

REPUBLIC OF TÜRKİYE
YILDIZ TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

**ORIENTATION ANALYSIS BETWEEN HELMET
MOUNTED IMAGING AND TURRETED GUN SYSTEMS IN
HELICOPTER AVIONICS SYSTEMS**

Kerem ÇALIŞKAN

MASTER OF SCIENCE THESIS

Department of Avionics Engineering

Program of Avionics Engineering

Supervisor

Prof. Dr. Ufuk SAKARYA

July, 2024

REPUBLIC OF TÜRKİYE

YILDIZ TECHNICAL UNIVERSITY

GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

**ORIENTATION ANALYSIS BETWEEN HELMET MOUNTED
IMAGING AND TURRETED GUN SYSTEMS IN HELICOPTER
AVIONICS SYSTEMS**

A thesis submitted by Kerem ÇALIŞKAN in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** is approved by the committee on 10.07.2024 in Department of Avionics Engineering, Program of Avionics Engineering.

Prof. Dr. Ufuk SAKARYA
Yıldız Technical University
Supervisor

Approved By the Examining Committee

Prof. Dr. Ufuk SAKARYA, Supervisor
Yıldız Technical University

Doç. Dr. Peyman MAHOUTİ, Member
Yıldız Technical University

Dr. Öğr. Üye. Rıfat BENVENİSTE, Member
Fenerbahçe University

I hereby declare that I have obtained the required legal permissions during data collection and exploitation procedures, that I have made the in-text citations and cited the references properly, that I haven't falsified and/or fabricated research data and results of the study and that I have abided by the principles of the scientific research and ethics during my Thesis Study under the title of "Orientation Analysis Between Helmet Mounted Imaging And Turreted Gun Systems In Helicopter Avionics Systems" supervised by my supervisor, Prof. Ufuk SAKARYA. In the case of a discovery of false statement, I am to acknowledge any legal consequence.

Kerem ÇALIŞKAN

Signature



*Dedicated to my family
and my best friend*

ACKNOWLEDGEMENTS

First and foremost, I wish to extend my appreciation to my advisor, Professor Dr. Ufuk SAKARYA, for his unwavering guidance and assistance throughout my master's thesis research. His continual support and advice were instrumental during the challenging phases of this endeavor.

Moreover, I wish to convey my gratitude to my beloved family members who facilitated the circumstances and tasks for me, consistently demonstrating their unwavering support throughout this demanding process.

Kerem ÇALIŞKAN

TABLE OF CONTENTS

LIST OF ABBREVIATIONS	vi
LIST OF FIGURES	vii
LIST OF TABLES	viii
ABSTRACT	ix
ÖZET	xi
1 INTRODUCTION	1
1.1 Literature Review.....	2
1.2 Objective of the Thesis	3
1.3 Hypothesis.....	3
1.4 Structure of the Thesis	4
2 RELATED WORKS	5
2.1 Overview of the Helmet Mounted Display System	5
2.1.1 Basic Helmet Functions	5
2.1.2 HMD (Helmet Mounted Display) Functions	6
2.1.3 Helmet Mounted Sight (HMS) Function.....	8
2.2 Usage Of Turreted Gun Systems on Helicopters	10
2.3 Relation Between Turreted Gun System and Head Mounted Display System on Helicopters	11
2.3.1 Avionic Architecture of Platform.....	11
2.3.2 Turreted Gun Aiming with Helmet Mounted Display System	12
2.4 Filtering	12
2.4.1 Kalman Filter Applications in Target Tracking	13
2.4.2 Innovative Studies in Kalman Filter Applications	14
3 THE PROPOSED METHOD	19
4 SIMULATIONS	22
5 CONCLUSION	30
REFERENCES	32
PUBLICATIONS FROM THE THESIS	35

LIST OF ABBREVIATIONS

EKF	Extended Kalman Filters
HMDS	Helmet Mounted Display System
LOS	Line of Sight
UKF	Unscented Kalman Filters



LIST OF FIGURES

Figure 4.1 Kalman filter model.....	23
Figure 4.2 Overview of the proposed method	24
Figure 4.3 Aiming error [4, -4] mrad and gun dispersion [10, -10] mrad standard deviations	25
Figure 4.4 Aiming error [1, -1] mrad and gun dispersion [10, -10] mrad standard deviations	26
Figure 4.5 Aiming error [4, -4] mrad and gun dispersion [5, -5] mrad standard deviations	27
Figure 4.6 Aiming error [1, -1] mrad and gun dispersion [5, -5] mrad standard deviations	28

LIST OF TABLES

Table 4.1 Standard deviations of azimuth and elevation angles with LOS values (in degrees)..... **29**



Orientation Analysis Between Helmet Mounted Imaging and Turreted Gun Systems in Helicopter Avionics Systems

Kerem ÇALIŞKAN

Department of Avionics Engineering

Master of Science Thesis

Supervisor: Prof. Ufuk SAKARYA

This thesis investigates the operational dynamics and performance characteristics of Helmet Mounted Display Systems (HMDS) and Turreted Gun Systems within helicopter avionics. These systems are integral to modern rotary-wing platforms, enhancing target detection, aiming capabilities, and overall operational effectiveness. Despite their significance, the interplay between aiming error, gun dispersion, and their impact on azimuth and elevation accuracy remains complex and underexplored. This study aims to bridge this gap by analyzing how variations in aiming error and gun dispersion affect the standard deviations of these critical angles, using advanced simulation methodologies.

The research utilizes Monte Carlo simulations and Kalman filter integration to model and evaluate the effects of differing ranges of aiming error and gun dispersion on azimuth and elevation angles. Simulations were conducted with varied parameters to replicate realistic operational conditions and assess the resultant variability in angle measurements. The findings demonstrate that wider ranges of aiming error and gun dispersion significantly increase the standard deviations of azimuth and elevation angles, indicating greater variability and reduced accuracy in targeting.

Notably, the combination of extensive aiming error and gun dispersion amplifies these effects, suggesting a synergistic relationship that exacerbates angle variability. This highlights the need for minimizing these errors to improve precision in helicopter avionics systems. The results underscore the critical role of optimizing HMDS and Turreted Gun Systems to enhance the accuracy and reliability of ballistic targeting.

Moreover, this thesis contributes to the broader discourse on the optimization of helicopter avionics, offering insights that are valuable for both military and civilian applications. The methodologies and findings provide actionable guidance for the development and refinement of targeting systems, aiming to improve operational effectiveness and survivability in diverse mission scenarios. Overall, this research advances our understanding of the factors influencing angle measurement precision in helicopter avionics and proposes strategies for mitigating risks associated with aiming and dispersion errors.

Keywords: Helicopter avionics, helmet mounted display systems (HMDS), turreted gun systems, kalman filter, monte carlo simulations.

