of the fundamental significance of HMDS and Turreted Gun Systems in the realm of helicopter avionics, highlighting their potential for collaboration. Additionally, the Kalman filter and its various adaptations are identified as formidable instruments in the realm of target tracking and prediction, offering prospects for progress in a wide range of dynamic scenarios. The valuable insights derived from this review serve as a cornerstone for future research and development in these critical areas of inquiry.

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Evaluation of the Studies on Unmanned Aircraft System Safety Management Systems with Bibliometric Analysis

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Abstract

UAV operations and their literature are developing rapidly. Along with the increasing number of risky situations, new technologies and measures are being developed to eliminate the unsafe situations created by them. Increasing UAVs have the potential to lead to unsafe situations in airspace with incident and accident backgrounds. In addition to all other studies related to UAVs, studies on safety management systems, as well as other topics related to the safety management system, need to increase. In this study, a bibliometric analysis of the studies on UAVs between the years 2003-2022 was conducted from the perspective of safety management. For this purpose, the publications found in the Dimensions database were examined. Those publications related to UAVs were filtered according to certain criteria such as year, author, country, and institution, and a sample was formed with 741 publications by using the bibliometric analysis method. VOSviewer application was used for bibliometric analysis and the achieved data were visualized in the form of tables, graphics, and visual maps. The findings show that the vast majority of publications on keywords were published in 2021. The most cited publication was written by Colomina and Molina in 2014. Most of the publications came up from the United States of America in total where 86 studies were conducted. The most cited organization is the University of Florida. In the cluster work, the words remote sensing, sensor, and drones appear frequently.

Key Words: Bibliometric Analysis, VOSviewer, UAV, Safety

İnsansız Hava Aracı Sistemlerinin Emniyet Yönetim Sistemlerine İlişkin Çalışmaların Bibliyometrik Analiz ile Değerlendirilmesi

Öz

İHA operasyonları ve literatürü hızla gelişiyor. Riskli durumların artmasıyla birlikte, bunların yarattığı emniyetsiz durumları ortadan kaldırmak için yeni teknolojiler ve önlemler geliştirilmektedir. Artan UAV'ler hava sahasında emniyetsiz durumlara yol açmaktadır. UAV'lerle ilgili diğer tüm çalışmaların yanı sıra emniyet yönetim sistemi ile ilgili diğer konu başlıklarının yanı sıra emniyet yönetim sistemlerine ilişkin çalışmalarında artması gerekmektedir. Bu çalışmada 2003-2022 yılları arasında İHA'lar üzerinde yapılan çalışmaların emniyet yönetimi perspektifinden bibliyometrik analizi yapılmıştır. Bu amaçla Dimensions veri tabanında bulunan yayınlar incelenmiştir. İHA'larla ilgili yayınlar yıl, yazar, ülke, kurum gibi belirli kriterlere göre filtrelenmiş ve bibliyometrik analiz yöntemi kullanılarak 741 yayından oluşan bir örneklem oluşturulmuştur. Bibliyometrik analiz için VOSviewer programı kullanılmış ve elde edilen veriler tablo, grafik ve görsel haritalar halinde görselleştirilmiştir. Bulgular, anahtar kelimelerle ilgili yayınların büyük çoğunluğunun 2021 yılında yayınlandığını göstermektedir. En çok alıntı yapılan yayın ise 2014 yılında Colomina ve Molina tarafından yazılmıştır. Toplamda 86 çalışmanın yapıldığı yayınların çoğu Amerika Birleşik Devletleri'ndedir. En çok alıntı yapılan kuruluş Florida Üniversitesi'dir. Kümeleme çalışmalarında uzaktan algılama, sensör, drone kelimeleri sıklıkla karşılan çalışma alt başlıklarıdır.

Anahtar Kelimeler: Bibliyometrik Analiz, VOSViewer, İHA, Emniyet.

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INTRODUCTION

Unmanned aerial vehicle systems and technologies are becoming increasingly important. Both the need for unmanned technologies and the large economic market created by these technologies reaching great value. Although unmanned aerial vehicles and system's tactical use for defense and military purposes seems to be more common, they are becoming more widespread in many different industrial areas (Nisser and Westin, 2006). Their usage is increasing in many fields such as agriculture, energy, mining, construction, real estate, media, film, and advertising makes the concept of safety even more important (Piloutsias et al., 2018). In recent years, incidents of UAVs flying near airports, airplanes, and helicopters without authorization have been increasing. Along with the increasing number of risky situations, new technologies and measures are being developed to eliminate the unsafe situations created by them. Academic studies on these developed technologies and measures will gain importance in the coming years. For this reason, knowing and analyzing the works done in the past years will create significant added value.

Bibliometric analysis is a quantitative research and statistical method and allows to see the development of academic studies in a field in terms of quality and quantity (Dixit and Jakhar, 2021). Bibliographic analysis, as opposed to systematic literature review, is an analytical technique that produces formal, quantitative data about the current state of a field and facilitates tracking academic trends using visualization software (Dirik et. al, 2021). Thus, with the data obtained, information about the publication year, keywords, number of citations, and authors of academic studies are revealed. Bibliometrics provides quantitative information about the productivity of countries, authors, universities and documents, weak and strong research areas, literature gaps, collaborative networks, potential opportunities and the far-reaching impact of results produced in a field (Dirik et. al, 2021). It has provided a lot of data to other researchers who want to work on the subject.

In this study, the most productive researchers in the field of UAV were determined by bibliometric analysis. By accessing information such as the number of studies and researchers by country, new study subjects may arise between these researchers and the institutions they work with. The topics studied in those publications will be discussed and potential opportunities for interdisciplinary studies will be created. In this study, 741 studies were analyzed in the Dimensions database between 2003 and 2022. Firstly, the methodology of the study will be explained, then the findings will be given and finally the results and recommendations will be discussed.

1. SAFETY MANAGEMENT SYTEM

Disasters such as Chernobyl, Challenger, Tenerife airport disaster, Herald of Free Enterprise, King's Cross, Piper Alpha, and Clapham Junction increased interest in the concept of safety. Therefore, the focus has shifted from accident prevention based on technical and human errors to "safety management" based on dynamic processes. This situation has led to focusing not only on the visible causes of accidents, but also on their invisible indirect causes. The concept of safety has provided a better approach to changing perspectives on the predictability and prevention of such disasters (Altıntaş, 2023).

Safety Management System (SMS) is a systematic approach to managing safety in aviation and other safety-critical industries such as aviation. In aviation activities where SMS is applied, by identifying the safety risks they are exposed to during operations, these can be reduced and, as a result, increased safety performance (IATA, 2024).

Aviation authorities facilitate air transport and establish operating rules for all aircraft and other vehicles involved in aviation activities. These rules cover all the procedures, regulations, infrastructure, aircraft, and personnel that make up the air transportation system (Weibel and Hansman, 2006). SMS for aviation authorities becoming a standard across the global aviation industry and will integrate modern safety risk management and safety assurance concepts into repeatable, proactive systems (FAA, 2022). The integration of UAVs into the aviation system and manned, flight-based systems raises various safety issues, including the possibility of collision in the air, collision on the ground and system reliability (Carr, 2013).

The purpose of SMS is to facilitate safe, efficient and effective Unmanned Aircraft System (UAS) operations. The Safety Management System (SMS) is designed to identify safety risks and hazards and implement corrective processes and procedures. An organizational management structure is created that includes key security personnel responsible for planning, implementation, and execution. Arrangements are made to implement emergency measures. Change control procedures, continuous improvement processes, improvement of safety performance, establishment of measurement and monitoring procedures, and safety education, communication and training are provided to create a safety culture throughout the organization (Yang et al., 2022).

The usage areas of UAVs have gradually expanded and as they become more widespread, there is an increase in cases. This situation should not be ignored in the development of UAVs. Establishing the SMS reporting culture and system on solid foundations and identifying hazards and risks are important for the development and future of UAVs.

2. DESIGN/METHODOLOGY/APPROACH

This study was carried out to understand how much the issue of unmanned aerial vehicles and their systems, which has been mentioned frequently in the field of aviation in recent years, takes place in academic literature with the overview of the safety perspective and SMS. It is large enough to warrant bibliometric analysis within the scope of the study. Preliminary research was conducted on the number of publications to be analyzed. Dimensions, an academic search database, was used in this study to select the study sample for analysis and collect data. Dimensions was chosen because it covers a wide range of publications in academic fields and provides a greater number of publications. During this selection, a comparison of the publication numbers of Dimensions and Web of Science was also made. The collected data was made by choosing VOSViewer, a broadcast visualization tool that provides visual analysis of broadcasts. In this way, the relationships between publications are visualized with scientific mapping. This will allow researchers to make general judgments about the past research sequences and future research. The collected data were analyzed with the selected software. In this analysis, citations provide information about authors, institutions, countries, and collaborations.

2.1. Purpose and Importance of the Research

The increase in the use and production of UAVs in the aviation industry increases the number of studies on these aircraft in the academic field. For this reason, in this study, it is aimed to examine the academic studies on unmanned aerial vehicles and the safety management system and the relationships between these studies. The research has the unique feature as the first and original study in the literature that deals with the concepts of UAV and Safety together. It will also contribute to literature and future studies in terms of showing the trend of the articles in the field of UAV from past to present.

2.2.Scope of the Research

Within the scope of this study, answers to the following research questions will be sought with the keywords "Unmanned Aircraft System Traffic Management (UTM)", "Unmanned Aviation", "Unmanned Aircraft", "Drone", "Remotely Piloted Aircraft" and "Safety":

- What is the number and origin of articles in the international index between 2003-2022?
- Which articles were published in the international index and been cited in the international directory between 2003-2022?
- By whom the articles in the international directory between 2003-2022 were made?
- The organizations that wrote the articles in the international directory between 2003-2022.
- The top most cited authors and citation numbers in the international index between 2003-2022.

2.3.Research Data Collection Process

During literature analysis, data mining, software selection, data analysis, findings and discussions were conducted. The data for the analysis is collected from the Dimension.ai website. WOS has 23 million and Scopus 27 million documents, while Dimensions have 36 million documents and 21 million documents overlapping with Scopus (Visser et al., 2021). The selected keywords for the study: ("UTM" or "unmanned aviation" or "unmanned aircraft" or "drone" or "remote controlled aircraft" and "safety". According to the initial results, the number of 2716 publications on these keywords were released. When the results of the analysis were re-examined with open publications and articles, the number of publications was 741 in the last case. This process is shown in Figure 1 with PRISMA tool.

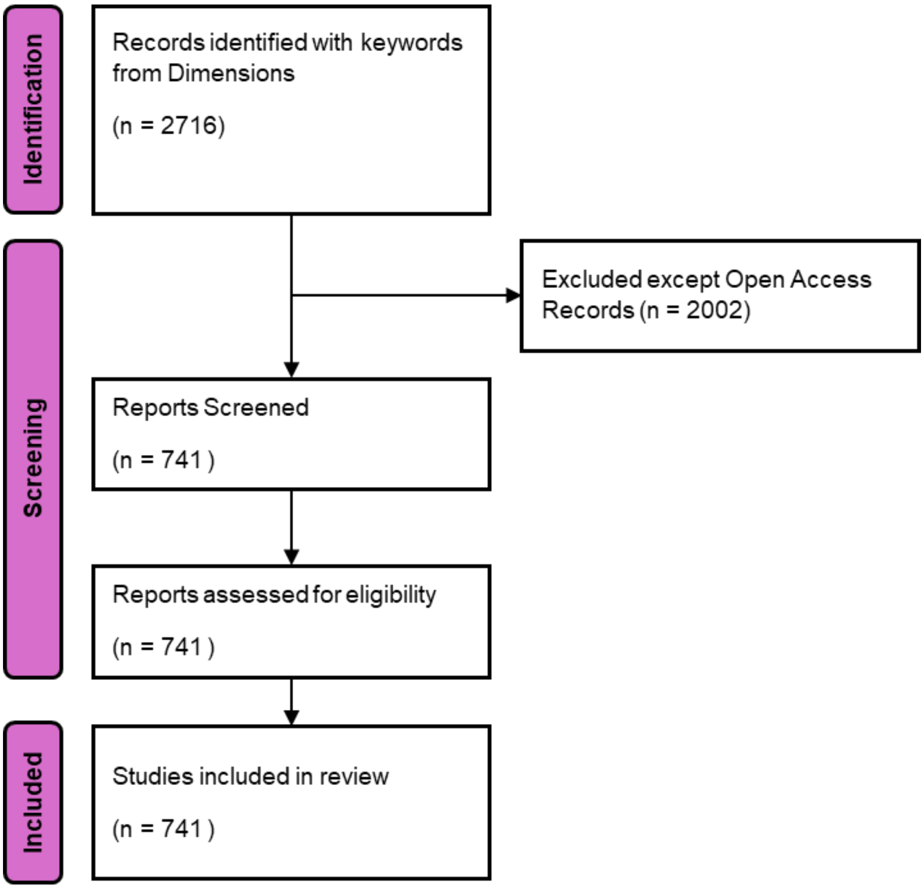


Figure 1. PRISMA Flow Chart for UAS Safety Article Collection

2.4. Analysis of Research Data

The analysis of data collected in the study and the data visualization were analyzed using version 1.6.18 of the "VOSviewer" package program. VOSviewer helps to produce findings that are visually easy to understand and aid in results analysis. It is preferred because it gives information with network relationships. In this study, information about articles, information about documents, information about authors, document co-citation network, author co-citation network, information about countries, information about keywords were analyzed and graphs were created. The maximum number of authors in the analyzes was limited to 15. The minimum number of citations per author was selected as 2 citations and the analyzes were performed according to these criteria.

2.5.Limitations of the Study

The data used in the study were obtained from the Dimensions database that was used between the years 2003-2022, there is a time limit. Accepting that the data shaped by processing in the VOSViewer program used is correct can be seen as another limitation. Another limitation is the development of literature at an accelerating pace. As seen in Figure 2, the number of publications has increased especially in the last 3 years. A new publication takes time to gather a certain impact and citation. Therefore, the predominance of older publications affects the analysis.

3. FINDINGS

In the study, information about articles, information about documents, information about authors, document co-citation network, author co-citation network, information about countries, and information about clusters were analyzed and graphics were created.

3.1.Distribution by Years

In the study, in which publications on UAV and safety issues were considered, a total of 741 articles were examined between 2003 and 2022. The distribution of publications by years is given in Figure 2. According to Figure 2, the most publications were made in 2021. In 2021, 220 studies were conducted. This number constitutes 29% of the total number of publications. There are no publications on keywords between 2003 and 2008. After one publication was made in 2003, it started to be published again in 2008, but no study was conducted in 2010 that included these keywords. After 2012, the number of publications started to increase. Considering the number of articles by year, it is seen that there has been an increase in recent years.

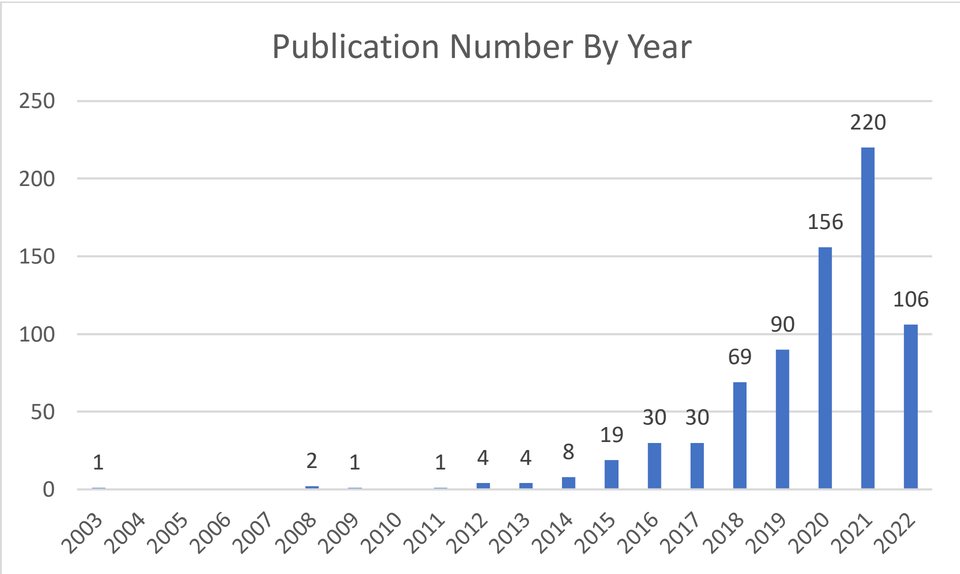


Figure 2. Publication Quantity Between 2003 and 2022

3.2.Co-Authorship Analysis

Co-authorship of a work is a formal expression of the involvement of two or more authors or institutions (Newman, 2004). Co-authorship analysis is widely used to understand and evaluate models of scientific collaboration. Co-authorship is examined by authors, then by organizations, and finally by country. As a result of the analysis, 132 authors who met the criteria were analyzed. For each of the authors, their co-authorship connections with other authors were analyzed and the authors with the highest connection strength were selected. According to this analysis, the top five most cited authors are given in Table 1.

Table 1. Top Five Most Cited Authors in Co-Authorship Analysis

Ranking	Authors	Citations
1	Ma, Ou	218
2	Alsami, Saeed H.	218
3	Shoufan, Abdulhai	90
4	Baxter, Glenn	89
5	Murray, John	89

The most cited in the co-author and author analysis are Ma and Alsami. The number of citations in both is 218. There is a serious decrease in the number of citations of the authors who come after Ma and Alsami in the ranking. In this analysis of co-authorship, some of the 132 items in the network are unconnected. The largest linked item set consists of 6 items.

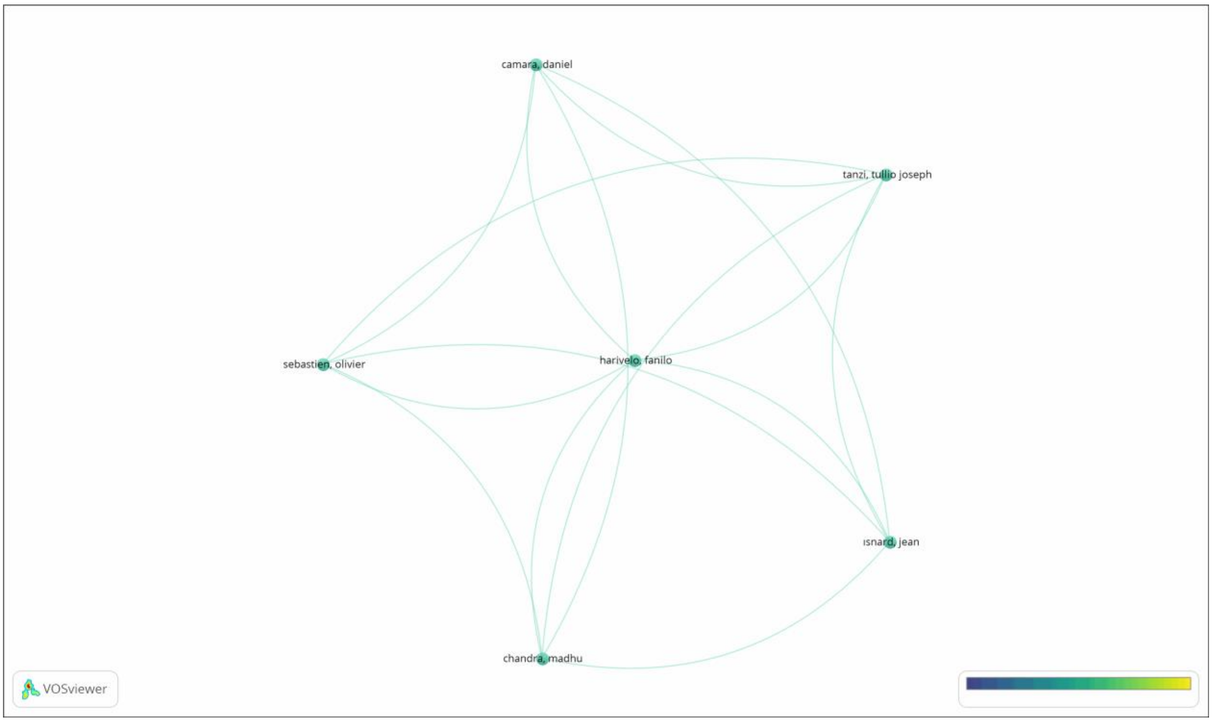


Figure 3. Overlay Visualization of the 6 Most Connected Items in The Co-Authorship Network.

As a result of the analysis conducted by the criteria, 141 out of 602 organizations passed the threshold. The first five of these organizations are given in Table 2.

Table 2. Top 5 Most Cited Organizations with Co-Authorship Networks.

Ranking	Organization	Citations
1	University of Florida	632
2	Northern Arizona University	305
3	IBB University	264
4	Nanjing University of Aeronautics an..	244
5	Nazarbayev University	232

In the co-authorship and organization analysis, it is seen that the University of Florida is the organization with the highest number of citations. Figure 4 shows the overlay visualization of the organizations' connections to each other regarding co-authorship.

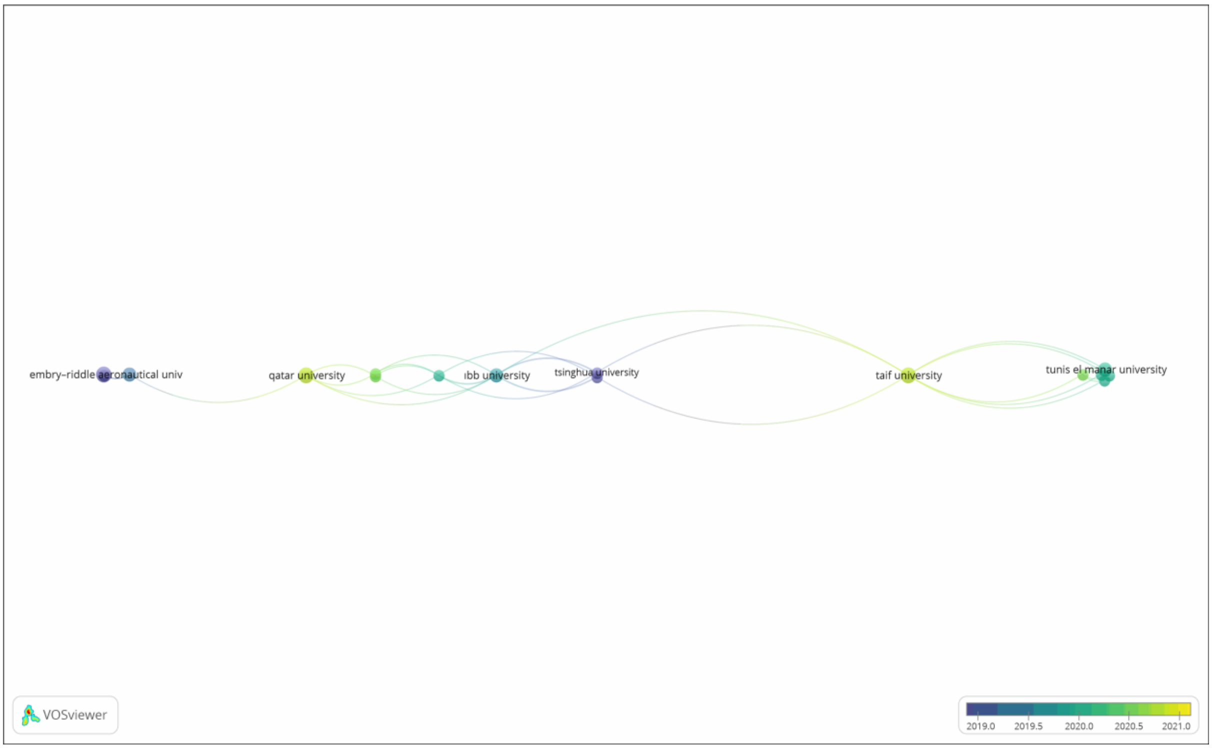


Figure 4. Overlay Visualization of Analysis of Co-Authorship and Organizations.

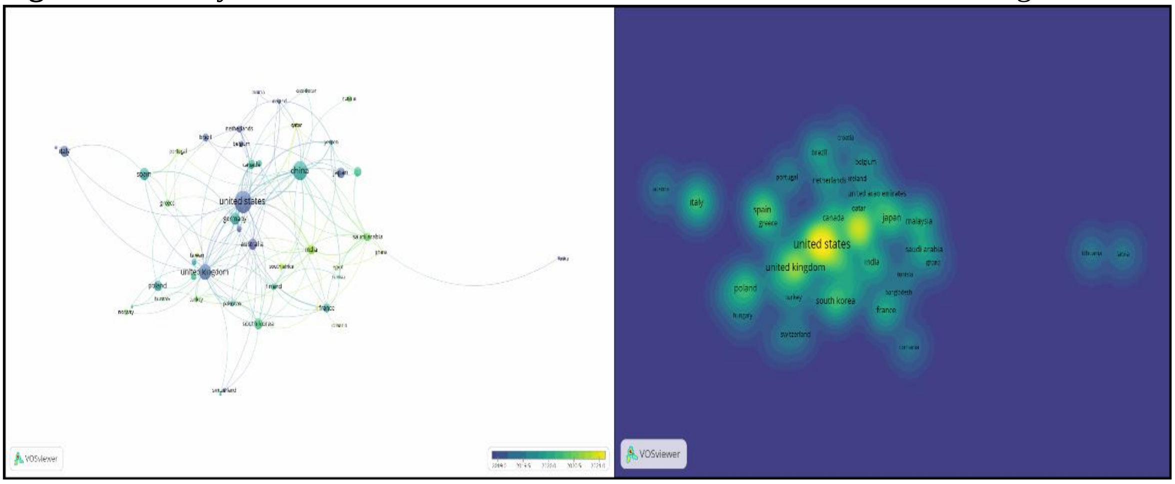
Finally, when co-authorship and countries were analyzed, 52 out of 72 countries passed the threshold. The first five of these are given in Table 3.

Table 3. Top 5 Most Cited Countries with Co-Authorship Networks.

Ranking	Country	Citations
1	United States	2217
2	Spain	1820
3	China	1052
4	United Kingdom	1012
5	Australia	429

In the co-authorship and country analysis, the top five countries among the number of countries reduced to 52 are from different parts of the world. The United States is in first place. Spain is followed by the number of citations, followed by China. Australia, which is a different part of the world, is in fifth place after the United Kingdom in fourth place.

Figure 5. Overlay Visualization of The Most Cited Countries with Co-Authoring Networks.



In Figure 5, overlay visions related to countries are seen. As can be seen from the image, the center of the works is the United States.

3.3.Citation Analysis

Citation analysis reveals various insights related to a particular field of research. It helps identify the most influential authors and publications that have contributed to and made a significant impact on a particular field of research. In short, citation analysis helps identify studies and track their popularity and progress over time (Rejeb et al., 2022).

In this section, influential studies in the field are given using citation analysis, and the 5 most cited studies are listed in Table 4. Out of 739 documents, 2 of them not being listed due to limitations, 395 documents meeting this criterion passed the threshold. The article written by Colomina and Molina (2014) is the most cited in its field with 1653 citations followed by Watts et al. (2012) as second with 564 citations. In the study, photogrammetry and remote sensing disciplines are focused together on nano-micro-mini UAS segments. It reviews the sensing, navigation, routing, and data processing developments for UAS photogrammetry and remote sensing, with a brief analysis of the historical background and regulatory framework.

Table 4. List of Most Cited 5 Articles.

Ranking	Document	Publication Year	Citations
1	Colomina and Molina	2014	1653
2	Watts et al.	2012	564
3	Zeng et al.	2020	259
4	Ding et al.	2017	227
5	Naqvi et al.	2018	158

Naqvi et al. (2018), Alsahmi et al. (2019), Forlani et al. (2018), Sandbrook (2015), Abdel-Basset et al. (2020), Taha and Shoufan (2019), Rosser et al. (2018), Perez et al. (2019), Cruz et al. (2016), Pierdicca et al. (2018) and Balasingam (2017) are on the list of the 15 most cited articles. Unlike others, Zeng et al. (2020), Abdel-Basset et al. (2020), Rosset et al. (2018), Perez et al. (2019) and Sandbrook (2015) are not primarily linked to safety issues of UAS operations or aspects aimed at improving safety. The remaining articles cover a wide range of issues such as remote sensing and sensors, georeferenced systems, 5G, the Internet of things, and drone detection and classification.

