



**ANALYSIS OF UNMANNED AIRCRAFT  
SYSTEMS OCCURRENCE REPORTS IN THE  
SCOPE OF ICAO SAFETY MANAGEMENT  
SYSTEM PERSPECTIVE**

**Master's Thesis**

**Osman Atilla ALTINTAŞ**

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**Master's Thesis**

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**July 2023**

## FINAL APPROVAL FOR THESIS

This thesis titled ANALYSIS OF UNMANNED AIRCRAFT SYSTEMS OCCURRENCE REPORTS IN THE SCOPE OF ICAO SAFETY MANAGEMENT SYSTEM PERSPECTIVE has been prepared and submitted by Osman Atilla ALTINTAŞ in partial fulfillment of the requirements in “Eskişehir Technical University Directive on Graduate Education and Examination” for the Degree of Master’s in Air Traffic Control Department has been examined and approved on 11/07/2023.

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## ABSTRACT

### ANALYSIS OF UNMANNED AIRCRAFT SYSTEMS OCCURRENCE REPORTS IN THE SCOPE OF ICAO SAFETY MANAGEMENT SYSTEM PERSPECTIVE

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Department of Air Traffic Control

Eskişehir Technical University, Institute of Graduate Programs, July 2023

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The use of unmanned aerial vehicles is becoming more widespread in the world every day, and easy access and use is one of the biggest factors in this spread. With the diversification of usage areas and needs and the advancement of technology, unmanned aerial vehicle systems are designed with various performances and capabilities. This makes it difficult to gather unmanned aerial vehicle systems under certain standards. Many classification methods have been created for military and civilian purposes, but none of them have a specific standard classification. These systems, which can be considered as new users of the airspace, should give priority to the safety management system, like all users, and should deal with the safety management system components and with them develop their systems and operations. In this study, occurrence reports of unmanned aerial vehicles were collected and examined under the ICAO standards. The data in the reports were classified into a single standard, analyzed reactively from the perspective of the safety management system, according to ICAO classifications, and statistics were created. It has been observed that research on unmanned aerial vehicle systems and their relations with safety systems has increased today and it is thought that this thesis will benefit the studies to be done in the future.

**Keywords:** Unmanned Aviation, Unmanned Aircraft Systems, Safety Management System, Occurrence Reporting, Accident and Incident

## ÖZET

### İNSANSIZ HAVA ARAÇLARI SİSTEMLERİ OLAY RAPORLARININ ICAO EMNİYET YÖNETİM SİSTEMİ PERSPEKTİFİ KAPSAMINDA ANALİZİ

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İnsansız hava araçlarının kullanımı dünyada her gün daha da yaygınlaşmaktadır ve bu yaygınlaşmada, sistemlerin erişiminin ve kullanımının kolay olması büyük etmenlerdendir. Kullanım alanlarının ve ihtiyaçlarının çeşitlenmesi ve teknolojinin ilerlemesiyle insansız hava aracı sistemleri çeşitli performanslarda ve kabiliyette tasarlanmaktadır. Bu durum insansız hava aracı sistemlerinin standart gruplar altında toplanmasını zorlaştırmaktadır. Askeri ve sivil amaçlar doğrultusunda birçok sınıflandırma metodu oluşturulmuştur fakat hiçbirinde belirli bir standart sınıflandırma yoktur. Hava sahalarının yeni sayılabilecek kullanıcısı olan bu sistemler, bütün kullanıcılar gibi emniyet yönetim sistemine öncelik vermelidir ve emniyet yönetim sistemi bileşenleriyle operasyonlarını ele almalı, sistemlerini geliştirmelidir. Bu çalışmada insansız hava araçlarının, olay raporları toparlanmış ve ICAO standartları çatısı altında incelenmiştir. Raporlarda yer alan veriler sınıflandırılarak tek bir standarda dönüştürülmüş, emniyet yönetim sistemi bakış açısıyla reaktif olarak ICAO sınıflandırmalarına göre incelenmiş ve istatistikleri oluşturulmuştur. İnsansız hava aracı sistemleri ve bunların emniyet sistemleriyle ilişkileri üzerine araştırmaların günümüzde arttığı görülmüş ve bu çalışmanın gelecek zamanlarda yapılacak çalışmalara fayda sağlayacağı düşünülmektedir.

**Anahtar Sözcükler:** İnsansız Havacılık, İnsansız Hava Aracı Sistemleri, Emniyet Yönetim Sistemi, Olay Raporlama, Kaza ve Olay

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Finally, I would like to thank my family who supported, believed and trusted me throughout my education life.

Osman Atilla ALTINTAŞ



## **STATEMENT OF COMPLIANCE WITH ETHICAL PRINCIPLES AND RULES**

I hereby truthfully declare that this thesis is an original work prepared by me; that I have behaved in accordance with the scientific ethical principles and rules throughout the stages of preparation, data collection, analysis and presentation of my work; that I have cited the sources of all the data and information that could be obtained within the scope of this study, and included these sources in the references section; and that this study has been scanned for plagiarism with “scientific plagiarism detection program” used by Eskişehir Technical University, and that “it does not have any plagiarism” whatsoever. I also declare that, if a case contrary to my declaration is detected in my work at any time, I hereby express my consent to all the ethical and legal consequences that are involved.

Osman Atilla ALTINTAŞ

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## **GLOSSARY OF SYMBOLS AND ABBREVIATIONS**

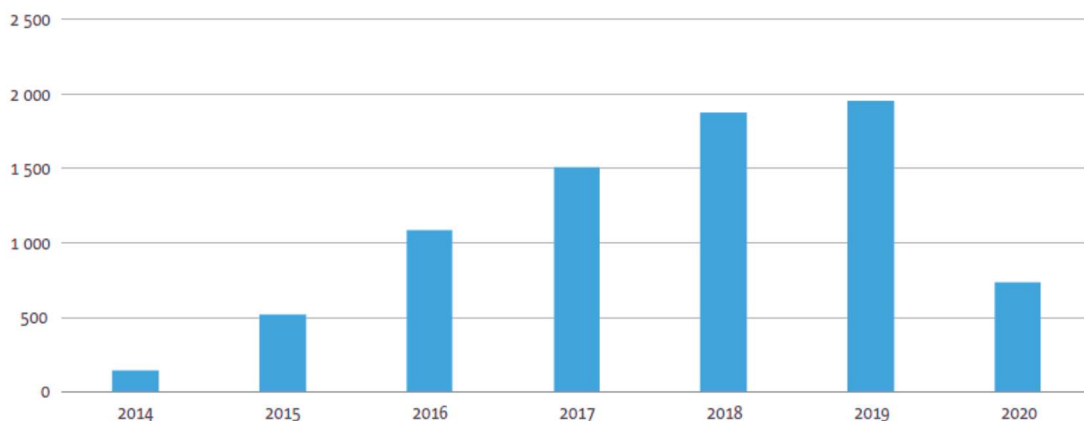
|        |                                                                                   |
|--------|-----------------------------------------------------------------------------------|
| AAIB   | : Air Accident Investigation Branch                                               |
| ADREP  | : The Accident/Incident Data Reporting                                            |
| ATC    | : Air Traffic Controller                                                          |
| ATSB   | : Australian Transport Safety Bureau                                              |
| BIRD   | : Bird Strike                                                                     |
| BLOS   | : Beyond Line-of-Sight                                                            |
| BVLOS  | : Beyond Visual Line-of-Sight                                                     |
| C2     | : Control and Command                                                             |
| CFIT   | : Controlled Flight into or Toward Terrain                                        |
| EASA   | : European Union Aviation Safety Agency                                           |
| EO     | : Electro-Optical                                                                 |
| GCS    | : Ground Control Station                                                          |
| GPS    | : Global Positioning System                                                       |
| HTOL   | : Horizontal Take-off and Landing                                                 |
| ICAO   | : International Civil Aviation Organization                                       |
| IR     | : Thermal Infrared                                                                |
| LALT   | : Low Altitude Operations                                                         |
| LOC-G  | : Loss of Control – Ground                                                        |
| LOC-I  | : Loss of Control – Inflight                                                      |
| LOS    | : Line-of-Sight                                                                   |
| MAC    | : Airprox/TCAS Alert/Loss of Separation/Near Midair Collisions/ Midair Collisions |
| MTOW   | : Maximum Take-off Weight                                                         |
| NAS    | : National Airspace System                                                        |
| RLOS   | : Radio Line-of-Sight                                                             |
| RPA    | : Remotely Piloted Aircraft                                                       |
| RPAS   | : Remotely Piloted Aircraft System                                                |
| SCF-NP | : System/Component Failure or Malfunction (Non-Powerplant)                        |
| SCF-PP | : System/Component Failure or Malfunction (Powerplant)                            |
| SMM    | : Safety Management System Manual                                                 |
| SMS    | : Safety Management System                                                        |
| SRM    | : Safety Risk Management                                                          |
| TBD    | : To be Defined                                                                   |
| UA     | : Unmanned Aircraft                                                               |
| UAS    | : Unmanned Aircraft System                                                        |

UAV : Unmanned Aerial Vehicle  
UNK : Unknown  
USOS : Undershoot/Overshoot  
VTOL : Vertical Take-off and Landing



## 1. INTRODUCTION

Although there are many uses for the name such as drone, remote-controlled aircraft, model aircraft, unmanned aerial vehicle, remote controlled aircraft, although there have been definitions that have caused differences in the authorities over the years, the use of "unmanned aerial vehicle" is widely used today. ICAO has officially recommended this use. This name has also been accepted by the EU and EASA (Mendes de Leon & Scott, 2016) UAS technologies are developing every day, and this development diversifies its usage areas. In addition to its military use, the use of advanced cameras, special sensors, and communication equipment for real-time image transmission has increased its usage areas and numbers in the civil aviation sector. With the spread of usage areas in this civil aviation, serious increases have been seen in the number of occurrences (EASA, 2021). This increase is shown in Table 1.1. It is expected that the global market size of UASs is 5.8 billion dollars in 2016 and will reach 130 billion dollars in 2025 (Jeelani & Gheisari, 2021). Some studies indicate that the European drone market will more than double between 2018 and 2024. Others predict that revenues from commercial UAS use in Europe will grow from US\$251 million in 2020 to US\$3 billion in 2025. Different projections show that the region's drone market exceeds €10 billion annually by 2035 and €15 billion annually by 2050 (Konert & Kasprzyk, 2021). The expansion of the usage area differentiates the needs of UASs and creates many new systems and these systems have different capabilities in line with their purposes. Besides that, the architecture of the airspace and procedures primarily aims to support manned aircraft (Weibel & Hansman, 2005). Due to these situations, it is difficult to determine the standards of the systems and place them in a certain framework.



**Figure 1.1.** *UAS Occurrences between 2014 and 2020 (EASA, 2021)*

Safety, which is one of the most important elements of aviation, is also the most important element in all UA and UASs ranging from a few hundred grams to the size of the Boeing 777 (Konert & Kasprzyk, 2021). On January 15, 2021, the pilot of a DJI Inspire 5 UAS on an aerial work mission in VMC conditions in Darling Harbor Sydney, Australia, lost control of the UA and subsequently lost sight of it. It crashed into a guest room window at a hotel about 330 meters west of the take-off point and broke it. As a result of this serious incident, it was determined that the UAS caused injuries to the people in the hotel room (ATSB, 2022). The increase in the number of such incidents, serious incidents and accidents emphasizes that the safety management system is also important for the UASs and the necessary regulations are necessary. However, the diversity and prevalence of use make it difficult to evaluate in terms of security management systems, as it is faster than the development of standards (ICAO, 2023). Therefore, reporting of accidents or incidents is differently integrated into safety systems by authorities. In this study, the reports of the authorities were examined, the distribution and contents of the reports were revealed. Accidents and incidents were examined according to report classes and brought together in ICAO standards. Within the scope of these standards, accident and incident causes of UASs are revealed by taking into account the safety management system and statistics are presented.

### **1.1. Purpose of The Study**

Everything in aviation has a standard and systematic. These standards are followed in all aviation activities processes. All of this also applies to the investigation and reporting of incidents and accidents. As in airplanes and other aircraft, certain standards and rules for incidents and accidents will become widespread in UASs in the coming years. While doing this, it will be done within the framework of the safety management system. Investigating and classifying incidents and accidents within the framework of the safety management system will also facilitate the integration of UASs and other aircraft.

In this study, this process was examined from the point of view of the safety management system, the details of the reports created were examined, the content was revealed, and the statistics were kept. According to these data, it is aimed to bring together UASs under common standards, and accident and incident categories under ICAO standards. As a result of the standard data that emerged, the reports of different authorities were examined and revealed under a single roof.

Within the scope of this study, answers to the following questions were obtained.

- How many UAS occurrences have been experienced over the years?
- What are the contents and sources of UAS occurrence reports?
- In which flights and flight phases did the occurrences experienced?
- In which occurrence and ICAO categories did the reported accidents and incidents occur?
- In which UA classes did the occurrences experienced more and what kind of damage did they cause?
- In which ICAO categories different UAS classes experienced more occurrences and what are the overall causes of occurrences?

## **1.2. Problem**

UASs are constantly and rapidly evolving, making standardization difficult. This difficulty differentiates how authorities handle UASs and makes it difficult to study them under one roof. In order to be able to examine from a broad safety management system perspective and to obtain results, it is necessary to determine the standard framework and transform the data into a single type.

## **1.3. Importance of The Study**

The fact that the reporting of incidents, serious incidents and accidents of unmanned aerial vehicles, and therefore the causes, measures to be taken and root cause analyzes as a result of these, is still not widespread in some countries creates problems for the aviation industry in terms of safety. There is a serious imbalance when the number of drones in the sector and the number of reports are compared. In this study, it was wanted to make analyzes about the incidents with the data obtained, different authorities' accident and incident reports were gathered under a single roof and combined under the same standards. The resulting data revealed the accidents and incidents experienced by UASs in detail under ICAO standards and brought them to the aviation literature.

## **1.4. Limitations**

Today, the number of UASs and the types of usage areas are increasing. Along with this increase, the number of incidents and accidents started to increase in parallel.

However, these incidents or accidents are not reported like commercial airline occurrences. It is difficult to access details about accidents and incidents, since UASs are mostly used in the field of defense. Especially in some countries, this is the case due to the country's security and defense policies. In this study, incidents and accidents between 2015 and 2022 were accessed. These are mostly data shared by UK and Australian aviation authorities.