Helikopter Aviyonik Sistemlerinde Kaska Monteli Görüntüleme ve Taretli Top Sistemleri Arasındaki Yönlendirme Analizi

Kerem ÇALIŞKAN

Aviyonik Mühendisliği Anabilim Dalı
Yüksek Lisan Tezi

Danışman: Prof. Dr. Ufuk SAKARYA

Bu tez, helikopter aviyonik sistemlerinde Kaska Monteli Görüntüleme Sistemleri ve Taretli Silah Sistemlerinin operasyonel dinamikleri ve performans özelliklerini incelemektedir. Bu sistemler, modern döner kanatlı platformların hedef tespiti, nişan alma yetenekleri ve genel operasyonel etkinliğini artırarak kritik bir rol oynamaktadır. Önemi büyük olmasına rağmen, nişan hatası, silah saçılması ve bunların azimut ve elevasyon doğruluğuna etkisi arasındaki etkileşim karmaşıktır ve yeterince araştırılmamıştır. Bu çalışma, nişan hatası ve silah saçılması varyasyonlarının bu kritik açıların standart sapmaları üzerindeki etkilerini ileri simülasyon metodolojileri kullanarak analiz ederek bu boşluğu doldurmayı amaçlamaktadır.

Araştırmada, farklı nişan hatası ve silah saçılması aralıklarının azimut ve elevasyon açılarına etkilerini modellemek ve değerlendirmek için Monte Carlo simülasyonları ve Kalman filtre entegrasyonu kullanılmıştır. Gerçekçi operasyonel koşulları taklit etmek ve açı ölçümlerindeki değişkenliği değerlendirmek için çeşitli parametrelerle simülasyonlar gerçekleştirilmiştir. Bulgular, daha geniş nişan hatası ve silah saçılması aralıklarının azimut ve elevasyon açıları standart sapmalarını önemli ölçüde artırarak daha fazla değişkenlik ve azalan hedefleme doğruluğu gösterdiğini ortaya koymaktadır.

Özellikle, geniş nişan hatası ve silah saçılması kombinasyonu bu etkileri daha da artırarak açısal değişkenliği kötüleştiren sinerjistik bir ilişki olduğunu öne sürmektedir. Bu, bu hataların en aza indirilmesi gerektiğini ve helikopter aviyonik sistemlerinde hassasiyetin artırılması gerektiğini vurgulamaktadır. Sonuçlar, Kaska Monteli Görüntüleme Sistemleri ve Taretli Silah Sistemlerinin optimize edilmesinin balistik hedeflemenin doğruluğunu ve güvenilirliğini artırmadaki kritik rolünü vurgulamaktadır.

Ayrıca, bu tez, helikopter aviyonik sistemlerinin optimizasyonu konusundaki geniş tartışmalara katkıda bulunarak, askeri ve sivil uygulamalar için değerli bilgiler sunmaktadır. Metodolojiler ve bulgular, çeşitli görev senaryolarında operasyonel etkinliği ve hayatta kalma oranını iyileştirmeyi amaçlayan hedefleme sistemlerinin geliştirilmesi ve rafine edilmesi için uygulanabilir rehberlik sağlamaktadır. Genel olarak, bu araştırma, helikopter aviyonik sistemlerinde açısal ölçüm hassasiyetini etkileyen faktörlere dair anlayışımızı ilerletmekte ve nişan alma ve saçılma hatalarıyla ilişkili riskleri azaltmak için stratejiler önermektedir.

Anahtar Kelimeler: Helikopter aviyonik sistemleri, kaska monteli görüntüleme sistemleri, taretli silah sistemleri, kalman filtresi, monte carlo simülasyonları.

The advancement of technology in aviation has revolutionized military operations and civilian transportation, leading to increased efficiency, safety, and capabilities. Among the myriad of technological innovations, Helmet Mounted Display Systems (HMDS) and Turreted Gun Systems stand out as critical components in modern helicopter avionics. HMDS integrates cutting-edge display technologies with advanced sensors, providing pilots with real-time situational awareness and enhanced targeting capabilities. On the other hand, Turreted Gun Systems offer precision firepower, enabling helicopters to engage ground targets with unprecedented accuracy. Together, these systems play a pivotal role in enhancing the operational effectiveness and survivability of helicopters in diverse mission scenarios, ranging from combat operations to search and rescue missions. However, despite their significance, the performance characteristics and operational dynamics of HMDS and Turreted Gun Systems remain subjects of ongoing research and development. The complex interplay between technological advancements, human factors, and environmental variables poses unique challenges in optimizing the effectiveness and reliability of these systems. Understanding the intricate relationships between these factors is crucial for maximizing the potential of helicopter avionics and ensuring mission success in dynamic and challenging environments.

Against this backdrop, this study aims to delve deep into the operational significance and intricacies of HMDS and Turreted Gun Systems within the framework of helicopter avionics systems. By exploring their pivotal roles in target detection, aiming capabilities, and defense mechanisms against a wide array of threats, this research seeks to provide comprehensive insights into the operational dynamics of these critical components. The primary focus lies in meticulously examining the performance characteristics of Turreted Gun Systems, with particular emphasis on understanding the nuanced effects of dispersion values on their functionality and efficacy in real-world scenarios.

Through rigorous analysis and evaluation, this research endeavors to elucidate the intricate interplay between technological advancements and operational effectiveness in helicopter avionics systems, underscoring the pivotal role played by HMDS and Turreted Gun Systems in enhancing mission success and survivability. Additionally, the study

seeks to shed light on the complex relationship between dispersion values and in-use performance, offering valuable insights into the optimization of these systems for diverse operational environments.

By leveraging advanced methodologies, including the integration of the Kalman filter, the research aims to provide a nuanced understanding of how these systems can be synergistically utilized to maximize operational capabilities and mitigate risks effectively. Furthermore, the findings of this study are expected to contribute significantly to the ongoing discourse surrounding the optimization and evolution of helicopter avionics systems, providing actionable insights for both military and civilian applications.

1.1 Literature Review

Helmet Mounted Display System is one of the guidance systems used to engage the target on rotary wing attack platforms. This system allows the sensors in the cockpit to track the pilot's head movements during flight and transmit this data to Helmet System Computer. In Helmet System Computer, sensor data is analyzed and 3D orientation data is obtained.

In case the firing will be made with aid of the Helmet System, this data generated on the Helmet System Computer must provide the pilot's line of sight to the sub-equipment of the platform's weapon system. By transmitting the data set of the pilot's line of sight from the Helmet System Computer to the Fire Control Computer, the position of the target is provided to the ballistic algorithm developed for the weapon system to be used. The outputs of the ballistic algorithm are modified according to the location of the target and the platform and the environmental conditions of the platform. These outputs are displayed to the pilot on screens in the cockpit and/or in the visor of the Helmet Mounted Display System before the ammunition is fired.

The data obtained as a result of the aforementioned process steps will be affected by disruptive factors such as head shaking and cockpit vibration. It has been evaluated that the weapon system, in which the results of the ballistic algorithm output can be seen most clearly if the disruptors are transmitted without filtering, is the turreted gun system. The turreted gun system has higher firing rate than rocket and other similar systems. For this reason, it is considered that during the integrated use of weapon system and Helmet Mounted Display System, the transmission of the data transmitted to the ballistic

algorithm in a state free of disruptive factors compared to its raw state will have a positive effect on the performance.

It is aimed to compensate for the delays that may arise from the performance of the sub-equipment of the system and the disruptive factors in the process from the acquisition of the data to its processing and transmission to the ballistic algorithm, with an appropriate filter design.

1.2 Objective of the Thesis

Helmet Mounted Display System is one of the guidance systems used to engage the target on rotary wing attack platforms. This system allows the sensors in the cockpit to track the pilot's head movements during flight and transmit this data to Helmet System Computer. In Helmet System Computer, sensor data is analyzed and 3D orientation data is obtained.