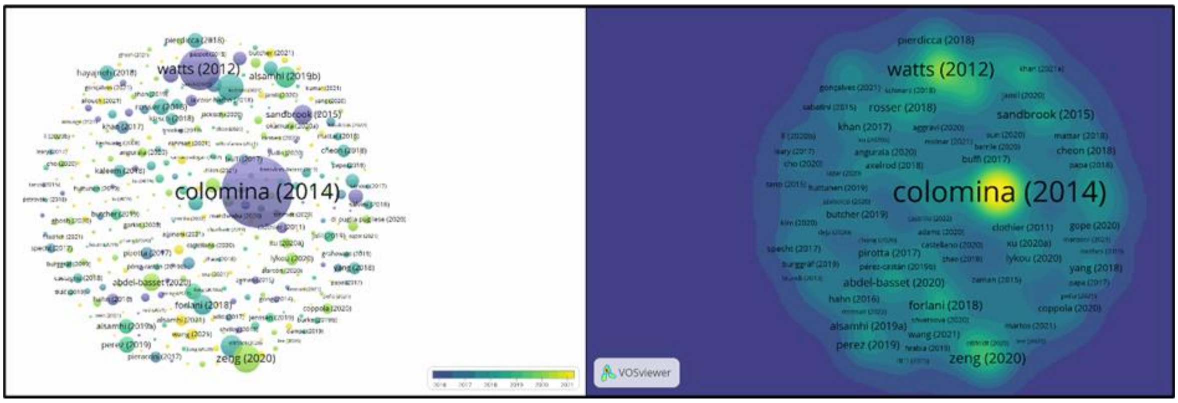


Figure 6. Overlay Visualization of The Most Cited Authors.

When analyzed according to the criteria in citation and source analysis, only 65 of 382 sources exceeded the threshold. The first 5 of these sources are given in Table 5.

Table 5. Top 5 Sources with The Highest Number of Documents and The Highest Number of Citations.

Ranking	Source	Documents	Source	Citations
1	IEEE Access	43	Remote Sensing	775
2	Sensors	33	IEEE Access	702
3	Drones	29	Sensors	531
4	Journal of Physic Conference series	23	IEEE Communications Magazine	446
5	Applied Sciences	22	Drones	253

IEEE Access ranks first in Table 5 with 43 documents, while Remote Sensing ranks first in Table 6 with 775 citations. While Remote Sensing is in the first position in reference, it is not in the top five when analyzed according to the number of documents. Still, the sources of IEEE Access, Sensors, Drones, Applied Science, Aerospace, The International Archives of the Pho., and Electronics are on both lists in terms of the highest number of citations and the highest number of documents. This shows the parallelism between the number of documents and the number of citations. Overlay and density visualization for attribution and source analysis are given in Figure 7.

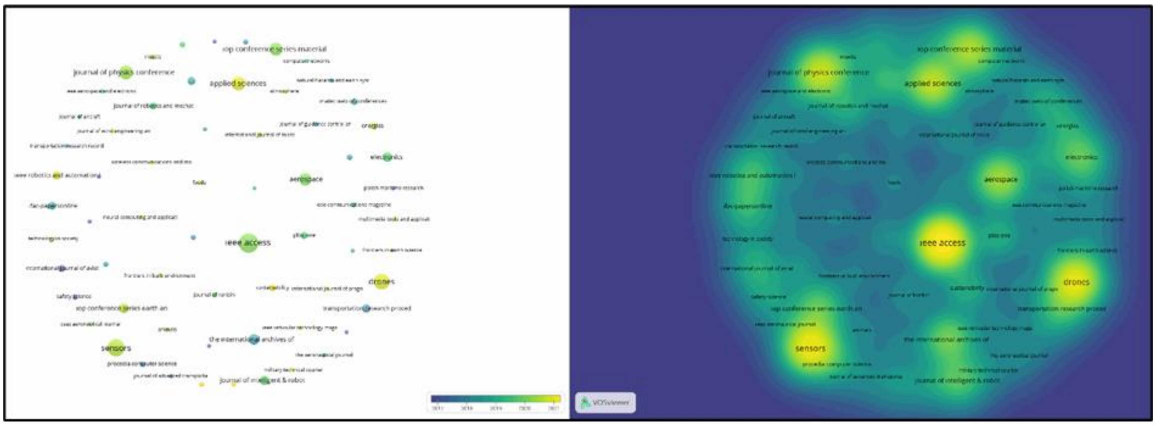


Figure 7. Overlay Visualization of The Citation and Sources Analysis.

When analyzed according to 15 documents and 2 citation criteria, 132 out of 2566 authors passed the threshold. The first five authors with the most documents and most citations among 132 authors are given in Table 6.

Table 6. The Top Five Authors with The Most Documents and The Most Citations

Ranking	Author	Documents	Author	Citations
1	Ellerbroek, Joost	6	Ma, Ou	218
2	Sabatini, Roberto	5	Alsamhi, Saeed H.	218
3	Gardi, Alessandro	4	Shoufan, Abdulhadi	90
4	Konnert, Anna	4	Baxter, Glenn	89
5	La Cour-Harbo, Anders	4	Murray, John	89

The first author with the most documents and the first author with the most citations are different people. Although Ellerbroek has 6 documents, it is not in the top five in terms of the number of citations. Ma's citation count is 218 and he is the most cited author. Ma's number of documents is 3.

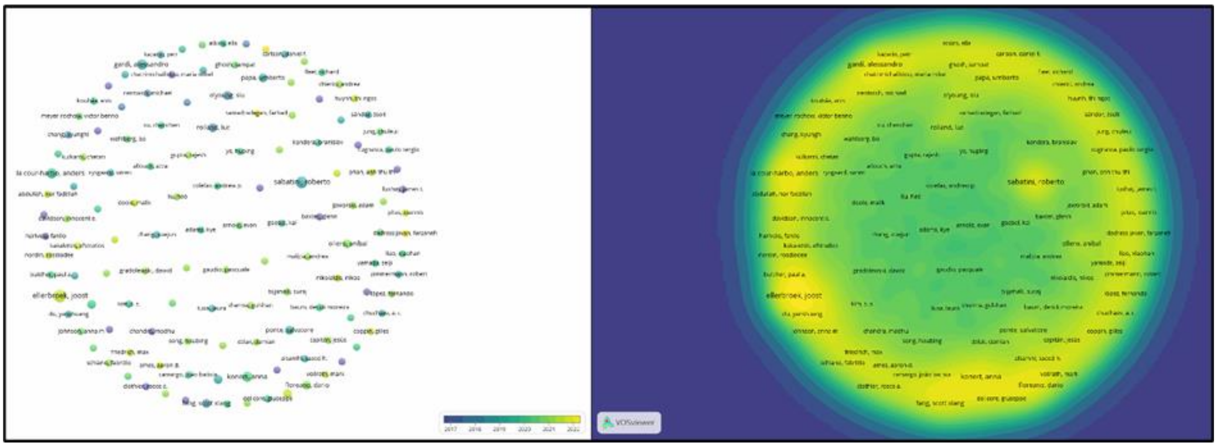


Figure 8. Overlay and Density Visualization of The Authors.

Figure 8 shows the number of authors and distribution is distributed according to the number of citations and documents. For this reason, the number of authors from 2566 was reduced to 132 for analysis. In the citation and organization analysis, 141 out of 602 organizations exceeded the threshold with the limitations made for documents and citations. Among these

141 organizations, the first five organizations with the most documents and citations are given in Table 7.

Table 7. Top Five Organizations with The Highest Number of Documents and The Most Citations

Ranking	Organizations	Documents	Organizations	Citations
1	RMIT University	8	University of Florida	632
2	University of Technology Malaysia	7	Northern Arizona University	305
3	Beihang University	6	IBB University	264
4	German Aerospace Center	6	Nanjing University of Aeronautics An...	244
5	National University of Sciences and Te…	5	Nazarbayev University	232

RMIT University ranks first among the top five organizations with the most documents. This university has 8 documents and 186 citations. RMIT University ranks tenth in the citation count with this number of citations. This again reveals the difference and importance between the number of documents and the number of citations, as in the previous analysis. For this reason, there are many items in Figure 9 like Figure 8.

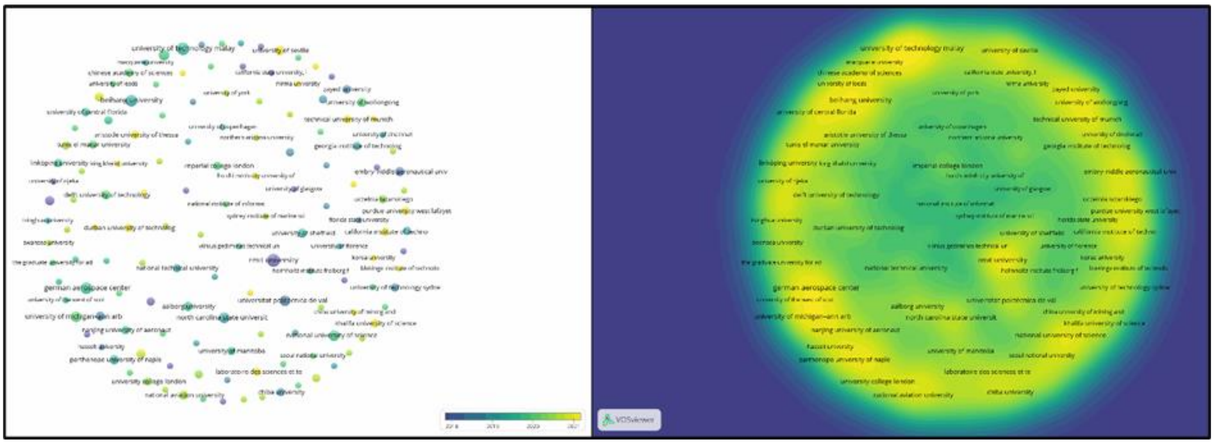


Figure 9. Overlay Visualization of The Analysis of Citations and Organizations.

When the citation and countries are evaluated together, 52 countries out of 72 countries passed the threshold. For this merger, the maximum number of countries per document is 15. The minimum number of documents and citations per country is 2 for both. The top five countries with the most documents among 52 countries are given in Table 8. The United States gave the most contribution to the field related to the keywords we selected.

Table 8. Top Five of The Countries with The Most Documents and Most Citations.

Ranking	Country	Documents	Country	Citation
1	United States	86	United States	2217
2	China	63	Spain	1820
3	United Kingdom	44	China	1052
4	Spain	27	United Kingdom	1012
5	Germany	26	Australia	429

Regarding the countries, Table 8 shows the top five countries contributing to the literature, while Spain and China are at the top of the list after the United States. The United States has the most documents and citations. In addition, the United States is the country where most UAS models are produced or developed in the world. 403 models of UAS were produced or developed in the country. After that, Spain produced or developed 36 units, and China, as the second manufacturer or developer in the world, produced or developed 227 UAS models (Blyenburgh, 2021). Figure 10 shows the overlay visualizations of the countries with documents and citations. The United States and China have higher densities than other countries.

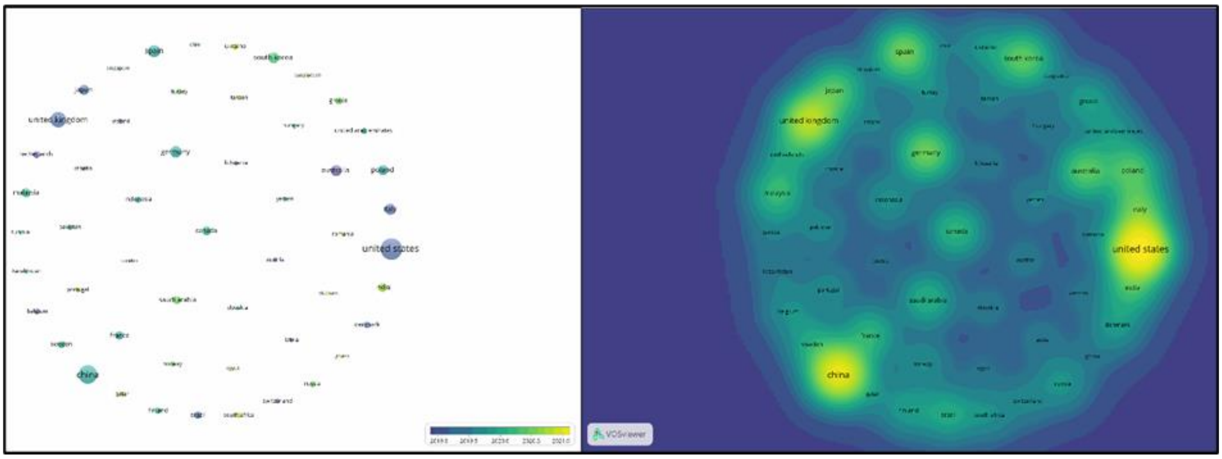


Figure 10. Overlay Visualization of The Analysis of The Citation and Countries.

3.4.Citation ranking of the sources and their clusters

As a result of the analysis, 4 clusters and the highest citation ranking of the documents were defined (Table 9). The first cluster consists of "Remote Sensing", "International Archive of Photogrammetry Remote Sensing and Spatial Information Sciences", "Electronics" and "Applied Sciences". These journals are mostly about general engineering, electronics, and engineering and its applications. The second cluster consists of "Sensors" and "Drones", which are the focus sensor technologies and UAS design and implementation. Cluster 3 consists of "Aviation" and "Transport Research Procedure". Cluster 4 consists of "IEEE Access" and "Plos one", which are more multi-domain and multi-disciplinary.

Table 9. Citation Ranking of The Sources and Their Clusters

Rank	Source	Clusters
1	Remote Sensing	Cluster 1: Remote Sensing, The International Archives of The Photogrammetry Remote Sensing and Spatial Information Sciences, Electronics, Applied Sciences
2	IEEE Access	
3	Sensors	
4	Drones	
5	Aerospace	
6	The International Archives of The Photogrammetry Remote Sensing and Spatial Information Sciences	
7	Applied Sciences	Cluster 2: Sensors, Drones
8	Plos One	Cluster 3: Aerospace, Transportation Research Procedia
9	Electronics	

10	Transportation Research Procedia	Cluster 4: IEEE Access, Plos one

With common citation analysis, it is possible to identify scientific societies and their publications, and the results provide information about the internal structure of the relevant field (Gmur, 2003). After this analysis, five clusters were identified based on the similarity of the content areas. Table 10 shows the matching of the clusters and their common content. Each of the content is linked to safety improvements and implementations.

Table 10. Clusters and Their Common Contents

Clusters	Common Contents
Cluster 1	UAS Commercials and Businesses Areas, Regulations
Cluster 2	IoT, Autonomous Systems, Multi-UAV Networks, Intelligent Transportation Systems
Cluster 3	UTM Concept, Airspace Design, Regulations, Separation and Conflict Detection
Cluster 4	Artificial Intelligence, Object Detection, Image Classification, Neural Nets
Cluster 5	Autonomous And Remotely Operated Aerial Vehicles, Artificial Intelligence and Learning, Wireless and RF Technologies

Cluster 1 mainly focuses on the UAS usage areas as commercial and business as building inspection, transportation of goods or medicals or agriculture, etc., and regulations of UAS. The second cluster is more concerned with self-flying systems using IoT and autonomy. Along with these technologies, studies focus the multi-UAV networks and intelligent transportation systems. Unmanned traffic management and airspace design gather under cluster 3. Besides that, conflict detection and avoidance systems, traffic separation methods, and regulations are in that coverage area. Cluster 4, slightly different from the others, does not directly include UAS. The cluster deals with UAS as the user of the subjects it focuses on. Cluster 5 focuses on wireless and radio frequency technologies, autonomous and remotely operated systems, artificial intelligence, and its learning methods.

4. CONCLUSION AND DISCUSSION

Unmanned aerial vehicles and/or systems are one of the indispensable aviation developments of our age. For this reason, it is important to examine the unsafe conditions of unmanned aircraft and/or systems in all these operations and air traffic so that all aircraft in aviation activities can operate safely. Examination of academic studies and bibliometric analysis will be beneficial for academic studies to be carried out in the coming years.

In this study, publications after 2003 were examined. The reason for this is that publications on UASs began to be carried out in the 2000s, and after 2020, there have been great increases in the number of publications. It is seen that the work has increased after 2020. According to the co-authorship analysis, Ma and Alsami are the most cited authors with 218 citations. Ma is an academician in the USA, the country with the highest number of unmanned aerial vehicles and systems, and Alsami is an academician in China, another country with the highest number and development. A lot of work is being done on the subject in these countries, therefore the quality of publications and the number of citations is increasing. The organization with the most citations to the co-authorship network is the University of Florida, with 632 citations, nearly double that of runner-up Northern Arizona University, with 305 citations. Additionally, when countries are examined for the same network, the

United States ranks first with 2217 citations. Spain follows with 1820 citations. The reason why Spain is included in this ranking is that the UAV industry in the country is service-oriented and has entered all kinds of sectors. These range from lifesaving UAVs in Valencia to inventory UAV implementation at Ikea, as well as security, police use, and delivery services, among dozens of other applications. The UAV industry average in Spain is above the global average (Alvarado, 2023). Therefore, the number of studies and citations were also positively affected.

The most cited article was written by Colomina and Molina (2014) and received 1653 citations. It is thought that the reason why Colombina and Molina's publications have received so many citations is that they include basic topics about UAVs and explain the concepts at an understandable level in their article "Unmanned Aerial Systems for photogrammetry and Remote Sensing: A Review". Additionally, the publication was conducted at the Technology and Telecommunications Center in Spain. In second place is the work by Watss et al. (2012), which received 564 citations. In third place, the work written by Zeng et al. received 259 citations. This article and the other 4 articles in the top 15 most-cited articles list are not primarily linked to the safety issues of UAS operations or improving safety. The top three countries with the most broadcasts are America, Spain, and China. Turkey is not in the top 10. The most cited organization is the University of Florida. It is followed by Northern Arizona University and IBB University. It is seen that the most published and cited publications are research centers and technical universities. The most preferred source for publication of the articles is Remote Sensing following the IEEE Access and then Sensors. There are five common content clusters observed by using citation analyses. Each of the contents is linked with the safety applications and may improve the safety of the UAS. More studies can be done on unmanned aerial vehicles and systems. Although there is both production and use in the field of defense in Turkey, a sufficient number of academic studies have not been performed.
As a result of the findings obtained, with the increase in safety studies on UAV systems year by year, it is important to continue the studies carried out with the safety management system in a multidisciplinary manner. It is recommended that sciences such as engineering, computer science, and aviation management work together to address complex challenges. By understanding regional differences by conducting comparative studies with countries with high levels of UAV activity, such as the USA, China, and Spain, specific safety measures can be determined, and policies can be developed.

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A Systematic Research on Ballistic Characteristics of Aerial Ammunitions

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Abstract

Aviation has come a long way since its early days, and as technology has advanced, air vehicles have become even more advanced and effective, especially on the battlefield. In addition, in-depth research and discoveries in the field of aviation have a significant impact on the aviation industry, especially in the field of munitions. In this context, aerial ammunition is an important component of aviation and is widely used in combat. Because a malfunction that may occur during separation or premature detonation during separation from the aircraft may cause fatal effects on the crew. That's why the bomb must be safely separated from the air vehicles. Modern bombs are therefore equipped with advanced safety features that guarantee a precise and safe separation from the aircraft before explosion. In addition, the determination of the ballistic coefficient according to the size of the desired effect reveals the importance of the choice of munition types. Otherwise, it will not be possible to achieve the desired level of target destruction. This study aims to provide a comprehensive understanding of the basic characteristics of aerial munitions, including the composition and operation of generic aircraft bombs.

Keywords: Aerial Ammunition, Generic Bomb Types, Air-to-Ground Bombs, Safe Separation, Tactical Ammunition

JEL Classification: L93.

Havacılık Mühimmatlarının Balistik Karakterizasyonuna Yönelik Bir Sistematik Araştırma

Öz

Havacılık ilk günlerinden bu tarafa çok yol kat etmiştir ve teknoloji ilerledikçe uçaklar daha da gelişerek özellikle harp sahasında çok etkili hale gelmiştir. Ayrıca havacılık alanında derinlemesine gerçekleştirilen araştırma çalışmaları ile ortaya konan buluşlar özellikle mühimmat konusunda havacılık sektörünü büyük ölçüde etkilemektedir. Bu bağlamda, havacılık mühimmatları havacılığın önemli bir bileşenidir ve muharebede yaygın olarak kullanılmaktadır. Havacılık mühimmatının, uçağa konuşlanma sırasında meydana gelebilen bir arıza veya uçaktan ayrılırken meydana gelen erken patlamanın mürettebat üzerinde ölümcül etkilere neden olmasından dolayı bombanın emniyetli bir şekilde ayrılması gerekmektedir. Bu nedenle çağdaş bombalar, patlamadan önce uçaktan kesin ve güvenli bir şekilde ayrılmayı garanti eden gelişmiş güvenlik özellikleriyle donatılmaktadır. İlave olarak, istenen etkinin boyutuna göre balistik katsayının belirlenmesi, mühimmat

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tiplerine yönelik seçimin önemini ortaya koymaktadır. Aksi takdirde hedefteki tahribatın istenilen ölçüde gerçekleşmesi mümkün olmayacaktır. Bu çalışmanın amacı, hava mühimmatlarının temel özellikleri ve jenerik uçak bombalarının bileşimi ile işleyişi hakkında kapsamlı bir kavrayış sunmaktır.

Anahtar Kelimeler: Havacılık Mühimmatları, Jenerik Bomba Türleri, Havadan Yere Bombalar, Emniyetli Ayrılma, Taktik Mühimmatlar

JEL Sınıflandırma: L93.

INTRODUCTION

Aerial bombs, versatile munitions that can be released from airplanes or other flying machines, are designed to perform a wide range of combat tasks in modern aviation. Their classification is based on various principles, including the combat task they are designed to solve, the appearance of the effect or destruction factors they create, and the type of target they are intended to destroy.

Airborne bombs are divided depending on the combat task they are designed to solve. These include primary-purpose aerial ammunition, auxiliary aerial ammunition, and particular-purpose aerial ammunition. Aerial ammunition for the primary purpose is designed to destroy various ground (underground) and sea (surface, underwater) targets of the enemy. As a result of their direct impact on various targets, it is accepted to destroy or disable the target due to the destructive effect of the impact, the explosion of the explosive discharge (explosive products, impact wave, and shrapnel), and the effect of the high temperature and flame of the combustion of incendiary substances.

Different types of primary-purpose bombs are used to damage or destroy targets, and these bombs are classified based on their destruction effect and the type of target to be destroyed. The following are the main types of primary-purpose bombs, as shown in Figure 1:

- *High-explosive aerial bombs:* These bombs use the gas-like products of the explosion and the shock wave as the main factors of destruction (e.g., Mk 82, Mk 84).
- *Shrapnel-effective aerial bombs:* These bombs use shrapnel formed during the fragmentation of the body as the main factor of destruction (e.g., 9N123K)
- *Cumulative effective aerial bombs:* These bombs use the powerful armoring effect of the molten metal stream formed during the compression of the metal coating of the specially shaped projectile by the explosive products as the main factor of destruction (e.g., JDAM).
- *Armor-piercing and concrete-piercing aerial bombs:* These bombs use the impact of kinetic energy and other factors of destruction on the target as the main factor of destruction (e.g., Brab500).
- *Incendiary aerial bombs:* These bombs use fire, flame, and separate sources of fire caused by the burning of combustible material as the main factors of destruction (e.g., Mk 77).

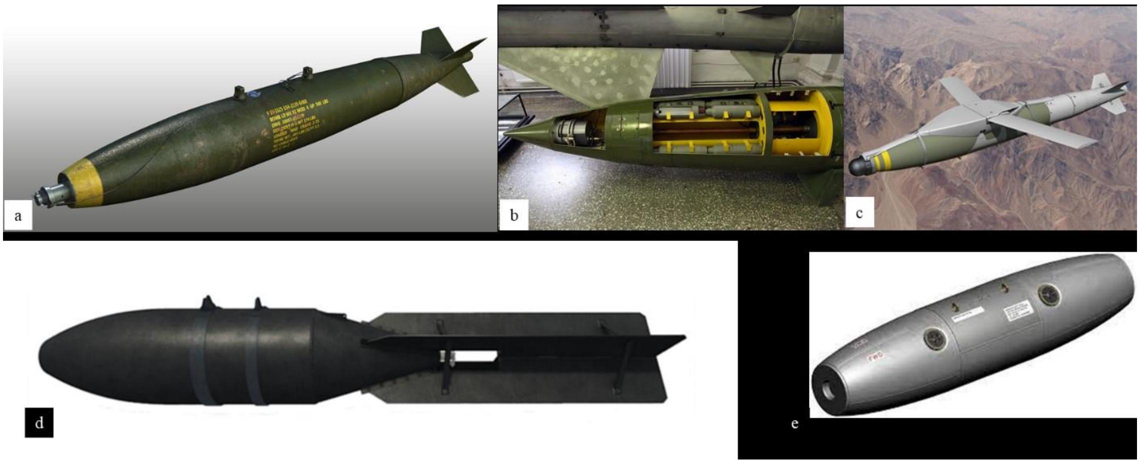

Figure 1.a. High-Explosive Bomb, **1.b.** Shrapnel Effective Bomb, **1.c.** Cumulative Effective Bomb, **1.d.** Armor-Piercing (Concrete-Piercing) Bomb, **1.e.** Incendiary Bomb (The Figure was Collected Based on the information) (Balagansky, 2022).

Depending on the target type, there may be anti-tank (cumulative) or anti-submarine (explosive) aerial bombs. However, many primary-purpose aerial bombs have a combined destruction effect, such as cluster-explosive, cluster-incendiary, cumulative-cluster, etc.

Cluster munitions with a fougasse effect are versatile aerial ammunition that can destroy a variety of targets, including enemy personnel on the battlefield or in concentration areas, aircraft parked in open areas or behind trenches, guided anti-aircraft missile positions, operational-tactical missiles, RLS, brick and reinforced concrete buildings, warehouse buildings, underwater and underground targets.

The effectiveness of cluster munitions is evaluated based on their general and unique characteristics of destruction. For example, the fougasse effect is assessed using criteria such as overpressure, the impulse of the explosion products, shock wave during the explosion in the air, as well as the radius of destruction and the dimensions of the hole created during the explosion on the ground. Shrapnel-effect munitions are evaluated based on the total number of shrapnel, their initial velocity, the fragmentation pattern of the body into shrapnel, and the laws of their flight in different directions.

Additional characteristics of shrapnel munitions include their ability to penetrate obstacles and ignite fuel, as well as the characteristics of the explosion of explosives or solid-fuel rocket engines. Cumulative-effect munitions are evaluated based on the armor-piercing thickness and the armor-back characteristics of the cumulative warhead, including the number of shrapnel produced after armor-piercing, their weight, velocity, and flight angles.

The unique characteristics of incendiary ammunition are the number of parts of the flame mixture (flame sources), their weight, temperature, and burning time, as well as their ability to ignite flammable materials, stickiness, incendiary effects, and the activation and destruction of burns.

Impact munitions have special characteristics related to their depth of penetration into various media (soil, concrete, etc.) and the thickness of the barrier being penetrated.

Aviation ammunition manuals and official reference books provide more comprehensive information on ammunition's special characteristics and appropriate formulas for calculating them.

This chapter discusses physical processes that lead to the formation of different types of destruction effects and provides numerical values for some unique characteristics, such as visibility.

The special characteristics of the destruction effect of aviation and its means of destruction form the basis for calculating their general characteristics. The extermination zone is used as a general characteristic. The target destruction zone is a particular conditional area of the target that, when hit, causes one unit of damage. The induced destruction zone is much larger than the target's ground frontal area for ranged munitions that can destroy a target upon detonation at some distance from the target (fougasse, shrapnel, and incendiary). For impact munitions capable of destroying the target by direct impact (cumulative bombs, anti-aircraft shells), the induced destruction zone is usually smaller than the actual area of the target.

In some cases, the average number of hits required is used as a generalized characteristic of impact munitions, which is equal to the ratio of the area of the target to the area of destruction delivered, which is equal to the sum of the areas of the easily defeated units of the target. Particular calculations determine the price of the generalized characteristics of impact ammunition. The main content of these calculations consists of assessing the dependence of the probability of destroying the target on the coordinates of the bomb's explosion point and, as a result, determining the average value of this probability (Ghose, 2004).

The numerical value of the characteristics of the field of destruction depends on several factors. These include the ease with which targets can be defeated, the degree of destruction required, and the conditions of combat training that determine the speed and angle of meeting the target. Additionally, the effectiveness of this or that type of destruction effect is also determined by the characteristics of ammunition.

The target's defeat characteristics include the various units that are easily defeated, the destruction of which would cause the target to be disabled. The degree of protection of each vital unit and their areas, as well as their location in the target area, are also important factors.

The degree of target destruction required is characterized by the time it takes for the target to lose its function as a combat unit. This time is determined by the tactical and strategic tasks set before the aviation that uses the given means of destruction.

The numerical value of the generalized characteristics of the field of destruction is based on several factors. These factors include the ease of defeating targets, the required degree of destruction, and the conditions of combat training. The conditions of combat training determine the conditions for meeting the target, such as the speed and angle of meeting ammunition. The characteristics of ammunition also play a role in determining the effectiveness of this or that type of destruction effect.

The target's defeat characteristics include the various units that can be easily defeated and whose destruction would cause the target to be disabled. The degree of protection of each vital unit, as well as their areas and location in the target's area, also contribute to the target's defeat characteristics.

The degree of target destruction required is characterized by the time the target loses its function as a combat unit. This time is determined by the tactical and strategic tasks set before the aviation that uses the given means of destruction.

The placement of guided missile units on and inside the body of a missile is called a missile assembly. It is divided into two parts, namely, the aerodynamic assembly and the structural assembly. The placement of control units, war supplies, engine units, power supply systems, and electrical systems inside the body of guided missiles is called constructive assembly.