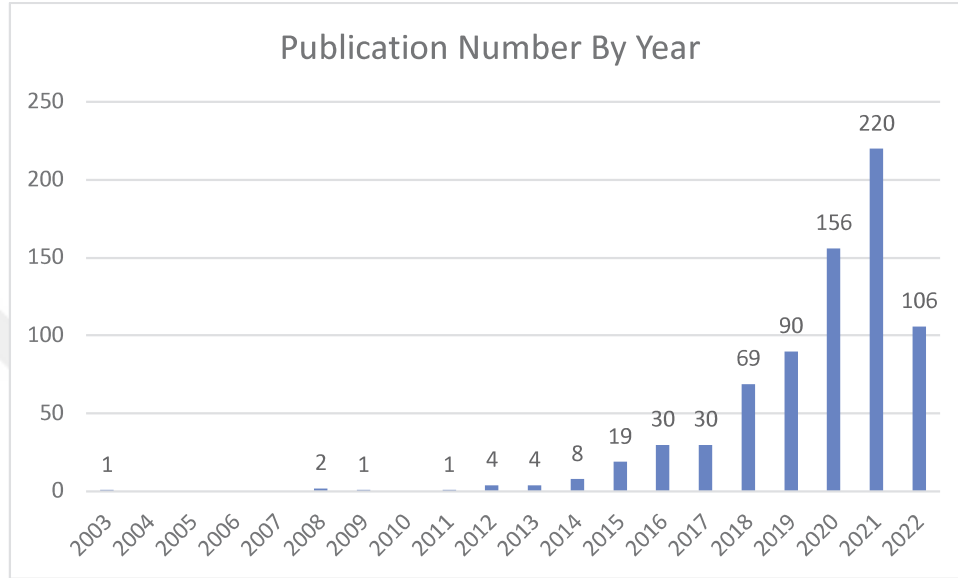
Not all ICAO-approved authorities that conduct accident and incident investigations share their reports. Within the scope of this study, the authorities were examined and the reports of the authorities that publicly published the UAS-related accident and incident reports could be examined. Since there was no confusion for every data in the reports, only the corresponding data could be analyzed.

### **1.5. Related Studies and Literature Analysis**

The study on UAS safety over the years has been discussed and the literature search was conducted on Dimensions.ai and the link between the names of “UASs” and its derivatives and “safety management” were used as keywords. Data collected from Dimensions.ai were analyzed with the VosViewer (1.6.18 Version) package program. According to this analysis, 741 publications with open access were found starting in 2003. Especially after 2018, a serious increase has been seen in UAS safety-related research. The distribution over the years is given in the Figure 1.1. 220 studies were conducted in 2021, the year with the most publications. Between 2003 and 2008, there was no publication about the selected keywords. Ma and Alsami co-author and authors are the most cited in the author analysis. The number is 218 for both authors. There is a serious decrease in the number of citations of authors coming after Ma and Alsami. The University of Florida is the most cited organization for co-authorship and organization analysis. In subsequent organizations in the ranking, the number of citations drops to approximately the age of the University of Florida. Considering the number of citations, the article written by Colombina and Molina (2014) is the most cited article in its field with 1653 citations. The subject of the study is photogrammetry and remote sensing disciplines together with nano-micro-mini UAS segments. The study reviews the developments in sensing, navigation, routing and data processing for UAS photogrammetry and remote sensing, with a brief analysis of the historical background and regulatory framework. While the most cited sources rank first in the number of IEEE



Access documents, Remote Sensing ranks first with 775 citations. While Remote Sensing ranks first in the application, it is not in the top ten when analyzed according to the number of documents. Still, IEEE Access, Sensors, Drones, Applied Science, Aerospace, The International Archives of the Pho., Electronics sources are on both lists for the highest numbers.



**Figure 1.2.** Publication quantity

**Table 1.1.** Content clusters related UASs Safety Management Systems

| Clusters  | Common Contents                                                                                                      |
|-----------|----------------------------------------------------------------------------------------------------------------------|
| Cluster 1 | UAS Commercials and Businesses Areas, Regulations                                                                    |
| Cluster 2 | IoT, Autonomous Systems, Multi-UA 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 |

Considering the countries according to the number of citations, the USA comes first with 2217 citations. It is followed by Spain, China, and England, and all of them have 1000 or more citations. Following that, Australia is in the 5th place with 429 citations. Türkiye could not enter the top 10. At the same time, when the literature review was conducted, studies on UAS and safety management systems were gathered under the roof of 5 subject clusters according to their common references, and the topics discussed with UAS safety management systems were revealed in Table 1.2.

## **1.6. Thesis Structure**

This thesis is divided into five chapters to make the preliminary preparation of what is to be told, to prepare the reader, and then to provide an effective narration.

In order to understand the UAS and increase the reader's knowledge on the systems, the UASs are discussed in detail in the second chapter. Detailed information is given from system elements to the classification of systems.

Chapter Three introduces the safety management system and its components to the reader. In addition to the components of the SMS, this chapter explains risk and risk mitigation assessments and how they work. Besides all these, also aviation standards and used taxonomy are explained.

In Chapter Four, the used methodology and the findings of this thesis are introduced and data gathering, and process are explained. Also, this chapter contains all the analyses, explanations, and evaluations. Firstly, general information about the reports is evaluated, and after that related UAS data analyses are explained. Findings about the occurrence categories have been explained in detail.

Chapter Five, which is the last, the findings obtained from the study are presented. In addition, the resulting discussions are shared, and recommendations are made for future studies.

## 2. UNMANNED AIRCRAFT SYSTEMS

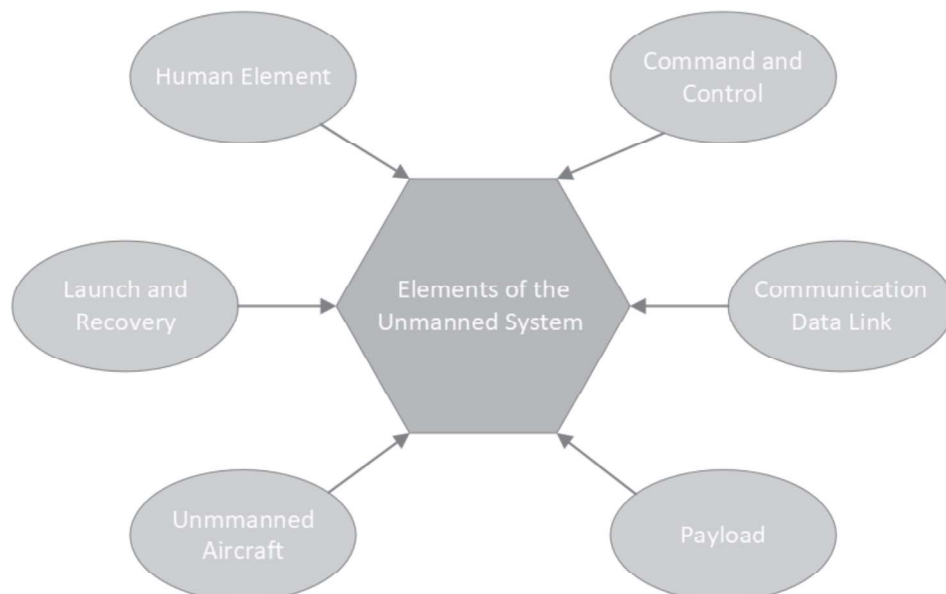
### 2.1. Description of the UAS

Unmanned aircraft systems are a group of customizable elements including unmanned aerial vehicles, control and command link, and any other elements as may be needed regarding the purpose of operation (Valvanis & Vachtsevanos, 2015). There are six basic elements which are unmanned aircraft, command and control element, communication data link, payload, launch and recovery element, and human element (Brungardt & Carraway, 2021).

In recent years, the term of UAS pushed to change the term UA to RPA (Remotely Piloted Aircraft) by some part of military offices because “Unmanned Aircraft” term might cause to be a misunderstanding about the human factors in the UAS (Dalamatidis, Definitions and Terminology, 2015). “UAS” term will be used and considered as RPA or UAV.

### 2.2. Elements of UAS

A UAS generally consists of an aircraft with no pilot on board, a remote pilot station, a command and control link, human, launch and recovery element, and a payload specific to the intended application/operation, which often includes specialized cameras or other sensors that collect data for near term analysis.



**Figure 2.1.** *Elements of the UAS (Adapted from (Barnhart, Marshall, & Shappe, 2021))*

### 2.2.1. Unmanned aircraft

Unmanned aircraft (UA) are generally known as air vehicles that do not carry a human operator or pilot on board. They can be piloted remotely or fully autonomously and can be deployed with payload depending on the purpose of operation (Valvanis & Vachtsevanos, 2015). Especially thanks to these features, they can continue their operations for hours by changing operational personnel without any interruption in operation.

UAs have been categorized along to the wing type: fixed wing, rotary wing, and hybrid platform. Fixed wings mostly have better endurance than other wing types, but they need a flat surface or equipment like catapults to take off and start the operation. Rotary-wing and hybrid platforms do not require a flat area for take-off or landing, unlike fixed-wing. Besides the rotary wings, hybrid platforms have fixed-wing and rotary-wing designs simultaneously that can change over after the take-off and take fixed-wing aerodynamic efficiencies (Brungardt & Carraway, 2021). VTOL (Vertical Take-off and Landing) term may be confused with hybrid platforms like a wing-type category, but the term is just about the take-off and landing capabilities of aircraft. Although they make up a lesser amount of present and future UAS, other vehicle designs, such as airships and paragliders, may be regarded as a different category (Namuduri, Chaumette, Kim, & Sterbenz, 2018). Examples of the wing types are shown in Figure 2.2.

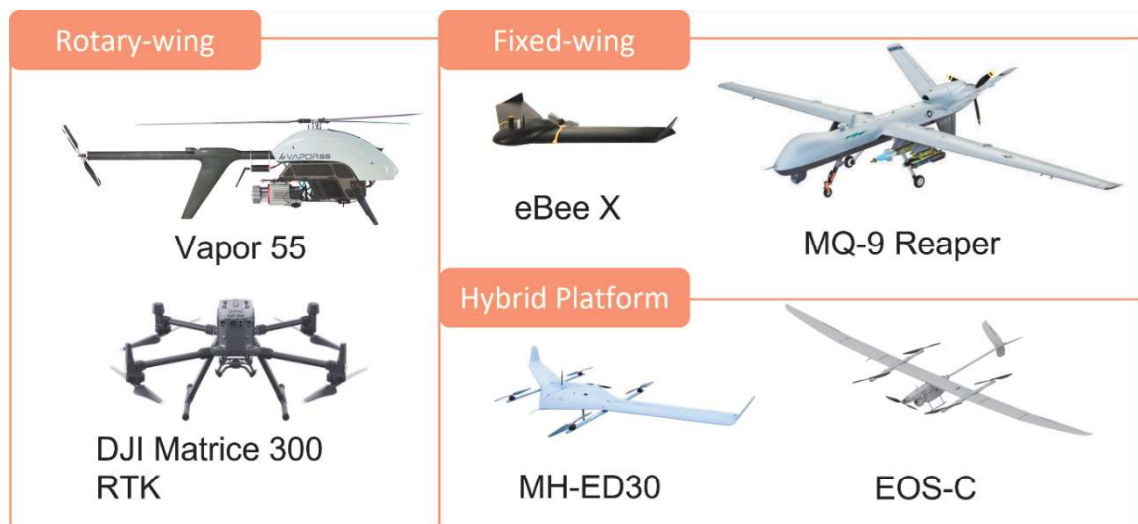


Figure 2.2. Examples of the wing types

### **2.2.2. Command and control**

Command and control (C2) element is divided into two main subjects which are autopilot and ground control station (GCS).

#### **2.2.2.1. Autopilot**

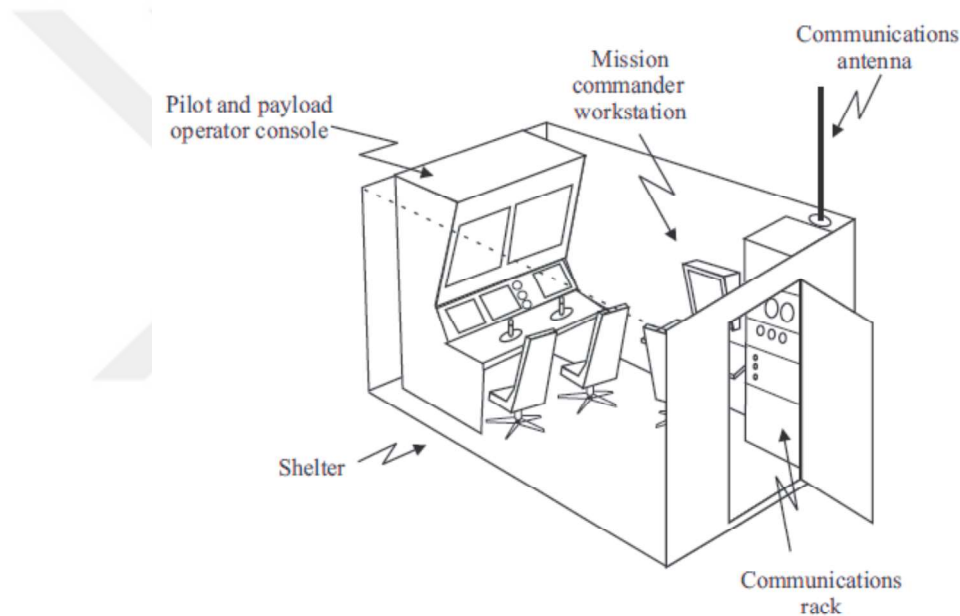
An autopilot is the ability of a system to follow the set of programmed instructions during operations without any operator input. Level of autonomy in the UAS changeable from none to full autonomy (Brungardt & Carraway, 2021). According to human dominance over the system, UAS control evaluates under three categories which are remote pilot control, remote supervised control, and fully autonomous control. Remote pilot control is also referred to as operator static automation because all decisions are made by a human operator using the control system. The aircraft used for hobby purposes are generally remotely controlled by their operator. If a system allows simultaneously enables human intervention while enabling the drone to complete the mission process without human commands, the system is called remote supervised control. This type of control is anticipated that UAS used for the delivery of products would use in which one operator will be a charge of overseeing several systems at once. The last control type called full autonomous control relies on the UAS to make all decisions necessary for the task to be successfully completed (Altawy & Youssef, 2016). At this level of control, UAS can navigate itself and relies upon its sensors to perform complete preprogrammed tasks.

Some of the systems like RQ-2A need to external pilot to operate the take-off and landing phases. These phases operate with no autonomy but by the external pilots. After the take-off, the external pilot gives control to the GCS (Sadraey, 2020).

#### **2.2.2.2. Ground control station**

Sadraey defined in his work, the GCS is “A land or sea-based control center that provides facilities for the human control of unmanned vehicles in the air or space.” It collects the data by a UA, measures that data, and resend it via a data link to an operator. The human operator controls the UA via up-link, to direct contact with flight instruments, or to update the autopilot and flight plan (Sadraey, 2020). The GCS is capable of functioning as a central command center for the personnel responsible for planning missions, receiving mission orders from supported headquarters, and communicating

acquired data and information to the relevant unit, such as weapon fire direction, intelligence, or command and control. This personnel, who is typically the mission commander, can utilize the GCS to oversee and coordinate the mission effectively. Additionally, the GCS has designated areas for both the aircraft and mission payload operators to carry out monitoring and mission execution tasks. The size of the GCS and the operator on duty are changeable due to operational needs, GCS can be a single laptop and antenna, or a large container located maybe in a continent from where the aircraft is flying (Fahlstrom & Gleason, 2012). One of the future goals of the systems is to make a possibility for one operator to operate multiple aircraft from one GCS (Brungardt & Carraway, 2021). A typical field GPS view is shown in Figure 2.3.