1.3 Hypothesis

In the realm of helicopter avionics systems, the accuracy of azimuth and elevation measurements is crucial for mission success and operational effectiveness. It is hypothesized that aiming error and gun dispersion significantly influence the accuracy of these measurements, thus impacting the overall performance of helicopter avionics systems. This hypothesis is grounded in the understanding that aiming error introduces deviations from the intended target trajectory, while gun dispersion adds further variability to the observed angles. Therefore, it is anticipated that wider ranges of aiming error and gun dispersion will result in increased standard deviations of azimuth and elevation angles, reflecting a decrease in accuracy.

Furthermore, it is hypothesized that the combined effect of aiming error and gun dispersion will exacerbate angle variability, leading to a synergistic impact on azimuth and elevation accuracy. This hypothesis stems from the recognition that aiming error and gun dispersion are not isolated factors but rather interact dynamically within the avionics system. As such, deviations introduced by aiming error may be amplified by gun dispersion, further compromising the precision of angle measurements. Consequently, it is expected that simulations exploring wider ranges of both aiming error and gun dispersion will reveal a nonlinear relationship between these factors and

azimuth/elevation accuracy, emphasizing the importance of considering their combined effects in avionics system design and optimization.

This hypothesis sets the foundation for the subsequent analysis and evaluation of azimuth and elevation accuracy in helicopter avionics systems. By systematically investigating the effects of aiming error and gun dispersion through Monte Carlo simulations and Kalman filter-based estimation, this research aims to provide empirical evidence supporting or refuting these hypotheses. The outcomes of this study are expected to yield valuable insights into the factors influencing angle variability and contribute to the enhancement of avionics system design and performance optimization strategies.

1.4 Structure of the Thesis

Below is an outline of the parts of the thesis:

The first chapter provides a brief overview of the topic and explains the thesis' main purpose.

The second chapter discusses the literature on disruptive factors of Head Mounted Display System performance, Turreted Gun Systems on Helicopter, and signal filtering methods.

The third chapter proposed method given in this study is explained.

The fourth chapter explains simulations.

The fifth chapter gives the results and engages in discussions about the results.

2.1 Overview of the Helmet Mounted Display System

2.1.1 Basic Helmet Functions

2.1.1.1 Head Protection

The Helmet Mounted Display System (HMDS) is a sophisticated and multifaceted system comprising 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 [1]. This evolution has greatly enhanced the Helmet's functionality and versatility, enabling seamless integration of these subsystems and ensuring 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.

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 a 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 [2].

The Helmet Mounted Display System is a complex and essential system, with the Helmet playing a vital role in connecting the pilot to the various subsystems. Its meticulous design and craftsmanship ensure it meets the specific requirements of the aircraft and its platform. The Helmet's evolution into a mounting platform enhances its functionality and

versatility, allowing for seamless integration of subsystems. Furthermore, the Helmet provides crucial protection for the pilot, defending against potential.

2.1.1.2 Intercommunication

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 is 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 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 exposure to potentially harmful levels of noise pollution that may have detrimental effects on the auditory system [3].

2.1.2 HMD (Helmet Mounted Display) Functions

The main objective of a Helmet Mounted Display (HMD) system is to project a diverse array of artificially generated images and videos onto its viewfinder. This advanced technology enhances 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 a Forward-Looking Infrared (FLIR) system, which is responsible for detecting and identifying targets within the operational platform. The HMD system serves as a crucial interface between the operator and FLIR system, enabling seamless integration and real-time visualization of detected targets [4].

This advanced technology significantly 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 a viewfinder, the HMD system offers a comprehensive and immersive visual experience. This empowers the operator to make informed decisions and take appropriate actions based on the detected targets.

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

Overall, the Helmet Mounted Display system 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 [5].

2.1.2.1 Video Presentation

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 [6]. 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 the Helmet Mounted Display viewfinder, which remains accessible at all times [7].

2.1.2.2 Symbology Presentation

The symbology display is a vital component of the Helmet Mounted Display System, serving the crucial purpose of visually presenting essential flight and weapon utilization indicators to the pilot. This presentation is achieved through a strategic placement of a variety of signs and symbols on the viewfinder, employing a two-dimensional approach. 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 [1]. These cues are displayed within the pilot's line of sight, 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.

Furthermore, the display incorporates a variety of signs and symbols that are specifically designed to represent different aspects of the aircraft's operation, including flight parameters, weapon status, and navigational information [7]. By utilizing these signs and symbols, the symbology display presents a comprehensive overview of the aircraft's current state, enabling the pilot to make informed decisions regarding flight operations.

The symbology display is an indispensable tool in aviation, providing pilots with the necessary information to operate the aircraft and its weaponry effectively. Its two-dimensional approach, 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.

2.1.3 Helmet Mounted Sight (HMS) Function

The Helmet Mounted Sight (HMS) is an advanced technology that plays a significant role in the aviation industry. Its primary function is to track 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 line of sight (LOS), ensuring accurate and efficient operations within the aircraft [8].

One of the key functionalities of the Helmet Mounted Sight is its ability to precisely monitor and analyze the pilot's head position and movements. By constantly tracking the pilot's head, the system can determine the exact location of their line of sight, which is crucial for aligning the symbology and aiming systems within the aircraft [9]. This alignment is paramount for the pilot to have a clear and accurate view of the information displayed on the Helmet Mounted Display.

In order to achieve this alignment, the Helmet Mounted Sight utilizes advanced sensors and algorithms that are capable of capturing and processing real-time data regarding the pilot's head movements [10]. 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.

Once the data regarding the pilot's head movements are captured, the Helmet Mounted Sight then analyzes this information and calculates the appropriate adjustments required to align the symbology and aiming systems with the pilot's line of sight. 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 Helmet Mounted Display [11].

Furthermore, the Helmet Mounted Sight also plays a vital role in enhancing situational awareness for the pilot. By accurately aligning the symbology and aiming systems with the pilot's line of sight, 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 [5].

In conclusion, the Helmet Mounted Sight 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 line of sight, 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.

2.1.3.1 Tracking and Sensors

Various methods have been employed to obtain line-of-sight information thus far. Currently, optical and magnetic trackers are the preferred options. The Tracker System, a constituent of the Helmet Mounted Display System, may comprise multiple subunits depending on the prevailing conditions. The sensors on the helmet, which are responsible for indicating the line of sight, along with the position-detecting sensors, transmit the gathered data to the Mission Computer.

As evident from, the operation of the Helmet Mounted Display System, 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 the Helmet Mounted Display System, serving as a bridge between the subsystems and the platform [12].

2.2 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 line-of-sight data [13]. 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 [14].

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 [15].

2.3 Relation Between Turreted Gun System and Head Mounted Display System on Helicopters

The utilization of a Helmet Mounted Display System (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 [12].

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 Forward Looking Infrared or Radar, as these technologies were not available during the era when the helicopter was initially conceived in the 1970s [16].

The prime focus of the Helmet Mounted Display System is to optimize the aiming performance, particularly in the context of firing the turreted gun system. This sophisticated system actively transmits crucial line of-sight information to the pilot, enabling them to seamlessly align their target and weapon systems [17]. The criticality of this functionality cannot be overstated, as it plays a pivotal role in ensuring the successful execution of operational tasks.

2.3.1 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 [18]. In a similar vein, the Helmet Mounted Display System 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 [18].