The mutual placement of elements of systems that create aerodynamic control forces in the body is called aerodynamic assembly.

The constructive assembly should ensure the reliability of systems and units of guided missiles and bombs, convenient and safe operation, high production accuracy, and small weight and volume dimensions. The aerodynamic assembly should ensure proper control of guided missiles and bombs, which is characterized by balancing the missile at the maximum angle of attack and the static stability of the missile at all speed and height limits of the flight.

From a closer look at the assembly characteristics of a small-caliber missile in Figure 2 to a short-range air-to-air missile, a typical rocket of this class can be seen. It has a passive infra-red self-guided warhead and is designed with an axisymmetric "duck" aerodynamic scheme with stabilizer spoilers.

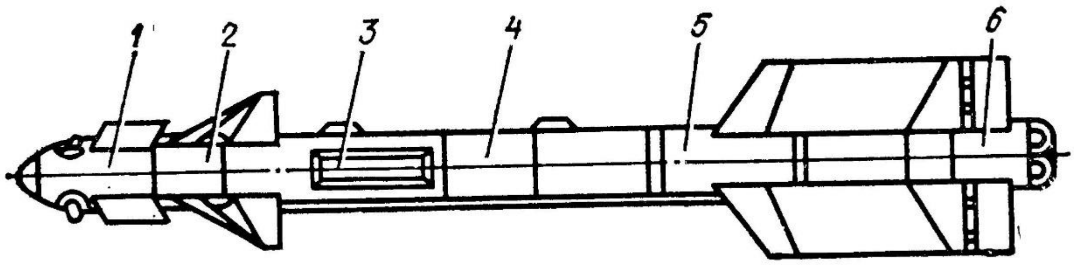

Figure 2. Small range "air-to-air" guided aviation missile (duck pattern) (The Figure was re-illustrated based on the information) (Shiyao, 2019)

1-infrared self-guided warhead; 2-rudder transmission, contact explosive device; 3-blocks of the autopilot, non-contact detonator, automation and switching block; 4-combat part and protective-executive mechanism; 5-solid fuel rocket engine; 6-rudder transmissions of ailerons, gas transmissions.

Structurally, these missiles consist of six sections. The first section is a passive-infrared homing warhead with an angle-of-attack transmitter and stabilizer disruptors mounted on the fuselage. The second compartment is a rudder on which a contact detonator is installed. In the third compartment, you'll find the blocks of the autopilot, contactless detonator, automation, and switching unit. The fourth section contains the fighting part and the protective-executive mechanism. The fifth section is a solid propellant rocket engine, and the sixth section is the steering gear of the autopilot.

Medium-range "air-to-air" guided missiles are also made in the "duck" aerodynamic scheme with axisymmetric and stabilizing spoilers. A typical assembly scheme of modern medium-range air-to-air guided missiles is shown in Figure 3.

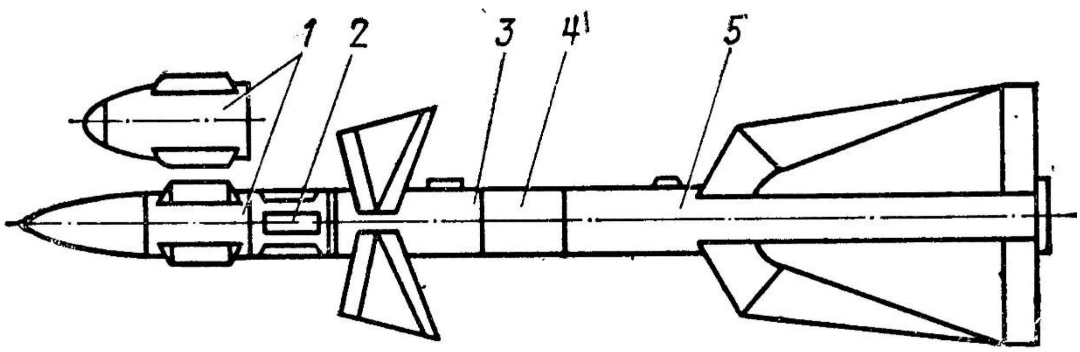

Figure 3. Medium-range air-to-air guided missile

1-Infrared or Radiolocation Self-Directing Head, 2-Equipment Section; 3-Steering Transmission and Feeding Unit, 4-Fighting Part, 5-Solid Propellant Rocket Motor (The Figure was re-illustrated based on the information) (Chadha et al., 2018).

This rocket is made up of six parts that are joined in an aerodynamic "duck" configuration. Stabilizers are put on an optical or radio-technical coordinator, which is the first section. The missile control units and radio detonator are in the equipment portion, which makes up the second section. The rocket's electrical power source and steering gear are located in the third portion. The battle section is the fourth division. An engine that uses solid propellants makes up the fifth part. The blaster's body has attached wings.

Figure 4 depicts a typical long-range air-to-air guided missile assembly system. There are four pieces to this missile. A multifunction control unit, autopilot hardware, a radio detonator, and a contact detonator are all included in the first segment. The missile's onboard digital computer (BRHM), semi-active radio technical target coordinator, and inertial unit comprise the control unit, which communicates digitally with the aircraft carrier. The combat portion and the protective-executive mechanism make up the second division. A solid propellant rocket motor (BYRM) makes up the third unit. The fourth section has a power supply system, a battery pack, and a steering gear and is covered with a nozzle extension. High tactical-technical features can be achieved with such an internal and external assembly.

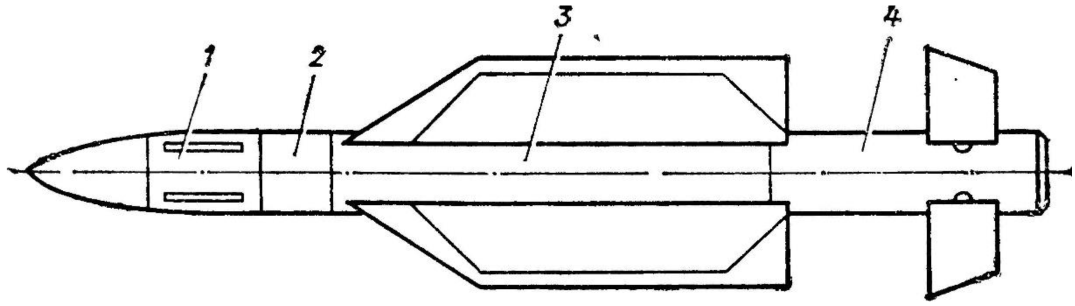

Figure 4. Long-range air-to-air guided missile

1-Multifunction Control Unit, 2-Fighting Part and Protective-Executive Mechanism, 3-Solid Fuel Rocket Engine (Byrm), 4-Steering Gear and Feed Unit. (The Figure was re-illustrated based on the information) (Jones, 2018; Altmann & Suter, 2022).

In tactical "air-to-ground" guided aviation missiles, they also differentiate between aerodynamic (external) and structural (interior) assembly. The items given below are all guaranteed by the constructive collection of such means of destruction.

- The effective destruction of the target due to the specific type, shape, and location of the combat element;
- The maximum reliability and survivability;

- The maximum simplicity and high technology of construction;
- The minimum weight with maximum compactness and slight displacements of the center of gravity during flight; the favorable working conditions of various units;
- The technicality of operation and access to aggregates;
- The modularity of the construction and the uniformity of the connections;
- The ability to be repaired;
- The application of modern materials adopted in the industry

The aerodynamic assembly of "air-to-ground" guided destruction vehicles should do the following: locate the rocket or bomb's wing; locate the areas and locations of the feathers within the rocket or bomb; The internal assembly, which is dependent on the aerodynamic scheme and depends on the fuel burning process breaking centrality (balancing), is closely related to the resolution of these problems. This is a look at some of the standard assembly procedures for modern "air-to-ground" tactical manned aircraft destroyers. Figure 5 shows a missile with a "duck" aerodynamic scheme that is controlled remotely via a radio command system.

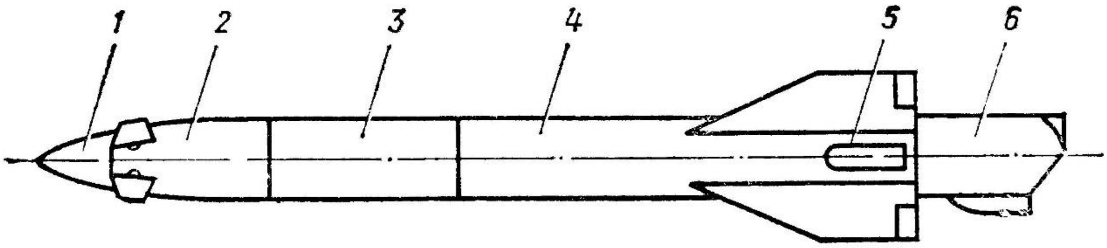

Figure 5. Tactical "air-to-ground" guided aviation missile

1-Ballistic Cone, 2-Steering Gears and Additional Measuring Devices, 3-Fighting Part; 4-Solid Fuel Rocket Motor, 5-Energy Department, 6-Management Unit (The Figure was re-illustrated based on the information) (Michal, 2021).

This rocket has a crisscrossed arrangement of its rudders and wings. The rocket's body has a cylindrical shape. There are six sections to the rocket. The ballistic cone is the initial portion. Additional gauges and the steering gear of the second portion. With fougasse and shrapnel, the third unit proves to be a potent combat force. An engine that uses solid propellants makes up the fourth part. The section on energy is the fifth one. The antenna and control signal generation equipment are located in the sixth portion, which is called the control section.

Figure 6 shows an air-to-ground guided missile with a special solid warhead. The thick-walled body of a conventional aviation bomb is used as a particularly robust warhead. Such missiles, as a rule, have a television or laser self-guidance system and are designed for the destruction of small, specially fortified targets.

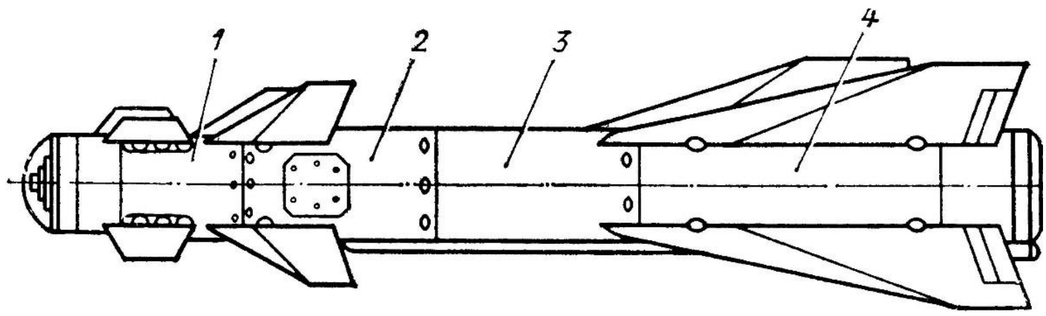

Figure 6. An air-to-ground guided missile with a special solid warhead

1-Television Coordinator; 2-Autopilot and Blasting and Feeding System; 3-Fighting Part; 4-Solid Propellant Rocket Engine and Aileron Block (The Figure was re-illustrated based on the information) (Roberts & Capezznto, 1999).

Figure 7 shows an illustration of a guided aviation bomb in assembly. The bomb consists of several parts that are put together in an aerodynamic scheme with stabilizers. These parts include the target's laser coordinator, the main conical shield that houses the electronic computing equipment, and the stabilizers. The tail section of the bomb contains a completed warhead, explosives, control units, a gas generator, a turbo generator, and steering gears.

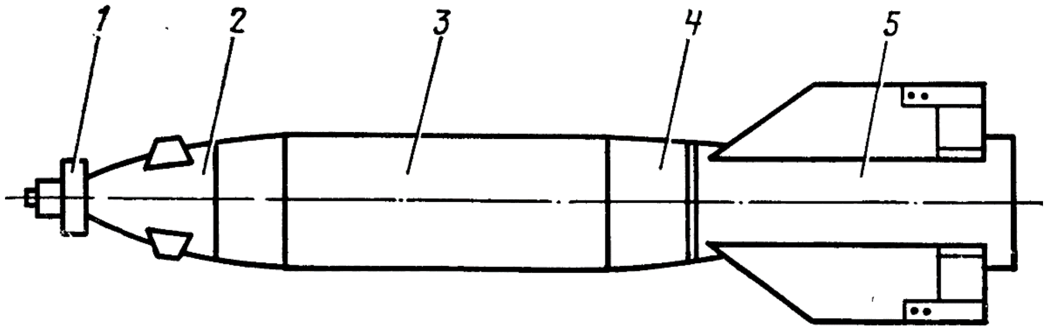

Figure 7. Controlled aviation bomb.

1-Target Laser Coordinator, 2-Conical Shield, 3-Fighting Part, 4-Contact Detonator and Control Unit, 5-Tail Part (The Figure was re-illustrated based on the information) (Kravchuk et al., 2021).

The weapon systems of strategic aviation aircraft include the Tomahawk-type missile, which is designed to destroy strategic targets located far from state borders. This missile is constructed using a conventional design and consists of missile wings and stabilizers, a power plant, a cooling system, an onboard control system, a static pressure receiving system, a warhead, and electrical equipment. The missile is powered by a turbojet two-stroke engine (TRIKM) and is equipped with a special warhead. The fuel supply, engine start, and regulation system includes a compact electronic regulator for controlling and adjusting engine modes. The electrical equipment comprises a power supply system with a turbo-generator and a control unit installed inside the engine.

The glider of the rocket consists of a body, a wing assembled (folded) with blocks and mechanisms, and a tail part. The body is divided into three parts:

- The front flow (shield).
- The middle part of the body (where the tank is located).
- The tail section.

The power plant includes a turbojet two-stroke engine, an engine starting system, and a fuel system.

It should be noted that the "air-to-ground" guided aviation missile is more complex, has many elements, and requires a lot of time to prepare for combat use. The diversity of such means of destruction is related to the large number of land and sea targets (Cressman, 1990).

The energy supply system of guided missiles (guided bombs) is designed to power the control system units and explosive devices after the missile is launched. The power supply system consists of a system for ensuring the operation of steering gears and a power supply system combined in a single power unit of the rocket.

Power units of short-range "air-to-air" guided missiles are designed to process stable voltage in terms of price and frequency and to supply working gas to steering gears. They consist of a gas generator, a turbo-generator, and a stabilization unit. Recently, heating-type disposable chemical current sources (batteries) activated using pyrotechnics are used as a power source. The batteries use a calcium-acid-tungsten electrochemical system with a solid electrolyte. Such a power source does not require voltage stabilization.

The power units of medium- and long-range air-to-air guided missiles are similar and integrated into the power unit. The following units are placed inside the power unit: gas distribution furnace with a power source, Stabilizers, and gyro motor power source assembled block. In the rear part of the gasification furnace, a heat-insulating cover is attached, which protects the engine igniter from overheating at the start of the gas generator. The primary energy source is the gasification furnace, equipped with a gas generator and a turbo-generator with an electro-gas valve. Stabilizers include an assembled block charge choke, a diode rectifier, and a circuit board.

The working principle of the stabilizers is that with the change in the voltage of the turbo-generator (or with the change in the current in the load), the inductive resistance of the working windings changes. As a result, the stability of the voltage of the load (energy consumers) is ensured. It is set to convert to two-phase voltage, which is essential for

"Air-to-ground" controlled means of destruction use power units with a concentration of electrical power sources and gas systems, which use air (pneumatic system), and gas produced by burning gunpowder cartridges (hot gas system) as a working source. Electric batteries are often used as electricity. The battery is assembled in a stainless-steel body and closed with a lid made of this material. The lid has five hermetic outlets. As an alternating current source, the rocket uses a power source that converts direct current into alternating current, which is vital for powering the gyro-motors of the autopilot and the target coordinators. Pneumatic systems are widely used to provide compressed air for rudder drives and aileron drives in "air-ground" controlled destruction vehicles, to maintain the angular speed of rotation of gyroscopes' rotors, as well as for locking gyroscopes, accelerometers, and rocket rudders. The pneumatic system of the missile consists of a pneumatic block, three-mouthed pipes, conductors, a collector (a channel that collects and transports liquids or gases), a discharger, arresters, and pipelines as shown in Figure 8. The cylinder of the pneumatic block is filled with compressed air at the factory. When voltage is applied from the carrier to launch the rocket, air is injected from the balloon into the pneumatic system. The air system can also be set to maintain the bulb battery's operating mode and cool the target conductor.

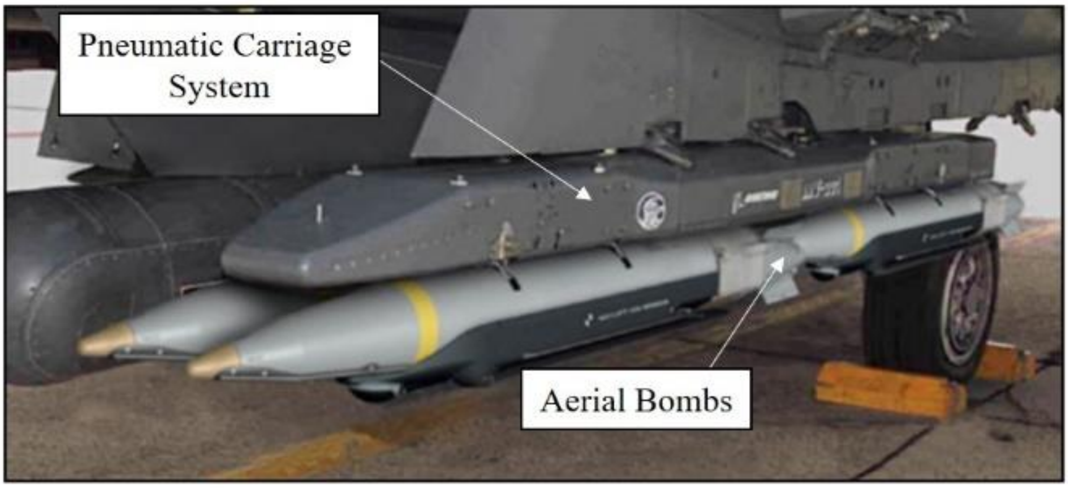

Figure 8. A Pneumatic Multi-Stores Carriage System Installed on Aircraft (The Figure was re-illustrated based on the information) (Nadar, 2014).

Packing, marking, and coloring of guided missiles and guided bombs are very important activities. Controlled aviation destroyers and their components are delivered to military units from crates and cemented metal containers from the manufacturing plants. Removable wings and rudders can be assembled in these containers or separate boxes. Destroyer components, manufactured separately in the industry, are collected in the designated boxes. Protection-executive mechanisms, detonators, igniters, tracers, pyrotechnic means, and other elements for controlled aviation destruction can be sent in single-use metal boxes or multi-use hermetic jars (Chesneau, 1980).

Containers are intended for long-term storage of missiles equipped or unequipped and for transporting missiles in them. They allow rockets to be used multiple times in dry and wet climates, in various unsuitable conditions, etc. they provide. Inside the hermetically sealed container, an air environment is created and maintained, depending on the ambient temperature, under excess pressure conditions, and dried up to the specified boiling point. Airtight shipping containers and crates can be bundled with unique packing materials.

Marking of guided missiles is usually carried out in the following order: factory code, type of product, quarter and year of release, serial number of the product in the series or batch.

1. MATERIAL AND METHODS

The main characteristics of aerial ammunition include the size of the bomb, the filling factor, ballistic characteristics, the characteristics of the destruction effect or the effect created, and the range of conditions of combat application.

The caliber of aerial ammunition is the nominal weight of an aviation bomb expressed in kilograms, for which the limits of the main volume-weight characteristics (mass, diameter, length, and size of the stabilizer when open) are set.

The bomb pattern mainly determines the degree of damage inflicted on the target or the effectiveness of the task being solved. Several standard prints are used for modern aerial bombs. 0.5, 1.0, 2.5, 5.0, 10, 25, 50, 100, 250, 500, and 1,500 kg and older bombs are available in 3,000, 5,000, and 9,000 kg.

The caliber of an aviation bomb is indicated by its conventional name, for example, OAB-10 (10 kg caliber). If the actual mass of the air bomb differs from its print by 10-15%, this difference is indicated in its conventional name: for example, OFAB-100-120-shell fuze air bomb print 100 kg weight 120 kg.

Suppose there are different types of aerial bombs of the same type and caliber, which differ in their structural or other features. This is also indicated in the conventional name, for example, FAB-500T 500 kg thick-walled fuga bomb.

The loading factor is the ratio of the mass of the combat supply (significantly the explosive charge) to the total mass of the aerial bomb. The value of the filling factor for air bombs can be in the range of 0.1-0.7 and mainly depends on the type of air bomb. For example, the filling coefficient of concrete-piercing aerial ammunition is 0.1-0.15, and that of fougasse aerial ammunition is 0.4-0.5.

The filling factor mainly determines the destructive effect and effectiveness of a given type of aviation bomb.

The ballistic characteristics of aerial ammunition determine the ballistic characteristics (aerodynamic characteristics) of an aviation bomb. Ballistic characteristics strongly influence bomb trajectory quantities, and these characteristics are factored into sighting devices when determining aiming angles.

Assault bombs differ from other bombs (explosive, shrapnel-explosive) by the presence of a braking device, which uses a parachute as a braking device. This is explained by the fact that when bombs of a conventional design are dropped from low altitudes, they lag behind the plane at a very small distance and approach the earth's surface at a very small angle. Therefore, when using air bombs with instantaneous action explosives, the shrapnel separated from the explosion can fly to the front of the aircraft and damage the aircraft, which means that the safety of the aircraft is not ensured during combat use. For this reason, the firing of conventional bombs from low altitudes is possible with explosives with an attack delay of 10-240 seconds. However, in this case, accurate bomb shooting is not obtained because the bomb misses the target; the bomb moves several hundred meters away until the detonator is detonated.

In addition, considering evasion in aiming does not ensure accurate bombing because the deviation in the evasion time depends on many external influences; that is, the deviation itself is a random quantity. In addition, when the aerial bomb approaches the earth's surface at a small angle and when it is deflected, the effect of the bomb on the shrapnel decreases to some extent. This result is explained by the fact that the main part of the shrapnel of the body of the cylindrical bomb flies in a narrow-angle area (Figure 8.) with a width of ψ=15-200, which forms an angle of about 900 with the longitudinal axis of the bomb. Therefore, when an aviation bomb explodes vertically, the destruction of ground targets can be shown as a circle with a large radius Rn. Still, when approaching the earth's surface at a small angle or when an aviation bomb explodes during a roll, in which the bomb is still in a horizontal position or close to it, the indicated destruction area drops suddenly. It is limited by two circumscribed circular regions, as shown in Figure 9, whose angular width is approximately equal to the width of the shrapnel flight region.

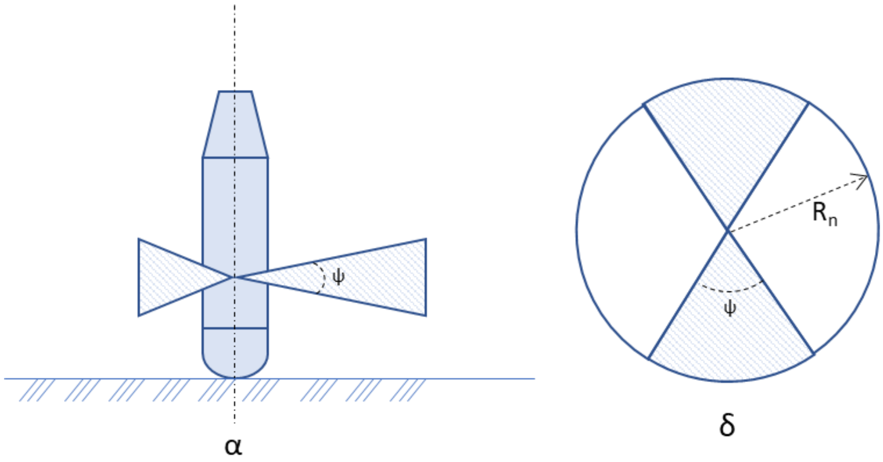

Figure 9. The destruction zone of an air-locked fuga bomb

a-Large Approach Angle; b-Small Approach Angle (The Figure was re-illustrated based on the information) (Krawczyk & Tomala, 2014).

The braking device reduces the speed of the aerial bomb due to some additional friction (braking) created, which ensures that the bomb lags behind the aircraft and allows the aircraft to move away from the point of impact of the bomb. The braking device increases the angle of the bomb falling on the surface and ensures effective destruction of the target with shrapnel.

Braking devices can be of different constructions or have different working principles, but attack bombs mainly use a parachute. The parachute is placed in a metal container together with the device that moves it, which is installed in the tail part of the bomb at the factory (Fig. 6a) and is considered an integral part of the bomb. The cords of the parachute are connected to the fuse mechanism of the detonator, which prevents the sudden detonation of the bomb and the activation of the detonator if the braking mechanism fails.

During normal operation, the parachute bomb is released into the air stream after 1-2 s by the team of the detonator after it is ejected from the aircraft. To ensure the safe and effective firing of conventional bombs of the old design at low altitudes, installed braking devices are used, which are installed on the bomb immediately before combat use. Installation braking devices is a thin-walled cylindrical container 4, which is connected to a parachute 5 to the bottom eye of the bomb with a cardan 1, flat washers 2 and a nut 3. Release mechanism 6 serves to move the device, which is connected to the launch of the detonator from the flying machine (Deng & Wang, 2005).

Volume detonation aviation bomb ODAB-500 destruction of manpower and lightly armored equipment (aircraft and helicopters in open stands, various types of radio location stations, automobile equipment, etc.) as well as manpower and equipment in open storage (trenches, defensive positions, etc., ensures high quality in the making.

ODAB-500 consists of a thin-walled body 1, a combat supply 2, which uses high-calorie liquid fuel with several auxiliary dispersing explosives 3 added as a supply, a brake parachute container 5, and a second detonating explosives.

Upon encountering an obstacle, the dispersive explosive substance is first activated by the command of the detonator; the body disintegrates, disintegrates, and the liquid fuel is dispersed due to the effects of the components obtained as a result of the explosion.

During dispersal, liquid droplets vaporize and, when mixed with air, form an explosive cloud of air-fuel mixture, the size of which depends on the pressure of the bomb. When the size of the cloud reaches a certain size, there is a second detonating explosive charge, which detonates and creates a detonation of the air-heat mixture throughout the entire volume of the cloud.

Classification and components of aviation artillery installations. The set of devices placed in flying machines and serving the effective use of artillery weapons are called aviation artillery devices. These devices ensure the attachment of the weapon to the flying machine, supply cartridges, direct the weapon to the target, remove the case and sleeves, and perform other operations related to the movement of the weapon.

The classification of devices is done primarily according to the degree of displacement of the weapon relative to the aircraft, the location of the device, and the method of attachment to the aircraft.

They are divided according to the degree of displacement of the weapon relative to the aircraft;

- Moving devices
- Fixed devices.

Fixed devices are called devices that maintain the weapon's position when installed and reset. Aiming the gun at the target is performed by maneuvering the flying machine. Due to their combat application characteristics, fixed devices are offensive. Fixed devices are used in the armament of fighters, fighter-bombers, and, in some cases, bombers (Dodson, 2005).

Movable devices are those in which it is possible to shoot from the weapons installed in them in a direction other than the direction of the shooting devices. Movable devices make it possible to complete or replace the maneuver of the aircraft with the firing maneuver. Aiming the weapon is performed by a crew member (shooter) not involved in the flight. Steep mounts are the only type of mount for heavy bombers and military cargo aircraft, as these aircraft have low agility. Front-line bombers can have both movable and fixed mounts.

It should be noted that the structure of both devices are significantly different and are determined by specific characteristics: the type of aircraft, the number and type of weapons, the location of the device on the plane, and the degree of mobility of the device, as well as from the kind of control system.

According to the device's location in the aircraft, it is divided into two parts: artillery mounted on the body and on the wing. The fuselage-mounted devices are mainly placed under the nose of the fuselage. It is one of the main types of equipment for fighter planes. However, due to the limited number of installations in the aircraft's body, the cannons can also be placed in the wing base of the flying machines. It should be noted that wing devices are used in individual cases in fighter and fighter-bombers, and in bombers, only body-mounted devices are used.

According to the attachment method of flying machines, they are divided into mounted and suspended devices. Mounted devices are permanently attached to aircraft.

Suspension devices are temporarily attached to the aircraft, which directly reinforces the artillery weapon system of the aircraft during the designated combat flight.

Hanging artillery installations further expand the combat capabilities of the flying machine, making them more applicable. Containers with cannons are attached to airplanes, along with bombs and missiles.

The main components of the equipment are the following: the carriage, the system of supplying the cartridges with electric current, the reloading system, and the power transmission.

The above components apply to all installations, i.e., fixed and movable installations. Power transmissions are additionally available in moving units. Power transmissions are designed to drive the weapon relative to the aircraft. Electric and hydraulic power transmissions are primarily used in operation.

Main units and systems of artillery installations. A mount is a power structure designed to attach a weapon to an aircraft and transfer all forces acting on the weapon to the aircraft structure. The carriage of the stationary unit keeps the weapon in a given position during assembly and reset. The carriage of the mobile device must ensure that the weapon can be turned in any direction within the firing zone.