**Figure 2.3.** Example of a cut-view field GCS (Fahlstrom & Gleason, 2012)

### 2.2.3. Communication data link

The communication data link term is used to describe the connection of one unit to another unit to transmit and receive digital information linked together with uplink and downlink. The data link generally consists of a transmitter and a receiver, an antenna, and a modem to link these parts with the sensors. These apply to both UA and GCS. Major 2 two purposes of the GCS:

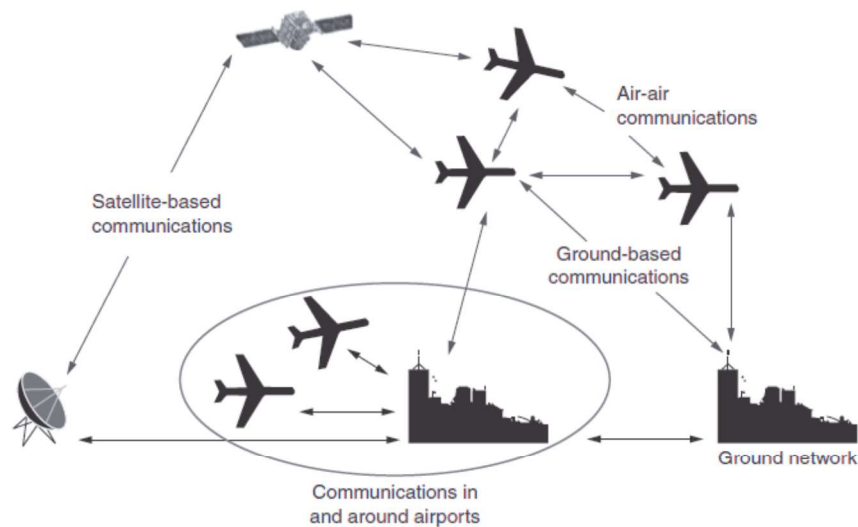
1. With uplink radio transmission, transform the operator commands to a radio signal and sends it to the antenna to deliver to UA,

2. With downlink radio transmission, it receives UA and payload parameters (Sadraey, 2020).

The flight path of the UA and commands to its payload are controlled via an uplink with a data rate of a few kHz. Despite that, a downlink offers a high data-rate channel for sensor or payload data like video, image, and radar as well as a low data-rate channel to identify commands and communicate status information about the UA. Moreover, by calculating the azimuth and range of the UA from the GCS, the data link may also be used to measure the UA's location (Fahlstrom & Gleason, 2012). This method can be used to assist in navigation systems to accurately the UA's location.

Operations of UAS can be considered for two categories which are radio frequency line-of-sight (RLOS) and beyond line-of-sight (BLOS) (Brungardt & Carraway, 2021). BLOS should not be confused with BVLOS (Beyond visual line-of-sight) which refers to the maximum visible distance where UA can be seen with the naked eye.

RLOS operations are provided with direct radio waves. This wave's efficiency can be altered by surrounding obstacles, the antenna's elevation and type, the strength of the transmitter and receiver, and atmospherical issues. In ideal conditions, radio waves can travel various miles. Instead of using the omnidirectional antenna, preferring to use a directional tracking antenna would be improved the signal strength and indirectly maximum range of waves. Today's commercial UAS operations are primarily operated with RLOS systems which are the most economic.



**Figure 2.4.** *An aerial network, which comprises unmanned aerial systems, along with communication infrastructure located on satellites and the ground (Namuduri, Chaumette, Kim, & Sterbenz, 2018)*



BLOS operations mention the operations which are beyond the limit of a radio. Ku band in the 12-18 GHz range is used in military BLOS operations conducted by satellites. Some UASs operate almost constantly via the Ku band. These UASs launch with a LOS data link and then after that when they are in the air, change the system of the data link to BLOS sources. BLOS operations can have several-second delays throughout the uplink and downlink due to relays and systems the link must travel through. This can cause time gaps between commands which is sent via GCS and responses of the UAS (Brungardt & Carraway, 2021). Figure 2.4. shows an aerial network within the infrastructure and the connection with each other.

#### **2.2.4. Payload**

In manned aviation, the payload is defined as a load carried by aircraft which was paid for by the customer to transport. In UASs, the payload is defined as the sensor or equipment on UA to perform the purpose of the mission. It should not be confused that when the payload is removed on the UA, that must not affect the safety measurement and flight performance. Besides that, launch and recovery system parts are not assumed as payload (Sadraey, 2020). Also, the payload can be evaluated as the weight that the UA can carry, and it is typically counted separately from the UA's weight. The flight time of the UA is directly affected by the weight of the payload. If the UA carries heavy weight, it will need additional power to create lift. The lighter the payload, the longer the flight time will be (Garg, 2021). For instance, if the UAS is designed to deliver cargo and equipped with a cage, only the cargo in the cell is considered as a payload, and the weight of the cage and UA is considered as part of the system.

In the commercial industry, the most common payload is optical sensors which may contain electro-optical (EO) cameras, thermal infrared (IR) cameras, or commercial off-the-shelf (COTS) cameras. Certain platforms have dual sensors containing both an EO and IR sensor. These payloads might be operated in coordinated mods or might be controlled independently (Brungardt & Carraway, 2021).

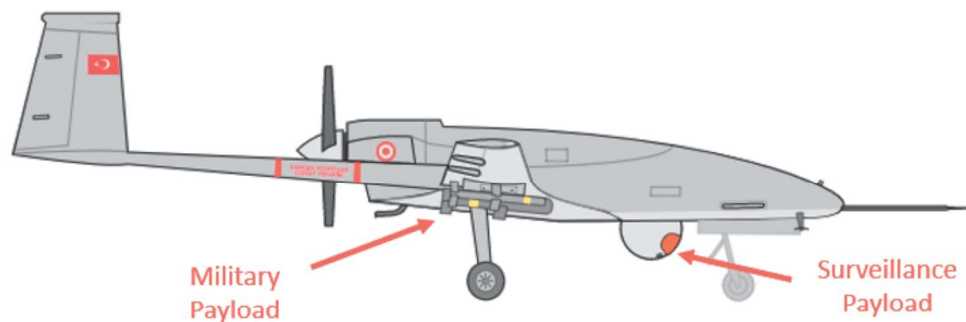
Sadraey defined payload in the five main classes for UASs in his work. These classes:

1. Merchandize/Cargo/Freight
2. Reconnaissance, surveillance, and monitoring sensors,
3. Scientific sensors,



4. Military payloads,
5. Electronic countermeasure system

Payloads can be changed for various UAS operation purposes. Payloads are civil goods, products or supplies, etc. are carried for commercial benefits. Surveillance payloads such as IR cameras, ER cameras, or radar can be used. These cameras can be fixed or can be a part of the mounting system called a gimbal. A gimbal is a mounting system that gives the ability to camera or sensors that move in two or three axes (Brungardt & Carraway, 2021). Scientific sensors can be equipped for measuring and monitoring environmental parameters for example dampness, pressure, temperature, etc. Military payloads generally include missiles and bombs for operations and defense aims (Figure 2.5.). An electronic countermeasure system is aimed to deceive the enemy detection systems with a dummy or electronic devices (Sadraey, 2020).



**Figure 2.5.** Bayraktar TB2 payloads adapted from (Alexpl, 2020)

#### **2.2.5. Launch and recovery element**

The launch and recovery elements of the UAS have a changeable labor level regarding the complexity of the system. Small VTOL UASs are generally to least complex procedure and equipment as only need suitable flat surfaces for take-off and landing. On the other hand, some large UAs need large runways and a lot of ground support equipment like tugs, fuel trucks, and ground power units (Brungardt & Carraway, 2021). These procedures and requirements make some UASs' ground and take-off operations almost as same as manned aviation.

There are three techniques for launching a UA:

1. Conventional horizontal take-off and landing (HTOL), this technique needs a runway for take-off and major users of the technique are medium or large-weight UAs.
2. Catapulted or powered launch, which is mainly utilized for generally fixed-wing systems that are aimed at less take-off distance.
3. Vertical take-off and landing, that technique is viable when the engine thrust is greater than the UA weight. All quadcopters and helicopters are users of this technique (Sadraey, 2020).

Launch systems as non-HTOL are usually referred to as “zero-length launch”. Although launching a fixed-wing UAS cannot be done without any distance due to the need for some acceleration, the distance which is needed to take off is usually a few times the length of the UA when catapult or rocket-boosted launch systems are used (Fahlstrom & Gleason, 2012). These are the examples of alternative launch methods for fixed-wing UAS:

1. Hand-Launching, it is possible to launch the lightweight fixed-wing UAS by using a straightforward upwind throw and it is applicable to UAS which is usually lighter than the 3 kg. Moreover, this method can be dangerous to the person who is launching the UAS due to the propellers.
2. Bungee Launch Systems, the method basically used a bungee for stored some energy to transform kinetic energy which is needed to accelerate the UAS. It is a very popular alternative to launching lightweight fixed-wing UAS which is unsuitable to hand-launched. The equipment of the system is mainly ideal to carry to remote field locations.
3. Catapult Launch Systems, it is basically a large and complex version of the bungee launch systems. The launch mechanism depends on the same basic principles, but catapult systems offer more stable launching compared to bungee systems. Besides that, the system is not suitable for remote field operations due to power requirements and has a potential hazard for UAS due to the possibility of creating electromagnetic interference.
4. Specialist Launch Systems, several innovative launch systems, like rocket-boosted or assisted systems and parasail launch systems, developed primarily for the purpose of launching fixed-wing UAS in changing circumstances (Skitmore, 2021).

The recovery is the phase that is referred to as landing, but it's eliminated the complexities of a runway landing. That can be considered a chain of events that includes deceleration, descent, approach, landing, taxiing, and returning its base or hangar. The landing and touch-down at the correct position and airspeed need significant judgment. For long-range systems like Global Hawk, control guide aids which use the radio beam may be useable and GPS can help with the initial positioning.

Concept of the recovery has two major objectives which are minimal damage and retrieval. Except for the conventional landing, practical recovery techniques are:

1. Parachute
2. Arrestor
3. Net recovery
4. Cable-assisted recovery
5. Skid and belly recovery (Sadraey, 2020)

Catapult-launched UASs are using these techniques. The launch and recovery system called SideArm uses the rail-mounted catapult technique for launch and hook for recovery. This system was developed for trucks, ships, and fixed bases (DARPA, 2017).

#### **2.2.6. Human element**

Unmanned Aerial Systems are often referred to as “unmanned” but it's clear that the human interaction on the system and their actions are critical for operational safety. While the UAS capabilities and automation competence increase, the human interaction need will be lesser than before. Even so, the pilot in command will always be responsible for operational safety (Jensen, 2021).

The role of the pilot and the observer cannot be underestimated, because without them the flight would not take place. This is true even for the most sophisticated drones like the Predator. Thirty people per aircraft are needed for the Predator Reaper model to fly even between unmanned aerial vehicles. In addition, more people are involved in the analysis of the data collected after the flight. The human element is involved in all of the following aspects of operating a UAS:

- Mission/Task planning and control: It should be done by a business team.
- Launch and recovery procedure: must be performed by an operating team.
- Payload management and control: Must be managed by a business team.

- Data links monitoring: Must be managed by a business team.
- Ground support equipment coordination and management: Must be performed by an operating team.

Automation in the operation of UAS results in less human intervention, but never eliminates the human role in such an operation. On an airliner plane that is flown only by autopilot, your captain would not want to travel on a ship, nor would they want a UAS to operate without a pilot and an observer (Williams K. W., 2006).

Integrating UAS in the NAS (National Airspace System) affect not only the flight crew, maintenance crew, or company, but all aviation system user and members. The proactive approach is always relevant, but this time this approach will not represent tomorrow's UAS. Because of the exacting design, operational, production, and training approaches, it is anticipated that UASs will be considerably more standardized in many respects than in the past. Yet, UAS characteristic features are very different from today's airspace users, and this causes specific gaps between manned and unmanned aviation according to the human factor's perspective. When considering the pilot operations, there are several specific gaps determined. Firstly, due to the pilot or operator commanding and controlling the UA from GCS, the ability of the natural sense is lost. Naturel sense means to use visual, aural, tactile, vestibular, etc. to be aware of the aircraft's status and its local environment. UAS pilots or operators cannot feel the maneuvers of the aircraft, or hear the engines with their sense organs, but they gather every information about the flight from the GCS. Also, this information and others are carried by wireless data links. This situation is fundamentally less dependable than the direct hardwired links used in manned aircraft. Moreover, this wireless connection between UA and GCS creates a new regime of control loop delay. The RLOS operations have the smallest time delays, but they are limited in distance between UA and GCS. Contrary to that, the BLOS operations are almost limitless in distance, but they have the largest time delays due to signal transportation distance (Kaliardos & Lyall, 2015). No matter how much the system is called as "unmanned", the human is the designer, operator, manager, technician, etc. in the UAS. For this reason, like in all aviation systems, the specific characteristic of the UAS needs to be evaluated from the point of the human factor's approach to keeping the safety of operations.

### **2.3. UAS Classification**

Different UAS classifications have been identified to sort the variety of existing systems based on their performance and capabilities. Besides the authorities developing rules for all UASs is not possible and the different UAS categories need different requirements. There is a large number of metrics that have been used for UAS classification. For example, maximum take-off weight (MTOW), flight capabilities, dimensions, operation type, ground impact risk, and the combination of these and other characteristics. Some of these metrics may have minimum effect on safety performance but are still important from the regulatory, commercial, and operational points of view (Dalamagkidis, Classification of UAVs, 2015). In this section, different classifications of literature are presented.

#### **2.3.1. Classification based on UAS performance metrics**

The detailed classification which proves the variety of the UAS based on range, flight altitude, endurance, and MTOW is presented in Table 2.1. There are three main categories which are tactical, strategic, and special purpose. In the tactical category, UAS separated into 10 categories according to flight capability to 100 m altitude up to 14.000 m altitude. They have various flight times minutes to hours and a maximum take-off weight of up to 1.500 kg. There is only one category described in the strategic category have a 12.000 kg MTOW and flight time of 24 hours to 48 hours with a 20.000 m flight altitude. The special purpose category has 6 categories different from each other and needs to be defined. Only Exo-stratospheric category RPAS are not flying currently (Blyenburgh, RPAS The Global Perspective Volume 1, 2021).

Another example of UAS classification according to performance metrics has been shown in Table 2.2. Unlike the other classification, this has 11 UAS classes and there are no main classes. The name of the classes and the parameters except the size are similar. The size parameter refers to the wingspan or fuselage length which one is larger and for the quadcopters, it refers outer distance between the tip of one propeller to the neighboring one (Sadraey, 2020). Another example has been given in Table 2.3. This classification has 7 categories. The names of the categories are similar in the classification standards, but it does not mean exactly the same things.

### 2.3.2. Classification based on regulatory framework

In this section, two different types of regulatory classification are examined. First one, for all unmanned aircraft, the regulatory framework was developed by EASA in three categories based on metrics which are operational-centered, proportional risk, and performance-based. These are “open,” “specific”, and “certified” in the literature and priority has been given to developing the “open” and “specific” categories regulation. The “Certified” category regulatory framework is presently under development.