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 line-of-sight information, which has been meticulously generated by the Helmet Mounted Display System, to the turreted gun system.

2.3.2 Turreted Gun Aiming with Helmet Mounted Display System

In the context of weapons cueing, it is customary for pilots to position a fixed targeting reticle at the central region of the Helmet Mounted Display (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 [19]. On the other hand, there is acceptance in Hewlett studies that the targeting accuracy is around 4 milliradians [20].

2.4 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.

2.4.1 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 [21].

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 [22].

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 2.1 to 2.6, orchestrates both the prediction and update stages of the tracking process [23].

Equation 2.1 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.

$$\hat{x} = F\hat{x}^{k-1} + B\hat{u}^{k-1} + \hat{u}^{k-1} \quad (2.1)$$

Simultaneously, Equation 2.2 formulates the prediction error covariance matrix (P_k), reflecting the uncertainty associated with the predicted state, incorporating the process noise covariance matrix, Q .

$$P_k = FP_{k-1}F^T + Q \quad (2.2)$$

The Kalman Filter's prowess extends beyond prediction, as detailed in Equations 2.3 to 2.6. In this update stage, real-time measurements z_k refine predictions, dynamically adjusting estimates based on observed data. Equation 2.3 expresses the measurement

residual \tilde{y} , signifying the disparity between predicted and observed measurements, with H as the measurement matrix.

$$\tilde{y} = z_k - H\hat{x}^k \quad (2.3)$$

Leveraging this information, Equations 2.4 to 2.6 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 2.4 involves the Kalman Gain, where I is the identity matrix R is the measurement noise covariance matrix [23].

$$K_k = P_k H^T (H P_k H^T + R)^{-1} \quad (2.4)$$

$$\hat{x}^+ = \hat{x}^k + K_k \tilde{y} \quad (2.5)$$

$$P_k^+ = (I - K_k H) P_k \quad (2.6)$$

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 2.3 to 2.6, 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 [24].

2.4.2 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 [25].

In the pursuit of enhancing the adaptability of the Kalman Filter, researchers explore adaptive Kalman filters, introducing Equation 2.7 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 [26].

$$\tilde{y} = Hx_k + v_k \quad (2.7)$$

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 [27]. 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 [28].

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 expansion. 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 [29].

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 [30]. These filters have shown promising results, especially in scenarios with highly nonlinear dynamics and complex uncertainties.

The observation model, elegantly expressed in Equation 2.7, 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 [30].

In applications prioritizing high precision, the literature highlights the Kalman filter's effectiveness in target prediction. Equation 2.8, 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 [31].

$$z_k = Hx_k + v_k \quad (2.8)$$

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 [32]. 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 2.9, 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.

$$\hat{x}^+ = Fx_{k-1} + Bu_{k-1} + w_{k-1} \quad (2.9)$$

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 [33].

Equations 2.10 and 2.11 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.

$$\hat{x}^+ = \hat{x}^k + K_k \tilde{y} \quad (2.10)$$

$$P_k^+ = (I - K_k H) P_k \quad (2.11)$$

THE PROPOSED METHOD

In this study, we propose an approach based on Monte Carlo simulation to evaluate the impact of aiming errors and gun dispersion on the standard deviations of azimuth and elevation angles in helicopter avionics systems. This method focuses on the performance characteristics of Turreted Gun Systems, particularly the effects of dispersion values, and evaluates the use of Kalman filters when these systems are integrated with Helmet Mounted Display Systems (HMDS).

First, to ensure statistical significance, 100,000 Monte Carlo simulations were conducted. This large number of simulations increases the reliability and validity of the results. The simulation parameters and the ranges for aiming errors and gun dispersion were defined as follows:

- Aiming Error Range: Two different ranges were evaluated: [4, -4] and [1, -1] mrad
- Gun Dispersion Range: Two different ranges were evaluated: [10, -10] and [5, -5] mrad

To investigate the effects of different levels of aiming errors and gun dispersion, four different combinations were simulated:

- Combination 1: Aiming Error [4, -4] mrad and Gun Dispersion [10, -10] mrad
- Combination 2: Aiming Error [1, -1] mrad and Gun Dispersion [10, -10] mrad
- Combination 3: Aiming Error [4, -4] mrad and Gun Dispersion [5, -5] mrad
- Combination 4: Aiming Error [1, -1] mrad and Gun Dispersion [5, -5] mrad

Monte Carlo simulations for each combination were conducted as follows; at the start of the simulations, random values for constant wave azimuth and elevation were generated within the range of -45 to 45 degrees. These values were chosen to reflect a wide range of real operational conditions. For each combination, random values for aiming errors and gun dispersion were generated within the defined ranges. These values were meticulously selected to simulate the real-world performance of the systems.

The azimuth and elevation of the gun's line of sight (LOS) were calculated by adding the aiming errors and gun dispersion to the constant wave values. This calculation is critical for simulating real operational scenarios. A Kalman filter was applied to estimate azimuth

and elevation angles based on noisy observations (gun LOS values). The Kalman filter is known for its ability to provide optimal estimates even in nonlinear systems and was configured with the following parameters:

- Process Noise Variance (Q): 1×10^{-3} ,
- Measurement Noise Variance (R): 1×10^{-2} ,
- Measurement Matrix (H): 1,
- Initial Estimates (x_0): 0,
- Initial Estimate Error Covariance (P_0): 1.

Initial angles of the pilot's line of sight are provided during the initialization stage of the process. It is at this crucial stage that the foundational data regarding the angles are established, setting the basis for all subsequent calculations and predictions. Moving on to the prediction stage, which comes after the initialization stage, intricate predictions concerning the state estimate and the error covariance are meticulously formulated, following the mathematical formulations presented in equations 2.1 and 2.2. These predictions are essential in order to anticipate the future trajectory and behavior of the system under consideration. Transitioning to the update stage, which is the subsequent phase in the sequence, a series of complex calculations are conducted to determine the measurement residual and the Kalman gain, utilizing the equations 2.4 and 2.11 as the guiding principles. These calculations play a pivotal role in refining the estimations and reducing uncertainties associated with the system. Furthermore, it is imperative to note that in this update stage, not only are the measurement residual and Kalman gain calculated, but also the state estimate and the error covariance are updated based on the outcomes of the aforementioned calculations, as outlined in equation 2.11. This comprehensive update process ensures that the estimations and predictions remain accurate and aligned with the real-time data, enhancing the overall efficiency and reliability of the system.

The standard deviations of the estimated azimuth and elevation angles were calculated for each simulation run. This process was performed for all 100,000 simulations and across all four combinations. The results were stored in arrays for subsequent analysis. The simulation results were analyzed by plotting histograms of the standard deviations of azimuth and elevation angles for each combination. The mean values of the standard deviations were also calculated and marked on the histograms. This analysis provided

valuable insights into how aiming errors and gun dispersion affect the accuracy of azimuth and elevation estimates.

The proposed method effectively evaluates the impact of aiming errors and gun dispersion on the standard deviations of azimuth and elevation angles through extensive Monte Carlo simulations and Kalman filter-based estimation. The results offer valuable insights into optimizing the accuracy of aiming systems under various error and dispersion conditions. This approach can be extended to other parameters and configurations, making it a versatile tool for accuracy analysis in complex systems.