The carriage consists of a body and joints that ensure rotation and fastening of the weapon. The body of the carriage is considered the main power element of the carriage. It is intended for connecting the device to the flying machine. The rest of the elements of the carriage are placed in the body - the power transmission device, the system of supplying the cartridges with electric current, and other devices that ensure the regular operation of the device.

The swivel joint only applies to the movable unit and allows the weapon to rotate in any direction during firing in the firing zone. The connection of the turning joint elements with each other and the chassis is carried out directly with different types of bearings and on the power transmission.

The core of the carriage and the rotary joint form a structure that is determined by the degree of movement of the device, the type of weapon mounted on the aircraft, and the device's location on the air vehicle.

The working principle of the turret top assembly is as follows. The weapon is held in the "kachalka" 4 with front 2 and rear 3 fastening nodes, as provided in Figure 10. Through the Kachalka transmission 7, the moving ring 8 is set to rotate around the O-O the axis of the transmission motor 5. The movable ring is rotated by the motor 6 in the fixed ring 9. A fixed ring secures the device to the aircraft (Evans & Peattie, 1997).

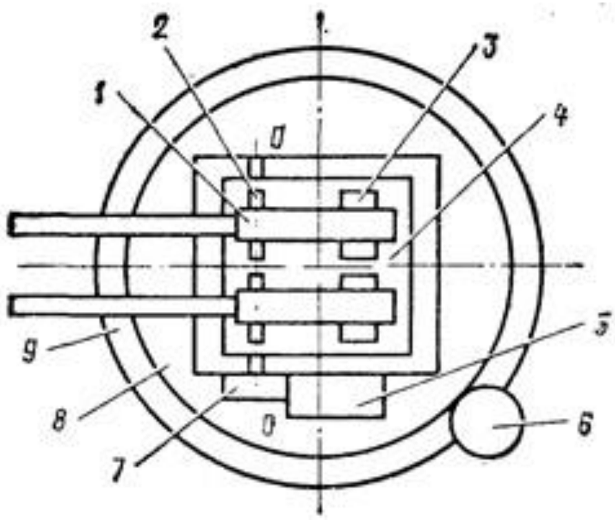

Figure 10. The top device of the circular rotation

1-Gun, 2-Front Mounting Assembly, 3-Rear Mounting Assembly, 4-Carrier, 5-Vertical Aiming Motor, 6-Horizontal Aiming Motor, 7-Gear (Reducer), 8-Moving Ring, 9-Fixed Ring

The basis of the "Lafetinarcha" device is post 1, as seen in Figure 11, in which the front fastening joint 2 rotates on the pads. A movable ring 3 rotates inside the pole on which the weapon is mounted. Weapon mounting joints ensure that the weapon is fixed to the carriage and directly receives all the forces from the side of the weapon, as well as ensure the adjustment of the position of the weapon in the installation. The device has two attachment joints for each weapon, one of which is the base and the other is the retainer. The main joint holds the gun in the shock absorber and the keeper directly behind the gun body. The main joint receives forces in three directions: longitudinal and two transverse directions. During firing, the weapon changes its position in the longitudinal direction, so the retaining device is installed in such a way that it prevents the weapon from changing its position in this direction. In addition, in order to ensure the angular displacement of the weapon in necessary situations, the holding device is made in an adjustable structure.

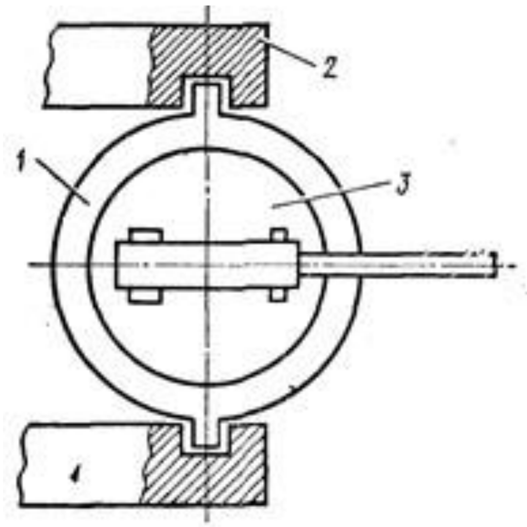

Figure 11. Lafetinarcha (branch) device

1-Pole, 2-Upper Fixed Bracket; 3-Moving Ring, 4-Bottom Fixed Bracket

The device for supplying cartridges to the weapon is designed to supply cartridges to the receiver of the weapon, as well as to remove spent casings and cartridges. Modern supply systems are divided into tape and comb.

In the tape supply system, cartridges are loaded onto tapes with the help of cartridges. In general, a belt system consists of a cartridge case, transfer arms, case and cartridge pullers, case and cartridge accumulators, and cartridge pull mechanisms.

The complexity of the tape supply system depends on the degree of mobility of the weapon, the assembly scheme of the device, and the ability to safely eject the cartridges and cartridges from the aircraft. Simpler systems are systems for securing fixed installations (Ewing, 2004).

If the weapon has two degrees of freedom, then the securing system is considered the most complex. Such systems have rigid and flexible drive arms and a motor for pulling the cartridge tape.

The traction motor is designed to facilitate the operation of the transmission mechanism, which fulfills the working conditions that are motivated by the large friction of the transmission arms during the movement of the cartridge tapes. They engage when the shooter presses the battle button.

The operation of the ball feeding system, for example, in the upper unit is as follows. Cartridge tape 1 is transferred to ball 2 from cartridge box 6, which is firmly fixed on the movable ring 7 of the frame of device 3 with a solid sleeve 4. A hammer motor 5, which moves the cartridge tape, is attached to the solid arm.

Cartridges are fed into the device by means of a cartridge hammer 9, and shells are fed into the device by means of a cartridge hammer 10, from where they are dispersed into a stationary hopper 8, which serves as a shell stacker and a cartridge stacker.

The external drum 2 of the comb system is shown in Figure 12. stores cartridges and spent shells. Cartridges and shells are held by longitudinal guides from the rear of the outer drum and from the rear side of the cylindrical part by three spiral protrusions of the inner drum. When firing, the inner drum rotates and transfers the cartridges to the output joint 1, which is collected in the transporter. Cartridges are transferred to the ball 7 with the transmission lever 8 of the conveyor. The fired shells' transportation and placement in the drum is performed by the hammer arms 5 and the output connection 4 of the transporter.

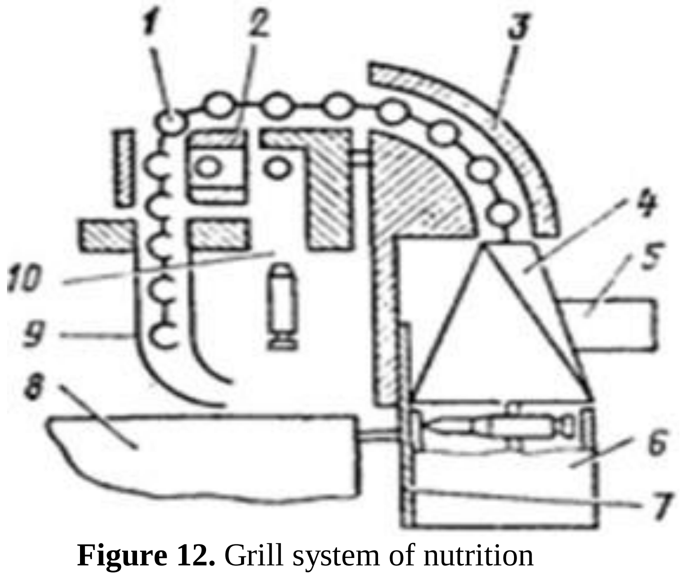

Figure 12. Grill system of nutrition

1-Cartridge Tape, 2-Ball, 3-Moving Ring, 4-Arm, 5-Traction Engine, 5-Box, 7-Rama, 8-Bunker, 9-Manga Hammer, 10-Shell Hammer.

The conveyor is moved from the input device to the output device by the drive arm 6. The transmission of the carrier and the internal drum is carried out from the motor of the ball, which is essential to ensure the coordinated (joint) operation of the gun feeding system].

During the take-off of the aircraft to eliminate accidental shots, the final preparation of the weapon for the first shot is performed by the reloading system in the air, which eliminates delays during the shot and activates the cannon's mechanisms.

Reloading is the process of performing a series of operations of the mechanisms of gunpowder-gas-powered conventional and drum-type weapons using energy from an external source. During reloading, the unfired cartridge in the ball cartridge is discarded and replaced by the next cartridge.

The reloading system includes a reloading mechanism and a power source, which is considered the structural mechanism of the ball. Recharging systems differ according to the type of energy used. Two types of reloading mechanisms are most commonly employed: pneumatic and pyrotechnic. The type of system is selected depending on the weapon's characteristics.

The pneumatic recharging system receives compressed air from the onboard source of the aircraft through reducer 1, rotary joint 2, and counter valve 3, as shown in Figure 13.

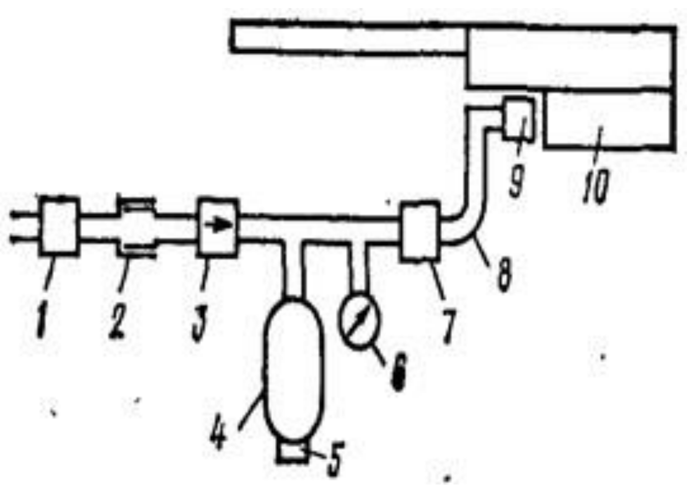

Figure 13. Pneumatic refill system

1-Reductor, 2- Turning Joint, 3-Reverse Valve, 4-Balloon, 5-Protective Valve, 6-Manometer, 7-Electropneumoklapana, 8-Pipe Transmitter, 9-Switch Valve, 10-Refill Cylinder.

The reducer reduces the pressure of the onboard air source to the working pressure of the mechanisms of the pneumatic recharging system. The rotary joint supplies the air pressure to the moving elements of the unit. The check valve ensures that the air supply in cylinder 4 is maintained when the pressure in the onboard source decreases. In the balloon unit, the reserve is important for air generation and use during refilling.

The pressure in the system is measured by manometer 6. Safety valve 5 releases excess air when the pressure in the cylinder exceeds the norm.

Opening and closing the air supply to the refill cylinder 10 is performed by an electro-pneumo-valve, which is actuated by the refill control system by a switch valve 9. When air is supplied for refilling, the bypass valve securely connects the refill cylinder and the tube actuator 8. When the air supply stops, the bypass valve opens wide, accelerating air release from the refill cylinder and reducing the refill time.

In the pyrotechnic reloading system, the energy of the gunpowder gases of the pyro cartridges activated by the reloading control system is used for reloading.

The advantages of the pyrotechnic reloading system are as follows: -lightweight, simple structure, and high reliability.

The main disadvantage is the limitation of the number of reloads performed during one flight in the air (which is determined by the number of pyro-cartridges).

Power transmission of moving devices. The power transmission of mobile artillery units performs the rotation of the weapon relative to the flying machine in flight. It should provide tracking of the target under conditions of non-constant external influences (aerodynamic, kick and inertia, continuous and large changes in the angular velocity of the target line).

The power transmission must work reliably under strong vibrations associated with shooting; it must have great strength so that the affected parts of the device do not lead to more scattering of projectiles during shooting. High-altitude and high-speed flights of modern flying machines create unfavorable conditions for cooling transports. To those listed above, adding the requirements of small weight and volume dimensions is necessary.

Two types of transmission mostly meet the requirements listed above:

- Electric power transmission with an electric machine amplifier;
- Hydraulic power transmission with wide adjustment.

Electric power transmission with an electric machine amplifier is built into a generator-engine system. The motor armature is fed only from a separate direct current generator - an electromechanical amplifier (EMG). The signal to the excitation loop of the amplifier of the electric machine is given in the form of voltage. The core of the generator of the electric machine amplifier rotates with the engine of the generator at a constant speed. In the loop of the armature, an electric motive force corresponding to the magnetic flux of the control loop is generated. As a result, a voltage is generated at the generator's output, which is supplied to the propulsion engine and rotates the weapon.

DC motors are widely used as transfer motors. The main requirement for direct current propulsion motors of artillery installations is that the rotation speed does not depend on external influence.

2. BALLISTIC CHARACTERISTICS OF AERIAL AMMUNITION

In general, the ballistic characteristics of aerial ammunition are determined by their mass m and characteristic area S. The dependence of the S-like cross-sectional area and the frontal resistance on the number M=cx(M) is taken. However, for convenience in practice, instead of these indicators, any generalized quantity is used, which is the ballistic characteristic of an aviation bomb. With this in mind, one of the following quantities is currently used as the ballistic characteristics of aerial ammunition.

Ballistic coefficient is given in Equation 2.

$$c = \frac{\dot{\mathrm{I}} d^2}{m} 10^3 \quad (1)$$

where d is the maximum diameter of the aviation bomb; $\dot{\mathrm{I}} = \frac{C_x(M)}{C_x{}^e(M)}$ is the form factor of the aerial bomb;$C_x(M) = \frac{v}{a}$, is the dependence of the given aerial bomb impact on the number M; $C_x(M)$-M is the standard of cx from the number is dependent, the group is the same for aerial bombs and is also called the law of friction; v is the speed of the air bomb in its trajectory; a is the speed of sound.

An example views of dependences cx (M), C_x e (M), and i (M) is shown in Figure 14. It can be seen from here that it depends on the number M in i, but always the average value of the intervals (ranges) of changes in the air of the given aerial bomb M is taken.

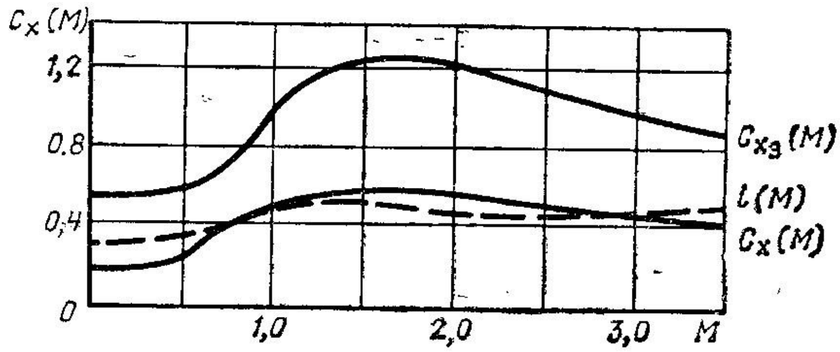

Figure 14. View of dependencies of cx (M), C_x e (M) and i (M)

The characteristic time is defined as the time of fall of a bomb dropped from an airplane flying horizontally at a speed of 144 km/h (40 m/s) at an altitude of 2000 m under normal atmospheric conditions.

Characteristic speed - the value of which is determined as given in Equation 2.

$$\upsilon_A = \sqrt{\frac{2mg_0}{S\rho N_0 C_{x0}(M{=}0.4)}} \quad (2)$$

Where g_0 is the acceleration of gravity at sea level, No is the normal density of air at sea level.

There is a certain functional dependence between all these quantities; when one of them is known, the rest can be calculated. It can be said that the smaller the diameter of the air bomb and the larger its mass, or if its head is designed to reduce air resistance during movement, the value of the ballistic coefficient will be smaller, as depicted in Figure 15.

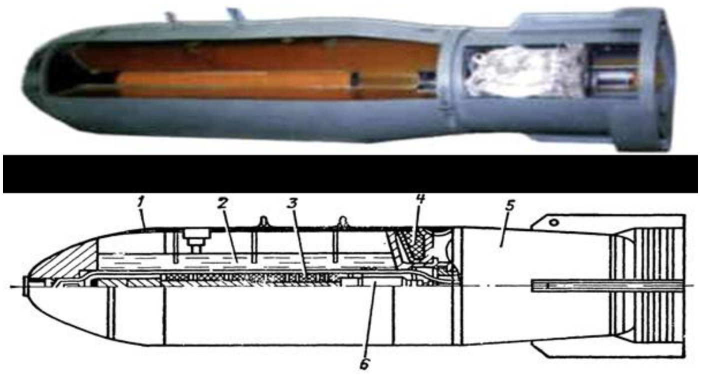

Figure 15. Typical scheme of volume detonation aviation bomb ODAB-500) (Krishnamoorthy et al., 1997).

1-Trunk, 2-Supply, 3-Dispersive Load, 4-Second Cargo (Landing), 5-Parachute Container, 6-Explosive.

The difference between ODAB-500 with the same cap and the usual FAB is explained by the fact that in ODAB-500, the supply's energy is used more efficiently. Indeed, when ordinary solid explosives detonate near the detonation point, a high-energy mixture (the pressure of the explosion products is 150-200 thousand atmospheres) is formed, rapidly decreasing as the shock waves at the detonation point move away.

As a result of the explosion of the fuel-air mixture, less pressure (20-30 atmospheres) is created, but it covers an area equal to the radius of the created cloud, thereby increasing the ability to destroy practically any target (airplanes and helicopters in open stands have a pressure of 0.3-0.4 atmospheres they take average damage from shockwaves). Thus, a sufficiently high pressure is created within the dimensions of the fuel-air mixture cloud, outside of which shock airwaves are produced, which can destroy targets.

In addition, the fuel-air mixture in the process of cloud formation leaks into trenches and covered spaces and fills areas under trees, which increases the destruction capability of ODAB.

The latest advancements in bomb technology exemplify a strategic shift from conventional large-yield munitions to compact, precision-guided bombs with sophisticated capabilities. A key breakthrough is the development of Small Diameter Bombs (SDBs), which can strike targets with unparalleled accuracy from considerable distances, thus significantly minimizing collateral damage. These bombs leverage GPS, inertial navigation, and laser guidance systems for pinpoint precision. Moreover, their programmable fuzes facilitate airburst, delayed, or ground-penetrating detonations, offering adaptability to engage various targets effectively. Going beyond precision, integrating networked capabilities in munitions signifies a groundbreaking advancement. Weapons like the Small Diameter Bombs are equipped with datalinks, enabling mid-flight targeting updates and mission adjustments, substantially reducing the risk of unintended casualties (Elert & Sokołowski, 2018).

Furthermore, the future of aerial bombs revolves around modularity, aiming to create bombs with interchangeable seeker heads and warhead sections. This innovative approach allows a single aircraft to engage a diverse range of targets by interchanging components easily, from armored vehicles to fortified bunkers. Ultimately, these technological advancements underscore a departure from sheer destructive capabilities and a deliberate focus on enhancing precision, versatility, and discrimination- a definitive testament to the evolving landscape of modern warfare.

3. DISCUSSIONS

Although there are many different types of aerial ammunition, most of them have a similar structure, as shown in Figure 16. A typical aviation bomb consists of body 1, combat equipment 2, suspension lugs 3, and stabilizing device 4.

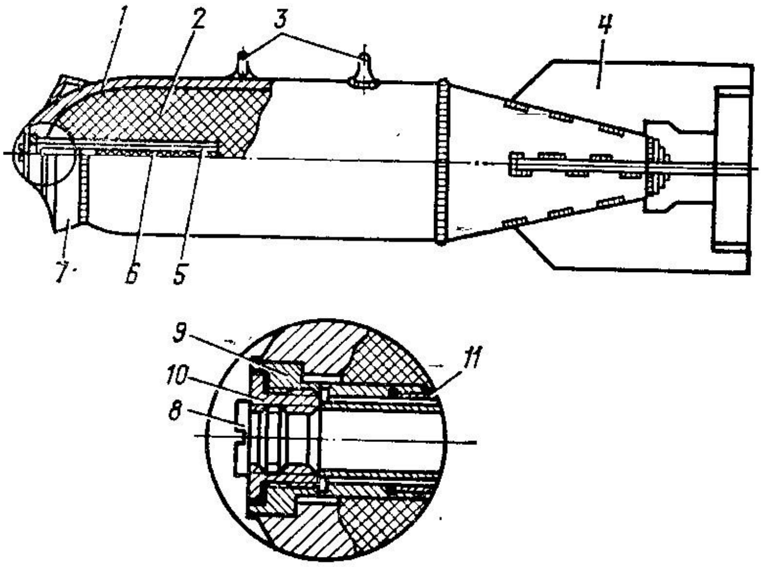

Figure 16. Structure of a typical aviation bomb:

1-Trunk, 2-Combat Supplies, 3-Hanging Headphones, 4-Stabilizing Device, 5-Wick (Detonator) Cup, 6-Additional Detonator, 7-Ballistic Circle, 8-Cover, 9-Head Carving, 10-Transient Carving, 11-Wick Cup Tube) (Momcilo, 2015).

The body is designed to combine all the elements of the aviation bomb in one unit and to accommodate combat supplies. The strength of the body should ensure the ability to combat the application, storage, and maintenance of the bomb. Usually, according to the body's structure, it consists of head, middle, and tail parts, and they are connected to each other by welding. The head part is made in two intersecting cones in half space. The shape and dimensions of the warhead strongly influence the aerodynamic characteristics of the bomb, especially against drag. The warheads of aerial ammunition designed to penetrate solid obstacles are made of significantly stronger material. Most small-caliber aerial ammunition has a threaded hole in the head corresponding to the detonator groove's diameter (the groove's diameter is 26mm). In large-caliber aerial ammunition, a fuse (detonator) cup 5 is installed on the head, which consists of a head recess 9, a transient recess 10, and a fuse cup tube 11. The diameter of the head and transitional recesses ensures the connection of detonators with a groove of 36 and 52 mm to the bomb. An additional detonator (incendiary bullet) 6 is placed in the fuse cup, which causes the explosion (fire) impulse to increase (Holmes, 1979).

The middle part of an aviation bomb is cylindrical. The thickness of the wall may vary depending on the purpose (type) and print of the bomb.

In the middle part of the body, the ears of the suspension system 3 are fixed.

The tail part of the fuselage is made in the form of a cone, which improves the ability of the bomb to break the airflow and the reliable operation of the stabilizers.

Most large-caliber bombs have one or two threaded fuse cups installed in the tail section for detonators. Sometimes, the wick cup is also installed on the side.

A metal or plasma cover 8 is attached to each threaded eyelet to protect detonators and explosives so that the threaded eyelets are not damaged and moisture and foreign elements do not fall into the detonator cups (Hakim, 1995).

The body of most bombs is made of steel plate by welding. The body of most bombs is typically constructed using steel plates that are welded together. In some cases, to ensure high strength, the body of aerial ammunition is made using cast (steel, steel cast iron) or seamless sections of steel tubing.

The stabilizing device (stabilizer) gives the bomb the necessary stable motion in the air after launching it. An aviation bomb is considered stable when, during the fall, its axis tries to coincide with the velocity vector, which continuously changes its position in space due to the free fall momentum.

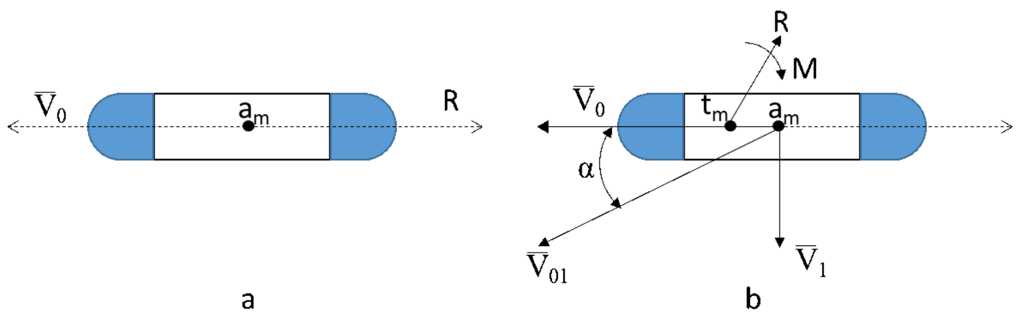

Figure 17.a. Initial Moment After the Launch of an Aerial Bomb Without a Stabilizer, **17.b.** The Vertical Velocity Component

Figure 17.a is the initial moment after the launch of an aerial bomb without a stabilizer during the horizontal flight of the aircraft. In this case, the velocity vector of the bomb, which is equal to the speed of the plane, $\overline{V}0$, is directed in the direction of the axis of the bomb, and the frictional force of the air acting on the bomb is directed in the opposite direction. After some time has passed, the vertical velocity component $\overline{V}1$ as shown in Figure 17.b is added to the initial velocity vector of the air bomb due to the release acceleration, and the velocity vector of the bomb relative to the air $\overline{V}01=\overline{V}0+\overline{V}1$ will deviate from the axis of the bomb by several angles of attack α.

When the angle of attack is formed, the aviation bomb is not located symmetrically concerning the air stream flowing along the vector $\overline{V}01$. Therefore, the air resistance in $\overline{R}$ will no longer be directed along the axis of the bomb but will form an angle of several degrees with it. The point of action of this force, i.e., the center of pressure for an axisymmetric oblong bomb, is located in front of the center of mass of the aerial bomb, and the force R will create a pitching moment M relative to it, which will try to increase its angle of attack. Under the influence of this moment, the bomb will start to spin as it falls. A spinning aerial bomb does not allow out an aiming bomb, as its trajectory and the point of final drop depend on many factors that cannot be taken into account when aiming. When the bomb is dropped from the plane, it already has an initial angle, which makes it even more challenging to aim.

3.1. Safety Rules During the Operation of Aerial Ammunition

1. Working with aerial ammunition is dangerous; therefore, during these works, essential conditions must be created that comply with technical safety rules, fire safety, and labor protection rules. Technical safety regulations must be followed in all cases.

2. Persons who know the structure and working principle of aerial ammunition, the rules of preparation for their combat application, who have studied the management of storage and protection of aviation ammunition, the relevant technical and safety regulations, who have passed special training and passed the approval, are allowed to work in aerial ammunition.

3. It is prohibited during the operation of aerial ammunition:

- To drop, press, or hit aerial bombs on tarred or untarred, as well as to drag or roll them on untarred soil or concrete
- Loading bombs without a lift by sliding
- Slide the aerial bomb onto the tarred soil or concrete
- Placement of bombs under power lines
- Carrying out the loading of aerial ammunition in faulty tanks, repairing the tank when there is a bomb inside the tank
- Overloading of transport equipment intended for the transportation of aerial ammunition
- Dismantling of aerial ammunition
- Sliding of the ball hook of the electric release device of the software switching mechanisms on the rack of the impulse transmitter mechanism of the bomb handle during the hanging or removal of the bomb
- Use of bombs with electric release devices with damaged wires
- Standing on the stabilizer side of the bomb when the ball hook of the electric release device is transferred to or removed from the impulse mechanism of the bomb handle
- To drop a bomb without making sure that the plane's bombing system is completely disconnected from the electrical network when the bomb is dropped
- To connect the electrical circuit of the bombing system after the bomb is hung until combat application.

Safety rules during the operation of aerial ammunition differ for different bombs, and this information is indicated in their technical explanations for different aerial ammunition.

3.2. Safe Separation

Safe separation of aerial bombs from fighter aircraft is a critical process that involves meticulous planning and execution. This procedure ensures the safe deployment of bombs from a fighter aircraft, minimizing the risk of accidental detonation and ensuring the safety of both the aircraft and the ground personnel (Pan et al., 2023).

Throughout the history of aviation, engineers have consistently made efforts to enhance their capacity to deliver weapons with precision, reliability, and safety. In contemporary times, the successful engagement of a target necessitates seamless integration between the aircraft and the weapon, enabling the full exploitation of the weapon's capabilities. However, this integration process presents challenges, including ensuring safe separation and assessing the structural integrity of the aircraft when a weapon is released. Furthermore, the complexity of integrating weapons onto aircraft is compounded when considering the intricate requirements for priming and aiming. Thus, the effective integration of weapons onto aircraft requires a multi-disciplinary approach within the integration organization (Daso, 2008). Ensuring the safe separation of these weapons from the aircraft is paramount to the success of any mission. The potential consequences of improper separation are dire, ranging from inadvertent detonation to compromising the structural integrity of the aircraft. Therefore, meticulous planning and execution are essential components of the process, underscoring the critical importance of safe bomb deployment from fighter aircraft.

The first step in safely separating aerial bombs is a thorough pre-flight inspection. This critical phase ensures that every aspect of the bomb deployment process is meticulously scrutinized before takeoff. During the pre-flight inspection, highly trained personnel meticulously visualize the bombs and their supporting equipment, such as bomb racks and release mechanisms, to ensure they are securely attached and free from any visible defects or anomalies. Additionally, technicians meticulously verify that the bombs are properly armed and fused according to operational requirements, minimizing the risk of accidental detonation during deployment. Furthermore, compatibility checks are conducted to ensure that the bombs are suitable for the specific aircraft and mission parameters. Any identified defects or malfunctions are promptly addressed and rectified to maintain the highest standards of safety and operational readiness. This comprehensive pre-flight inspection process plays a crucial role in mitigating risks and ensuring the safe and successful separation of aerial bombs from fighter aircraft.