**Table 2.1.** UAS categorization for different systems (Blyenburgh, *RPAS The Global Perspective Volume 1*, 2021)

| UAS Categorization<br>(Abbreviation)     | Range (km)       | Flight<br>Altitude (m) | Endurance<br>(hours) | MTOW (kg)     |
|------------------------------------------|------------------|------------------------|----------------------|---------------|
| <b>Tactical</b>                          |                  |                        |                      |               |
| Nano (η)                                 | < 1              | 100                    | < 1                  | < 0,025       |
| Micro (μ)                                | < 10             | 150                    | 1                    | < 5           |
| Mini (Mini)                              | < 10             | 150*                   | < 2                  | < 25          |
| Close Range (CR)                         | 10 to 25         | 3.000                  | 2 to 4               | 150           |
| Short Range (SR)                         | 25 to 70         | 3.000                  | 3 to 6               | 200           |
| Medium Range (MR)                        | 70 to 200        | 5.000                  | 6 to 10              | 1.250         |
| Medium Range Endurance<br>(MRE)          | > 500            | 8.000                  | 10 to 18             | 1.250         |
| Low Altitude Deep<br>Penetration (LADP)  | > 250            | 50 to 9.000            | 0,5 to 1             | 350           |
| Low Altitude Long<br>Endurance (LALE)    | > 500            | 3.000                  | > 24                 | < 30          |
| Medium Altitude Long<br>Endurance (MALE) | > 500            | 14.000                 | 24 to 48             | 1.500         |
| <b>Strategic</b>                         |                  |                        |                      |               |
| High Altitude Long<br>Endurance (HALE)   | > 2000           | 20.000                 | 24 to 48             | 12.000        |
| <b>Special Purpose</b>                   |                  |                        |                      |               |
| Unmanned Combat Aerial<br>Vehicle (UCAV) | Approx.<br>1500  | 10.000                 | Approx. 2            | 10.000        |
| Offensive (OFF)                          | 300              | 4.000                  | 3 to 4               | 250           |
| Decoy (DEC)                              | 0 to 500         | 5.000                  | < 4                  | 250           |
| Stratospheric (STRATO)                   | > 2000           | > 20.000 & <<br>30.000 | > 48                 | To be defined |
| Exo-stratospheric (EXO)                  | To be<br>defined | > 30.000               | To be defined        | To be defined |
| Space (SPACE)                            | To be<br>defined | To be defined          | To be defined        | To be defined |



The open category is including UAS operations that neither need prior authorization by relevant authority nor declaration by the UAS operator before the starting operation. There are 3 subcategories in the scope of the open category that are A1, A2, and A3. A1 conditions are not permitted to fly over assemblies of people and uninvolved people. A1 is divided into 2 groups according to UAS MTOW. For up to 250 grams of UAS, the drone operator does not need to register if the UAS has no camera sensor and no minimum age to fly the UAS. No training is required for these UAS. For up to 500 grams of UAS, the operator/pilot must have a registration, need complete training, pass the exam, and have a minimum of 16 years old. The A2 subcategory contains up to 2 kilograms of UAS and lets the fly close to people but is not permitted to fly over uninvolved people. The operator/pilot must have registered, complete the training, pass the exam, and have a minimum of 16 years old. The A3 subcategory is up to 25 kilograms UAS and does not allow the fly near or over people. UAS must keep a minimum of 150 meters distance to residential, commercial, or industrial areas. The operator/pilot needs to complete training and pass the exam and have a minimum of 16 years old. A1 and A2 operation subcategories also let to fly in the A3 subcategory. These regulations are applicable until 31 December 2023 (EASA, Open Category - Civil Drones, 2022).

**Table 2.2.** *UAS Classification Standards According to Sadraey (2020)*

| No | UAS Class       | MTOW (lb)   | Size     | Normal Operating Altitude | Range (km)  | Endurance  |
|----|-----------------|-------------|----------|---------------------------|-------------|------------|
| 1  | Micro           | < 0.55      | ≤ 10 cm  | < 100 ft                  | 0.1-0.5     | ≤ 1 hr     |
| 2  | Mini            | 0.55-2      | 10-30 cm | < 500 ft                  | 0.5-1       | ≤ 1 hr     |
| 3  | Very small      | 2-5         | 30-50 cm | < 1000 ft                 | 1-5         | 1-3 hr     |
| 4  | Small           | 5-55        | 0.5-2 m  | 1000-5000 ft              | 10-100      | 0.5-2 hr   |
| 5  | Medium          | 55-1000     | 5-10 m   | 10000- 15000 ft           | 500-2000    | 3-10 hr    |
| 6  | Large           | 10000-30000 | 20-50 m  | 20000- 40000 ft           | 1000-5000   | 10-20 hr   |
| 7  | Tactical/combat | 1000-20000  | 10-30 m  | 10000- 30000 ft           | 500-2000    | 5-12 hr    |
| 8  | MALE            | 1000-10000  | 15-40 m  | 15000- 30000 ft           | 20000-40000 | 20-40 hr   |
| 9  | HALE            | > 5000      | 20-50 m  | 50000-70000               | 20000-40000 | 30-50 hr   |
| 10 | Quadcopter      | 0.5-100     | 0.1-1 m  | < 500 ft                  | 0.1-2       | 20 min-1hr |
| 11 | Helicopter      | 0.001-200   | 13mm-2m  | < 500 ft                  | 0.2-5       | 10min-2hr  |

**Table 2.3.** *UAS Classification Standards According to Garg (2021)*

| Category       | Weight of UA (kg) | Operating Altitude (m) | The Radius of Mission (km) | Endurance (hr) | Typical Uses                               |
|----------------|-------------------|------------------------|----------------------------|----------------|--------------------------------------------|
| Micro          | < 2               | 250                    | < 5                        | 1              | Reconnaissance, inspection, surveillance   |
| Mini           | 2-20              | 150-300                | < 25                       | 1-6            | Surveillance, data gathering               |
| Small          | 20-150            | Up to 5000             | 50                         | 8-24           | Surveillance, data gathering               |
| Tactical       | 150-600           | Up to 10000            | 300                        | > 24           | Surveillance, data gathering               |
| MALE           | > 600             | 14000                  | > 1000                     | > 24           | Surveillance, cargo transportation         |
| HALE           | > 600             | Up to 65000            | > 1000                     | > 24           | Surveillance, data gathering, signal relay |
| Strike/ Combat | > 600             | Up to 65000            | > 1000                     | Days/weeks     | Surveillance, data gathering, signal relay |

The specific category is defined by EASA as “a category of UAS operation that, considering the risks involved, requires authorization by the competent authority before the operation takes place, taking into account the mitigation measures identified in an operational risk assessment, except for certain standard scenarios where a declaration by the operator is sufficient or when the operator holds a light UAS operator certificate (LUC) with the appropriate privileges”.

The certified category is including UAS operations that considering the risks involved, need certification of the UAS, a licensed pilot or operator approved by the relevant authority to ensure a suitable safety level (EASA, Drones - regulatory framework, 2022).

**Table 2.4.** *Regulated UASs categories by SHGM (SHGM, 2020)*

| UAS Categories | MTOW            |
|----------------|-----------------|
| İHA0           | 500 gr to 4 kg  |
| İHA1           | 4 kg to 25 kg   |
| İHA2           | 25 kg to 150 kg |
| İHA3           | 150 kg and more |

The second one is the classification that is regulated by SHGM and implemented in Türkiye. This classification divides the UASs into 4 categories based on maximum take-off weights. These categories and weights shown in Table 2.4. 499 grams and lighter



UASs not covered by the regulation (SHGM, 2020). These systems are not recorded and are not subject to any permits or training for flight.

### 2.3.3. Classification based on airframe and propulsion characteristics

In section 2.3.1., UAS classifications are described based on performance metrics and in this section, airframe and propulsion system types are using matched to these categories according to this classification.

**Table 2.5.** *UAS categories with using airframes (Blyenburgh, RPAS The Global Perspective Volume 1, 2021)*

| UAS Categories                 | Rotary Wing    | Fixed Wing        | Other               | Lighter-Than-Air |
|--------------------------------|----------------|-------------------|---------------------|------------------|
| <b>Tactical</b>                |                |                   |                     |                  |
| Nano                           | ■              |                   | ■ D, E, F           |                  |
| Micro                          | ■              | ■                 | ■ D, E, F           |                  |
| Mini                           | ■              | ■                 | ■ D, E, H           | ■                |
| Close Range                    | ■              | ■                 | ■ D, E, F, H, N     | ■                |
| Short Range                    | ■              | ■                 | ■ E, G, H, N, T     | ■                |
| Medium Range                   | ■              | ■                 | ■ H, N, T           |                  |
| Medium Range Endurance         | ■              | ■                 |                     |                  |
| Low Altitude Deep Penetration  |                | ■                 |                     |                  |
| Low Altitude Long Endurance    |                | ■                 |                     |                  |
| Medium Altitude Long Endurance | ■              | ■                 |                     | ■                |
| <b>Strategic</b>               |                |                   |                     |                  |
| High Altitude Long Endurance   |                | ■                 |                     | ■                |
| <b>Special Purpose</b>         |                |                   |                     |                  |
| Unmanned Combat Aerial Vehicle | ■              | ■                 |                     |                  |
| Offensive                      |                | ■                 |                     |                  |
| Decoy                          | ■              | ■                 |                     |                  |
| Stratospheric                  |                | ■                 |                     | ■                |
| Exo-stratospheric              |                | ■                 |                     |                  |
| Space                          | TDB            | TDB               | TDB                 | TDB              |
| D = Shrouded Fan               | E = Multirotor | F = Flapping Wing | G = Gyroplane       |                  |
| H = Motorized Parafoil         | N = Tit Wing   | T = Tilt Rotor    | TDB = To be decided |                  |

Different types of airframes have been used for UAS. Mainly rotary wings and fixed wings are used just like manned aviation. Other types as shrouded fan, multirotor, flapping wing, gyroplane, motorized parafoil, tilt wing, and tilt-rotor have been used for

six categories. Besides that, lighter-than-air concepts are used like others (Blyenburgh, RPAS The Global Perspective Volume 1, 2021). In Table 2.5, UAS categories and airframe types are matched.

In the UAS, seven propulsion types are used, and these types are piston-avgas, piston-diesel, turboprop, jet turbo, electric/battery, electric/solar, and electric/hydrogen. Some categories are using different types of propulsion system designs, but others are only one type. Table 2.6 has shown the propulsion systems matching with the used category.

**Table 2.6.** UAS categories with using propulsion systems (Blyenburgh, RPAS The Global Perspective Volume 1, 2021)

| UAS Categories                 | Piston Avgas | Piston Diesel | Turboprop | Jet Turbo     | Electric /Battery | Electric /Solar | Electric /Hydrogen |
|--------------------------------|--------------|---------------|-----------|---------------|-------------------|-----------------|--------------------|
| <b>Tactical</b>                |              |               |           |               |                   |                 |                    |
| Nano                           |              |               |           |               | ■                 |                 |                    |
| Micro                          | ■            |               |           |               | ■                 |                 | ■                  |
| Mini                           | ■            |               |           |               | ■                 | ■               | ■                  |
| Close Range                    | ■            | ■             |           |               | ■                 | ■               | ■                  |
| Short Range                    | ■            | ■             |           |               | ■                 | ■               | ■                  |
| Medium Range                   | ■            | ■             |           | ■             |                   | ■               |                    |
| Medium Range Endurance         | ■            | ■             |           | ■             |                   |                 |                    |
| Low Altitude Deep Penetration  | ■            |               |           | ■             |                   |                 |                    |
| Low Altitude Long Endurance    | ■            |               |           |               |                   | ■               | ■                  |
| Medium Altitude Long Endurance | ■            | ■             | ■         | ■             |                   | ■               | ■                  |
| <b>Strategic</b>               |              |               |           |               |                   |                 |                    |
| High Altitude Long Endurance   | ■            |               |           | ■             |                   | ■               |                    |
| <b>Special Purpose</b>         |              |               |           |               |                   |                 |                    |
| Unmanned Combat Aerial Vehicle |              |               |           | ■             |                   |                 |                    |
| Offensive                      | ■            |               |           |               |                   |                 |                    |
| Decoy                          | ■            |               |           |               |                   |                 |                    |
| Stratospheric                  |              |               |           |               |                   |                 |                    |
| Exo-stratospheric              |              |               |           |               |                   |                 |                    |
| Space                          |              |               |           | To be defined |                   |                 |                    |

### 2.3.4. Military classification

As in civil aviation, there is no standard classification of UAS in military aviation. National Intelligence Manager for Aviation of USA refers to The Department of Defense UAS Group Classification by their maximum gross take-off weight, operating altitude, and airspeed. Group classification contains 5 different groups. Unlike other classifications, they use the unit of lbs to define the UA's weight. Table 2.7 shows detailed information about Group Classification. Also, they use another category standard according to the range and endurance of UAS (NAI2O, 2022). This classification divides UAS into 5 different types. Detailed information and examples of the types show in Table 2.8.

**Table 2.7.** *The Department of Defense UAS Group Classification (NAI2O, 2022)*

| Category | Size    | Maximum Gross Takeoff Weight (MGTW) (lbs) | Normal Operating Altitude (ft) | Airspeed (knots) |
|----------|---------|-------------------------------------------|--------------------------------|------------------|
| Group 1  | Small   | 0-20                                      | <1,200 AGL                     | <100             |
| Group 2  | Medium  | 21-55                                     | <3,500 AGL                     | <250             |
| Group 3  | Large   | <1320                                     | <18,000 MSL                    | <250             |
| Group 4  | Larger  | >1320                                     | <18,000 MSL                    | Any airspeed     |
| Group 5  | Largest | >1320                                     | >18,000 MSL                    | Any airspeed     |

**Table 2.8.** *Range and endurance categorization (NAI2O, 2022)*

| Type                           | Example       | Range    | Functionality                                               | Endurance Time |
|--------------------------------|---------------|----------|-------------------------------------------------------------|----------------|
| Very Low Cost Close-Range UAVs | Puma          | 5 km     | Spying, Aerial Photography, Biological Warfare              | 20-45 min      |
| Close-Range UAVs               | ScanEagle     | 50 km    | Reconnaissance, Surveillance                                | 1-6 hrs        |
| Short-Range UAVs               | STUAS         | < 150 km | Reconnaissance, Surveillance                                | 8-12 hrs       |
| Mid-Range UAVs                 | M-1B Predator | 650 km   | Reconnaissance, Surveillance, Gathering Meteorological Data | 12 hrs         |
| Endurance UAVs                 | MQ-9 Reaper   | 300 km   | Reconnaissance, Surveillance, Long Distance                 | < 36 hrs       |

On the other hand, NATO divides weight classes according to UA's maximum gross take-off weight and after these classes are divided again according to the operational altitude of the UA (JAPCC, 2010). There are three weight classes as Class I, II, and III, and 7 categories are divided under these classes. The class I contains UA which is under 150 kilograms and this class has 3 categories as Micro, Mini, and Small. Each of these categories is limited to the RLOS operations. The class II contains 150 kg to 600 kg UA, and it has only one category which is Tactical. The class III contains UAs which has 600

kg or more. It divides into three categories: Strike/Combat, HALE, and Male. Each of them has BLOS operations. Detailed information can be reached in Table 2.9.

**Table 2.9.** *Classification of UAS according to NATO Standards (Adapted from (JAPCC, 2010))*

| Class                           | Category      | Normal Operating Altitude | Normal Mission Radius | Example Platform    |
|---------------------------------|---------------|---------------------------|-----------------------|---------------------|
| Class I<br>(Less than 150 kg)   | Small > 20 kg | Up to 5000' AGL           | 50 km (RLOS)          | Luna, Hermes 90     |
|                                 | Mini 2-20 kg  | Up to 3000' AGL           | 25 km (RLOS)          | Scan Eagle, Skylark |
|                                 | Micro < 2 kg  | Up to 200' AGL            | 5 km (RLOS)           | Black Widow         |
| Class II<br>(150 kg to 600 kg)  | Tactical      | Up to 10000' AGL          | 200 km (RLOS)         | Sperwer, Iview 250  |
| Class III<br>(More than 600 kg) | Strike/Combat | Up to 65000'              | Unlimited (BLOS)      |                     |
|                                 | HALE          | Up to 65000'              | Unlimited (BLOS)      | Global Hawk         |
|                                 | MALE          | Up to 45000' MSL          | Unlimited (BLOS)      | Predator B, Heron   |

## 2.4. Operations

UAS usage and operations are divided into 2 main titles which are governmental and non-governmental. Table 2.10 shows the classification of operation types of UASs.