This study helps us understand the profound impact of technological advancements in helicopter avionics on operational effectiveness, while also shedding light on the effects of dispersion values on performance during use. Specifically, the integration of HMDS and Turreted Gun Systems has been examined to see how these systems enhance defensive capabilities against threats and optimize their performance characteristics.

In conclusion, this research makes significant strides in developing new methods and analytical techniques to enhance the accuracy of target detection and aiming in helicopter avionics systems. The use of Monte Carlo simulations and Kalman filters provides powerful tools for detailed evaluation and optimization of these systems' performance. These findings lay an important foundation for future research and applications, playing a critical role in improving the effectiveness of helicopter avionics systems.

4

SIMULATIONS

This research delves deeply into the operational significance and intricacies of Helmet Mounted Display Systems (HMDS) and Turreted Gun Systems within the framework of helicopter avionics systems. By exploring their pivotal roles in target detection, aiming capabilities, and defense mechanisms against a wide array of threats, this study aims to provide comprehensive insights into the operational dynamics of these critical components. The primary focus lies in meticulously examining the performance characteristics of Turreted Gun Systems, with particular emphasis on understanding the nuanced effects of dispersion values on their functionality and efficacy in real-world scenarios.

Through rigorous analysis and evaluation, the research endeavors to elucidate the intricate interplay between technological advancements and operational effectiveness in helicopter avionics systems, underscoring the pivotal role played by HMDS and Turreted Gun Systems in enhancing mission success and survivability. Additionally, the study seeks to shed light on the complex relationship between dispersion values and in-use performance, offering valuable insights into the optimization of these systems for diverse operational environments. By leveraging advanced methodologies, including the integration of the Kalman filter, the research aims to provide a nuanced understanding of how these systems can be synergistically utilized to maximize operational capabilities and mitigate risks effectively.

Furthermore, the findings of this study are expected to contribute significantly to the ongoing discourse surrounding the optimization and evolution of helicopter avionics systems, providing actionable insights for both military and civilian applications. Through its comprehensive approach and meticulous analysis, this research endeavors to advance our understanding of the operational dynamics and technological advancements driving the efficacy and performance of HMDS and Turreted Gun Systems in modern helicopter avionics.

The Monte Carlo simulations conducted in this study aimed to investigate the effects of aiming error and gun dispersion on the standard deviations of azimuth and elevation angles in a ballistic system. The simulations were performed with varying combinations

of aiming error ranges ([4, -4] and [1, -1]) and gun dispersion ranges ([10, -10] and [5, -5]).

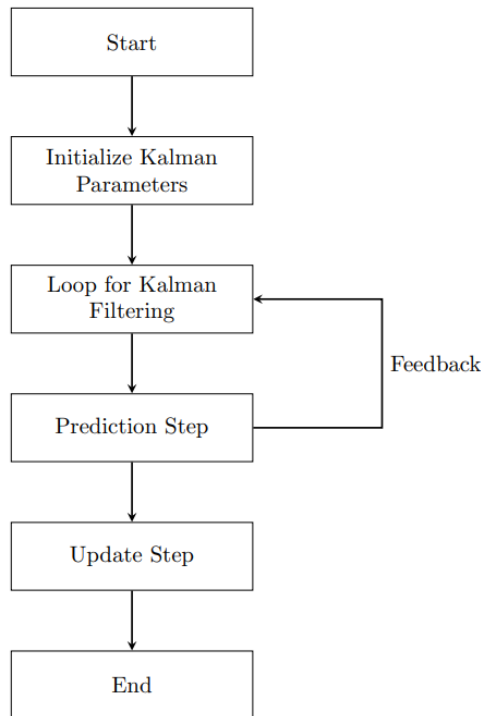


Figure 4.1 Kalman filter model

Within the contents of this particular chapter, a thorough examination is conducted on the proposed methodology of the present study. The methodology in question involves the integration of the Kalman Filter and Monte Carlo simulations in order to formulate the analyzed aiming performance of helicopter. The development of this proposed algorithm, as well as the execution of essential simulations, is facilitated through the use of the MATLAB program [34]. A visual representation outlining a simplistic framework of the proposed methodology can be observed in Figure 4.2 located below:

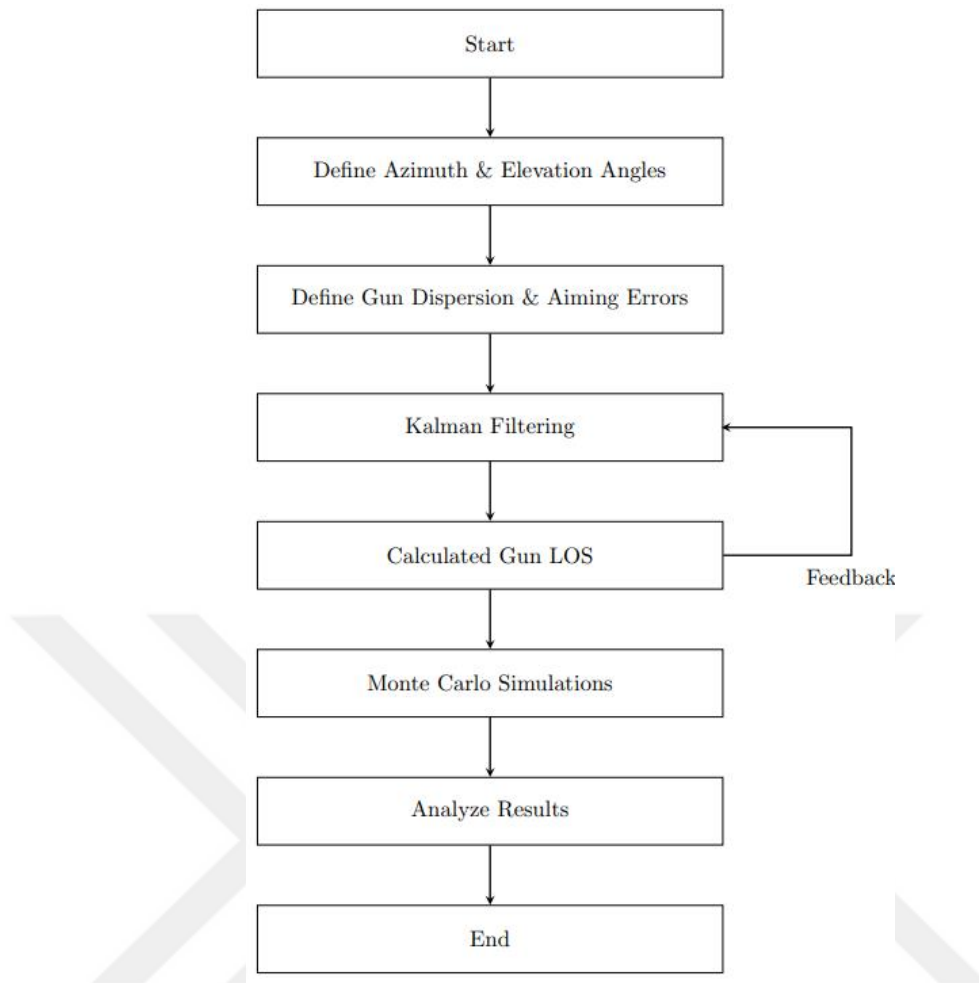


Figure 4.2 Overview of the proposed method

The results reveal several key insights into the relationship between aiming error, gun dispersion, and the resulting standard deviations of azimuth and elevation angles.