To gain a comprehensive understanding of the complexities involved in aerial bomb deployment, it's imperative to first grasp the fundamental technical requirements that govern this process. Recognizing the critical role of suspension and positioning requirements sets the stage for a deeper exploration of the intricacies involved. Additionally, understanding the significance of front lug shifting for stability and aerodynamics, along with the necessity of increasing suspension lug base for large bombs, provides essential insights into the challenges and considerations at play. These technical factors not only ensure the secure attachment of bombs to the aircraft but also optimize their positioning for deployment, thereby laying the groundwork for safe and efficient separation. By delving into each of these components, we can develop a nuanced understanding of their collective importance in facilitating the successful deployment of aerial bombs, ultimately contributing to the enhanced performance of aerial operations.

3.2.1. Suspension and Positioning Requirements

3.2.1.1.Determining the Point of Bomb Suspension

Determining the point of bomb suspension is a critical step that requires meticulous planning and engineering precision. This process entails considering a range of factors and accurately identifying the point where the bomb will be suspended, ensuring its safe deployment and movement towards the intended target during flight. It's imperative to recognize that this determination is not solely based on engineering parameters; rather, it's intricately tied to operational objectives that define the mission's success.

Operational objectives play a pivotal role in determining the point of bomb suspension. These objectives encompass a spectrum of goals, from directing the bomb accurately towards its target to ensuring optimal detonation and damage potential. Engineers leverage mathematical models and simulations not only to calculate the physical parameters but also to align the suspension point with these operational objectives. By integrating these factors seamlessly, engineers can pinpoint the optimal suspension point that maximizes mission effectiveness and safety.

Additionally, the point of bomb suspension should be selected considering the aircraft's aerodynamic structure and flight characteristics. Specifically, the most suitable position for the bomb should be calculated, taking into account factors such as the aircraft's center of gravity balance, interaction with airflow, and other aerodynamic considerations. This is a crucial factor that can affect the aircraft's stability and maneuverability. These aerodynamic factors, intertwined with the structural and safety considerations, form the cornerstone of the bomb suspension process.

Furthermore, safety and risk factors must be considered when determining the point of bomb suspension. It is particularly important that the point of bomb suspension does not compromise the structural integrity of the aircraft or jeopardize flight safety. Therefore, engineers must also consider factors such as the aircraft's carrying capacity and structural durability when identifying the point of bomb suspension. By harmonizing aerodynamic precision with structural robustness, engineers ensure not only optimal flight performance but also the safety and integrity of the aircraft throughout its mission.

Finally, collaboration and communication are essential during the process of determining the point of bomb suspension. Engineers must maintain constant communication with the aircraft's design team and operational personnel, working together to meet the requirements of all stakeholders. This collaboration ensures the identification of the correct and safe point of suspension and can be key to operational success.

3.2.1.2.Design and Features of the Suspension Lug

Designing the suspension lug and specifying its features is a fundamental aspect of ensuring the safe deployment and stable positioning of aerial bombs on fighter aircraft. This process involves a comprehensive understanding of the bomb's characteristics, the aircraft's structural dynamics, and the aerodynamic forces experienced during flight.

To begin with, engineers must consider the structural integrity and load-bearing capacity of the suspension lug. The design should be robust enough to withstand the forces exerted during acceleration, deceleration, and maneuvering while ensuring the bomb remains securely attached to the aircraft.

Moreover, the design of the suspension lug must take into account compatibility with the aircraft's bomb racks and release mechanisms. This requires precise engineering to ensure seamless integration and operation within the aircraft's existing infrastructure.

Additionally, aerodynamic considerations play a crucial role in the design of the suspension lug. Engineers must optimize the lug's shape and placement to minimize drag and airflow disruption, thereby enhancing the aircraft's overall performance and stability during flight.

Furthermore, the materials used in the construction of the suspension lug are critical to its performance and longevity. High-strength alloys or composite materials are typically employed to withstand the harsh operating conditions experienced during aerial missions while minimizing weight to optimize the aircraft's payload capacity.

Finally, rigorous testing and evaluation are essential to validate the design and ensure its compliance with safety standards and regulatory requirements. This may involve simulated flight testing, structural analysis, and real-world field trials to verify the suspension lug's performance under various operating conditions.

3.2.1.3.Adapting the Suspension Lug According to the Size and Weight of the Bomb

Adapting suspension lugs according to the size and weight of the bomb is a critical aspect of ensuring optimal performance and safety during deployment. Engineers must meticulously tailor the design and specifications of the suspension lugs to accommodate variations in bomb dimensions and masses, considering factors such as aerodynamic stability, structural integrity, and load-bearing capacity.

Firstly, engineers analyze the specific dimensions and weight distribution of the bomb to determine the optimal configuration for attachment to the aircraft. This analysis involves assessing the center of gravity, moments of inertia, and aerodynamic characteristics to ensure proper balance and stability during flight.

Next, engineers modify the suspension lug design to accommodate the unique requirements of different bomb sizes and weights. This may involve adjusting the lug's geometry, dimensions, or materials to provide adequate support and secure attachment while minimizing added weight and aerodynamic drag.

Furthermore, engineers consider the dynamic behavior of the aircraft-bomb system during maneuvers and operational scenarios. They optimize the suspension lug design to mitigate any potential issues related to vibration, oscillation, or dynamic loading, ensuring smooth and stable deployment under all conditions.

Moreover, the adaptation of suspension lugs may involve incorporating features such as adjustable mounting points or modular components to facilitate versatility and compatibility with a range of bomb configurations. This flexibility allows for streamlined logistics and maintenance while ensuring optimal performance across diverse mission requirements.

Finally, comprehensive testing and validation procedures are conducted to verify the effectiveness and safety of the adapted suspension lug designs. This may include simulated flight tests, structural analysis, and field trials to assess performance under real-world conditions and ensure compliance with stringent safety standards.

Following the meticulous pre-flight inspection detailed above, the loading and securing of bombs onto the aircraft demand utmost precision and attention to detail. Every step in this complex process is critical, from attaching the bombs securely to the bomb racks to ensuring the placement of all safety pins and locks. Moreover, meticulous calculations regarding the weight and balance of the aircraft are imperative to guarantee stability during flight. A thorough understanding and execution of proper loading and securing procedures are essential to mitigate any risks of unintended release during flight.

The actual separation of the bombs from the aircraft is a critical moment that requires careful coordination between the pilot and the ground control team. Building upon the meticulous preparations, detailed procedures guide the pilot in executing the release of the bombs with precision and safety in mind. The pilot's adherence to specific protocols minimizes the risk of unintended detonation and ensures the safe separation of each bomb. Simultaneously, the ground control team plays a crucial role, closely monitoring the release process and confirming the safe detachment of each bomb from the aircraft before signaling the all-clear. This coordinated effort between the pilot and ground control team is essential to ensure the success and safety of the bomb separation process. Simulating the bombing activity is also of vital importance (Sabatini et al., 2000).

3.2.1.4.Assembly Process and Correct Assembly Methods

The first step in safely separating aerial bombs is a thorough pre-flight inspection. This involves visualizing the bombs and their supporting equipment, such as bomb racks and release mechanisms. The inspection also includes properly arming and fusing the bombs and verifying that they are compatible with the aircraft. Any defects or malfunctions must be identified before the aircraft takes off.

The assembly process and proper mounting techniques are crucial aspects of ensuring the safe and effective attachment of bombs to fighter aircraft. Engineers and technicians follow meticulous procedures to guarantee secure installation and minimize the risk of detachment or malfunction during flight.

Firstly, the assembly process begins with preparing the aircraft and bomb racks for mounting. This involves inspecting the mounting points, ensuring they are free of debris or damage, and verifying the integrity of associated hardware such as bolts, nuts, and locking mechanisms.

Next, technicians carefully position the bombs on the designated racks, aligning them according to precise specifications provided by engineering guidelines. Attention to detail is paramount during this step to ensure proper weight distribution, balance, and clearance with surrounding components.

During the mounting process, technicians use specialized tools and equipment to secure the bombs to the aircraft securely. Torque wrenches, fasteners, and locking pins are employed to achieve the required tightness and prevent loosening or shifting during flight.

Moreover, technicians follow specific torque values and tightening sequences prescribed by aircraft manufacturers and regulatory standards to ensure consistent and uniform attachment across all mounting points. This standardized approach minimizes the risk of over-tightening, which could compromise structural integrity, or under-tightening, which could lead to loosening or detachment.

Additionally, technicians may employ additional measures such as safety wire or adhesive bonding to provide extra reinforcement and prevent accidental release or separation of the bombs. These supplementary techniques enhance the overall reliability and security of the mounting assembly.

Finally, thorough inspection and quality control procedures are conducted following the mounting process to verify compliance with safety standards and technical specifications. This may involve visual checks, functional tests, and structural integrity assessments to confirm that the bombs are securely mounted and ready for operational deployment.

3.2.2. Front Lug Shifting for Stability and Aerodynamics

3.2.2.1. Shifting the Front Lug Forward 220 mm from the Center of Gravity of the Bomb: Reasons and Importance

The forward shifting of the front lug by 220 mm beyond the bomb's center of gravity is a critical adjustment in bomb suspension systems, with specific reasons and importance underlying this positioning. Firstly, this displacement aims to optimize the aerodynamic characteristics of the bomb during flight. By positioning the lug forward of the center of gravity, it facilitates a more stable and streamlined airflow around the bomb, reducing aerodynamic drag and enhancing overall stability. This adjustment is particularly crucial during high-speed maneuvers and adverse weather conditions, where precise aerodynamic performance is essential for safe and accurate bomb delivery. Moreover, the forward displacement of the front lug plays a significant role in mitigating the risk of inadvertent bomb release or separation during flight. By positioning the lug ahead of the center of gravity, any forces acting on the bomb tend to push it toward the aircraft rather than away from it. This inherent stability minimizes the likelihood of premature bomb release due to aircraft vibrations, turbulence, or sudden maneuvers, ensuring the safety of both the aircraft and ground personnel.

Furthermore, the forward shifting of the front lug contributes to the overall balance and handling characteristics of the aircraft-bomb combination. By strategically positioning the lug in relation to the bomb's center of gravity, engineers can optimize the weight distribution and moment of inertia, thereby improving the aircraft's maneuverability and responsiveness during bomb delivery missions.

Overall, the forward displacement of the front lug by 220 mm represents a carefully calculated adjustment that balances aerodynamic performance, stability, and safety considerations in bomb suspension systems. This positioning not only enhances the bomb's flight characteristics but also reduces the risk of accidental release, ensuring the effective and secure delivery of ordnance in diverse operational scenarios.

3.2.2.2.The Effect of Shifting on Aerodynamic Stability

The effect of the shifting process on aerodynamic stability is paramount in bomb deployment systems, influencing various aspects of flight performance. By shifting the front lug forward of the bomb's center of gravity, the overall aerodynamic profile of the bomb-aircraft system is optimized, minimizing aerodynamic drag and improving stability, particularly during high-speed flight regimes and dynamic maneuvers. This streamlined airflow around the bomb reduces turbulent airflow separation, ensuring smoother, more predictable aerodynamic behavior and enhancing overall flight stability. Moreover, this shifting process directly impacts the dynamic response of the bomb to external forces and disturbances. Positioning the lug ahead of the center of gravity provides the bomb with greater resistance to destabilizing influences such as gusts, turbulence, and aircraft vibrations. This increased stability mitigates the risk of unwanted deviations in flight path or orientation, ensuring precise and predictable bomb delivery under diverse operational conditions.

Furthermore, the shifting process contributes to the overall controllability and maneuverability of the aircraft-bomb system. By optimizing the aerodynamic stability of the bomb, pilots can achieve greater control authority and responsiveness during bomb delivery missions. This enhances their ability to accurately place ordnance on target, even in challenging environments or high-threat scenarios.

Aerodynamic stability stands as a cornerstone in the successful deployment of aerial bombs from fighter aircraft. By optimizing the bomb's airflow characteristics, the shifting process significantly enhances aerodynamic stability. This optimization not only improves the bomb's resistance to external disturbances but also enhances its overall controllability. In essence, aerodynamic stability plays a critical role in ensuring the safe, precise, and effective delivery of ordnance from fighter aircraft across diverse operational scenarios. Besides, the assessment of missile stability encompasses both static stability and dynamic stability. A statically stable missile has the capability to counteract an increasing angle of attack with a certain degree of pitching moment (Fleeman, 2001). In practical terms, statically stable missiles demonstrate weathercocking tendencies, resulting in shifts in orientation in response to changes in flight conditions. In order to hold this aerodynamic characteristic, a sign of the Cmα (pitch stiffness derivative) must be negative, as given in Equation 3.

$$C_{m\propto} = \frac{\Delta C_m}{\Delta \propto} < 0 \qquad (3)$$

The aerodynamic stability of aerial bombs is greatly influenced by the control alternatives, as illustrated in Figure 18.

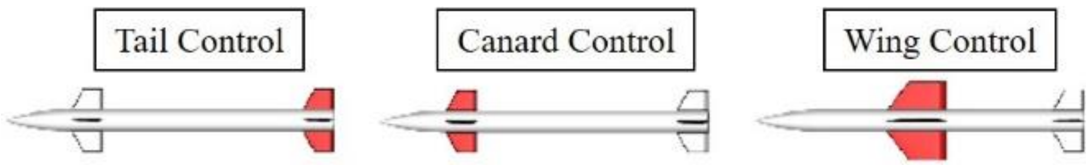

Figure 18. Control Variations of Aerial Ammunitions (The Figure was re-illustrated based on the information (Arslan, 2014).

3.2.2.3.The Importance of Front Lug Position for Safe Aircraft Separation

The positioning of the front lug plays a crucial role in ensuring the safe separation of bombs from the aircraft, directly influencing the dynamics and outcome of the separation process. By strategically placing the front lug at an optimal position relative to the aircraft's center of gravity, engineers aim to achieve controlled and predictable separation behavior, critical for minimizing the risk of interference between the bomb and the aircraft structure during release, which could lead to unintended collisions or disturbances. Moreover, the precise positioning of the front lug is essential for maintaining the stability and integrity of the aircraft-bomb system throughout the separation event. Placing the lug at the correct location ensures that the bomb's release does not induce excessive pitching, rolling, or yawing moments on the aircraft, which could compromise flight safety, instead facilitating a smooth and stable separation trajectory, allowing the bomb to clear the aircraft's wake without endangering its structural integrity or aerodynamic stability.

Additionally, the front lug's positioning significantly influences the trajectory and behavior of the released bomb, directly impacting its accuracy and effectiveness in reaching the designated target. By meticulously adjusting the lug's position, engineers aim to ensure that the bomb follows a predictable flight path and maintains proper orientation during separation, thereby improving overall delivery accuracy and mission success rates.

To summarize, the precise placement of the front lug is paramount for ensuring the safe and efficient separation of bombs from aircraft, thereby minimizing the risk of interference, preserving flight stability, and optimizing delivery precision. Through rigorous engineering analysis and testing, engineers strive to identify the optimal lug position that strikes a balance between these factors, facilitating reliable and consistent bomb deployment in operational settings.

3.2.3. Increasing Suspension Lug Base and Front Lug Shifting for Large Bombs

3.2.3.1.Increasing Suspension Lug Base for Mounting Large Bombs: Rationale and Importance

The decision to increase the suspension lug base for the mounting of large bombs stems from a combination of engineering considerations and operational requirements, all aimed at enhancing the safety and effectiveness of bomb deployment from aircraft. Large bombs, due to their size and weight, pose unique challenges during the suspension and release process, necessitating modifications to existing suspension lug configurations.

Primarily, the rationale behind enlarging the suspension lug base lies in improving the structural integrity and load-bearing capacity of the mounting system to accommodate the increased weight and size of large bombs. By widening the base, engineers aim to distribute the load more evenly across the aircraft's structure, reducing stress concentrations and minimizing the risk of structural deformation or failure during bomb deployment.

Moreover, enlarging the suspension lug base enhances the system's stability and resistance to dynamic forces encountered during flight maneuvers or turbulent conditions. Large bombs inherently introduce additional aerodynamic loads and moments on the mounting system, which must be adequately countered to maintain flight safety and stability. By expanding the lug base, engineers increase the system's resistance to lateral and torsional forces, thereby reducing the likelihood of sway or oscillations that could compromise the bomb's release accuracy or the aircraft's controllability.

Furthermore, the larger lug base provides a more secure and robust attachment point for large bombs, reducing the risk of detachment or displacement during high-stress flight scenarios such as combat maneuvers or evasive actions. This enhanced attachment stability is crucial for ensuring reliable bomb delivery and minimizing the potential for unintended releases or malfunctions that could jeopardize mission success or pose safety risks to the aircraft and its crew.

In summary, increasing the suspension lug base for mounting large bombs is driven by the need to enhance structural integrity, stability, and attachment security, thereby ensuring the safe and effective deployment of heavy ordnance from aircraft. Through careful engineering analysis and validation, engineers strive to optimize the lug configuration to meet the demanding requirements of modern aerial warfare while maintaining the highest standards of safety and reliability.

3.2.3.2. Forward Shifting of Front Lug by 440 mm from the Center of Gravity for Large Bombs: Reasons and Importance

Furthermore, continuous training and periodic inspections are essential to maintain the safety of the aerial bomb separation process. Pilots and ground personnel must undergo regular training and evaluation to ensure they are up-to-date with the latest procedures and protocols. The equipment and systems used in the separation process must also be regularly inspected and maintained to ensure reliability and functionality.

The decision to shift the front lug forward by 440 mm from the center of gravity for the mounting of large bombs is grounded in a thorough analysis of aerodynamic principles, structural requirements, and operational considerations. This adjustment aims to optimize the positioning of the front lug to ensure stability, control, and safety during the release of large bombs from aircraft.

The primary reason for moving the front lug forward is to improve the aerodynamic performance of the bomb-aircraft system during release maneuvers. Large bombs, due to their size and weight, exert significant aerodynamic forces on the aircraft when suspended beneath it. By shifting the front lug forward, engineers seek to mitigate potential aerodynamic disturbances and moments that could affect the aircraft's stability and controllability during bomb release.

Furthermore, relocating the front lug enhances the overall balance and weight distribution of the bomb-aircraft configuration, minimizing trim changes and control surface deflections required to maintain stable flight conditions. This optimized weight distribution is particularly crucial for high-performance aircraft operating at varying speeds and altitudes, where minor deviations in aerodynamic balance can have significant impacts on flight characteristics and handling qualities.

Moreover, moving the front lug forward improves the system's mechanical advantage during bomb release, reducing the required release force and ensuring smoother and more predictable bomb separation dynamics. This enhanced mechanical efficiency not only reduces the risk of unintended bomb hang-ups or partial releases but also minimizes stress on the release mechanisms and associated components, enhancing their reliability and longevity.

In summary, shifting the front lug forward by 440 mm for the mounting of large bombs is motivated by the need to optimize aerodynamic performance, weight distribution, and mechanical efficiency during bomb release from aircraft. Through careful analysis and testing, engineers aim to maximize the safety, effectiveness, and reliability of bomb deployment operations, ensuring mission success and the protection of aircraft and personnel.

3.2.3.3. The Role of Front Lug Position in Aerodynamic Stability and Safe Separation

The role of the front lug position in aerodynamic stability and safe bomb separation is fundamental to the overall design and operation of aircraft-bomb systems. The precise location of the front lug plays a crucial role in maintaining aerodynamic stability during various flight phases, particularly during the critical moment of bomb release.

First and foremost, the position of the front lug directly influences the aerodynamic forces that act on the aircraft-bomb configuration. The optimal placement of the front lug helps to minimize disturbances to the airflow around the aircraft, reducing the risk of aerodynamic instability and control issues during bomb release maneuvers. By carefully positioning the front lug, engineers can mitigate undesirable effects such as pitch, yaw, or roll moments that could compromise the aircraft's flight characteristics and handling qualities.

Furthermore, the front lug's position significantly affects the dynamic behavior of the aircraft-bomb system during bomb release events. The front lug serves as a pivotal point for the release mechanism, determining the trajectory and separation dynamics of the bomb. An accurately positioned front lug ensures smooth and predictable bomb separation, minimizing the likelihood of hang-ups, swings, or other undesirable behaviors that could jeopardize safety or mission success.

Moreover, the front lug position is intricately linked to the overall structural integrity and load distribution of the aircraft-bomb system. A properly positioned front lug helps to distribute the load evenly across the aircraft's structure, reducing stress concentrations and potential points of failure. This balanced load distribution is essential for maintaining structural stability and preventing structural damage, particularly under high-stress conditions during bomb release and subsequent flight maneuvers.

In summary, the front lug's position is paramount for ensuring aerodynamic stability, predictable separation dynamics, and structural integrity during bomb deployment from aircraft. By carefully considering and optimizing the front lug's location, engineers can enhance the safety, effectiveness, and reliability of aerial bomb separation operations, contributing to overall mission success and the protection of aircraft and personnel.

Finally, the safe separation of aerial bombs from a fighter aircraft is a complex and highly regulated procedure that involves multiple steps, from pre-flight inspection to post-flight evaluation. It requires high coordination, precision, and attention to detail to ensure that the bombs are deployed safely and accurately. Strict adherence to established protocols and continuous training and evaluation are crucial for this process's success and everyone's safety.

4. CONCLUSIONS

The following information pertains to the deployment of aerial bombs. When it comes to bombs, their size and displacement are critical factors that require careful consideration. For instance, more giant bombs with displacements between 1500 and 5000 kg demand a thoughtful approach in terms of suspension and detonation mechanisms. To ensure safe and effective deployment, the base of the suspension lugs for these bombs should be 480 mm. This distance is crucial as it allows the bomb to hang properly and maintain balance during transport. Additionally, the front lug of the bomb must be shifted 220mm towards the head from the center of gravity. This shift in position is crucial in providing the necessary stability and aerodynamics during flight.

For even larger bombs with a displacement of 9000 kg, the base of the suspension lugs must be increased to 1000mm. This is necessary due to the weight and size of the bomb, as a larger base is needed to support its mass. Similarly, the front lug must be shifted forward 440 mm from the center of gravity. This shift is essential in maintaining the balance and stability of the bomb during flight, ensuring it reaches its intended target accurately.

In addition to proper suspension, aerial bombs must be equipped with different detonators to set them off immediately upon impact. These detonators serve a crucial role in ensuring the mission's success, whether for strategic or tactical purposes. Aerial bombs are designed to create a maximum impact upon detonation, and a delay in the explosion could harm the mission's success.

Different detonators are used for different types of aerial bombs based on their intended use. For example, incendiary bombs require a different detonator than high-explosive ones, aiming to start fires rather than cause maximum destruction. The detonators must also be calibrated to the size and weight of the bomb, ensuring a precise and instantaneous explosion upon impact.

In conclusion, it is vital to adhere to the specifications mentioned above when handling aerial ammunition. The size and displacement of aerial bombs play a significant role in determining the necessary specifications for their proper deployment. Any miscalculation or error in these areas could have severe consequences, making it imperative to adhere to these guidelines when handling aerial bombs.

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Data Availability Statements

The datasets used or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing Interests

The authors state that no known competing financial interests or personal relationships could have appeared to influence this proceeding paper.

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Havalimanı Çalışanlarında Örgütsel Çekicilik Algısı ile Örgütsel Vatandaşlık Davranışı İlişkisinin İncelenmesi

Hakan Gökgöz[1]

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Öz

Örgütsel çekicilik, bir örgütün bireyler tarafından beğenilmesi, çalışmak için cazip ve çekici görülmesi gerek marka bakımından gerekse bulunduğu sektör bakımından oraya ait olma arzusu uyandırması şeklindeki olumlu tutum ve algıları ifade etmektedir. Örgütsel vatandaşlık ise çalışanın kendisini bulunduğu kuruma ait hissetmesi, kurumu benimsemesi, özümsemesi, içselleştirmesi ve kendini kurumun bir parçası yani vatandaşı olarak görmesi davranışlarıyla belirtilmektedir. Bu çalışmada havalimanı çalışanlarının algıladıkları örgütsel çekiciliğin, örgütsel vatandaşlık davranışı üzerindeki etkisi incelenmiştir. Yapısal eşitlik modellemesi sonucuna göre örgütsel çekicilik algısının örgütsel vatandaşlık davranışı üzerinde pozitif yönde ve anlamlı bir etkisinin olduğu ve değişkenler arasındaki yol katsayısının 0.72 olduğu görülmüştür. Sonuç olarak araştırmaya katılan havalimanı çalışanlarının örgütsel çekicilik algılarının, örgütsel vatandaşlık davranışlarını olumlu yönde arttırdığı söylenebilir.

Anahtar Kelimeler: Örgütsel Çekicilik Algısı, Örgütsel Vatandaşlık Davranışı, Havalimanı Çalışanları, Sivil Havacılık.

JEL Sınıflandırma: C20, D23, M10.

Analysis of the Relationship between Organizational Attractiveness Perception and Organizational Citizenship Behavior in Airport Employees

Abstract

Organizational attractiveness refers to the positive attitudes and perceptions held by individuals towards an organization, wherein the organization is liked, seen as an attractive and appealing place to work, and fosters a desire to be associated with it, both in terms of its brand and its position within the industry. Organizational citizenship, on the other hand, is characterized by the behaviors of an employee who feels a sense of belonging to the organization, embraces, internalizes, and identifies with the organization, engages in cooperative efforts, and views themselves as a part of the organization - in essence, a “citizen” of the organization. In this study the impact of airport employees' perceived organizational attractiveness on organizational citizenship behavior has been examined. According to the structural equation modeling results, it was observed that the perception of organizational attractiveness has a positive and significant effect on organizational citizenship behavior, with a path coefficient of 0.72 between the variables. In conclusion, it can be stated that the organizational attractiveness perceptions of the airport employees who participated in the research positively enhanced their organizational citizenship behaviors.

Key Words: Organizational Attractiveness Perception, Organizational Citizenship Behavior, Airport Employees, Civil Aviation.

JEL Classification: C20, D23, M10.

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GİRİŞ

Günümüzde örgütler, insan kaynakları ve çalışanlar bakımından en iyi yeteneklerin kazanılması ve elde tutulması için çaba sarf etmektedir. Örgütler, çalışanlarının gözünde çekiciliğe sahip olmanın, yetenekli çalışanları elde tutma konusunda anahtarı rol oynadığının farkına varmışlardır (Waal, 2022: 2). Örgütlerin örgütsel çekiciliği anlaması, örgütlerin kurumsal kaynaklarını ve yeterliliklerini uygun şekilde tasarlamalarına ve yönetmelerine olanak tanımaktadır. Bu durum spesifik özelliklerinden dolayı, çalışma şartları zor olan havacılık sektörü için özellikle önemlidir. Havacılık sektörünün temel kaynağı insanlardır ve ekonomiye değer katan bir sektördür. Bu yüzden örgütsel performanstaki başarı, insan kaynaklarının kalitesi ve performansıyla büyük ölçüde ilişkilidir (Vatankhah ve Ilkhanizadeh, 2021: 444).

İşletmeler, ekonomik, sosyal, kültürel ve sosyal sorumluluktan endüstriyel çevredeki değişikliklere, faaliyet gösterdikleri projelerden, ticari örgütlere kadar iş ortamında olup biten her şeyden açık bir sistem olarak etkilenmektedir (Maaroof vd., 2022: 19). Küreselleşen dünyada örgütler büyürken yoğun rekabetten kaçınmak imkansızdır. Örgütsel başarı, çalışanların kalitesine ve performansına bağlıdır. Bu yüzden örgütsel vatandaşlık davranışının örgütleri daha destekleyici hale getireceği düşünülmektedir (Zalzela vd., 2023: 107). Örgütsel vatandaşlık davranışının, çalışanın temel iş gereksinimlerini aşan ve isteğe bağlı örgütsel davranışlar olması nedeniyle, çalışanların her türlü olumlu davranışı sergilemeleri örgütlerin ayakta kalmasına ve gelişmesine katkı sağlamaktadır (Jahangir vd., 2004: 75). Dolayısıyla örgütsel vatandaşlık davranışı, çalışanların kendi tercihleriyle yaptığı, iş arkadaşlarını destekleyen ve örgüte fayda sağlayan olumlu ve yapıcı her şeyi kapsamaktadır (Thiruvenkadam ve Durairaj, 2017: 46).

Bu araştırmanın amacı, havalimanı çalışanlarının algıladıkları örgütsel çekiciliğin, örgütsel vatandaşlık davranışı üzerindeki etkisinin incelenmesidir. Araştırmanın önemi ise çalışanların görev yaptıkları kuruma dair olan örgütsel çekicilik algılarının, çalışanların bulundukları kuruma karşı olumlu hisler beslemeleri, burada çalışmaktan memnun olmaları ve bunun sonucu olarak da örgütsel vatandaşlık davranışı geliştirerek kendilerini kuruma ait hissetmelerine yol açmasıdır. Bunun sonucunda ise işletmelerin uzun dönemde bağlı ve sadık çalışanlarını elde tutmalarına ve rekabet avantajı yaratmalarına olanak sağlamasıdır.