Governmental operations include military and non-military operations, and non-military operations are stated flight security-related and non-state flights safety-related. State flight operations are included customs, police, border guards, and coast guard operations. Civil protection, firefighters, and national mapping agencies are classified as not state flights and professional flights.

Non-governmental operations include 4 subgroups which are commercial air transport, general aviation, aerial work, and leisure. These are evaluated as non-military operations besides state flights and not-state flights. Commercial air transport operations are intended to transport persons or freight as scheduled air service, non-scheduled revenue operations, and non-revenue operations. General aviation includes corporate operations, flight training and instruction, and pleasure operations. Pleasure operations are private non-commercial and flight training and instruction operations evaluated as a

duo in which student instruction by a licensed pilot, a solo which is unaided student flight, and check which is qualification verification of pilot license holder. Aerial work is evaluated as commercial, non-commercial, training/instruction, and other miscellaneous. Non-scheduled revenue operations are in the commercial air transport group and are considered as not state and professional flight operations as non-governmental. Leisure includes model aircraft, recreational drones, and flying toys (Blyenburgh, The Professional Drone Operations Market, 2022).

**Table 2.10.** *UAS Operation Classification (Blyenburgh, The Professional Drone Operations Market, 2022)*

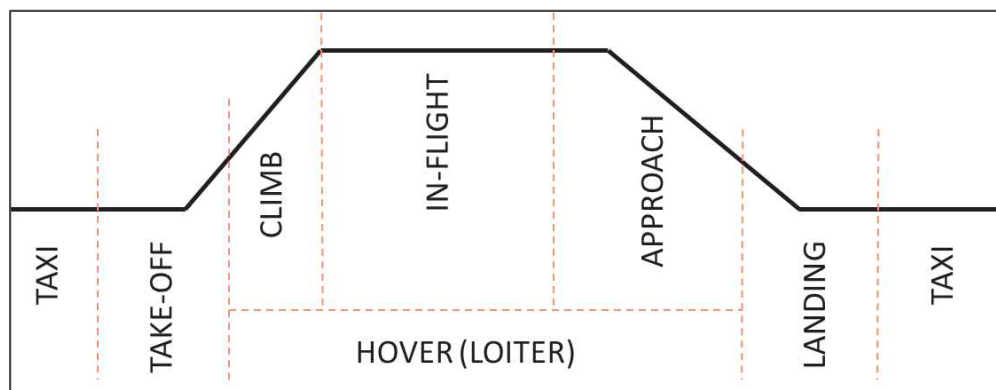
|                  |                          |                   |                                                                              |
|------------------|--------------------------|-------------------|------------------------------------------------------------------------------|
| Governmental     | Military                 |                   |                                                                              |
|                  | Non-military             | State Flights     | Customs<br>Police<br>Border Guards<br>Coast Guard                            |
|                  |                          | Not State Flights | Civil Protection<br>Fire Fighters<br>National Mapping Agencies               |
|                  |                          |                   |                                                                              |
| Non-Governmental | Commercial Air Transport |                   | Scheduled Air Service<br>Non-scheduled Air Service<br>Non-Revenue Operations |
|                  | General Aviation         |                   | Corporate Operations<br>Flight Training/Instruction<br>Pleasure              |
|                  | Aerial Work              |                   | Commercial<br>Non-Commercial<br>Training/Instruction<br>Other Miscellaneous  |
|                  | Leisure                  |                   | Model Aircraft<br>Recreational Drones<br>Flying Toys                         |

#### 2.4.1. Flight phases of the UAS

UAS might have the same flight phases as manned aircraft. Besides, UAS might have differences due to performance characteristics. No matter what, the pilot/operator will command the aircraft in line with the rules of the air for the State and the airspace they are in (ICAO, 2011). In this study, flight phases of the standard operation of the UAS are evaluated under seven different phases so that they can be gathered on a common

denominator. These phases will be named taxi, take-off, climb, in-flight, approach, landing, and hover. The wide variety of UASs expands the scope of standard definitions. This section aims to define the flight phases that will cover all UASs in the study.

The ICAO (2013) defines the taxi phase as a movement of an aircraft on the surface of an aerodrome under its own power occurs, excluding take-off and landing. This includes air taxiing for rotorcraft in this study. The take-off phase is evaluated as a flight phase from the application of take-off power until reaching the first prescribed power reduction, or until reaching the first planned waypoint, which comes first or aborts the take-off. The climb phase is evaluated as a flight phase starting after the take-off phase finished until reaching the planned flight altitude or waypoint. The in-flight phase is a flight phase covering most of the flight until the purpose of the flight is accomplished. This phase is starting with the completion of climbing to the planned altitude or waypoint and is finished with the other or same waypoint or altitude. The approach phase is starting with the controlled descent from the planned altitude or a waypoint until reaching the point of transition from nose-low to nose-high altitude or designated altitude on the runway or surface. The landing phase is the flight phase from the point of transition from nose-low to nose-up altitude, through touchdown, and until the aircraft exits the landing runway. For rotary wings, this phase is evaluated as a flight phase starting with passing a designated altitude of the runway or surface until touched the surface. The hover phase is the flight phase when the aircraft maintains a constant position at a selected point (ICAO, 2013). The loitering for fixed-wing aircraft is evaluated as the hover phase. Unlike the others, it is possible to switch to phase hover from phases climb, in-flight, or approach. After this phase, the aircraft can continue its flight from where it left off for the same purpose.



**Figure 2.6.** *Flight phases of the UAS*

## **2.5. Pilot Certification and Pilot Training**

According to the EASA regulatory classification for open category, A1 subcategory pilots operating with UAS lighter than 250 grams have not required any training. Other subcategories and A1 pilots operating with UAS lighter than 500 grams must complete the online training and pass the exam for their categories and accepts the reading user manual carefully as a competency (EASA, Open Category - Civil Drones, 2022). These regulations have not achieved their goal of sameness yet. When it comes to pilot education and training, there is no standardization of the curriculum. “Learning objectives” is specific but no accessible question databases for evaluation organizers are available. It is questionable that the skill of pilot assessment in different countries may not be the same. Some member countries are not offer training for A1 and A3 subcategories pilots which is free and fast in other member states. Such situations can create inconsistency. The pilot who has a specified category certification in his country could see in the different countries his skills and competence are null due to different practices in the process of the certification and training (Gérard, 2022).

For small drone operations, in U.S.A to corresponds the open category for EASA., initial knowledge and training test covers the following areas (Small Unmanned Aircraft Systems, 2022) :

1. Applicable regulations relating to small unmanned aircraft system rating privileges, limitations, and flight operation,
2. Airspace classification, operating requirements, and flight restrictions affecting small unmanned aircraft operation,
3. Aviation weather sources and effects of weather on small unmanned aircraft performance,
4. Small unmanned aircraft loading,
5. Emergency procedures,
6. Crew resource management,
7. Radio communication procedures,
8. Determining the performance of the small unmanned aircraft,
9. Physiological effects of drugs and alcohol,
10. Aeronautical decision-making and judgment,
11. Airport operations,
12. Maintenance and preflight inspection procedures; and



### 13. Operation at night.

According to the DGCA in Türkiye regulations, the trainings that the pilots have to complete according to the UAS categories they want to get a license are specified in detail. Accordingly, the duration of the training varies from 12 hours to 150 hours in total, depending on the license desired (SHGM, 2020). The training requires and durations are shown in Table 2.11 and Table 2.12. In addition to these, İHA2 pilots must get a minimum of 36 hours of flight training and a minimum of 3 hours of maintenance training from the manufacturer or an authorized representative of related UAS. For İHA3 systems, only for flight training, the limitation is a minimum of 54 hours of flight training (SHGM, 2020). And unlike EASA, UAS lighter than the 500 grams have not required any training.

**Table 2.11.** Training required for İHA0 and İHA1 for pilot license (SHGM, 2020)

| Course                                          | İHA0            | İHA1            |
|-------------------------------------------------|-----------------|-----------------|
| UAS Introduction                                | 1 Hour          | 3 Hours         |
| Air Law and Responsibilities                    | 2 Hours         | 6 Hours         |
| Aircraft, Flight Dynamics and Flight Principles | 1 Hour          | 4 Hours         |
| Meteorology                                     | 1 Hour          | 2 Hours         |
| ATC Procedures and Standard Phraseology         | 1 Hour          | 3 Hours         |
| Navigation and Operation                        | 2 Hours         | 5 Hours         |
| Controllable Systems                            | 1 Hour          | 4 Hours         |
| Propulsion Systems                              | 1 Hour          | 3 Hours         |
| Avionics                                        | 1 Hour          | 3 Hours         |
| Maintenance and repair                          | 1 Hour          | 3 Hours         |
| <b>Total</b>                                    | <b>12 Hours</b> | <b>36 Hours</b> |

**Table 2.12.** Training required for İHA2 and İH3 for pilot license (SHGM, 2020)

| Course                                                                                                       | İHA2            | İHA3             |
|--------------------------------------------------------------------------------------------------------------|-----------------|------------------|
| Aircraft General Information -Frame and Systems -Electricity and Engine (Energy System) -Emergency Equipment | 14 Hours        | 24 Hours         |
| Operational Procedures (Management Methods)                                                                  | 8 Hours         | 14 Hours         |
| Flight Planning and Monitoring                                                                               | 11 Hours        | 19 Hours         |
| Meteorology                                                                                                  | 9 Hours         | 15 Hours         |
| Air Law and ATC Procedures                                                                                   | 9 Hours         | 15 Hours         |
| Navigation                                                                                                   | 13 Hours        | 22 Hours         |
| Flight Principles                                                                                            | 11 Hours        | 18 Hours         |
| Human Performance and Limitations                                                                            | 6 Hours         | 10 Hours         |
| Communication                                                                                                | 5 Hours         | 8 Hours          |
| Maintenance and repair                                                                                       | 3 Hours         | 5 Hours          |
| <b>Total</b>                                                                                                 | <b>90 Hours</b> | <b>150 Hours</b> |



### 3. SAFETY MANAGEMENT SYSTEM

Safety has different definitions. The definition of "safety" in the Merriam-Webster Online Dictionary is: "a state of being safe from suffering or causing injury, injury, or loss" (Nilsen et al. 2004). For those building a nuclear power plant, efficient control of the nuclear chain reaction means proper cooling of the reactor core and preventing the release of radioactive materials. Or, if you are a skier, skiing without breaking your ankle, spraining your arm, or experiencing head trauma meets the concept of safety. Considering the concept of safety in transport modes, people complete their journey safely without experiencing an accident or incident, dying, or being injured (Stolzer, Halford, & Goglia, 2011).

Major disasters such as Chernobyl, Challenger, Tenerife Airport Disaster, Herald of Free Enterprise, King's Cross, Piper Alpha, and Clapham Junction have increased safety interest. For this reason, the focus of the issue has shifted from accident prevention based on technical and human error to "safety management" based on a dynamic process. This situation also drew attention to the invisible and implied causes of the accidents rather than the apparent causes. In terms of predictability and prevention of such disasters, the concept of safety has brought a better approach to the changing perspective (Maurino, Reason, Jonston, & Lee, 2017).

Safety is the control of losses that may occur as a result of accidents and incidents by identifying, analyzing, and reducing risks. Losses prevented or reduced by the safety management system (SMS) are as follows:

- Injuries and deaths,
- Occupational diseases,
- Equipment and property damage,
- Environmental damages,
- Problems related to the quality of products and services, hidden losses such as company reputation (Stefana, Ustolin, & Paltrinieri, 2022).

Aviation authorities facilitate air transportation and determine which rules all their vehicles, including tenders, act. These rules are the sum of the procedures, regulations, infrastructure, aircraft, and personnel that make up the air transport system (Weibel & Hansman, 2005). Including UASs in a manned flight-heavy system creates several safety issues, including potential air collisions, ground collisions, and system reliability (Carr, 2013).

UAS operations, unmanned vehicle control, and traffic avoidance within the air traffic control system (ATC) are functionally different from the manned flight system. In a manned aircraft, ATC commands the pilot by radio and the pilot takes action to avoid a collision (Weibel & Hansman, 2005).

In addition to ATC, pilots have two methods of detecting and avoiding the aircraft: either by visually detecting a potential collision or the Traffic Collision and Avoidance System (TCAS), which compares local air traffic transponders with the unit's altitude and warns of potential collisions. To avoid potential collisions, UASs must have the same sensing and avoidance capabilities while in the air as other aircraft (Carr, 2013).

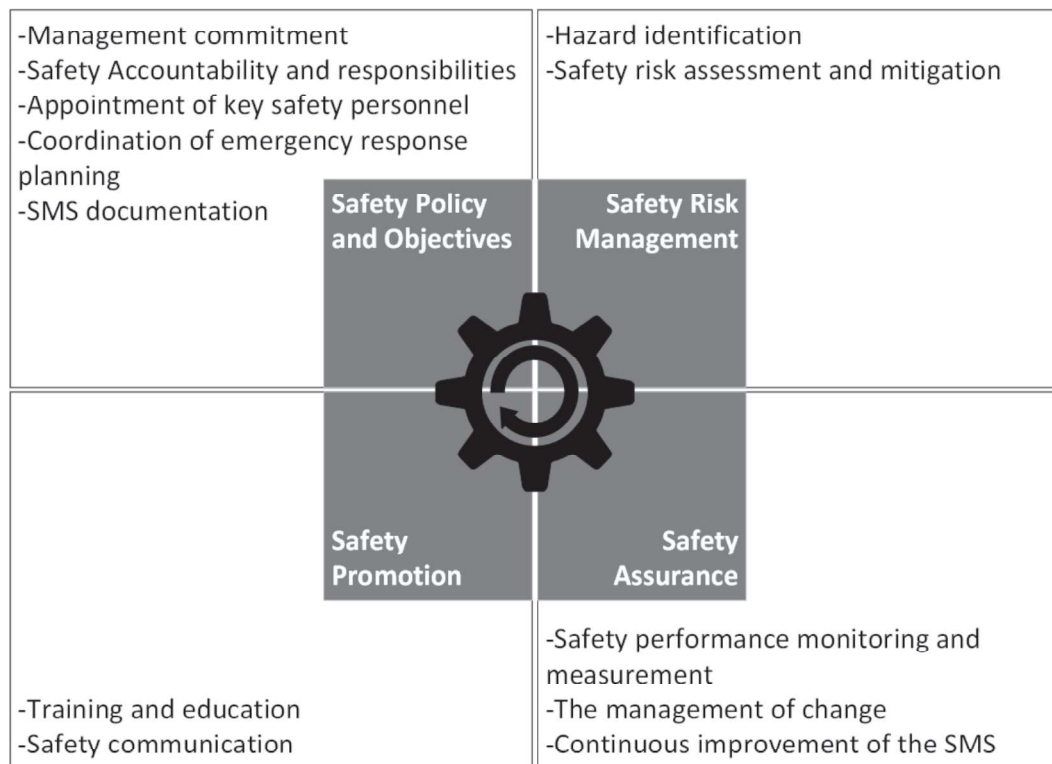
The purpose of SMS is to promote safe, efficient, and effective UAS operations. The Safety Management System (SMS) is used for (Namian, Khalid, Wang, & Turkan, 2021):

- Identify safety risks and hazards and implement mitigation processes and procedures.
- Establish an organizational management structure with key safety personnel to plan, implement, and execute.
- Implementing emergency response procedures.
- Establishing change management procedures, continuous improvement processes and safety performance improvement, measurements, and monitoring procedures.
- To provide security education, communication, and training to create an organization-wide safety culture.