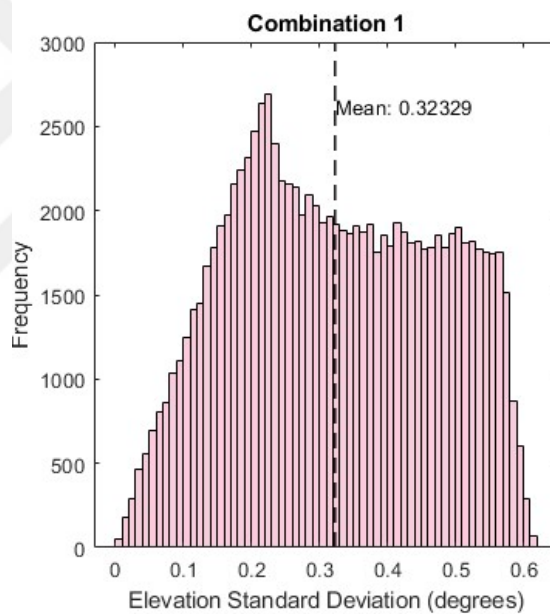
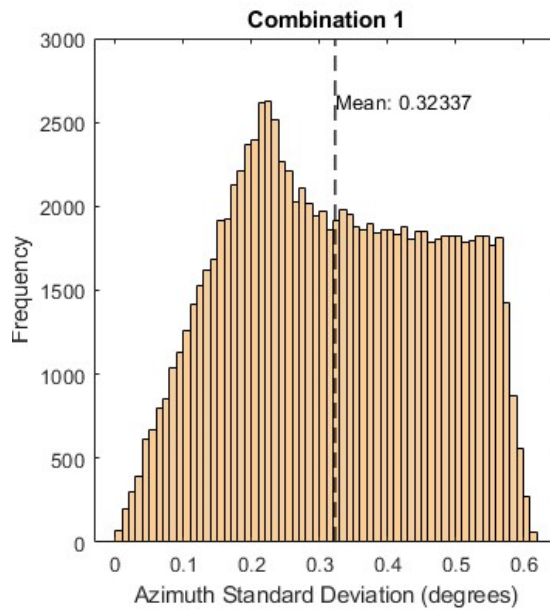


Figure 4.3 Aiming error [4, -4] mrad and gun dispersion [10, -10] mrad standard deviations

When the aiming error range was wider ([4, -4]), both azimuth and elevation standard deviations tended to be higher compared to the narrower aiming error range ([1, -1]). This indicates that larger aiming errors lead to greater variability in both azimuth and elevation angles.

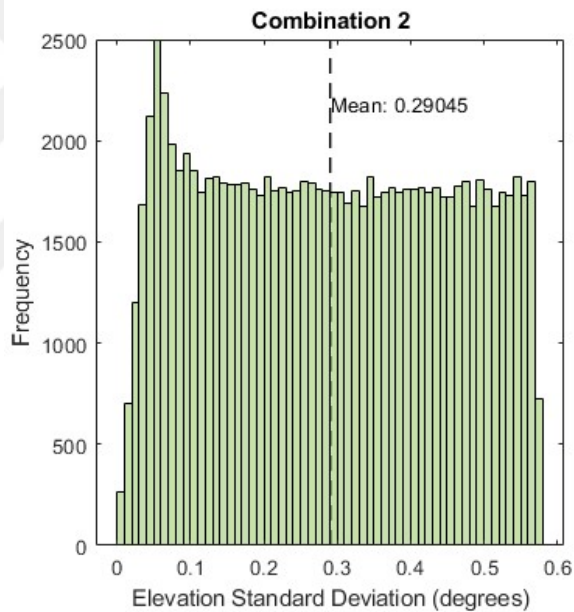
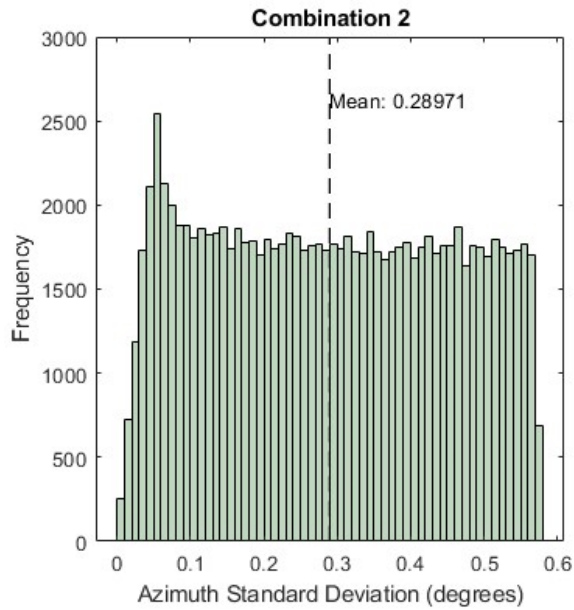


Figure 4.4 Aiming error [1, -1] mrad and gun dispersion [10, -10] mrad standard deviations

Similarly, simulations showed that wider gun dispersion ranges ([10, -10]) resulted in larger standard deviations for both azimuth and elevation angles compared to narrower dispersion ranges ([5, -5]). This suggests that increased gun dispersion contributes to higher variability in angle measurements.

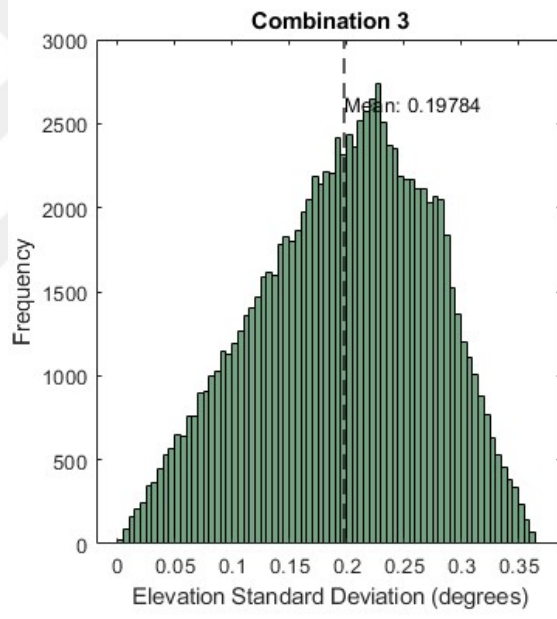
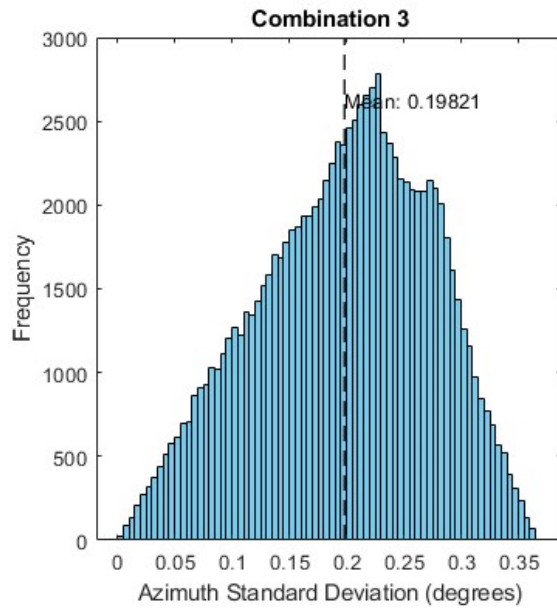


Figure 4.5 Aiming error [4, -4] mrad and gun dispersion [5, -5] mrad standard deviations

Interestingly, the combination of wider aiming error and wider gun dispersion yielded the highest standard deviations for both azimuth and elevation angles. This suggests that aiming error and gun dispersion may have a synergistic effect on angle variability, exacerbating each other's impact. Across all simulation scenarios, the standard deviations of azimuth and elevation angles followed consistent patterns, with wider error and dispersion ranges leading to increased variability.