1. KAVRAMSAL ÇERÇEVE

1.1. Örgütsel Çekicilik Algısı

Artan rekabet ortamında örgütler, işgücüne uygun yetenekli çalışanları kendilerine çekmek veya ellerinde tutmak için çaba sarfetmektedirler. Yetenekli çalışanların kıtlığı, potansiyel yetenekleri çekmek ve örgütte olanların devamlı kalmalarını sağlamak, örgütler için önemlidir. Örgütsel çekicilik, insan kaynakları yönetimine dahil olan yeni bir kavramdır. Buna göre örgütsel çekicilik, çalışanların bulunduğu örgütü çalışmak için iyi yer olarak algılama derecesini ifade etmektedir (Bakanauskiene vd., 2017: 6) ve potansiyel bir çalışanın belirli bir örgütte çalışırken karşılaşacağı öngörülen faydalar olarak tanımlanmaktadır. Kısacası bireyin algıladığı ve belirli bir örgüt hakkındaki düşüncelerini belirleyen örgütsel özellikler olarak ifade edilmektedir (Joseph vd., 2014: 41). Günümüzün iş ortamında yetenekli işgücü bulma ve elde tutma savaşı, stratejik insan kaynakları yönetiminin en önemli gündemlerinden biridir. Çünkü gelişen teknoloji ve artan rekabet ortamı, yüksek vasıflı çalışanlar gerektirmektedir. Örgütsel çekicilik sayesinde, daha yüksek ücretler yerine, güçlü ve olumlu itibara ve prestije sahip örgütlerde çalışmak isteyen yetenekli çalışanlar bulunabilmektedir. Ayrıca örgütsel çekicilik, mevcut çalışanların çalıştıkları örgütün kültürüne ve stratejisine bağlılıklarını güvence altına almasını sağlamaktadır (Bakanauskiene vd., 2017: 5).

Yoğun rekabet ortamında insan sermayesi bir örgütün sahip olabileceği en değerli varlıklardan biridir ve yetenekli çalışanların varlığı örgütsel açıdan oldukça önemlidir (Hoye ve Lievens, 2007: 2024). İşletmelerin, daha kaliteli adayları elde etmesi, yalnızca uygun kişilerin işe alınmasını sağlaması ve onları elde tutabilmesi, örgütsel çekiciliğe bağlıdır. Çünkü yetenekli çalışanlara sahip örgütler, örgütsel etkinliği arttırarak rakiplerine karşı büyük bir rekabet avantajı elde etmektedirler (Uen vd., 2011: 239). Örgütsel çekicilik, olası çalışanların belirli bir örgütü çalışmak için iyi bir yer olarak algılama derecesini ve o örgütle bir iş ilişkisi geliştirmenin olumlu yöndeki arzusu olarak tanımlanmaktadır (Salim, 2018: 77). Örgütsel çekicilik, bireyin örgüt hakkındaki algılarının temel derecesi ve bireyin belirli bir örgütte çalışma konusundaki genel isteği olarak belirtilmektedir. Örgütsel çekicilik, bir örgütü tüm çalışanlar için daha iyi ve arzu edilen bir işyeri haline getirmektedir. Örgütsel çekicilik, bireyin kişisel olarak bir örgütü işveren olarak arama veya bir örgütü işveren olarak tavsiye etme derecesi olarak açıklanmaktadır. Başka bir tanıma göre ise örgütsel çekicilik, örgütün gelecekteki çalışanlara sağladığı soyut ve görünmez faydalar olarak ifade edilmektedir (Baş ve Ertan, 2020: 1022). Örgütsel çekicilik, işverenin veya örgütün markasının etki alanından kaynaklanmaktadır. Bu yüzden mevcut çalışanın bakış açısını ele alan tutumsal bir yapı olduğu düşünülmektedir. Dolayısıyla örgütsel çekicilik, mevcut çalışanların, örgütün çekici bir kurum olup olmadığına ilişkin genel tutumlarıyla ilgili bir kavramdır. Bu duruma göre örgütsel çekicilik, mevcut çalışanların genel kümülatif tutumlarını ve kurumu arzu edilen bir yer olarak görüp görmediklerini yansıtmaktadır (Mutonyi vd., 2022: 5).

Örgütsel çekicilik algısı, bireylerin istihdam için potansiyel yerler olarak gördüğü belirli örgütler hakkındaki duygusal ve tutumsal düşüncelerini ifade etmektedir (Wörtler vd., 2021: 582). Örgütsel çekicilik, kişinin bir örgütü çalışılacak bir yer olarak olumlu algılama derecesi ile ilgilidir. Bir örgütte çalışmayı arzu edilir olarak gören olumlu bir tutumu ifade etmektedir (Gomes ve Neves, 2010: 206). Örgütsel çekicilikte bireylerin örgütün özelliklerine veya fonksiyonlarına önem verdikleri görülmektedir. Benzerlik-çekim paradigmasına göre bireylerin sosyal kimliklerini başkaları ile kategorize ederek belirledikleri bilinmektedir. Buna göre benzer bireylerin kişiler arası çekime sahip olacağı veya örgütsel bağlamda, bireylerin kendileriyle eşleştiğini algıladıkları belirli özelliklere sahip örgütlere daha fazla ilgi duyacakları varsayılmaktadır (Schreurs vd., 2009: 37). Dolayısıyla örgütsel çekicilik, çalışanların veya potansiyel adayların tepkilerinin ortak bir ölçüsünü ifade etmektedir (Siegel vd., 2021: 105). Örgütsel çekicilik algısı, bir örgütün çalışanları ve dış paydaşları ile uyumunu düzenleyen bir kavramdır. Örgütsel çekicilik sayesinde nitelikli iş gücünün dikkatini çeken örgüt hem kuruma değer katmakta hem de kuruma küresel bir rekabet avantajı sağlamaktadır. Örgütsel çekicilik, bireylerin zihninde daha iyi çalışma alanı yönelimine ilişkin olumlu bir algı yaratmaktadır. Örgütsel çekicilik sayesinde, çalışanların bireysel kişiliği etkilenmekte, örgüte karşı özel bir bağ kurulmakta ve dolayısıyla sadık, güven veren, değerli hissettiren ve elde tutma psikolojisine sevk eden bir örgütsel çalışma kültürü ve öz motivasyon gücü ortaya çıkmaktadır (Joseph vd., 2014: 42).

1.2. Örgütsel Vatandaşlık Davranışı

Örgütsel vatandaşlık davranışı kavramını literatüre kazandıran Organ (1988), örgütsel vatandaşlık davranışının bir örgütün ayakta kalması için hayati öneme sahip bir unsur olduğunu savunmaktadır. Organ, örgütsel vatandaşlık davranışının hem çalışanın hem de örgütün verimliliğini ve üretkenliğini en üst düzeye çıkarabileceğini ve sonuçta bir örgütün etkin işleyişine katkıda bulunabileceğini ifade etmektedir (Jahangir vd., 2004: 76). Organ (1990), örgütsel vatandaşlık davranışını, görev performansını destekleyen, sosyal ve psikolojik bağlamın sürdürülmesine ve geliştirilmesine katkıda bulunan bir örgütsel davranış olarak tanımlamaktadır. Bu davranış resmi olarak gerekli olanın ötesinde çaba göstermeyi içermektedir. Bunlara örnek olarak işlerde gönüllü olmak, yardım etmek, işbirliği yapmak, başkalarına destek vermek, kuralları izlemek belirtilebilir (Bayar, 2019: 124). Ayrıca Organ'a (1990) göre örgütsel vatandaşlık davranışı, biçimsel ödül sisteminde doğrudan, tam olarak bulunmayan ve dikkate alınmayan, fakat bir bütün olarak örgütün işlevlerini verimli bir biçimde yerine getirmesine yardımcı olan, gönüllülüğe dayalı davranışları kapsamaktadır (Polat ve Ceep, 2008: 310).

Örgütlerin başarısı, bünyelerindeki çalışanlara bağlıdır. Örgütsel etkinlik, örgütsel vatandaşlık davranışına sahip çalışanlar tarafından görülmektedir. Çünkü örgütsel vatandaşlık davranışı, resmi bir çalışma sisteminde dolaylı veya açık bir şekilde tanımlanabilen ve toplu olarak örgütsel etkinliği arttırabilen bireysel davranışlardır. Örgütsel vatandaşlık davranışının temeli, işbirlikçi, yardımsever, düşünceli ve ciddi çalışanların özelliklerini yansıtmaktadır. Çalışanların örgüte yaptığı katkılar, herhangi bir emir, etki veya ücretle kontrol edilmeye gerek kalmadan, gönüllü, içten ve mutlulukla gerçekleştirilen ve aynı zamanda örgütün performansını destekleyebilecek davranışlardır. Örgütsel vatandaşlık davranışının varlığı ile örgüt içindeki üyeler arasındaki sosyal etkileşim artmakta ve anlaşmazlıkların ortaya çıkması azalmaktadır, bu da örgütsel performansı arttırmaktadır (Diafatma vd., 2023: 308).

Örgütsel vatandaşlık davranışı, resmi olmayan, doğrudan veya açıkça ifade edilmeyen, ancak isteğe bağlı olan ve toplu olarak örgütün verimli ve etkili işleyişini teşvik eden bireysel bir davranış olarak tanımlanmaktadır (Wörtler vd., 2021: 582). Dolayısıyla belirlenmesi veya seçilmesi isteğe bağlı olan, resmi ödül sistemi tarafından doğrudan veya açıkça ödüllendirilmeyen ve genel olarak örgütün işlevlerinin etkinliğini teşvik eden bireysel bir davranışı belirtmektedir (Putri vd., 2023: 593). Örgütsel vatandaşlık davranışı, kişisel nitelikler nedeniyle veya çalışma ortamı ya da örgüt kültürü aracılığıyla uygulanabilen bireysel yetenekler veya özelliklerdir (Muhammad vd., 2023: 82). Bu tanım, gönüllülük veya ödül terimlerini değil, teknik çekirdeğin ötesinde örgütsel ortamı destekleyen davranışları ifade etmektedir (Ramos ve Ellitan, 2023: 355). Dolayısıyla, resmi çalışmanın gerektirmediği ancak örgütsel faaliyetlerin etkinliğini destekleyen gönüllü bir davranıştır (Jufrizen vd., 2023: 255). Örgütsel vatandaşlık davranışının, kişinin örgütüne duyduğu bağlılıktan dolayı kendiliğinden gerçekleştiği ve istediği hedeflere ulaşmada örgütün kendisini teşvik ettiği bilinmektedir (Aphrodita, 2023: 73). Örgütsel vatandaşlık davranışı, uyumun veya itaatin varlığı, çalışanların örgütsel kural ve prosedürleri kabul etme ve bunlara uyma konusundaki istekliliğini göstermeleri, tutarlı olmaları, sorumluluklarını yerine getirmeleri, sadakat göstermeleri, işin kolaylaşmasına yardımcı olmaları, çabaların ödüllendirilmesi, sorunları çözmek için ekip oluşturulması, katılım sağlanması, çalışanların destek ve yenilikçi düşünce sağlayarak örgütü geliştirme arzusu veya istekliliğinin olması ve tüm bunların gönüllü olarak yapılması unsurlarını içermektedir (Ramos ve Ellitan, 2023: 357).

Örgütsel vatandaşlık davranışı üç ana özellik ile tanımlanmaktadır: davranışın gönüllü olması, davranışın örgütsel açıdan fayda üretmesi ve örgütsel vatandaşlık davranışın çok boyutlu bir yapıya sahip olması. Dolayısıyla örgütsel vatandaşlık davranışı, çalışanın isteğe bağlı davranışı olup, bunun işin gereği olarak yaptırılabilecek bir davranış olmadığını ve inisiyatifin çalışanda olduğunu ifade etmektedir. Bununla birlikte, örgüte ait kurumsal faydaya ve bireysel faydaya yönelik genel bir uyum davranışıdır (Ndoja ve Malekar, 2020: 90-91). Örgütsel vatandaşlık davranışı, çalışanların kendi tercihleri doğrultusunda diğerlerine yardım etmek ve örgüte fayda sağlamak için yaptıkları olumlu ve verimli katkı olarak nitelendirilmektedir (Nijhawan vd., 2023: 141). Genel olarak örgütsel vatandaşlık davranışı, örgütün temel faaliyetlerini destekleyen psikososyal bir çalışma ortamının yaratılmasına katkıda bulunan örgütsel gelişim için çok önemli bir faktördür (Fan vd., 2023: 3). Bu yüzden örgütsel vatandaşlık davranışı, örgüte yararlı olan ve seçme özgürlüğü olan bireysel davranışlar olarak tanımlanan özel bir çalışma alışkanlığı türüdür (Andrasita ve Panjaitan, 2023: 493). Örgütsel vatandaşlık davranışı, örgütsel performansın verimliliğini ve etkinliğini arttırmaya yönelik, kişisel inisiyatif ve tercihe bağlı olan bir davranıştır (Putri vd., 2023: 594). Örgütsel vatandaşlık davranışı, çalışma ortamını daha keyifli bir yer haline getirerek örgütün nitelikli çalışanları yetiştirme ve elde tutma yeteneğini geliştirmektedir (Muttaqiyathun vd., 2023: 3713).

Örgütsel vatandaşlık davranışı, bireyin bulunduğu örgütün bir üyesi olduğunu hissederek doyum duygusu yaşamasından kaynaklanan bir davranıştır. Bu davranış, başkalarına yardım etme, ekstra görevlere gönüllü olma, işyeri kural ve prosedürlerine uyma gibi çeşitli davranışları içermektedir. Bu davranışlar, olumlu sosyal davranışın bir biçimi olan çalışan katma değerini, yani yardımcı olmaya yönelik olumlu, yapıcı ve anlamlı sosyal davranışları ifade etmektedir. Ayrıca bunun, gönüllü davranış olduğu ve zorunlu bir eylem olmadığı, resmi olarak emredilmemiş ancak performansa dayalı bir tatmin biçimi olarak gösterilen bireysel bir davranış olduğu, doğrudan ve açıkça resmi ödül sistemiyle ilgili olmadığı belirtilmektedir (Ramos ve Ellitan, 2023: 356; Abbasi vd., 2022: 81). Bu unsurlar ise örgütsel etkinliği arttırabilen bireysel davranışlar olarak sıralanmaktadır (Yansyah vd., 2022: 75). Dolayısıyla örgütün genel başarısı veya faaliyetlerinin doğası gereği, örgütsel vatandaşlık davranışının tanınması, çalışanların sorumluluğunun belirlenmesinde önemli bir rol oynamaktadır. Çalışanların örgütsel vatandaşlık davranışlarını gösterme şekli onların motivasyonlarına ve yeteneklerine bağlıdır (Pirzada vd., 2022: 88).

1.3. Sosyal Etki Teorisi

Sosyal bir canlı olarak insanın hem kendi benliği ile olan ilişkisi hem de toplum ile olan ilişkisi dinamik bir yapıdadır. Bu maruz kalma neticesinde insan hem içinde yaşadığı toplumdan etkilenmekte hem de üyesi olduğu toplumu etkilemektedir (Şüküroğlu, 2021: 151). Latane (1981), insanların duygularının, düşüncelerinin ve davranışlarının başka insanlar tarafından etkilenmesini ve bu etkilenme neticesinde ortaya çıkan değişimi "sosyal etki" olarak tanımlamaktadır (Abayhan ve Aydın, 2014: 109). Sosyal etki teorisi, topluluklarla birey arasındaki ilişkileri, bir veya birden fazla bireyin ya da toplulukların, birey üzerinde sahip olduğu etkiyi açıklamaktadır. Sosyal etki teorisi, bireylerin birbirlerini nasıl etkilediğini gösteren yöntemlerin, zaman ve mekân kısıtlamalarına, toplumsal ve çevredeki diğer bireylerin kuvveti, yakınlığı ve sayısı tarafından etkinin nasıl hafifletilebileceğine ilişkin bir kuramdır. Bu sayede bireyin sahip olduğu inanç, tutum ve davranışlarının etrafındaki diğer insanlar tarafından etkilendiğini açıklanmaya yardımcı olmaktadır. Sosyal etki, topluluğu oluşturan bireylerin bilinçli veya bilinçsiz olarak birbirlerini, herhangi bir konuda duygu, düşünce ve davranışlarını değiştirme çabası olarak kendisini göstermektedir (Şüküroğlu, 2021: 151). Bu teori, bireyin inançlarının, tutumlarının ya da davranışlarının çevresindeki kişilerden etkilendiğini açıklamak için geliştirildiğinden, bireyler, sergileyecekleri doğru davranışı belirlemek için başkalarının fikirlerine önem vermektedirler. Teorinin özünü oluşturan sosyal etki, bireyin başkalarıyla girmiş olduğu etkileşim sonucu düşüncelerinde, tutumlarında ve davranışlarında oluşan değişimi ifade etmektedir (Yüksel, 2018: 446). Kişiler, karşılarında bulunan örgütle olan etkileşimlerinin sonuçlarını değerlendirmektedir. Bu değerlendirmede kişinin kazanımları varsa ve örgütle olan ilişkisini olumlu algılamaktaysa göstereceği davranış, örgütsel vatandaşlık davranışı şeklinde olmaktadır (Demir, 2009: 199).

Çalışma yaşamında örgütler, amaçlarına ulaşabilmek için insan emeğine ihtiyaç duymaktadırlar. Bu yüzden örgütlerde insan önemli bir kaynak olarak görülmektedir. Nitelikli çalışanlara sahip örgütlerin rakipleri karşısında avantaj yarattığı bilinmektedir. Dolayısıyla örgütlerin hem potansiyel adaylar için hem de mevcut çalışanlar için çekici olması sadakat, bağlılık ve örgütsel vatandaşlık gibi olumlu etkilere de yol açmaktadır. Mevcut nitelikli çalışanların örgütsel vatandaşlık göstermesi, örgütün çekici olabilmesiyle yakından ilgilidir. Böylece örgütlerde sürdürülebilir insan kaynakları uygulamalarında nitelikli çalışanların örgütte uzun süreler görev yapmalarının, örgütlerin başarısında önemli olduğu ifade edilmektedir (Fırın, 2022: 14). Bu bakımdan örgütlerde mevcut nitelikli çalışanları elde tutabilmek adına, insan kaynakları uygulamalarının ve örgütte çalışanlara karşı olan uygulamaları hem örgütün çalışmaya değer çekici bir hâl alması, hem de çalışanların örgütsel vatandaşlık davranışı göstererek örgüte bağlı kalması konusunda örgütsel çekicilik ve örgütsel vatandaşlık kavramları kilit unsurlar olarak görülmektedir.

Dolayısıyla örgütsel çekicilik algısının sosyal etkiyi arttıran bir kavram olduğu ve örgütsel çekicilik algısının sosyal etkinin sonucu olarak çalışanlarda davranış değişikliğine yol açtığı ifade edilebilir. Sosyal etki teorisine dayanarak, çalışanların bulundukları işletmeyi hem kendilerinin çekici bulmaları hem de diğerlerinin o işletmeyi çekici bulduklarına dair algıları sonucu oluşan bu sosyal etki sayesinde, çalışanların kurumlarına bağlı kalma ve uzun vadede orada çalışmayı düşünmeleri, örgütsel vatandaşlık davranışı sergilemelerini sağlayacaktır.

Buradan hareketle çalışanların örgütsel çekicilik algıları ile örgütsel vatandaşlık davranışı göstermeleri arasında anlamlı ve pozitif yönde bir ilişkinin olabileceği düşünüldüğü için bu araştırmanın hipotezi şu şekilde belirtilmiştir:

Hipotez: Örgütsel çekicilik algısının örgütsel vatandaşlık davranışı üzerinde etkisi vardır.

2. YÖNTEM

Havalimanı çalışanlarının algıladıkları örgütsel çekiciliğin, örgütsel vatandaşlık davranışı üzerindeki etkisini incelemeye yönelik yapılan bu araştırma için gerekli veriler, yüzyüze anket uygulaması ile elde edilmiş olup, beşli Likert ölçeğine göre hazırlanan, Akman ve Özdemir (2018) tarafından geliştirilen, 11 maddeden oluşan "örgütsel çekicilik ölçeği" ile Podsakoff vd. (1997) tarafından geliştirilen, Türkçe uyarlaması, geçerliliği ve güvenirliği Yalçın ve Çobanoğlu (2022) tarafından yapılıp test edilen, 10 maddeden oluşan "örgütsel vatandaşlık davranışı ölçeği" kullanılmıştır. Örgütsel çekicilik ölçeği, "çalışanların bulundukları kurumu saygın görmeleri, başka insanların burada çalışmak istediklerine inanmaları, burada çalıştıkları için diğerlerinin kendilerine imrendiklerini düşünmeleri" gibi ifadelerden oluşurken; örgütsel vatandaşlık davranışı ölçeği ise "çalışanların arkadaşlarına yardımcı olmaları, deneyimlerini arkadaşları ile paylaşmaları, problemleri önlemek için girişimde bulunmaları" şeklindeki ifadelerden oluşmaktadır. Araştırma için Bilimsel Araştırmalar ve Yayın Etiği Kurulu'ndan E-35523585-302.99-88781 sayılı ve 23.06.2023 tarihli etik kurul izni alınmıştır. Araştırma kapsamında 2023 yılı ağustos ayında İstanbul Havalimanı'nda görev yapan havalimanı çalışanlarına kolayda örneklem yoluyla ulaşılarak anket uygulanmış ve bir aylık sürede geri dönüş sağlanan 176 anket üzerinden elde edilen veriler ile araştırma ve analizler yapılmıştır. Araştırmanın bağımsız değişkeni örgütsel çekicilik algısı ve bağımlı değişkeni örgütsel vatandaşlık davranışı şeklindedir. Oluşturulan araştırma modeline göre örgütsel çekicilik algısının örgütsel vatandaşlık davranışı üzerindeki etkisinin varlığını, yönünü ve düzeyini belirlemek amaçlanmıştır. Veri analizi kapsamında SPSS istatistik programı ve modelin test edilmesi kısmında da LISREL yapısal eşitlik programı kullanılmıştır.

3. BULGULAR

Örgütsel çekicilik algısı ile örgütsel vatandaşlık davranışı arasındaki ilişkiyi incelemek üzere yapılan araştırma kapsamında elde edilen veriler güvenirlik analizi, faktör analizi, örneklem yeterlilik analizi ve yapısal eşitlik modellemesi ile test edilmiş ve sonuçları sırasıyla yorumlanmıştır.

Tablo 1. Güvenirlik Analizi

	Madde Sayısı	**Cronbach's Alpha**
Örgütsel Çekicilik Algısı Ölçeği	11	0,837
Örgütsel Vatandaşlık Davranışı Ölçeği	10	0,867
Anketin Tamamı	21	0,897

Güvenilirlik analizi ile likert tipli ölçeklerdeki maddelerin iç tutarlılığını belirlemek için Cronbach's Alpha değeri kullanılmaktadır. Bu değer 0,80 üzerinde ise kullanılan ölçeğin yüksek güvenilirlikte bir düzeye sahip olduğu belirtilmektedir. Dolayısıyla yüksek düzeydeki değer, ölçekteki maddelerin birbirleriyle tutarlı olduğunu ve aynı özelliği ölçen maddelerden oluştuğunu ifade etmektedir (Yıldız ve Uzunsakal, 2018: 19). Araştırmanın güvenirlik analizi sonuçlarına göre hem örgütsel çekicilik algısı ölçeğinin (0,837) hem de örgütsel vatandaşlık davranışı ölçeğinin (0,867) Cronbach's Alpha değeri 0,80 değeri üzerinde bulunmuştur. Buna göre araştırmada kullanılan her iki ölçeğin de yüksek düzeyde güvenirliğe sahip oldukları görülmektedir.

Tablo 2. Ölçek Ortalamaları

	Ortalama	**Standart Sapma**
Örgütsel Çekicilik Algısı	3,48	0,73514
Örgütsel Vatandaşlık Davranışı	4,16	0,62717

Araştırmada beşli likert ölçeği kullanılmış ve 1 hiç katılmıyorum iken 5 kesinlikle katılıyorum olacak şekilde skala belirlenmiştir. Kullanılan iki ölçekte yer alan maddelerin tamamı olumlu ifadelerden oluştuğu için hem örgütsel çekicilik algısı değişkeninin (3,48) hem de örgütsel vatandaşlık davranışı değişkeninin (4,16) ortalamaları, orta düzeyin üzerinde değerlere sahiptir. Buna göre araştırmaya katılan çalışanların havalimanında görev yapmayı çekici olarak algıladıkları ve örgütsel vatandaşlık davranışı düzeylerinin de yüksek olduğu ifade edilebilir.

Ardından araştırma kapsamında elde edilen verilere açıklayıcı faktör analizi yapılmış ve sonuçlara göre her iki ölçeğin de tek faktör altında toplandığı, örgütsel çekicilik algısı ölçeğinin toplam varyansın %39,042'sini açıkladığı ve örgütsel vatandaşlık davranışı ölçeğinin ise toplam varyansın %47,022'sini açıkladığı görülmüştür. Yapılan faktör analizi ile örneklem yeterlilik analizi sonuçları da elde edilmiştir.

Tablo 3. Örneklem Yeterlilik Analizi

		Örgütsel Çekicilik	**Örgütsel Vatandaşlık**
KMO değeri		0,856	0,878
Bartlett's Küresellik Testi	Ki-Kare	581,385	670,599
	Serbestlik derecesi	55	45
	Anlamlılık değeri	0,000	0,000

Kaiser-Meyer-Olkin (KMO) örneklem yeterliliğini ölçmek için kullanılmaktadır ve bu değer 0,80 ile 0,90 arasında ise örneklem yeterliliğinin mükemmel olduğu ifade edilmektedir (Hadi vd., 2016: 216). Örneklem yeterlilik analizi sonuçlarına göre örgütsel çekicilik algısı ölçeğinin KMO değeri (0,856) ve örgütsel vatandaşlık davranışı ölçeğinin KMO değeri (0,878), örneklemin yeterli düzeyde olduğunu göstermektedir.

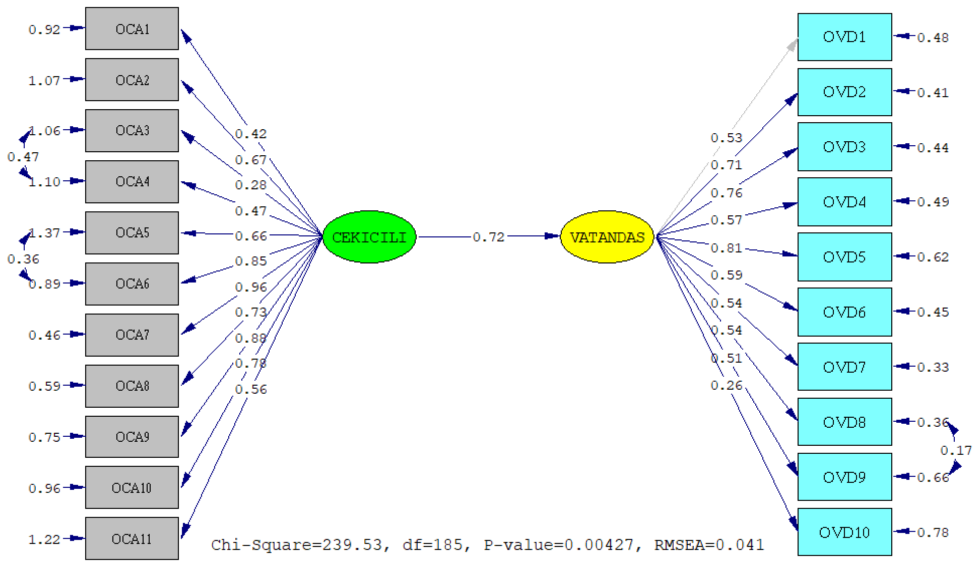
Araştırma modeli test edilmeden önce, araştırmaya katılan çalışanlara ait demografik değişkenlere yer verilmiştir.

Tablo 4. Araştırmanın Demografik Değişkenleri

Demografik Faktörler		**Sayı**	**Yüzde**	**Demografik Faktörler**		**Sayı**	**Yüzde**
Cinsiyet	Kadın	62	35,2	Eğitim durumu	Ön lisans	103	58,5
	Erkek	114	64,8		Lisans	64	36,4
Medeni durum	Evli	53	30,1		Yüksek lisans	9	5,1
	Bekar	123	69,9	Yaş aralığı	25 yaş ve altı	12	6,8
Çalışma süresi	1 yıl ve altı	26	14,8		26- 35 yaş arası	93	52,8
	2-5 yıl arası	77	43,7		36- 45 yaş arası	42	23,9
	6-10 yıl arası	53	30,1		46- 55 yaş arası	24	13,7
	11 yıl ve üzeri	20	11,4		56 yaş ve üzeri	5	2,8

Araştırmaya katılan havalimanı çalışanlarının demografik değişkenleri incelendiğinde, katılımcıların %35,2'sinin kadın ve %64,8'inin erkek; %30,1'inin evli ve %69,9'unun bekar; %58,5'inin ön lisans, %36,4'ünün lisans ve %5,1'inin yüksek lisans mezunu; %14,8'inin 1 yıl ve altı, %43,7'sinin 2-5 yıl arası, %30,1'inin 6-10 yıl arası ve %11,4'ünün 11 yıl ve üzeri çalışma süresine sahipken; %6,8'inin 25 yaş ve altında, %52,8'inin 26-35 yaş arasında, %23,9'unun 36-45 yaş arasında, %13,7'sinin 46-55 yaş arasında ve %2,8'inin 56 yaş ve üzerinde oldukları görülmektedir.