The safety management system aims to proactively reduce safety risks in aviation accidents and incidents before they have any consequences. States can manage safety activities in responsible areas in a more disciplined, focused, and integrative way through safety management practices. With these safety practices, governments and the aviation industry can more effectively address safety risks and manage their resources for the best results.

SMS application provides many benefits. The safety culture in organizations is strengthened by making the management policy visible and encouraging the active involvement of personnel as a part of the safety management system. By revealing inefficiencies in SMS requests, it can improve the ability to detect security issues and

reduce possible costs in operation (Yang, Chang, & Lin, 2022). SMS has four components and twelve elements according to the ICAO framework which can be found in Figure 3.1.



**Figure 3.1.** SMS Components and elements (Adapted from (ICAO, 2018))

The following safety management principles are used to improve SMS:

- Safety is considered by management and employees as an integral, vital, and necessary part of the organization.
- Safety is critical and the priority of the organization.
- There is a supervisor in charge of security.
- Each individual involved in an operation should consider the safety of himself, his colleagues, and the public as his primary responsibility.
- During flight operations, the RPIC is the chief executive and is responsible for safety, including:
  - Final authority to refuse to perform or suspend a task based on safety or security concerns.
  - Finalizing the planned take-off and landing positions according to the field conditions at the time of flight.
  - Changes or deviations from the planned flight due to site conditions at the time of flight.

SMS consists of the following documents:

- Flight Plan.
- Health and Safety Plan.
- In-flight Emergency Response Plan.
- Downed Aircraft Recovery Plan (DARP). (TxDOT Flight Services, 2018).

### **3.1. Safety Policy and Objectives**

The first component of the Safety Management System (SMS) aims to establish an environment where safety management can be done effectively. This component consists of five sub-elements. These are expressed in the form of safety policy and objectives, which are an indication of senior management's commitment to safety, its objectives, and the organizational structure that supports them (Yang, Chang, & Lin, 2022).

Management commitment and safety leadership are key to establishing an effective SMS. This can only be expressed with a well-defined safety policy and safety objectives developed accordingly. While management's commitment to safety is demonstrated through management decision-making processes and the allocation of resources, the consistency of these decisions and actions with safety policy and objectives ensures a positive culture throughout the enterprise.

The service provider is responsible for determining a safety policy on national and international requirements. The Safety Policy should have the following characteristics:

- Reflect an organizational commitment to safety, including the promotion of a positive safety culture.
- There should be a clear statement that the resources needed during the implementation of the safety policy will be provided.
- It should include safety reporting procedures.
- Which behaviors related to the aviation activities of the service provider are unacceptable and under what conditions criminal sanctions can be imposed?
- It should be clearly stated.
- It must be signed by the responsible manager of the enterprise.
- It should be reviewed periodically to keep it up-to-date and relevant to the service provider (CASA, 2022).

The safety policy should be supported by senior management and the responsible manager. It should make it clear to the rest of the organization that management's active support of the safety policy is supported. This can be done through any means of communication and with the compliance of activities with the safety policy. In other words, what is said about safety and what is done do not contradict each other.

Considering the safety policy that the service provider has determined, it should determine the Safety Objectives in line with what it wants to achieve in terms of safety outputs. Safety Objectives (Clothier & Walker, Determination and evaluation of UAV safety objectives, 2006) must have the following characteristics:

- Provide the basis for monitoring and measuring safety performance,
- Reflect the service provider's commitment to the maintenance or continual improvement of the effectiveness of the SMS,
- Must be communicated within the enterprise and,
- It should be reviewed periodically to keep it up-to-date and relevant to the service provider.

Safety objectives should be high-level phrases of the service provider's safety priorities and address the most significant safety risks. While these objectives may be included in the safety policy, they may also be recorded as a separate document.

As will be examined in detail in the third component of the SMS, Safety Assurance, safety performance indicators (SPI - Safety Performance Indicators), and safety performance targets (SPT - Safety Performance Indicators) depending on the said objectives to monitor and measure the determined operational safety objectives and to monitor their realization rates (Ferrell & Anderegg, 2020). Targets should be determined.

### **3.1.1. Safety accountabilities and responsibilities**

Accountabilities and responsibilities of all personnel, including senior management and employees, who are responsible for the safe delivery of products and ensuring that operations are carried out safely, should be clearly defined by service providers. While “accountability” from the terms mentioned here refers to obligations that cannot be delegated to others, “responsibilities” refers to functions and activities that can be delegated, that is, performed by others on behalf of the person responsible (Dekker, 2012).

Accordingly, the following issues must be fulfilled by the service provider within the scope of determining the responsibilities and responsibilities related to safety:

- Determine an accountable executive who is responsible for the establishment and maintenance of an effective Safety Management System (SMS), independent of all his other duties,
- Must clearly define all safety responsibilities within the enterprise, especially the direct responsibility of senior management for safety,
- Identify the responsibilities of all management, as well as all employees, regarding the safety performance of the enterprise, independently of their other duties,
- Record and disseminate safety accountability, responsibilities, and authorities within the enterprise; and
- Identify levels of management with decision-making authority on safety risk tolerability.

The employee of the service provider who is at the top hierarchically in terms of safety responsibilities is the accountable executive. The owner of this role, also commonly referred to as the chief executive officer (CEO), is the person who has final authority over the safe operation of the business. By setting and promoting the safety policy and objectives, the responsible manager in stills the business that safety is one of the most fundamental values for the business.

### **3.1.2. Assignment of key safety management personnel**

The appointment of the person or persons to fill the role of the safety manager is vital for an effectively established and functioning safety management system. In this regard, the service provider must appoint a safety manager responsible for the installation and maintenance of the SMS. The person performing the functions of the safety manager is responsible to the responsible manager for the performance of the SMS and the safety services provided to other departments within the enterprise. Depending on the size of the service provider and the complexity of the products or services it offers, the task of installing and maintaining the SMS (Melnik, 2021) can be assigned to one or more people. This role can be performed alone or in combination with other duties without any conflict of interest. However, service providers should establish appropriate safety committees to support the enterprise-wide implementation of SMS functions. Issues such



as who will take place on these committees and how often the committees will meet should also be clearly defined in this context. The highest level of the safety committees within the enterprise is the Safety Review Committee (SRB) and this committee consists of members such as the safety manager, who participates in the committee with an advisory role, together with the responsible manager and senior managers (Mazur, 2002). The Safety Review Committee (SRB) is at the strategic level and deals with high-level issues such as the organization's safety policy, allocation of resources, and organizational performance. After the strategic direction to be followed in terms of safety has been determined by the highest-level safety committee, the implementation of safety strategies appropriate to this direction needs to be coordinated across the organization. This coordination can often be accomplished by establishing operations-oriented safety action groups (SAG) (Ayers & Crawley, 2018). Safety action groups consist of managers and front-line personnel, but each group is chaired by a designated manager. SAGs are tactical formations that deal with specific safety issues during the implementation of the strategies developed by the SRB.

### **3.1.3. Coordination of emergency response planning**

By definition, an “emergency” is an unplanned situation or event that occurs suddenly and requires immediate action. Coordination of emergency response planning is the planning of activities that take place in a limited time frame during an unexpected aviation operational emergency. The Emergency Response Plan (ERP) is an integrated component of the service provider's safety risk management process that responds to aviation emergencies, crises, or events. Service providers, who are responsible for creating and maintaining an emergency response plan (ERP) for accidents and incidents in aviation operations, as well as other emergencies in the aviation field, coordinate this plan with the emergency response plans of other institutions with which they have to interact while offering their products or services (Guerin, Delmas, & Guiochet, 2021). This coordination should be tested during periodic exercises of the ERP. The issue that should be underlined here is that no provision in ICAO Annex 19 that requires the creation or maintenance of an ERP. Because the obligation to coordinate emergency response planning only covers those responsible for creating and maintaining an ERP from service providers by the relevant ICAO Annex, to which they are subject according to the nature of the product or service they provide (Zariouh, Haddout, & Benhadou, 2022).

#### **3.1.4. SMS documentation**

Safety management system documentation requires an "SMS Handbook" at the top, which defines the service provider's SMS policies, processes, and procedures for the internal administration, communication, and maintenance of SMS in the enterprise. This handbook should help business personnel understand how their organization's SMS works and how safety policy and objectives can be achieved (Cromwell, Giampaolo, Hupy, Miller, & Chandrasekaran, 2021). Accordingly, the service provider must create and maintain a Safety Management System Manual (SMM) (Clothier, Williams, Fulton, & Lin, 2013) that defines the following:

- Safety policy and objectives,
- SMS requirements,
- SMS processes and procedures; and
- Responsibilities, and authorities under SMS processes and procedures.

The SMS documentation should also include a system description specifying the limits of the safety management system. It should also help clarify the relationships between the various policies, processes, procedures, and practices and define how all these elements relate to the service provider's safety policy and objectives. It should also be adapted and documented in a way that allows daily safety management activities to be easily understood by all personnel across the enterprise. However, the service provider must establish and maintain SMS operational records as part of the safety management system documentation. Another issue to highlight here is that, depending on the size of the service provider and the complexity of its products or services, the SMS handbook and SMS operational records may be stand-alone documents as well as integrated with other organizational documents or records that the entity maintains (Hsu, Li, & Chen, 2010).

#### **3.2. Safety Risk Management**

The purpose of risk management is to identify safety-related hazards and reduce associated risks. This component, which includes hazard identification and safety risk assessment and mitigation, is called Safety Risk Management (SRM). When a pilot follows good decision-making practices, the risk inherent in a flight is reduced or even



eliminated. The ability to make good and sound decisions is based on direct or indirect experience and training.

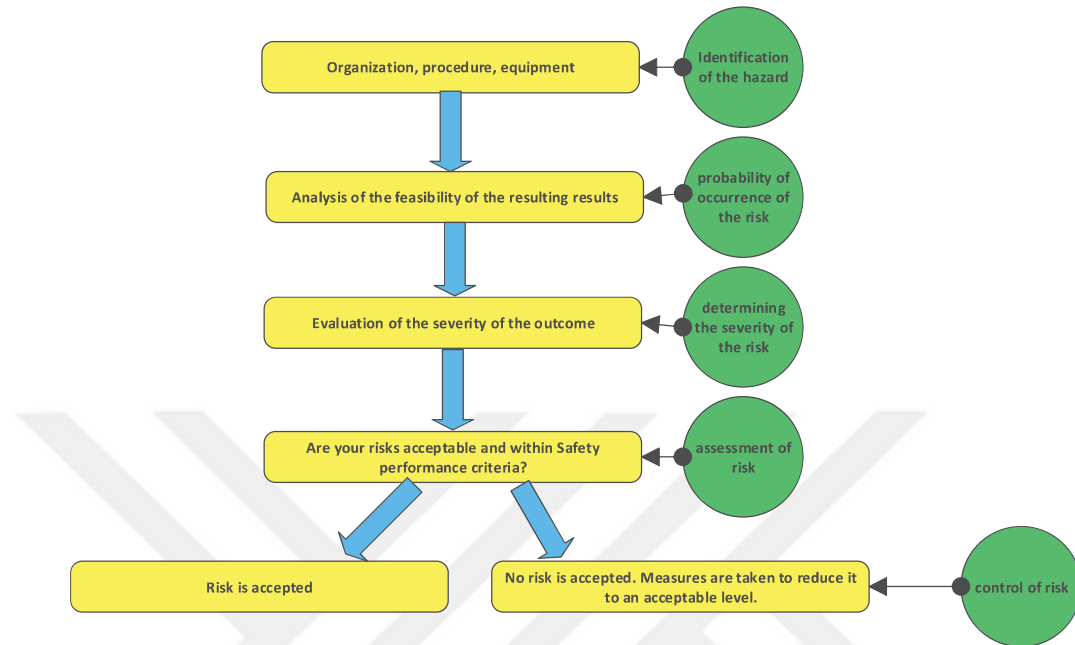
The SRM process systematically identifies hazards that exist within the product or service offered by the service provider. Hazards; They may be the result of systems with flawed design, technical functions, human interface, or interaction with other processes and systems. In addition, they can also be caused by the failure of existing processes and systems during adaptation to changes in the service provider's operational field. Careful analysis of these factors often allows potential hazards to be identified at any point in the operation or activity's lifecycle. In this context, the service provider is obliged to establish and maintain a process to identify hazards related to the aviation products or services it offers.

This hazard identification process should be based on a combination of reactive, proactive, and predictive methods. Reactive hazard identification looks for the event that already occurred. It is more common than others because identifying something already occurred is easier. Although it is common, proactive and predictive hazard analyses are more effective than reactive hazard identification because in these analyses, nothing is risked, and no one expects accidents to happen. Proactive hazard identification looks for the hazardous conditions which might occur but have not happened yet. A proactive process called predictive hazard identification uses data analysis to spot trends in order to foretell when safety performance will fall below desirable levels and what might be the reason for the reduction (CASA, 2022). In systems that have managed the just culture, proactive and predictive methods may be more common.

The service provider is responsible for establishing and maintaining a process for the analysis, assessment, and control of the safety risks associated with the hazards it has identified. This process may include predictive data analysis methods. A safety risk assessment model and procedures should be developed that allow for a consistent and systematic assessment of safety risks by the service provider. This model determines which safety risks are “acceptable”. It should also include a method to assist in determining whether it is acceptable or “unacceptable” and prioritizing the actions to be taken.

Once the safety risks have been assessed, appropriate safety risk controls can be put in place. At this point, before implementing any safety risk control, unexpected results that may arise after the implementation of the said risk control, especially new dangers

that may appear in the system should be determined in detail. As given in the ICAO Safety Management Manual, the hazard identification and risk management process can be schematized as in Figure 3.2.



**Figure 3.2.** Hazard identification and risk management process (ICAO, 2018)

The outputs of the SRM process should be documented, including the hazards and potential consequences, the safety risk assessment, and any safety risk controls taken. This information is usually collected in a risk register file so that it can be tracked and monitored. Said SRM documentation can become a historical source of corporate safety information and can be used as a reference for making safety decisions and exchanging safety information. This safety information provides material for safety trend analysis and safety education and communication. However, they are also very useful for internal audits in evaluating the implementation and effectiveness of safety risk controls and actions.

### 3.2.1. Safety reporting systems

The hazard or safety reporting systems may detect the situations or conditions that undesirable events. That systems can be reactive or proactive (CASA, 2022). Reporting after the event had occurred is a reactive approach to visualize the causes and the environment when it happened. On the other hand, reporting before the event might prevent the situations that can cause, which will be a proactive approach.

To achieve a safety culture, people in the systems must be encouraged to voluntarily report hazards without any fear. During hazard identification, all people involved in the system's different areas, not only managers, should contribute. Whether the reports are related to important or unimportant issues, the higher number of reports allows you to monitor the safety performance of the system (CASA, 2022).