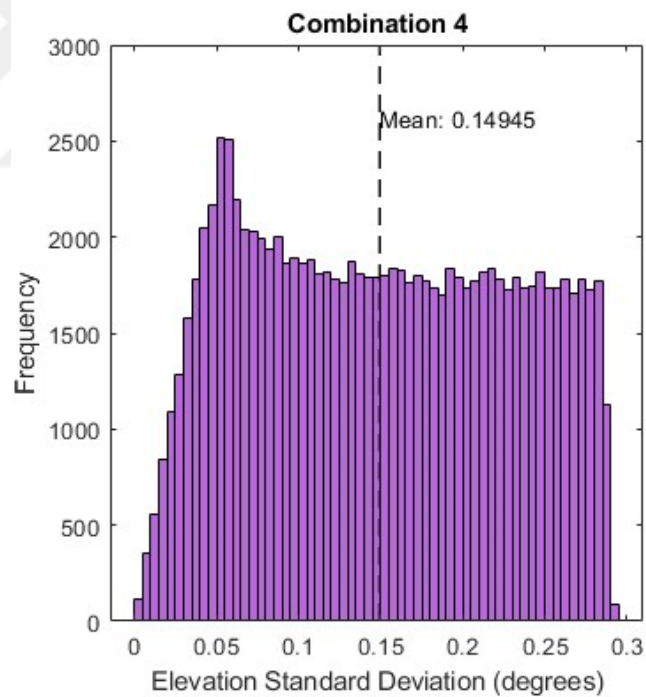
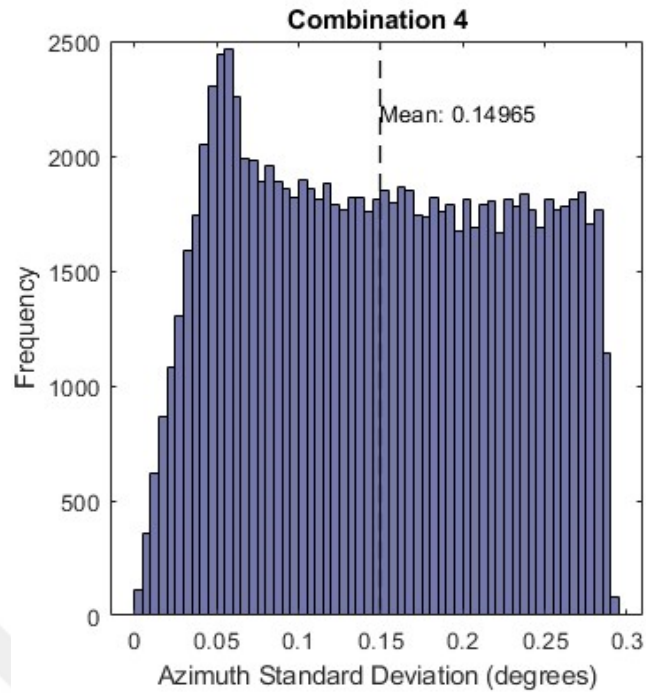


Figure 4.6 Aiming error [1, -1] mrad and gun dispersion [5, -5] mrad standard deviations

Below are the detailed results from the simulations, showing the standard deviations of azimuth and elevation angles under different conditions of aiming error and gun dispersion.

Table 4.1 Standard deviations of azimuth and elevation angles with LOS values (in degrees)

Comb. #	Azimuth		Elevation	
	Mean	Standard Deviation	Mean	Standard Deviation
1	-30,0000069	0,3234	-14,9999968	0,3233
2	-29,9999926	0,2897	-15,0000038	0,2905
3	-29,9999989	0,1982	-15,0000023	0,1978
4	-29,9999996	0,1497	-15,0000011	0,1495

These findings underscore the importance of minimizing aiming error and gun dispersion in ballistic systems to enhance the precision and accuracy of angle measurements. Strategies aimed at reducing these sources of variability could include improving aiming mechanisms, enhancing firearm manufacturing processes, and implementing advanced calibration techniques. Overall, the results of this study provide valuable insights into the factors influencing angle variability in ballistic systems, contributing to the optimization of firearm design and ballistic measurement techniques. Further research could explore additional parameters and system configurations to deepen our understanding of angle measurement precision in real-world applications.

Additionally, this study offers significant implications not only for the defense industry but also for civilian aviation. The advancement and optimization of helicopter avionics systems have the potential to enhance safety and performance not only in military operations but also in civilian air transportation. Specifically, the incorporation of technologies such as HMDS and Turreted Gun Systems in civilian helicopters can provide significant advantages in areas such as emergency management, search and rescue operations, and air ambulance services. Therefore, it is important to emphasize that the findings of this study may not only be limited to military purposes but also hold great potential for benefiting the civilian aviation industry.

5

CONCLUSION

In this study, comprehensive Monte Carlo simulations were conducted to evaluate the impact of aiming errors and gun dispersion on the standard deviations of azimuth and elevation angles in helicopter avionics systems. The proposed methodology integrated Monte Carlo simulations with Kalman filter-based estimation to analyze the performance of Turreted Gun Systems, with a particular focus on the effects of dispersion values when these systems are used in conjunction with Helmet Mounted Display Systems (HMDS).

Simulations were carried out for four different combinations of aiming error ranges and gun dispersion ranges:

- Combination 1: Aiming Error [4, -4] mrad and Gun Dispersion [10, -10] mrad
- Combination 2: Aiming Error [1, -1] mrad and Gun Dispersion [10, -10] mrad
- Combination 3: Aiming Error [4, -4] mrad and Gun Dispersion [5, -5] mrad
- Combination 4: Aiming Error [1, -1] mrad and Gun Dispersion [5, -5] mrad

Results from these simulations provided insights into how different levels of aiming errors and gun dispersion affect the accuracy of azimuth and elevation measurements.

- **Combination 1:** The highest standard deviations in both azimuth and elevation angles were observed due to the wider ranges of aiming error and gun dispersion, indicating that larger errors and dispersions lead to greater variability in angle measurements.
- **Combination 2:** Lower standard deviations were observed compared to Combination 1, attributed to the reduced aiming error range.
- **Combination 3:** Lower standard deviations than Combination 1 were observed, primarily due to the narrower gun dispersion range.
- **Combination 4:** The lowest standard deviations were observed, highlighting the combined effect of narrow aiming error and gun dispersion ranges in reducing measurement variability.

The analysis revealed that minimizing aiming errors and gun dispersion is crucial for enhancing the precision and accuracy of azimuth and elevation angle measurements. These findings underscore the importance of advanced aiming mechanisms, improved

firearm manufacturing processes, and effective calibration techniques in reducing these sources of variability.