Son olarak araştırma modelini test etmek amacıyla yapısal eşitlik modellemesi yapılmış, yapısal modelin uyum iyiliği değerleri ve yapısal eşitlik sonucu tespit edilmiştir.



Şekil 1. Yapısal Eşitlik Modeli

Analiz sonucu ortaya çıkan yapısal modelde örgütsel çekicilik algısının örgütsel vatandaşlık davranışı üzerinde pozitif yönde ve anlamlı bir etkisinin olduğu görülmektedir. Yapısal eşitlik modellemesine göre örgütsel çekicilik algısı ile örgütsel vatandaşlık davranışı arasındaki yol katsayısı 0.72 düzeyindedir.

Tablo 5. Yapısal Modelin Uyum İyiliği Değerleri

Ki-Kare	Serbestlik derecesi	P-değeri	RMSEA	NFI	CFI	IFI	RFI	SRMR	GFI
239.53	185	0.00427	0.041	0.94	0.98	0.98	0.93	0.055	0.88

Yapısal eşitlik modellemesinin uyum iyiliği sonuçlarına göre RMSEA değerinin 0.80'in altında (0.041) olması ve Ki-Kare ile serbestlik derecesi değerlerinin birbirine oranının 2'nin altında bir değere (1.29) sahip olması, yapısal modelin anlamlı bir model olduğunu göstermektedir. Elde edilen bu uyum iyiliği değerleri, araştırma modelinin kabul edilebilir değerlere sahip olduğunu ifade etmektedir (İlhan ve Çetin, 2014: 31; Schermelleh-Engel vd., 2003: 52). Araştırmanın yapısal eşitlik sonucu ise şu şekildedir:

Örgütsel Vatandaşlık Davranışı = Örgütsel Çekicilik Algısı x 0.72

Ortaya çıkan bu ifadeye göre örgütsel çekicilik algısındaki 1 puanlık artış, örgütsel vatandaşlık davranışında 0.72 puanlık bir artışa yol açmaktadır. Bununla birlikte örgütsel çekicilik algısı değişkeni, örgütsel vatandaşlık davranışı değişkeninin %51'lik kısmını açıklamaktadır (R^2 0.51). Ayrıca modelin t-değerinin 2.576 değerinin üzerinde olması (6.85), modelin 0.01 düzeyinde anlamlılığa sahip olduğunu göstermektedir (Çelik ve Yılmaz, 2016: 150; Şimşek, 2007: 86). Elde edilen bu sonuç ile oluşturulan araştırma modelinin test edilerek araştırma kapsamında belirtilen hipotezin doğrulandığı görülmektedir.

4. SONUÇ

Küreselleşen dünyada ve artan rekabet ortamında, örgütler açısından başarıya ulaşma çabasında en önemli faktör insan kaynağıdır (Muttaqiyathun vd., 2023: 3713) ve yetenekli çalışanların varlığı örgütsel açıdan oldukça önemlidir (Hoye ve Lievens, 2007: 2024). Günümüzde örgütlerin, daha kaliteli çalışanları elde etmesi, yalnızca uygun kişilerin işe alınmasını sağlaması ve onları uzun vadede elde tutabilmesi, örgütsel çekiciliğe bağlıdır. Çünkü yetenekli çalışanlara sahip örgütler, örgütsel etkinliği arttırarak rakiplerine karşı büyük bir rekabet avantajı elde etmektedirler (Uen vd., 2011: 239). Aynı zamanda çalışanların, örgütsel, sosyal ve psikolojik bağlamı şekillendirerek bir örgütün operasyonel sonuçlarını etkileyen çok sayıda faktörde doğrudan veya dolaylı bir rol oynadığı bilinmektedir. Bu bakımdan örgütsel vatandaşlık davranışının da örgütsel etkinliği arttırabilen bir unsur olduğu ifade edilmektedir (Fan vd., 2023: 1-2) çünkü, örgütsel vatandaşlık davranışı örgütsel performansı geliştirmek açısından örgütlerde önemli bir role sahiptir (Vargas-Hernandez ve Vargas-Gonzalez, 2022: 5). Dolayısıyla çalışanların, bulundukları örgütü dair oluşan örgütsel çekicilik algılarının, bu çalışanların örgütsel vatandaşlık davranışı göstermelerine yol açması, bu sayede de nitelikli çalışanların uzun vadede örgütte faaliyet göstermesi hem çalışan hem örgüt açısından olumlu katkılar sağlayacaktır.

Bu çalışmada havalimanı çalışanlarının algıladıkları örgütsel çekiciliğin, örgütsel vatandaşlık davranışı üzerindeki etkisi incelenmiştir. Elde edilen sonuçlara göre hem örgütsel çekicilik algısı hem de örgütsel vatandaşlık davranışı ölçeklerinin ortalamalarının ortanın üzerinde değerlere sahip olduğu, buna göre araştırmaya katılan havalimanı çalışanlarının örgütsel çekicilik algılarının ve örgütsel vatandaşlık davranışı düzeylerinin yüksek olduğu ifade edilebilir. Yapısal eşitlik modellemesi sonucuna göre ise örgütsel çekicilik algısının örgütsel vatandaşlık davranışı üzerinde pozitif yönde ve anlamlı bir etkisinin olduğu, buna göre havalimanı çalışanlarının algıladıkları örgütsel çekiciliğin, örgütsel vatandaşlık davranışını olumlu yönde arttırdığı söylenebilir.

Sivil havacılık sektörünün hızla gelişmesi ve büyümesi, uçuş sayılarındaki ve uçuş noktalarındaki artış, yolcu ve kargo sayılarındaki artış, gelişen teknoloji ile birlikte uçuş süresinin kısalması, kıtalararası ulaşımın mümkün olması, hava taşımacılığını diğer taşımacılık türlerine göre üstün kılmaktadır. Araştırmada elde edilen sonuçlara göre araştırmaya katılan havalimanı çalışanlarının örgütsel çekicilik algılarının, örgütsel vatandaşlık davranışlarını olumlu yönde arttırdığı görülmektedir.

5. TARTIŞMA VE ÖNERİLER

Bu çalışmada araştırmaya katılan havalimanı çalışanlarının, sivil havacılık sektörünü çekici olarak gördükleri ve örgütsel vatandaşlık davranışı düzeylerinin yüksek olduğu, ayrıca örgütsel çekicilik algılarının örgütsel vatandaşlık davranışını arttırdığı görülmüştür. Çalışanların örgütsel çekicilik algıları ile örgütsel vatandaşlık davranışı arasında yapılan benzer çalışma sonuçlarına bakıldığında, Khorasani ve Nairi (2012) havalimanı çalışanlarının örgütsel vatandaşlık davranışı ortalamalarının yüksek olduğunu, Lin vd. (2012) algılanan örgütsel vatandaşlığın, örgütsel çekiciliğe olumlu etki ederek çalışanların kariyer başarısı beklentisini arttırdığını ve bu durumun başarılı çalışanları işletmeye çekme konusunda rekabet avantajı sağladığını, Taghipourian ve Eslami (2016) örgütsel vatandaşlık davranışının örgütsel çekicilik üzerinde anlamlı bir etkisinin olduğunu, örgütsel vatandaş davranışının birimlerin ve örgütlerin eylemlerini teşvik etmeye yol açtığını, bu tür davranışların işbirliğini kolaylaştırdığını ve çalışanların daha üretken olmasına yol açtığını ve böylece sosyal yatırımı genişlettiğini ifade etmişlerdir. Mishra ve Subudhi (2017) örgütsel çekiciliğin örgütsel vatandaşlık davranışına olumlu katkı sağladığını, Güllü ve Şahin (2018) örgütsel vatandaşlık davranışının yüksek ortalamaya sahip olduğunu, ancak çalışma yapılan yerin kamu kurumu olmasından dolayı örgütsel çekicilik algısının düşük olduğunu, Mishra ve Subudhi (2019) marka değeri, örgüt kültürü, saygın çalışma ortamı gibi unsurların örgütsel çekiciliği arttırdığını ve bunun da örgütsel vatandaşlık davranışında önemli bir rol oynadığını belirtmişlerdir. Mojtaba vd. (2021) algılanan örgütsel çekiciliğin örgütsel vatandaşlık davranışı üzerinde olumlu etkisi olduğunu, Wörtler vd. (2021) örgütlerdeki karma çalışma düzenlemelerinin örgütsel çekiciliği ve örgütsel vatandaşlık davranışı gösterme niyetini arttırdığını, Haryati vd. (2022) havacılık çalışanlarında hem işe gömülmüş olmanın hem de örgütsel bağlılığın örgütsel vatandaşlık üzerinde anlamlı bir etkisinin olduğunu, Maaroof vd. (2022) ise havayolu şirketlerinin örgütsel vatandaşlık davranışı konusuna dikkat etmeleri gerektiğini, bu sayede örgütsel vatandaşlık davranışının geliştirilmesine katkıda bulunacak çalışanlar için uygun bir çalışma iklimin sağlanmasının önemini ifade etmişlerdir. Putri ve Martanti (2023) havalimanı çalışanları ile yaptıkları araştırmada, çalışma ortamının örgütsel vatandaşlık davranışı üzerinde anlamlı bir etkisinin olduğunu ve aynı zamanda örgütsel vatandaşlık davranışının performans üzerinde önemli bir etkisi etkisinin olduğunu, Rahman vd. (2023) havalimanı çalışanları açısından örgütsel iklimin, örgütsel vatandaşlık davranışı üzerinde önemli bir etki yarattığını, Supardam vd. (2024) havalimanı çalışanlarında örgütsel vatandaşlık davranışının çalışanların performanslarının iyileştirilmesinde önemli katkı sağladığını, ayrıca havaalanı yönetiminin örgütsel vatandaşlık davranışına katılımı teşvik ederek örgütsel performansın güçlendirebileceğini belirtmişlerdir.

Literatürdeki çalışma sonuçlarına göre çalışanlardaki örgütsel çekicilik algılarının hem çalışanlar hem de örgütler için olumlu katkılar sağladığı, tıpkı bu araştırmada elde edilen sonuç gibi örgütsel çekicilik algısının bir sonucu olarak da çalışanların örgütsel vatandaşlık davranışı göstermelerinin olası bir sonuç olduğu görülmektedir. Sosyal etki kuramına göre, insanların duygu, düşünce ve davranışlarının diğer insanlardan etkilenmesi kaçınılmazdır. Dolayısıyla çalışanların, bulundukları örgüte dair çevrelerindeki kişilerden gelen olumlu görüş ve düşünceler, çalışanların da duygularına ve davranışlarına olumlu katkılar yaptığı söylenebilir. Çalıştıkları örgütün diğer insanlar tarafından imrenildiği ve çekici bulunduğu düşüncesi de çalışanların o örgütte sürekli var olmayı amaçlamasına ve bu bağlamda örgütsel vatandaşlık davranışı sergilemesine yol açmaktadır.

Çalışanların bulundukları kurumdan ayrılmayı düşünmemeleri, çalıştıkları kurumu saygın görmeleri, burada çalışmaktan heyecan duymaları, kurumun kendi saygınlıklarını arttırdığını düşünmeleri, başka insanların burada çalışmak istediklerine inanmaları, burada çalıştıkları için diğerlerinin kendilerine imrendiklerini düşünmeleri, burada çalışmaktan gurur duymaları, tanıdıklarının bu kurumda çalışmalarını istemeleri, kurumu başarılı algılamaları, örgütsel çekicilik algısının belirleyicileri olarak sıralanmaktadır. Gerek örgütlerin gerekse de yöneticilerin, yetenekli ve başarılı çalışanlarını uzun vadede elde tutmaları ve sürekliliklerini sağlamaları, örgütsel çekiciliğin varlığı ile mümkündür. Ayrıca çalışanların, arkadaşlarının görevlerine yardımcı olmaları, uzman oldukları alanlarda bilgi ve deneyimlerini arkadaşları ile paylaşmaları, oluşabilecek problemleri önlemek için girişimde bulunmaları, işte sorun yaşayan arkadaşlarına yardım etmede istekli olmaları, motivasyonu düşen arkadaşlarını cesaretlendirmeleri, ekibin etkinliğine katkı sağlayan önerilerde bulunmaları, bulunulan durumun olumlu taraflarına odaklanmaları, önemsiz konularla ilgili şikâyet etmemeleri de örgütsel vatandaşlık davranışının unsurları olarak belirtilmektedir. Buradan hareketle işletmelerin rekabet ortamında hayatta kalmaları, verimlilikte ve performanslarındaki artışları, mevcut çalışanlarının örgüte olan bağlılıkları ile mümkündür. Dolayısıyla örgütler ve yöneticiler, çalışanların işletmeye olan olumlu katkılarını ve performanslarını arttırmaları için çalışanlarının kendilerini örgütün bir parçası, vatandaşı gibi hissetmelerine yol açacak ortam ve uygulamalara önem vermelidirler. Bu amaçla, örgütsel çekiciliği arttıracak yönetimsel uygulamalar, adil kararlar, çalışanlarla ilişkiler gibi konular, aynı zamanda örgütsel vatandaşlığa da katkıda bulunacaktır.

Günümüzde sivil havacılık sektörünün dinamik yapısı, artan yolcu ve uçuş sayılarında görülmektedir. En güvenli ve hızlı taşıma şekli olan havayolu taşımacılığının önemi ve dolayısıyla havayoluna olan talepte artmaktadır. Havalimanları gelen ve giden uçakların, yolcuların ve kargoların en yoğun şekilde bir arada bulunduğu ortamlardır. Teknolojinin yoğun olarak görüldüğü, farklı ırk ve kültürlerden yolcuların bir arada bulunduğu sektörlerden biri olan sivil havacılık sektörü de hiç şüphesiz hem çalışanlarına hem de diğer kişilere çekici olarak görülmektedir. Bu yüzden, örgütsel çekiciliğe sahip olduğu düşünülen havacılık sektöründe yapılan bu çalışma, önceki yapılan çalışma sonuçlarıyla paralellik gösterse de havalimanı çalışanları özelinde araştırma yapılmış olması özgünlük katmaktadır.

Yapılan bu çalışmada havalimanı çalışanları ile sınırlı kalınmıştır. Örgütsel çekicilik algısı ile örgütsel vatandaşlık davranışı ilişkisini inceleyecek sonraki çalışmaların başka zaman dilimlerinde ve başka sektörlerde yapılması farklı sonuçlar doğurabilir. Ayrıca benzer çalışmanın günümüzün popüler meslek gruplarına, çalışanlara, topluma çekici görünen sektörlere ya da imajı yüksek işletmelere yapılması halinde olumlu sonuçlar elde edilmesi olasıdır. Bunumla birlikte, araştırma yapılan örgütün marka değeri, marka imajı, toplum nezdindeki konumu da ele alınmalıdır. Bu çalışmada örgütsel çekiciliğin etki ettiği değişken olarak örgütsel vatandaşlık davranışı konu edinilmiştir, ancak örgütsel çekiciliğin olası sonucu olarak örgütsel bağlılık, örgütsel özdeşleşme, sadakat, performans, verimlilik gibi değişkenler de dikkate alınabilir.

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Peak Velocity Pressure of Air Traffic Control Towers: A Comparative Study

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Abstract

The aim of this study was to compare the structural resistance of air traffic control towers (ATCTs) in Europe over 100 feet (30.48 meters) in height by determining their peak velocity pressure. Based on EN-1991-1-4 criteria, data from 64 airport ATCTs supported the results of the study. Significant variations in wind speeds and peak velocity pressure values were observed in different geographical regions of Europe. The ATCT at Athens Airport recorded the highest peak velocity pressure at 2.52 kN/m², while the lowest value was recorded at Zagreb Airport at 0.89 kN/m². These differences play a crucial role in determining the structural resistance of ATCTs. ATCTs exposed to high peak velocity pressures should use stronger materials and incorporate aerodynamic designs. Considering the significant influence of geographical location on wind loads, these results provide important insights into the safety of existing and future ATCTs. It is recommended that these findings be extended by investigating ATCTs in different geographical regions and that structural design strategies against wind loads be more thoroughly investigated in future studies..

Key Words: Air traffic control tower; Peak velocity pressure; Wind loads.

JEL Classification: M10, M19.

Hava Trafik Kontrol Kulelerinin Tepe Hız Kaynaklı Rüzgar Basınçları: Karşılaştırmalı Bir Analiz

Öz

Bu çalışmanın amacı Avrupa genelindeki 30.48 m (100 feet) üzerindeki hava trafik kontrol kulelerinin tepe hız kaynaklı rüzgar basınçlarını belirleyerek yapısal dayanıklılığını karşılaştırmaktır. EN-1991-1-4 kriterlerini referans alarak yapılan çalışma bulguları Avrupa'daki 64 havalimanının verileriyle desteklenmiştir. Avrupa genelindeki farklı coğrafi bölgelerdeki hava trafik kulelerinin maruz kaldığı rüzgar hızları ve tepe hız kaynaklı rüzgar basıncı değerleri önemli farklılıklar göstermiştir. Atina Havalimanı hava trafik kontrol kulesi 2.52 kN/m² ile en yüksek tepe hız kaynaklı rüzgar basıncına ulaşıyorken, en düşük değer 0.89 kN/m² ile Zagreb Havalimanı hava trafik kontrol kulesi için tespit edilmiştir. Analizler sonucunda belirlenen bu farklar kulelerin yapısal dayanıklılığının belirlenmesinde önemli bir rol oynamaktadır. Yüksek tepe hız kaynaklı rüzgar basıncına maruz kalan kuleler için daha sağlam malzemeler kullanılmalı ve yapıların aerodinamik tasarımı dikkate alınmalıdır. Coğrafi konumların rüzgar yükleri üzerindeki belirgin etkisi göz önünde bulundurulduğunda, bu bulgular mevcut ve yapılacak olan hava trafik kontrol kuleleri güvenliği için önemli ipucu sunmuştur. Gelecekteki çalışmalarda farklı coğrafi bölgelerdeki hava trafik kontrol kulelerinin incelenmesi ve rüzgar yüklerine karşı yapısal tasarım stratejilerinin daha kapsamlı bir şekilde araştırılması yoluyla bu bulguların genişletilmesi önerilmektedir.

Anahtar Kelimeler: Hava trafik kontrol kulesi; Rüzgar yükleri; Tepe hız kaynaklı rüzgar basıncı.

JEL Sınıflandırma: M10, M19.

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1. INTRODUCTION

Air travel is a vital component of global mobility in today's interconnected world, enabling the transfer of people and goods over long distances (Gheorghe and Sebea, 2010; Ishutkina and Hansman, 2008). The complex system of air traffic control (ATC), which is essential to maintaining the efficiency, safety, and orderliness of air travel, is at the center of this complicated network (Chaloulos, 2011). The core of aviation operations is air traffic control, which manages aircraft movement both in the air and on the ground. The primary goal of ATC is to prevent collisions between aircraft, while also facilitating the expeditious and orderly movement of flights (Degas et al., 2021). This critical function ensures that air travel is seamlessly integrated into the broader transportation network by extending beyond the management of specific airports to include regional and global airspace management. Central to the operation of ATC are the air traffic control towers (ATCTs) located at airports worldwide (Moravej et al., 2016). These iconic structures serve as command centers, overseeing all aircraft movements within their airports and surrounding airspace. Among their primary functions is the coordination of take-off and landing, a task that demands precision timing and communication to ensure the safe and efficient flow of traffic. Additionally, ATCTs play a key role in managing ground operations, including taxiing, runway assignments, and gate utilization, further enhancing the overall efficiency of airport operations (Shiomi et al., 1997).

Given the critical role that mixing height plays in the take-off and landing cycles of aircraft, where it influences the required distance and duration to reach the 3,000 feet threshold, a comprehensive assessment of both present and expected air traffic patterns is to be conducted by the ATCT (Dalkıran, 2021). The height of the ATCT is crucial. It allows air traffic controllers to effectively monitor and oversee both the airport and its surrounding airspace, enabling them to maintain control. Moreover, structural reliability throughout the operational lifespan of the ATCT is imperative. Lastly, the ATCT must ensure consistent and dependable communication between controllers and aircraft during its operational tenure, as emphasized by ICAO regulations (ICAO, 1984).

Height is crucial in designing an ATCT. To ensure safety, the ATCT must clear obstacle limitation surfaces. The required height is determined by ensuring a 1° line of sight to the runway end, visibility of the entire active pavement, and no interference with approach or missed approach paths, as shown in Figure 1.

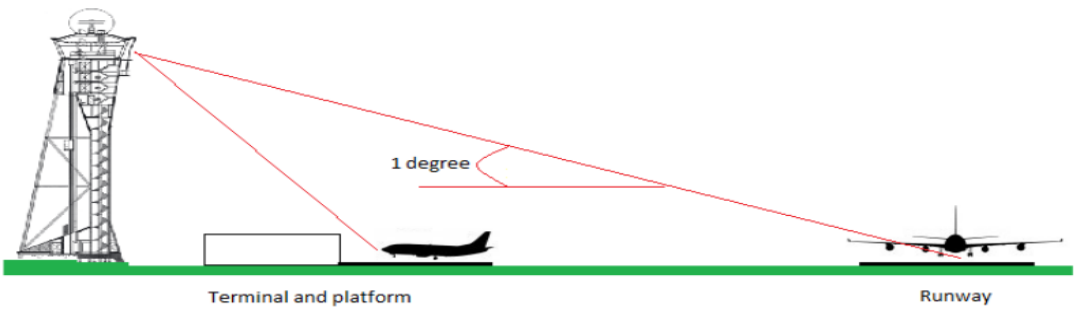

Figure 1. Minimum line of sight and direct visibility on active pavement (Hartmann, 2014)

With the increase in air traffic since the 1970s, there has been a significant rise in the number of ATCTs, as shown in Figure 2. Additionally, airports worldwide are expanding their runway infrastructure to accommodate increased air traffic, leading to the need for appropriate ATCT location and height (Prakash et al., 2020). The highest ATCTs of each construction period are shown in Figure 3. The ATCT at Jeddah King Abdul Aziz Airport in Saudi Arabia, constructed in 2014, is the tallest ATCT in the world, with a height of 136 meters, as shown in Figure 4 (Panethos, 2024).

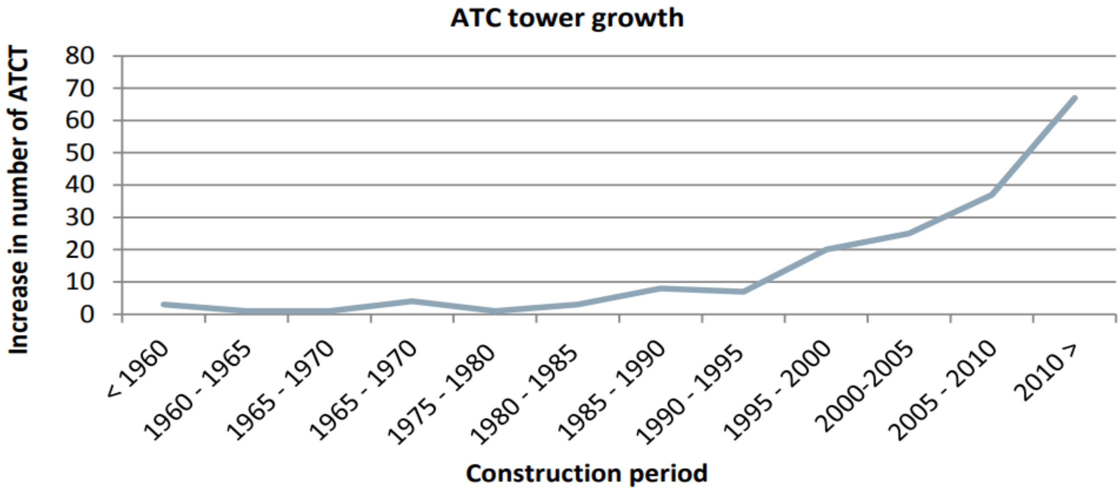

Figure 2. Air traffic control tower growth (Hartmann, 2014)

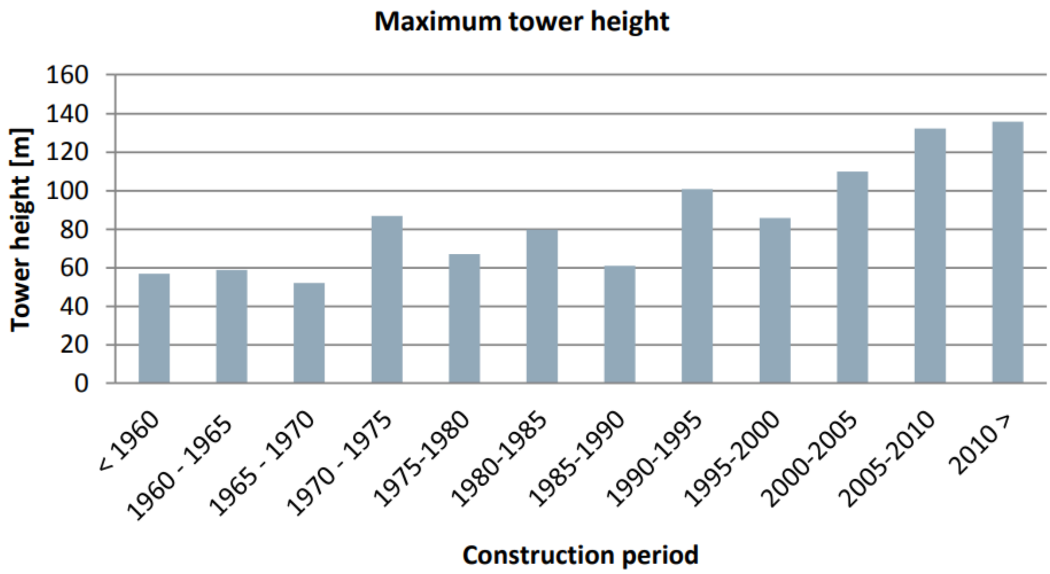

Figure 3. Maximum tower height development (Hartmann, 2014)

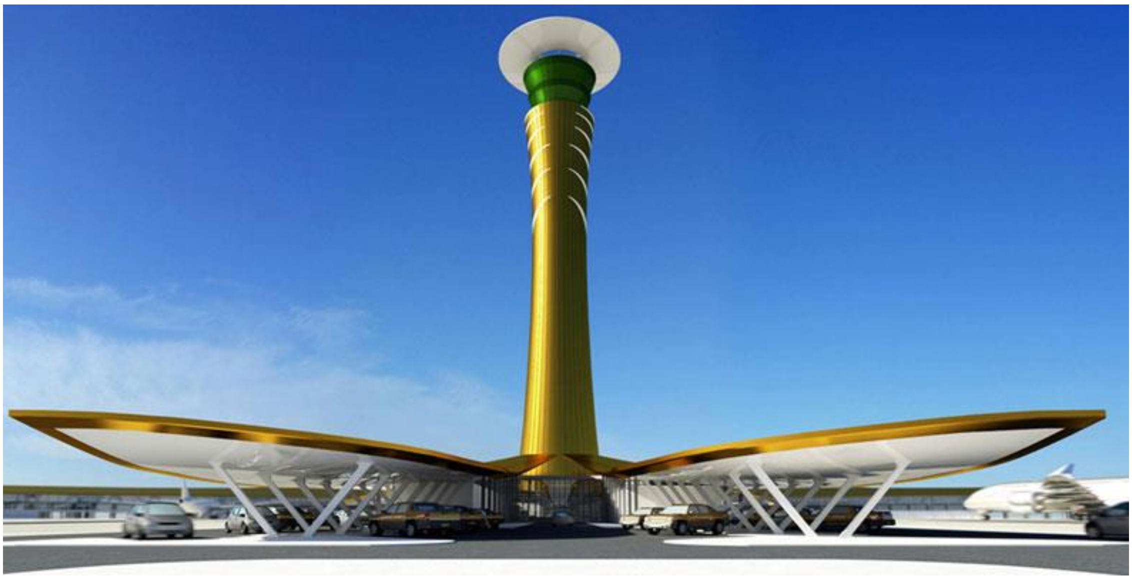

Figure 4. Jeddah King Abdul Aziz Airport ATC Tower (ACAMS, 2024)

Wind and earthquake actions are the most prevalent and significant lateral forces in structural engineering, as highlighted in the literature (Abu-Sabai 1995; Admassu, 2020; Heiza and Tayel, 2012; Raju et al., 2013). Wind, a persistent force across the Earth's surface, varies in intensity depending on geographical location and annual probability of exceedance. Notably, the effect of fluctuating wind forces generated by turbulence predominates in most building scenarios, necessitating a focus on horizontal wind loading in structural frame calculations. Estimating wind climate involves determining basic and peak velocity pressures based on local wind maps and meteorological data. Similarly, earthquake hazard assessments rely on local seismic hazard and ground-type evaluations (Preciado, 2015). These factors serve as crucial boundary conditions for structural tower design, influencing decisions regarding tower height, capacity, and vulnerability analysis against local wind and earthquake hazards (Venanzi et al., 2018). Moreover, wind force predominance is attributed to peak velocity pressure and shape factor contributions, prompting strategies to minimize the latter through aerodynamic shapes like polygons or circles, particularly in designs facing high peak velocity pressures (Hartmann, 2014). In the literature review, Wilcoski and Heymsfield (2002) examined the earthquake performance of three ATCTs at different heights (15 m and 9 m) and aimed to determine safety performance and develop approaches to enhance performance using analyses conducted with the SAP 2000 program. Eshghi and Farrokhi (2003) investigated the seismic vulnerability of ATCT's, revealing the complex behavior of these reinforced concrete structures under seismic loading conditions through finite element analysis and push-over analysis. Sexton et al. (2004) studied the seismic retrofit of the King County International Airport ATCT post-Nisqually Earthquake, focusing on foundation enhancements via compaction grouting and drilled shaft installation to mitigate liquefaction, aiming to improve seismic resistance and detailing the construction process. Vafaei and Adnan (2011) investigated the structural health condition of a 34 m high ATCT at Iran's Kirman Airport during earthquakes using sensors and nonlinear time domain analysis. Hartmann (2014) aimed to develop an optimal structural design methodology for ATCTs worldwide by studying local effects, guiding designers toward the most suitable solution considering cost factors. Vafaei and Alih (2016) calculated seismic design response spectrum factors for three existing ATCTs in Iran (23.7 m, 39.3 m, 51.7 m), noting a significant decrease in response spectrum factors with increasing tower height. Moravej et al. (2016) analyzed the seismic performance of Iran's Urmia International Airport ATCT (30.17 m) using nonlinear time domain analysis and found the current design inadequate, failing to meet CP level earthquake performance. Sullivan et al. (2017) conducted structural design for an ATCT (9-story, 12.5-degree inclined and column-free) in Lyall Bay, Wellington, foreseeing that initially selected three earthquake acceleration records would be insufficient. Vafaei and Alih (2018a) performed analyses to determine seismic effects and safety vulnerabilities of ATCTs at different heights (9 m, 23.7 m, 51.7 m), observing increased fragility with increasing height. Vafaei and Alih (2018b) conducted analyses in the nonlinear time domain to estimate seismic base shear forces in ATCTs using 45 earthquake acceleration records. Moravej and Vafaei (2019) evaluated the seismic performance of a 30.17 m high ATCT using the pushover analysis method and observed displacement demands of two stories. Sharma (2019) evaluated the design criteria of an ATCT located in Zone IV according to the Indian standard code, considering geographic location, number of floors, floor height, ground condition, load conditions, and foundation design. Amrutkar et al. (2022) examined the earthquake performance of ATCTs with different structural shapes (square, pentagon, hexagon, and octagon) at a height of 55 m, observing that towers designed in octagonal shapes exhibited the least displacement and lateral drift. Finally, Boztepe and Aktaş (2023) investigated the earthquake performance and seismic isolation effect of ATCTs in Türkiye, noting insufficient research in the country and the need for further studies.