### 3.2.2. Risk

Risk is the disruption caused by unforeseen circumstances for the future caused by the possibility of accidental deviations from planned targets. An assessment of the consequences of a hazard, expressed in terms of estimated probability and severity, concerning the worst predictable situation (Janic, 2000). This statement is the official definition of safety risk by ICAO; considers the identified hazard and divides it into two categories: “likelihood” and “seriousness”. The term “safety risk” is when a hazard persists in terms of a follow-up scenario because the hazard has been acknowledged. Since it is not only important to identify hazards and then engage in a mitigation process, it is also necessary to “assess the severity of consequences to prioritize the allocation of resources when proposing mitigation strategies”.

A hazard is a situation or situation that can only result in physical damage or loss. It should not be confused with safety risks. An obstacle at the end of the track poses a hazard. This obstacle can lead to at least three security risks. The first safety risk may be that an aircraft crashes into an obstacle during landing or take-off. The second safety risk may be that the pilot knows that the obstacle is there and can perform a steeper-than-normal approach to avoid the obstacle and arrive at the end of the runway "hot and high", continue the descent and overcome it. The third safety risk may be that the pilot in the second scenario realizes that he is "hot and high" and performs "wandering". The safety risk needs to be assessed to know the outcome of the hazard, where it might lead, and what action to take. This assessment is made by dividing the safety risk into two categories, probability and severity (Müller & Drax, 2014).



**Figure 3.3.** *Risk Exposure*

### 3.2.3. Assessing risk

A risk assessment methodology is used to determine the safety implications of UAS operations. The first step in a risk assessment is to identify hazards arising from the operation of a system, which are situations that present the potential for an accident. The probability of occurrence of each hazard is then estimated. The risk of a particular hazard is defined as the combination of the severity of the hazard and the probability of its occurrence (Weibel & Hansman, 2005).

A hazard is an existing event, object, or situation that can cause or contribute to an undesirable situation, such as an accident or incident (Piers, Montijn, & Balk, 2009). UAS safety hazards;

- High altitude loss,
- Loss of control,
- Transmission loss,
- Collision with manned, unmanned aircraft or buildings, power lines,
- Partial failure or loss of navigation systems,
- Severe weather or climate events,
- Presence of corrosion,
- The pilot is not familiar with the area,
- Rotor malfunctions,
- Takeoff and landing events such as undershot or overspeed are such situations

(Wackwitz & Boedecker, 2015).

Risk is the combination of the probability or frequency of an adverse effect caused by a hazard and the severity of that effect (Torretta, Rada, Schiavon, & Viotti, 2017). Risk is the potential for adverse consequences from a hazard to occur. The probability that the hazard's potential to cause harm will materialize. (ICAO, 2018). Risk types are given in Table 3.1. (FAA, 2009). Risk Assessment is the analysis process based on judgment and/or analysis methods to determine whether the acquired or perceived risk is acceptable or tolerable.

The UAS risk assessment in the SMS is carried out with the following step:

- Hazard identification and reporting,
- SMS audit,
- Safety inspections,

- Trend analysis,
- Safety cases,
- Change management,
- Other types of safety reviews.

**Table 3.1.** *Types of Risk (FAA, 2009)*

|                   |                                                                                                                                                                                                                                                                                   |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Total Risk        | It is the sum of identified and unidentified risks.                                                                                                                                                                                                                               |
| Identified Risk   | It is the risk determined by different analysis techniques.                                                                                                                                                                                                                       |
| Unidentified Risk | Unidentified risks are identified after a mishap has occurred. Some risks can never be predicted.                                                                                                                                                                                 |
| Unacceptable Risk | This type of risk is a risk that cannot be tolerated by the management activity. It is a subset of the identified risk that must be eliminated or controlled.                                                                                                                     |
| Acceptable Risk   | The portion of the identified risk is allowed to continue without further engineering or management action. Making this decision to allow is a difficult but necessary responsibility of the management activity.                                                                 |
| Residual Risk     | It is the type of risk that remains after the requirements for system safety have been fully implemented. It does not have to be the same as an acceptable risk. It is now the sum of acceptable risk and unidentified risk. This risk is the total risk transferred to the user. |

Events such as near misses or stealth conditions that cause or may cause UAS operational flight safety damage are identified. All identified hazards are evaluated according to the severity of the operational risks and the probability of the operational risk. They determine what needs to be done to reduce the risk based on the operational risk acceptance level. Not only the results but also the entire UAS safety risk assessment process must be documented to ensure continued safety throughout the entire process.

With the UAS safety risk assessment, operational drone safety hazards that occur during flight operations or that can be noticed in non-flight situations are determined and divided into "active failures" and "hidden conditions". The effect of active failures, including errors and breaches, is visible immediately. They are often viewed as unsafe acts. Active breakdowns are often used by pilots, air traffic controllers, engineers, etc. associated with. These are latent conditions that exist in the UAS system long before a detrimental outcome occurs. These latent conditions are not perceived as harmful but may occur later on. People who are removed from the event in terms of time and place usually ensure these conditions.

There are three methodologies for identifying security hazards: reactive, proactive, and predictive. The reactive methodology involves the analysis of past results or events. Hazards are identified through investigation of safety incidents. Incidents and accidents are clear indicators of system deficiencies. Therefore, they can be used to identify hazards contributing to the event or the latent. The proactive methodology includes analysis of real-time situations during drone operations. Predictive methodology, on the other hand, involves data collection. It is used during drone operations to identify possible future adverse consequences or events, analyze system processes and the environment, identify potential hazards, and initiate mitigation actions (e.g., FMEA) (Wackwitz & Boedecker, 2015).

The following methods can be used to identify security hazards:

- Flight Operations Data Analysis (FODA),
- Flight Reports,
- Maintenance Reports,
- Safety (& Quality) Audits / Evaluations,
- Voluntary reporting of incidents/accidents/near misses,
- Mandatory accident notification to the competent authority,
- Surveys.

Identified safety hazards should be conducted through a root cause analysis to identify their causes and potential consequences.

“Probability” means an accident caused by an identified hazard. or the probability of occurrence of the event or the probability of its consequences (Dalziell & Nicholson, 2001). The safety risk probability table is shown in Table 3.2 below.

“Severity”, on the other hand, is a measure of the damage that the said danger may cause when an accident or event occurs or its consequences occur (Wright, 2018). The safety risk severity table is shown in Table 3.3 below.

Additionally, risk assessors often use "probability of detection" as the third dimension of risk assessment. This is often required in product development and includes natural or technical safety barriers.

Additionally, risk assessors often use "probability of detection" as the third dimension of risk assessment. This is often required in product development and includes natural or technical safety barriers.



**Table 3.2.** *UAS safety risk probability (Wackwitz & Boedecker, 2015)*

| Likelihood           | Detail                                                                                                              | Value |
|----------------------|---------------------------------------------------------------------------------------------------------------------|-------|
| Frequently           | Likely to occur many times or has occurred frequently (five times during operation)                                 | 5     |
| Occasional           | Likely to occur sometimes or has occurred infrequently (every second operation)                                     | 4     |
| Remote               | Unlikely to occur, but possible or has occurred rarely (I know this situation from some events)                     | 3     |
| Improbable           | Very unlikely to occur or not known to have occurred (It happened once, and I've heard it before from someone else) | 2     |
| Extremely improbable | Almost inconceivable that the event will occur (It never happened, and I've never heard of it)                      | 1     |

**Table 3.3.** *UAS risk severity (Wackwitz & Boedecker, 2015)*

| Severity     | Detail                                                                     | Value |
|--------------|----------------------------------------------------------------------------|-------|
| Catastrophic | Death to people or Drones; equipment or buildings destroyed                | E     |
| Hazardous    | Serious injury to persons; major equipment or buildings damaged            | D     |
| Major        | Injury to persons; further operation not possible without major adjustment | C     |
| Minor        | Minor accident to person; minor effect on system performance               | B     |
| Negligible   | No injury to persons; minor consequences on the system                     | A     |

The level of a safety risk whose probability and severity values are determined is called the "risk index". The risk index is an alphanumeric value and is obtained by multiplying probability and severity. Let the probability of an identified hazard be 5 (frequent) and severity C (significant). Therefore, the safety risk index (5xC) for this hazard is 5C. All these risk indices are combined in a matrix to obtain a "safety risk matrix", which is used to calculate the level of risk associated with a safety risk whose probability and severity are known. The safety risk matrix is shown in Table 3.4. below (Wackwitz & Boedecker, 2015).

When the safety risk matrix is examined, it is seen that the risk indices in the matrix are divided into three categories "green", "yellow" and "red". These categories show the "acceptability levels" of safety risks. The green category corresponds to an acceptable level of risk without requiring any action. The yellow category, on the other hand, does not require stopping the operation but corresponds to the risk level that can be tolerated, provided that the risk level is reduced to an acceptable level by taking risk-mitigating



measures. The red category is an unacceptable safety risk level and requires immediate mitigation or immediate cessation of operation (ICAO, 2018).

**Table 3.4.** Customized UAS safety risk matrices (Wackwitz & Boedecker, 2015)

|                         |   |                      |    |    |    |    |
|-------------------------|---|----------------------|----|----|----|----|
| Safety risk probability | 5 | 5A                   | 5B | 5C | 5D | 5E |
|                         | 4 | 4A                   | 4B | 4C | 4D | 4E |
|                         | 3 | 3A                   | 3B | 3C | 3D | 3E |
|                         | 2 | 2A                   | 2B | 2C | 2D | 2E |
|                         | 1 | 1A                   | 1B | 1C | 1D | 1E |
|                         |   | A                    | B  | C  | D  | E  |
|                         |   | Safety risk severity |    |    |    |    |

The main goal here is to reduce the safety risks to an acceptable level by pulling the safety risks in the red and yellow categories towards the green area in the table as much as possible with various corrective, preventive, and risk mitigation measures.

### 3.2.4. Mitigating risk

UAS safety risk mitigation is an approach to responding to unacceptable or tolerable UAS safety risks. In other words, it is the systematic reduction of risk severity and probability of occurrence (Wackwitz & Boedecker, 2015).

**Table 3.5.** UAS safety risk acceptance matrix (Wackwitz & Boedecker, 2015)

| Acceptance level | Assessed UAS safety risk Index             | Recommended actions                                                                              |
|------------------|--------------------------------------------|--------------------------------------------------------------------------------------------------|
| Unacceptable     | 5C, 5D, 5E, 4E, 4D, 3E                     | Immediate mitigation action and escalation are required; an operation stop should be considered. |
| Tolerable        | 4A, 4B, 4C, 3B, 3C, 3D, 2C, 2D, 2E, 1D, 1E | The safety risk shall be mitigated as low as reasonably practicable and should be approved       |
| Acceptable       | 3A, 2A, 2B, 1A, 1B, 1C                     | No actions required                                                                              |

The UAS safety risk acceptance matrix describes the actions in Table 3.5. which are required for risk mitigation strategies.

- Unacceptable risks - The result is unacceptable. System redesign is required to reduce the likelihood or severity of the consequences of the safety hazard to an acceptable level.

- Acceptable level - The outcome and/or probability is alarming; Measures should be identified to reduce the risk to a reasonably low level.

- Acceptable level - The outcome is very unlikely or may not be severe enough to be worrying. The risk is tolerable and meets the security objective.

However, risk mitigation actions are taken to reduce risk to a reasonably practicable level. These are divided into two;

- Corrective actions - Actions with immediate effect for hazards.
- Preventive actions - Actions that have a long-term impact on the hazard to reduce the risk to an acceptable level.

UAS security risk mitigation is the final step in a UAS security risk assessment.

### **3.3. Safety Assurance**

Safety Assurance, which is the third component of the Safety Management System (SMS), consists of the processes and activities performed to determine whether the SMS is functioning by expectations and requirements. Safety assurance also includes the continuous monitoring of all processes and the operational site of the service provider to detect changes or deviations in the system that cause new risks to arise or adversely affect existing risk controls. Such changes or deviations are then handled in the safety risk assessment (SRM) processes of the enterprise and necessary actions are taken. Safety assurance activities should include the development and implementation of actions to be taken to address issues identified as having a potential impact on safety. These actions ensure the continuous improvement of the service provider's SMS performance (Mendonca & Carney, 2017).

The safety assurance component consists of three sub-elements:

#### **3.3.1. Monitoring and measurement of safety performance**

The service provider must develop and maintain a variety of ways to verify organizational safety performance and test the effectiveness of safety risk controls. In this context, it can be stated that the monitoring and measurement of safety performance generally consist of a combination of internal audit processes and the creation and monitoring of safety performance indicators (Chen & Li, 2016).

One of these tools monitors compliance with the safety management legislation on which the SMS is built and evaluates the effectiveness of safety risk controls, and the

entire SMS is the "internal audit" process. While internal audits evaluate the effectiveness of the SMS, they also allow the identification of areas with potential improvement opportunities. The majority of aviation safety legislation is general safety risk controls established by the State. Ensuring regulatory compliance through internal audits is therefore one of the key features of safety assurance. However, the service provider's safety performance can be combined with safety performance indicators (SPIs), which are elements that support the safety objectives of the enterprise (Szabo & Koblen, 2020).

Safety Performance Indicators and safety performance targets (SPT – Safety Performance Targets). SPIs are used to measure the overall performance of the service provider's operational safety performance and SMS and are based on analysis of data and information from a variety of sources, including data from the reporting system. These SPIs are unique to each service provider and should be linked to the current security objectives of the relevant service provider. Once the SPIs have been determined, the service provider should consider whether safety performance targets (SPTs) and associated alert levels need to be set. The “alert level” referred to here is a specified level or criterion that serves to trigger (initiate) an evaluation, decision, adjustment, or remedial action regarding a particular safety performance indicator. Therefore, the process of monitoring and measuring safety performance holistically includes selected SPIs as well as their associated SPTs and alert levels. It is also important to evaluate the effectiveness of safety risk controls, as the predicted results are not always achieved during the implementation phase. In this way, it will be possible to understand whether the right safety risk control has been selected and, if necessary, even to conclude that a different safety risk control strategy should be applied (Strong, 2020).

### **3.3.2. Change management**

Changes can change the effectiveness of existing safety risk controls. In addition, new hazards and associated safety risks may inadvertently be introduced into the operation after the change. Therefore, hazards that may arise during changes should be identified and the associated safety risks assessed and controlled, as defined in the entity's current hazard identification and safety risk management procedures (Santos-Reyes & Beard, 2002).

The following issues can be given as examples of the mentioned changes:

- Significant changes in institutional growth, downsizing or structuring,

- Business advances that affect safety (they may lead to changes in internal systems, processes, or procedures that support the safe delivery of products and services),
- Changes in the field of operation of the organization,
- Changes in SMS interfaces with other organizations,
- Legislative changes, economic changes, and emerging risks,
- Introduction of new technology or equipment,
- Changes in key personnel,
- Significant changes in staff numbers and
- Physical changes (new facility or base, airport layout changes, etc.) (Wincek, Sousa, Myers, & Ozog, 2015).

In this respect, the service provider has to develop and maintain a process to identify the changes that may affect the safety risk level of the aviation products and services it offers and to manage the safety risks that may arise from these changes.

### **3.3.3. Continuous improvement of SMS**

The service provider is responsible for monitoring and evaluating the SMS processes to maintain and continuously improve the holistic effectiveness of the safety management system. Maintaining and continuously improving the effectiveness of the SMS is supported by safety assurance activities. Since the organization itself and its field of activity will be in constant change, it should be known that the maintenance and continuous improvement of the SMS is an ongoing journey (Kontogiannis, Leva, & Balfe, 2017).