The application of the Kalman filter in estimating the azimuth and elevation angles demonstrated significant improvements in the accuracy of these measurements. By filtering out noise and providing optimal estimates, the Kalman filter played a pivotal role in enhancing the reliability of the simulation results.

The implications of this study extend beyond military applications, offering valuable insights for civilian aviation as well. The optimization and advancement of helicopter avionics systems, particularly through the integration of HMDS and Turreted Gun Systems, can significantly improve safety and performance in civilian air transportation. For instance, emergency management, search and rescue operations, and air ambulance services can benefit from the enhanced capabilities provided by these technologies.

Moreover, the study highlights the potential for future research to explore additional parameters and system configurations. By expanding the scope of the simulations and incorporating more complex models, further improvements in angle measurement precision can be achieved. This approach will contribute to the ongoing evolution of helicopter avionics systems, driving innovations that enhance both military and civilian applications.

Future studies could focus on developing more efficient and flexible Kalman filter models to address various operational scenarios. Additionally, incorporating models for enemy missiles and analyzing their impact on engagement outcomes would provide a more comprehensive understanding of the dynamics involved. These enhancements will further optimize the performance and reliability of helicopter avionics systems in real-world applications.

REFERENCES

- [1] C. E. Rash, W. E. McLean, J. C. Mora and M. H. Ledford, "Design issues for helmet-mounted display systems for rotary-wing aviation," 1998.
- [2] S. Carter and A. Cameron, "Eurofighter helmet-mounted display - status update," in *Helmet- and Head-Mounted Displays V*, 2000.
- [3] C. E. Rash, M. B. Russo, T. R. Letowski and E. T. Schmeisser, "Helmet-mounted displays: sensation, perception and cognition issues," 2009.
- [4] C. Seidel, C. Samuelis, M. Wegner, T. Münsterer, T. Rumpf and I. Schwartz, "Novel approaches to helicopter obstacle warning," *Proc SPIE*, May 2006.
- [5] J. K. Heinecke, "An evaluation of the AH-64 night vision systems for use in 21st century urban combat," 2006.
- [6] F. F. Mulholland, "Common software & interface for different helmet mounted display (HMD) aircraft symbology sets," in *Helmet and Head-Mounted Displays V*, 2000.
- [7] H.-D. Böhm and P. Erismann, "NH90 TTH: the mission adaptable helicopter - the mission flight aids," in *Proceedings of the 23rd European Rotorcraft Forum, Dresden*, 1997.
- [8] J. H. Brindle, "Advanced helmet tracking technology developments for naval aviation," in *Head-Mounted Displays*, 1996.
- [9] R. H. Y. So and M. J. Griffin, "Effects of a target movement direction cue on head-tracking performance," *Ergonomics*, vol. 43, p. 360–376, 10 April 2000.
- [10] S. D. Smith, "The effects of head orientation on head/helmet vibration response," vol. 30, p. 16, May 2001.
- [11] A. A. Cameron, S. Trythall and A. Barton, "Helmet trackers: the future," in *Helmet- and Head-Mounted Displays and Symbology Design Requirements II*, 1995.
- [12] H.-D. Böhm, C. Evers and K. Stenner, "Tests with an integrated helmet system for the TIGER helicopter," vol. 3362, August 1998.
- [13] J. N. Williams, "A piloted simulation investigating handling qualities and performance requirements of a single-pilot helicopter in air combat employing a helmet-driven turreted gun," Monterey, California: U.S. Naval Postgraduate School, 1987.
- [14] S. Osder, "Integrated flight/fire control for attack helicopters," in *IEEE/AIAA 10th Digital Avionics Systems Conference*, 1991.
- [15] G. A. Strahl and C. C. A. Center, "Physical Simulation Testing of Armament Systems," *US ARMY*, 1990.
- [16] B. Foote, J. Melzer and R. Collins, "A history of helmet mounted displays at rockwell collins," *Display Technologies and Applications for Defense, Security*,

- and Avionics IX; and Head- and Helmet-Mounted Displays XX*, vol. 9470, p. 155–165, April 2015.
- [17] R. L. Newman and K. W. Greeley, "Helmet-mounted display design guide," 1997.
- [18] J. R. Flint, "System design and aircraft integration," *SPIE*, vol. 2735, 2016.
- [19] F. Mulholland, "Helmet-mounted display accuracy in the aircraft cockpit," in *Helmet- and Head-Mounted Displays VII*, 2002.
- [20] D. Hewlett and A. A. Cameron, "Advances in rotary-wing helmet-mounted displays," in *Helmet- and Head-Mounted Displays V*, 2000.
- [21] J.-M. Li, C.-W. Chen and T.-H. Cheng, "Motion prediction and robust tracking of a dynamic and temporarily-occluded target by an unmanned aerial vehicle," *IEEE Transactions on Control Systems Technology*, vol. 29, p. 1623–1635, 2020.
- [22] G. Welch and G. Bishop, "An Introduction to the Kalman Filter," *Proc. Siggraph Course*, 2006.
- [23] Y. Kim and H. Bang, "Introduction to kalman filter and its applications," in *Introduction and Implementations of the Kalman Filter*, F. Govaers, Ed., Rijeka, IntechOpen, 2018.
- [24] A. Litvin, J. Konrad and W. C. Karl, "Probabilistic video stabilization using Kalman filtering and mosaicking," in *Image and Video Communications and Processing 2003*, 2003.
- [25] T. Huang, H. Jiang, Z. Zou, L. Ye and K. Song, "An Integrated Adaptive Kalman Filter for High-Speed UAVs," *Applied Sciences*, vol. 9, p. 1916, 2019.
- [26] B. D. O. Anderson and J. B. Moore, *Optimal Filtering*, Dover Publications, 2012.
- [27] H. W. Sorenson and D. L. Alspach, "Recursive Bayesian estimation using Gaussian sums," *Automatica*, vol. 7, p. 465–179, 1971.
- [28] W. W. Kim, "3d head pose estimation using adaptive face template," 2011.
- [29] I. Ribeiro, "Kalman and extended kalman filters: concept, derivation and properties," 2004.
- [30] F. Herranz, K. Muthukrishnan and K. Langendoen, "Camera pose estimation using particle filters," *2011 International Conference on Indoor Positioning and Indoor Navigation*, p. 1–8, September 2011.
- [31] M. Grewal and A. Andrews, *Kalman filtering: theory and practice using MATLAB Third Edition*, 2008.
- [32] R. V. Garcia, P. C. P. M. Pardal, H. K. Kuga and M. C. Zanardi, "Nonlinear filtering for sequential spacecraft attitude estimation with real data: Cubature Kalman Filter, Unscented Kalman Filter and Extended Kalman Filter," *Advances in Space Research*, vol. 63, p. 1038–1050, January 2019.

- [33] X. Li, K. Wang, W. Wang and Y. Li, "A multiple object tracking method using Kalman filter," in *The 2010 IEEE international conference on information and automation*, 2010.
- [34] MATLAB, 9.13 (R2022b). Natick, Massachusetts: The MathWorks Inc., 2022. [Online].



PUBLICATIONS FROM THE THESIS

Papers

1. K. Çalışkan and U. Sakarya, “The Turreted Gun System Technology Integrated To The Helmet Mounted Display System”, *Journal of Aviation Research*