It is noted that while seismic performance is a major focus in the structural design of ATCTs, academic studies comparatively give less attention to wind effects. ATCTs, being tall structures, are significantly affected by both seismic and wind-induced lateral forces. These towers are often exposed to wind effects due to their height, making it imperative for them to withstand critical wind parameters such as peak velocity pressure, which plays a crucial role in determining structural resilience. Tall structures, especially under the influence of wind, face heightened stress, necessitating meticulous evaluation of their structural integrity, particularly for high-rise structures like ATCTs. This research aims to analyze peak velocity pressure values to assess and compare the structural resilience of ATCTs, contributing significantly to the literature on the safety and structural integrity of these towers. However, there are some challenges, such as the need for a more detailed examination of the performance of ATCTs under wind effects in different geographical regions. This study will pave the way for more comprehensive research on the structural resilience of ATCTs.

2. MATERIALS AND METHODS

The study examined 64 ATCTs over 30.48 meters tall located in Europe. Fundamental Basic Wind Velocity values were determined using Dlubal Software GmbH according to EN 1991-1-4 and CTE DB SE-AE standards, as illustrated in Figure 5.

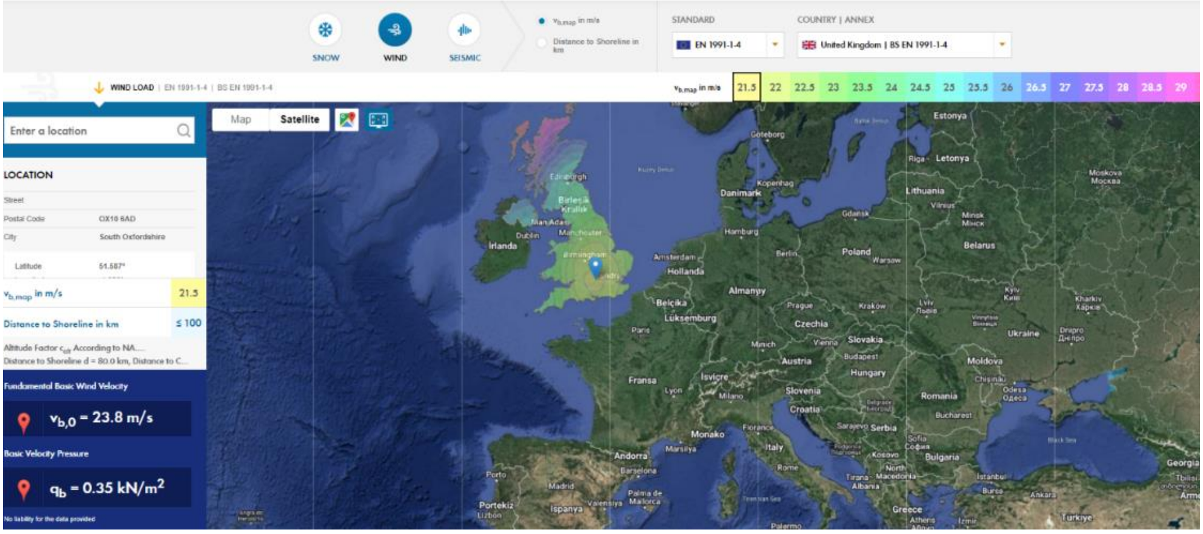

Figure 5. An example of fundamental basic wind velocity value (Dlubal, 2024)

Figure 6 illustrates the steps outlined below for calculating Peak Velocity Pressure based on EN-1991-1-4 standards (European Union, 2010). EN-1991-1-4, also known as "Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions," includes standards related to wind effects on structures. This standard provides guidance for calculating and designing the forces necessary for structures to withstand wind effects. It is particularly used for evaluating and designing structures to withstand wind loads appropriately.

Step 1: The heights of ATCTs (z) located in the European region that are over 30.48 meters (100 feet) were listed.

Step 2: Fundamental value of basic wind velocity ($v_{b.0}$) for each region where an ATCT is located was determined using Dlubal Software GmbH referencing EN 1991-1-4 and CTE DB SE-AE. The fundamental value of basic wind velocity describes a 10-minute mean at 10 m above ground in open country terrain, incorporating annual risks and additional parameters (European Union, 2010).

Step 3: The value of orography factor (c_0) was determined to be 1.0, as referenced in EN 1991-1-4.

Step 4: The value of turbulence factor (k_l) was determined to be 1.0, as referenced in EN 1991-1-4.

Step 5: Density of air (ρ) was determined to be 1.25 kg/m^3, as given in EN 1991-1-4.

Step 6: The reference height of terrain category II ($z_{o.II}$=0.05m) was determined in the study.

Step 7: Roughness length (z_0=0.05) was determined in the study.

Step 8: Terrain factor (k_r) was calculated the following formula (European Union, 2010).

$$k_r = 0.19 \cdot \left(\frac{z_0}{z_{0.II}}\right)^{0.07} \quad (1)$$

Step 9: Turbulence intensity (I_v) was calculated the following formula (European Union, 2010).

$$I_v = \frac{k_1}{c_0 \cdot \ln(\frac{z}{z_0})} \tag{2}$$

Step 10: Roughness intensity (c_r) was calculated the following formula (European Union, 2010).

$$c_r = k_r \ . \ \ln(\frac{z}{z_0}) \tag{3}$$

Step 11: The season factor (c_{season})was set to 1.0 for ATCTs since they are non-temporary structures.

Step 12: Directional factor (c_{dir}) was set to 1.0 as recommended in EN 1991-1-4 4.2 Note 2.

Step 13: Mean wind velocity (v_m) was calculated the following formula (European Union, 2010).

$$v_m = c_r \ . \ c_0 \ . \ v_{b.0} \tag{4}$$

Step 14: Peak velocity pressure (q_p) was calculated the following formula (European Union, 2010).

$$q_p = [\,1 + 7\,.I_v\,]\,.\frac{1}{2}\,.\,\rho\,.\,v_m^2 \tag{5}$$

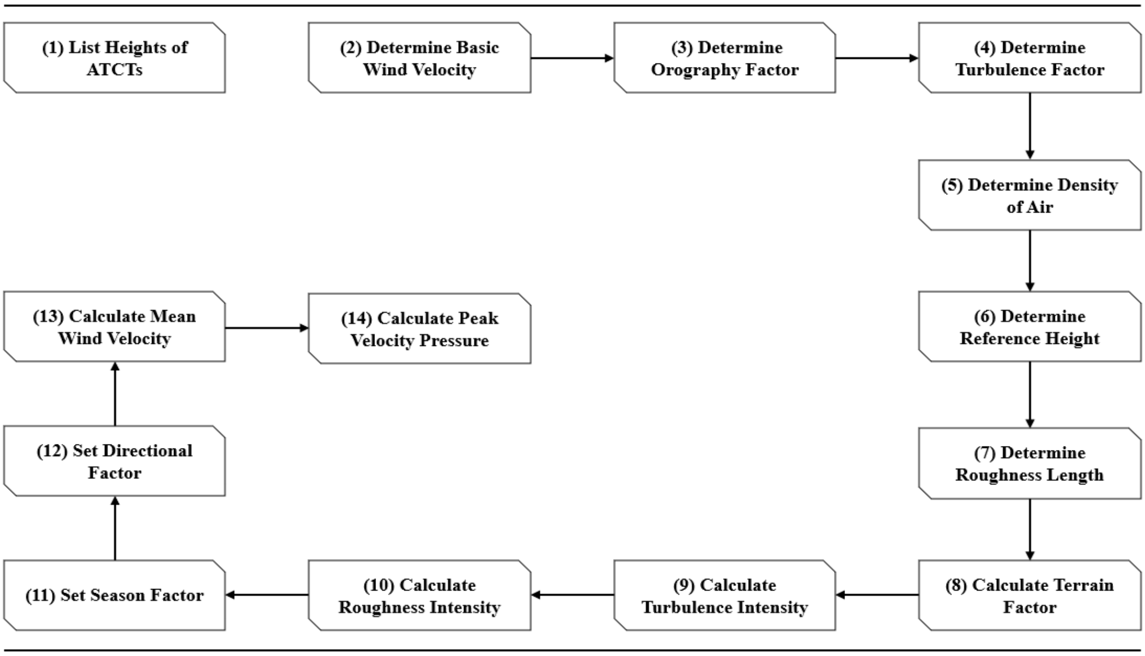

Figure 6. Calculating Peak Velocity Pressure Flow Chart

3. RESULTS

The maximum peak velocity pressure values experienced by various ATCTs at airports across Europe are determined based on their heights and the average wind speeds in their respective regions. The results are shown in Table 1, with detailed values provided in the Appendix.

The data from the 64 airports examined indicate that the ATCT heights range from 32 meters to 111.86 meters. The tallest ATCTs are at İstanbul Sabiha Gökçen Airport and Paris Charles De Gaulle Airport (primary/north), both standing at 111.86 meters. In contrast, the shortest ATCT examined in the study is at Gdansk (Wałęsa) Airport, with a height of 32 meters.

Regarding wind speeds, significant differences were observed among the airports. The highest wind speed was recorded at Athens Airport at 33.00 m/s, while the lowest wind speed was recorded at Zagreb Airport at 20.00 m/s.

The peak velocity pressure values also showed considerable variability. Athens Airport had the highest peak velocity pressure at 2.52 kN/m², whereas Zagreb Airport showed the lowest peak velocity pressure at 0.89 kN/m².

Table 1. The height, basic wind velocity, and peak velocity pressure of ATCTs

ATCT	z(m)	$v_{b.0}$ (m/s)	q_p (kN/m²)
1. İstanbul (Gokcen), Türkiye	111.86	28.00	2.01
2. Paris (De Gaulle-p/n), France	111.86	24.00	1.47
3. Vienna, Austria	110.03	25.10	1.61
4. Amsterdam (Schiphol-p), Netherlands	100.89	27.00	1.83
5. İstanbul (IGA), Türkiye	94.79	28.00	1.94
6. Oslo, Norway	91.14	22.00	1.19
7. Paris (De Gaulle-s), France	89.92	24.00	1.41
8. Dublin, Ireland	87.78	25.17	1.55
9. London (Heathrow), UK	86.87	22.10	1.19
10. Dusseldorf, Germany	85.34	22.50	1.23
11. Belgrade (Tesla), Yugoslavia	74.98	21.00	1.04
12. Munich, Germany	74.98	22.50	1.20
13. Paris (De Gaulle-c), France	74.98	24.00	1.36
14. Leipzig, Germany	73.15	25.00	1.47
15. Berlin (Brandenburg), Germany	71.93	25.00	1.46
16. Copenhagen, Denmark	71.93	24.00	1.35
17. Madrid (Barajas), Spain	71.02	26.00	1.58
18. Frankfurt, Germany	70.10	22.50	1.18
19. Milan (Malpensa), Italy	70.10	25.00	1.46
20. Athens, Greece	68.28	33.00	2.52
21. Hannover (DFS), Germany	67.97	25.00	1.45
22. London (Luton), UK	65.53	22.10	1.12
23. Paris (De Gaulle-4), France	64.92	24.00	1.32
24. London (Stansted), UK	63.09	22.10	1.11
25. Barcelona (El Prat-p), Spain	61.87	29.00	1.91
26. Amsterdam (Schiphol-w), Netherlands	60.05	27.00	1.64
27. Brussels, Belgium	60.05	25.00	1.41
28. Cologne-Bonn, Germany	60.05	22.50	1.14
29. Manchester, UK	60.05	22.50	1.14
30. Rome (Da Vinci), Italy	57.00	27.00	1.63
31. Edinburgh (Turnhouse), UK	56.69	25.00	1.39
32. Rota (Naval Station), Spain	56.08	29.00	1.87

33. Zagreb, Croatia	55.17	20.00	0.89
34. Liverpool (John Lennon), UK	54.86	23.00	1.17
35. Trondheim, Norway	54.86	26.00	1.49
36. Malaga, Spain	54.56	26.00	1.49
37. Barcelona (El Prat-s), Spain	53.64	29.00	1.85
38. Venice (Marco Polo), Italy	53.04	25.00	1.37
39. Nottingham (East Midlands), UK	52.43	22.00	1.06
40. Paris (Orly), France	52.12	24.00	1.26
41. Sofia, Bulgaria	49.99	27.71	1.66
42. Nurnberg, Germany	47.85	22.50	1.09
43. Alicante, Spain	46.94	27.00	1.56
44. Bordeaux (Merignac), France	46.02	22.00	1.03
45. Newcastle, UK	46.02	23.50	1.18
46. Katowice, Poland	45.72	22.00	1.03
47. Izmir (Menderes), Türkiye	45.11	28.00	1.66
48. Bratislava, Slovakia	42.67	26.00	1.42
49. Bilbao (Sondica), Spain	42.06	29.00	1.76
50. Nuremberg, Germany	42.06	22.50	1.06
51. Prague, Czech Republic	42.06	27.50	1.58
52. Alguaire, Spain	41.15	29.00	1.75
53. Tenerife Norte, Canary Islands, Spain	41.15	29.00	1.75
54. Jersey, UK	39.01	24.00	1.18
55. Warsaw (Chopin), Poland	37.49	22.00	0.98
56. Farnborough, UK	35.36	21.50	0.93
57. Hamburg, Germany	35.05	25.00	1.25
58. Luxembourg (Findel), Luxembourg	35.05	24.00	1.15
59. Rzeszow (Jasionka), Poland	32.92	22.00	0.96
60. Ajaccio, Corsica, France	32.61	26.00	1.33
61. Krakow, Poland	32.61	22.00	0.95
62. London (Southend), UK	32.00	22.10	0.96
63. Berlin, Germany	32.00	25.00	1.23
64. Gdansk (Walesa), Poland	31.09	26.00	1.32

4. DISCUSSION

4.1. Air Traffic Control Tower Heights and Wind

İstanbul Sabiha Gökçen and Paris De Gaulle Airports, with their ATCTs standing at 111.86 meters, are subjected to some of the highest regional wind speeds (28.00 m/s and 24.00 m/s, respectively). Similarly, Vienna and Amsterdam Schiphol Airports, with ATCTs over 100 meters, also experience high regional wind speeds (25.10 m/s and 27.00 m/s, respectively).

Tall towers are more exposed to the aerodynamic effects of wind due to their larger surface area (Li et al., 1998). As wind speed and pressure values increase, the durability and stability of the materials used in the structural design of the towers become crucial. The effect of wind on the tower requires consideration of not only static loads but also dynamic loads (Sollenberger, Billington, & Scanlan, 1980). This necessitates accurate calculation of wind speeds and tower heights, and optimization of structural designs accordingly.

The relationship between height and wind speed plays a critical role in the design of ATCTs. For towers exposed to high wind speeds, it's important to use robust and durable materials for structural stability, consider aerodynamic design elements, and ensure periodic maintenance of ATCTs. These factors are essential to ensure that air traffic controllers can manage air traffic continuously, efficiently, and safely, even under high wind conditions.

4.2.Geographical Variations

The wind speeds and pressures experienced by ATCTs vary significantly depending on their geographical locations. This is an important factor that needs to be considered in their design and engineering. ATCTs in airports of Northern Europe generally experience lower wind speeds and peak velocity pressures. For instance, The ATCT in Oslo Gardermoen Airport has a wind speed of 22.00 m/s, while the ATCT in London Heathrow Airport has a wind speed of 22.10 m/s. Both have peak velocity pressures of 1.19 kN/m². These values reflect the cooler and more stable climate conditions in the northern regions.

In contrast, ATCTs in airports of the Mediterranean region are exposed to higher wind speeds and peak velocity pressures. For example, the ATCT in Athens Airport has a wind speed of 33.00 m/s and a peak velocity pressure of 2.52 kN/m², which are among the highest values in the study. Similarly, the ATCT in Barcelona El Prat Airport shows high values with a wind speed of 29.00 m/s and a peak velocity pressure of 1.91 kN/m². This reflects the influence of the warmer and more variable weather conditions in the Mediterranean region.

These geographical differences are crucial factors to consider in the design and construction of ATCTs. In regions with high wind speeds and peak velocity pressures, towers need to be constructed with durable and robust materials (Ahmed et al., 2010; Gong et al., 2019). Additionally, these towers should be designed to withstand wind loads, incorporating aerodynamic shapes and reinforcing structural supports. The impact of geographical location on wind loads necessitates that structural engineers and designers develop optimal solutions by considering local climate conditions.

4.3. Peak Velocity Pressure and Safety

Peak velocity pressure is a critical parameter for the structural integrity and operational safety of ATCTs. Athens Airport, with the highest peak velocity pressure of 2.52 kN/m² in the study, requires the ATCTs structure to be highly resistant to wind loads. Similarly, Barcelona El Prat Airport also exhibits high values with a peak velocity pressure of 1.91 kN/m².

These high peak velocity pressures are an essential factor to consider in the structural design of the towers. High peak velocity pressure values necessitate the construction of towers with more robust materials and the optimization of structures aerodynamically. The impact of peak velocity pressure on safety becomes particularly evident under extreme weather conditions. Towers exposed to high peak velocity pressures are at greater risk during severe wind events (Sheng et al., 2018). Therefore, towers subjected to high peak velocity pressures should be designed to be more durable and secure, and they should undergo regular maintenance. These measures are necessary to ensure the safe and uninterrupted continuation of air traffic control operations. Structural engineering and aerodynamic solutions will enhance the ATCTs' resilience to wind loads, guaranteeing long-term performance and safety.

5. CONCLUSIONS

This study presents a comparative analysis of ATCTs at airports across Europe in terms of their heights, wind speeds, and peak velocity pressures. The findings indicate that ATCT heights vary from 32 meters to 111.86 meters, with wind speeds ranging from 20.00 m/s to 33.00 m/s. Peak velocity pressures vary between 0.89 kN/m² and 2.52 kN/m². These values highlight the critical nature of the wind loads that ATCTs are exposed to, emphasizing their importance in structural design and engineering.

The relationship between height and wind speed provides significant insights into how towers perform against wind loads. Tall ATCTs experience higher wind speeds, necessitating the use of more durable materials in construction. Geographical variations have a significant impact on airport wind speeds and peak velocity pressures. Airports in Northern Europe generally experience lower wind speeds and peak velocity pressures, while those in the Mediterranean region exhibit higher values. This underscores the need to consider local climate conditions in structural design.

Peak velocity pressure is a critical parameter for structural stability and safety. Towers exposed to high peak velocity pressures should be designed to be more durable and secure. Structural integrity of these towers should be optimized to resist wind loads effectively. In regions with high wind speeds and peak velocity pressures, more durable and aerodynamic structures should be designed, and towers should undergo regular maintenance and inspections to ensure safety.

In conclusion, the performance of ATCTs against wind loads should be carefully evaluated from both structural engineering and aerodynamic perspectives. These assessments are crucial for enhancing the operational efficiency and safety of airports. Future studies could expand on these findings by including airports from different geographical regions and examining structural design strategies against wind loads in more detail. Such analyses could provide insights into ensuring uninterrupted air traffic operations against potential structural risks.

Nomenclature

z	m	Height
$v_{b.0}$	m/s	Basic wind velocity
c_0	-	Orography factor
k_I	-	Turbulence factor
ρ	kg/m^3	Density of air
$z_{0.II}$	m	Reference height of terrain category II
z_0	m	Roughness length
k_r		Terrain factor
I_v		Turbulence intensity
c_r		Roughness intensity
c_{season}		Season factor
c_{dir}		Directional factor
v_m	m/s	Mean wind velocity
q_p	kN/m²	Peak velocity pressure

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Conflict of Interest

The author declares no known conflict of interest.

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Appendix

- Air Traffic Control Towers' Values

Air Traffic Control Towers	z (m)	$v_{b.0}$ (m/s)	I_v	c_r	v_m (m/s)	q_p (kN/m²)
1. İstanbul (Gokcen), Türkiye	111.86	28.00	0.130	1.465	41.0	2.01
2. Paris (De Gaulle-p/n), France	111.86	24.00	0.130	1.465	35.2	1.47
3. Vienna, Austria	110.03	25.10	0.130	1.462	36.7	1.61
4. Amsterdam (Schiphol-p), Netherlands	100.89	27.00	0.131	1.446	39.0	1.83
5. İstanbul (IGA), Türkiye	94.79	28.00	0.132	1.434	40.2	1.94
6. Oslo, Norway	91.14	22.00	0.133	1.427	31.4	1.19
7. Paris (De Gaulle-s), France	89.92	24.00	0.133	1.424	34.2	1.41
8. Dublin, Ireland	87.78	25.17	0.134	1.419	35.7	1.55
9. London (Heathrow), UK	86.87	22.10	0.134	1.417	31.3	1.19
10. Dusseldorf, Germany	85.34	22.50	0.134	1.414	31.8	1.23
11. Belgrade (Tesla), Yugoslavia	74.98	21.00	0.137	1.389	29.2	1.04
12. Munich, Germany	74.98	22.50	0.137	1.389	31.3	1.20
13. Paris (De Gaulle-c), France	74.98	24.00	0.137	1.389	33.3	1.36
14. Leipzig, Germany	73.15	25.00	0.137	1.385	34.6	1.47
15. Berlin (Brandenburg), Germany	71.93	25.00	0.138	1.382	34.5	1.46
16. Copenhagen, Denmark	71.93	24.00	0.138	1.382	33.2	1.35
17. Madrid (Barajas), Spain	71.02	26.00	0.138	1.379	35.9	1.58
18. Frankfurt, Germany	70.10	22.50	0.138	1.377	31.0	1.18
19. Milan (Malpensa), Italy	70.10	25.00	0.138	1.377	34.4	1.46
20. Athens, Greece	68.28	33.00	0.139	1.372	45.3	2.52
21. Hannover (DFS), Germany	67.97	25.00	0.139	1.371	34.3	1.45
22. London (Luton), UK	65.53	22.10	0.139	1.364	30.1	1.12
23. Paris (De Gaulle-4), France	64.92	24.00	0.139	1.362	32.7	1.32
24. London (Stansted), UK	63.09	22.10	0.140	1.357	30.0	1.11
25. Barcelona (El Prat-p), Spain	61.87	29.00	0.140	1.353	39.2	1.91
26. Amsterdam (Schiphol-w), Netherlands	60.05	27.00	0.141	1.347	36.4	1.64
27. Brussels, Belgium	60.05	25.00	0.141	1.347	33.7	1.41
28. Cologne-Bonn, Germany	60.05	22.50	0.141	1.347	30.3	1.14
29. Manchester, UK	60.05	22.50	0.141	1.347	30.3	1.14
30. Rome (Da Vinci), Italy	57.00	27.00	0.142	1.337	36.1	1.63
31. Edinburgh (Turnhouse), UK	56.69	25.00	0.142	1.336	33.4	1.39
32. Rota (Naval Station), Spain	56.08	29.00	0.142	1.334	38.7	1.87
33. Zagreb, Croatia	55.17	20.00	0.143	1.331	26.6	0.89
34. Liverpool (John Lennon), UK	54.86	23.00	0.143	1.330	30.6	1.17
35. Trondheim, Norway	54.86	26.00	0.143	1.330	34.6	1.49
36. Malaga, Spain	54.56	26.00	0.143	1.329	34.6	1.49
37. Barcelona (El Prat-s), Spain	53.64	29.00	0.143	1.326	38.4	1.85
38. Venice (Marco Polo), Italy	53.04	25.00	0.144	1.324	33.1	1.37
39. Nottingham (East Midlands), UK	52.43	22.00	0.144	1.321	29.1	1.06
40. Paris (Orly), France	52.12	24.00	0.144	1.320	31.7	1.26
41. Sofia, Bulgaria	49.99	27.71	0.145	1.312	36.4	1.66
42. Nurnberg, Germany	47.85	22.50	0.146	1.304	29.3	1.09
43. Alicante, Spain	46.94	27.00	0.146	1.300	35.1	1.56
44. Bordeaux (Merignac), France	46.02	22.00	0.147	1.297	28.5	1.03
45. Newcastle, UK	46.02	23.50	0.147	1.297	30.5	1.18
46. Katowice, Poland	45.72	22.00	0.147	1.295	28.5	1.03
47. Izmir (Menderes), Türkiye	45.11	28.00	0.147	1.293	36.2	1.66
48. Bratislava, Slovakia	42.67	26.00	0.148	1.282	33.3	1.42
49. Bilbao (Sondica), Spain	42.06	29.00	0.148	1.280	37.1	1.76
50. Nuremberg, Germany	42.06	22.50	0.148	1.280	28.8	1.06
51. Prague, Czech Republic	42.06	27.50	0.148	1.280	35.2	1.58
52. Alguaire, Spain	41.15	29.00	0.149	1.275	37.0	1.75

53. Tenerife Norte, Canary Islands, Spain	41.15	29.00	0.149	1.275	37.0	1.75
54. Jersey, UK	39.01	24.00	0.150	1.265	30.4	1.18
55. Warsaw (Chopin), Poland	37.49	22.00	0.151	1.258	27.7	0.98
56. Farnborough, UK	35.36	21.50	0.152	1.247	26.8	0.93
57. Hamburg, Germany	35.05	25.00	0.153	1.245	31.1	1.25
58. Luxembourg (Findel), Luxembourg	35.05	24.00	0.153	1.245	29.9	1.15
59. Rzeszow (Jasionka), Poland	32.92	22.00	0.154	1.233	27.1	0.96
60. Ajaccio, Corsica, France	32.61	26.00	0.154	1.231	32.0	1.33
61. Krakow, Poland	32.61	22.00	0.154	1.231	27.1	0.95
62. London (Southend), UK	32.00	22.10	0.155	1.228	27.1	0.96
63. Berlin, Germany	32.00	25.00	0.155	1.228	30.7	1.23
64. Gdansk (Walesa), Poland	31.09	26.00	0.155	1.222	31.8	1.32

Note: $c_0 = 1.00$; $k_I = 1.00$; ρ **(kg/m³)** =1.25; $z_{0.II} = 0.05$; $z_0 = 0.05$; $k_r = 1.19$; $c_{season} = 1.00$; $c_{dir} = 1.00$