The effectiveness of SMS should not be based solely on SPIs. Service providers should aim to apply many different methods to determine the effectiveness of SMS, monitor the outputs and results of the processes, and evaluate the information gathered from all these activities. Various methods can be used to measure the effectiveness of SMS, including internal and external audits, assessments, monitoring of incidents, safety surveys, management reviews, evaluation of SPIs and SPTs, and lessons learned from incidents and reports.

As a result, safety performance monitoring and internal audit processes contribute to the service provider's ability to continually improve safety performance. Continuous monitoring of the SMS, safety risk controls, and supporting systems assures the service

provider and State that the safety management processes are achieving the desired safety objectives.

### **3.4. Safety Promotion**

The fourth and final component of the safety management system is Safety Promotion, which serves to promote a positive safety culture throughout the aviation community. Safety promotion helps the service provider achieve its safety objectives through a combination of continuously enhanced technical competence, effective communication, and information sharing through education and training. Promoting a safety culture throughout the organization finds a strong response only when it is led by senior management. Effective safety management cannot be achieved by mere necessity or by strict adherence to policies and procedures. Safety promotion influences both individual and organizational behavior and reinforces the organization's policies, processes, and procedures by providing a value system that supports safety efforts. Safety promotion consists of two sub-elements: “education and training” and “safety communication” (Chatzi, 2018).

#### **3.4.1. Education and training**

The service provider is responsible for developing and maintaining a safety training program to ensure that its personnel is trained and competent to perform their SMS duties. Accordingly, the scope of the SMS training to be given to each employee must be appropriate for their role in the SMS (Roelen & Klompstra, 2012). The safety manager is responsible for ensuring that an appropriate safety training program is implemented in the business. The safety training program should include “initial” and “recurrent” training requirements so that competencies can be maintained. “Initial” safety training should include, as a minimum, the following:

- Organizational safety policies and safety objectives,
- Internal roles and responsibilities related to safety,
- Basic safety risk management (SRM) principles,
- Safety reporting systems,
- With the organization's SMS processes and procedures
- Human factors.



“Continued” SMS training should focus on changes in SMS policies, processes, and procedures, but should highlight specific organizational safety issues or lessons learned from incidents.

### 3.4.2. Safety communication

The organization's SMS objectives and procedures should be communicated to all relevant personnel by the service provider. A communication strategy should be established to improve safety communication, taking into account the most appropriate method of delivering messages and which employee needs what kind of safety information. Depending on this strategy, various channels such as safety news, announcements, bulletins, briefings, or training courses can be used to deliver messages effectively. An example of that which is published by EASA to give information about the usage of UASs for fun has been given in Image 3.1.



Image 3.1. Safety promotion example (EASA, 2023)

In addition, the safety manager must ensure that lessons learned from incident investigations, historical cases, or experiences from internal or external sources are widely disseminated.

Accordingly, the service provider has to develop and maintain formal communication channels for safety communication that have the following characteristics:

- Ensure that each staff member has the level of SMS awareness required by their position,
- Ensures the transmission of critical safety information,
- Explains the reason for specific actions taken to improve safety; and
- Explain the reasons for introducing or changing safety procedures.

In conclusion, another important point to underline is that safety promotion activities should continue to be carried out throughout the life cycle of the SMS, not just at the outset (Krivonos, 2007).

### **3.5. ICAO ADREP Taxonomy and Aviation Standards**

#### **3.5.1. Occurrence classes**

ICAO ADREP taxonomy defines six main different occurrence classes. In this study, three occurrences classes among them have been used which are accident, serious incident, and incident. The accident class is defined by ICAO that an event connected to an aircraft operation that occurs between the time somebody boards the aircraft with the purpose of flight and the time all such people have disembarked. This event contains a person who is fatally or seriously injured by the aircraft or an aircraft that sustains damage or structural failure or an aircraft that is missing or is completely inaccessible. A serious incident means an event when there were signs that an accident almost happened. Examples of serious incidents can be found in Attachment C of the ICAO Annex 13 (ICAO, 2020). Lastly, an incident means an event that has the potential to compromise safety associated with the operation of an aircraft (ICAO, 2013).

#### **3.5.2. Occurrence categories**

ICAO ADREP Taxonomy defines the occurrence categories under specific standards to be easy to classify, avoidance of confusion, and facilitate documentation and storage. For this, ICAO specifies thirty-five occurrence categories (ICAO, 2013). According to related investigation reports, ten occurrence categories are found relevant which are BIRD, CFIT, LALT, LOC-G, LOC-I, MAC, SCF-NP, SCF-PP, UNK, and



USOS. For some of the occurrences, if the conditions are met, more than one occurrence category can be used for classifying the occurrence.

The first occurrence category relevant to the study is bird strike (BIRD). This occurrence contains collisions or near collisions with or ingestion of one or several birds. After that, controlled flight into or toward terrain (CFIT) occurrences include collisions in flight or near misses with a surface, water, or obstacles without sign of control loss and only include occurrences during airborne. The aircraft, which has the ability to vertical take-off and landing, is only evaluated for occurrences that occurred during the transition into forward flight without indication of loss of control. Low altitude operations (LALT) occurrences include collisions or near-collisions with terrain/obstacles/objects while operating purposefully close to the surface except during take-off and landing phases. Occurrences relating to the loss of control are divided into two different categories according to flight phases. Loss of control – ground (LOC-G) occurrences contain losing control of the aircraft while on the ground. On the other hand, loss of control – inflight (LOC-I) occurrences contain losing control of the aircraft or deviation from the intended flight path during airborne. If a system or component malfunction or failure is the direct cause of the loss of control, these occurrence categories are not used. Loss of control may, meanwhile, occur after less serious system/component failures; in this instance, both categories can be encoded. Airprox/ACAS Alert/loss of separation/ (near) midair collisions (MAC) include occurrences that Airprox, ACAS alerts, loss of separation as well as near collisions or collisions between aircraft in flight, in the other words, include any collisions between aircraft that occurs while in airborne phases. System or component failure or malfunction of an aircraft is evaluated under two different categories according to related to powerplant or not. Powerplant failure or malfunction (SCF-PP) occurrences contain failures or malfunctions of any of the things that rotors, gearbox, transmission, rotors, etc. On the other hand, system/component failure or malfunction of the non-powerplant part (SCF-NP) occurrences contain any component or system other than the powerplant. This includes software and database systems, flight control systems, ground-based launch and recovery systems, and also for the UAS, includes transmission, ground-based or aircraft-based communication systems or components, or datalink systems or components. Another related occurrence category, undershoot/overshoot (USOS) occurrences contain undershoot or overshoot of the runway/helipad/helideck and offside touchdowns to the runway/helipad/helideck. Emergency landings that occur outside the

airport are excluded from this category. Lastly, the unknown or undetermined (UNK) occurrence category is used for classifying the occurrences if there is insufficient information to categorize the occurrence (ICAO, 2013).

### **3.5.3. Damage levels**

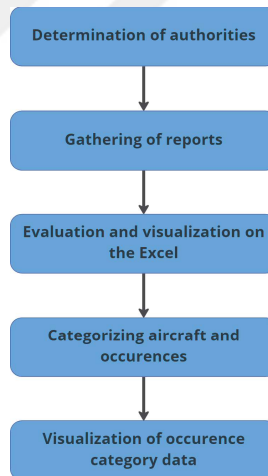
According to investigation reports, these occurrences are evaluated under eight different damage levels: destroyed, damaged beyond economical repair, extensively damaged, substantial, minor damaged, damaged, none, and unknown.

The destroyed damage level means that it is not advised to repair the aircraft to an airworthy state due to the damage it has received. A determination of “damaged beyond economical repair” is used when the aircraft is technically repairable, but economically the repair costs are unreasonable (ICAO, 2013). Extensively damaged means the aircraft’s structural stability has been affected or cannot be adequately fixed and must be completely replaced. Besides that such damages as missing wheels, tires, engine, etc. are included but not limited to this level of damage (Law Insider, 2023). The substantial level means that the aircraft suffered structural collapse or damage that negatively impacted the structural strength, performance, or flight characteristic of the aircraft or would typically require significant repair or replacement to the afflicted component. On the other hand, minor damage means simple repairs or replacements can make the aircraft airworthy and an extensive inspection is not required. The none means the aircraft suffered no damage in the occurrence and the unknown means that the condition of the aircraft is not known after the occurrence (ICAO, 2013). Besides these, in cases where the damage levels are not specified in the reports, but damages are mentioned, damage levels are expressed as Damaged.

## 4. METHOD

### 4.1. Methodology

In this research, descriptive research methods were used with a qualitative approach. In the 1250s A.D., quantitative research began to take shape by researchers who needed to quantify their data to provide new information and meaning (Williams C. , 2007). If defined in detail, the numerical representation and manipulation of observations with the purpose of describing and interpreting the phenomena those observations reflect are known as quantitative research. This includes physics, biology, psychology, sociology, and geology, among many other scientific and social disciplines (Sukamolson, 2007). The quantitative research approach divides four main types which are descriptive, correlational, causal-comparative/quasi-experimental, and experimental research methods. Descriptive research aims to characterize the current state of a variable that has been identified. These studies are created with the intention of offering systematic data regarding a phenomenon. Typically, the researcher does not start with a hypothesis; but, after gathering evidence, a hypothesis is likely to be developed (Winston-Salem State University).



**Figure 4.1.** *Data processing*

In order to form the framework of the research, first accident investigation authorities were determined and examined. According to these authorities, accident/serious incident/incident reports which are related to UAS were gathered. These reports were evaluated and visualized with the Excel tool. After all, resources were gathered and evaluated, accidents/serious incident/incidents have been categorized according to the ECCAIRS Aviation 1.3.0.12 Data Definition Standards. Moreover, related aircraft have been categorized according to performance metrics, airframe, and

engine types. After the categories are defined, all data have been visualized and evaluated. Figure 4.1. shows that data processing workflow chart.

## 4.2. Data Gathering

The databases of the investigation authorities were used to determine the accessible reports. There are 212 accident investigation authorities admitted by ICAO (ICAO, 2022). These authorities were eliminated according to how they presented the investigation reports. The analysis found that only two authorities provide the filtering in their databases to find UAS-indicated reports, and these are the Air Accident Investigation Branch (AAIB) and the Australian Transport Safety Bureau (ATSB). Seventy-seven completed investigation reports were gathered from these databases. Sixty-seven reports were gathered from the AAIB database and ten reports from the ATSB database. These reports commonly include:

- Occurrence Class,
- Aircraft type,
- Time and location of occurrence,
- Type of flight,
- Flight phase,
- The damage suffered,
- Casualties,
- Detailed information about flight, operation, and aircraft,
- Source of the report.

Using these data, occurrence categories according to ICAO were determined for each of the reports.

## 4.3. General Information

**Table 4.1.** *Report classes*

| Occurrence Class   | Reports   |
|--------------------|-----------|
| Accident           | 69        |
| Serious Incident   | 7         |
| Incident           | 1         |
| <b>Grand Total</b> | <b>77</b> |

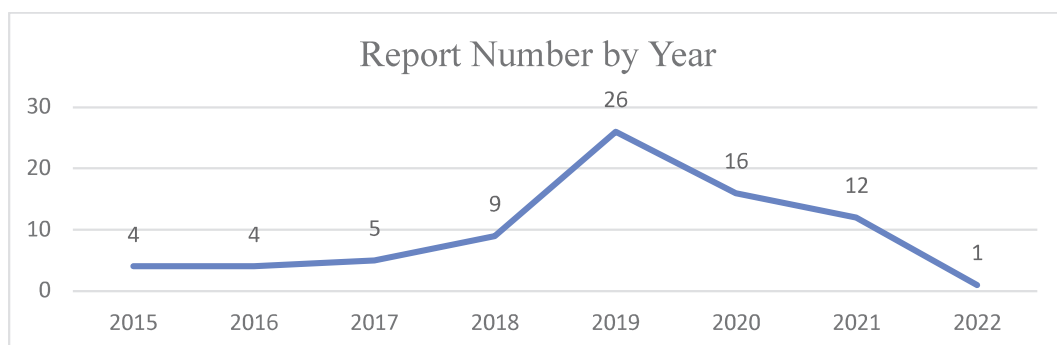
Table 4.1 shows that the gathered seventy-seven reports are divided according to classes which classes are Accident, Incident, and Serious Incident. The vast majority of

the reports with a count of sixty-nine reports are accident reports. Besides that, there are seven serious incident reports and only one incident report. These reports are divided into four groups when the sources of the occurrence are evaluated. The first of the sources is field investigations done by AAIB. Among the reports, AAIB prepared seven of them according to field investigations. The other source is ATSB reports which are prepared for ten occurrence investigations. The other investigation reports are based on Aircraft Accident Report Forms which are filled and submitted by the pilot. Thirty-seven reports are only submitted by the pilot and twenty-three reports are submitted by the pilot, and additionally, get investigated and additions have been made by authorities. Table 4.2 shows the number of reports and their sources.

**Table 4.2.** *Sources of the investigation reports*

| Sources                                                                                | Count of No |
|----------------------------------------------------------------------------------------|-------------|
| AAIB Field Investigation                                                               | 7           |
| ATSB Report                                                                            | 10          |
| Aircraft Accident Report Form submitted by the pilot and further inquiries by the AAIB | 23          |
| Aircraft Accident Report Form submitted by the pilot                                   | 37          |
| <b>Grand Total</b>                                                                     | <b>77</b>   |

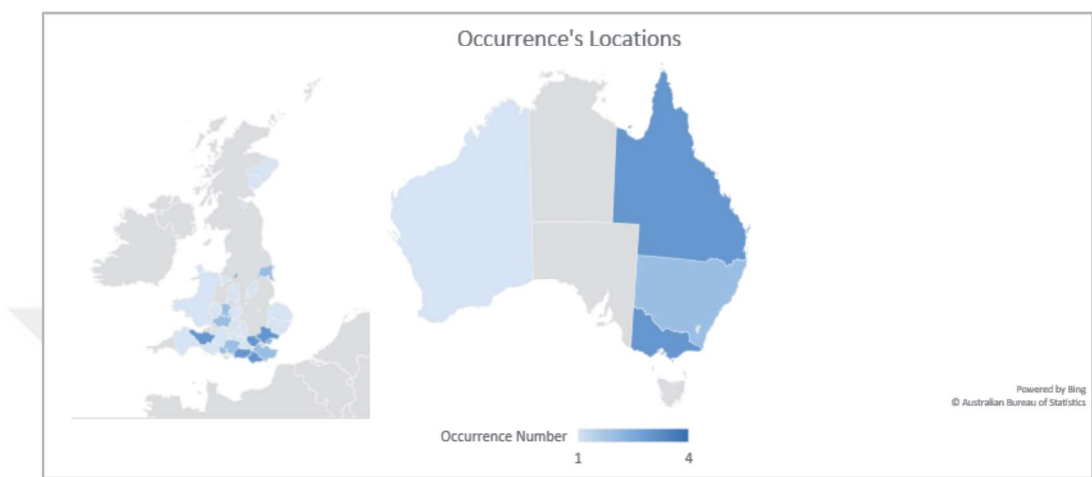
The first occurrence report according to databases published in 2015. Figure 4.2. shows that occurrence reports slightly increased during 2018 and in 2019, numbers increased 288% compared to 2018. After that, numbers started to decrease year by year. The last report gathered from the databases is dated April 2022.



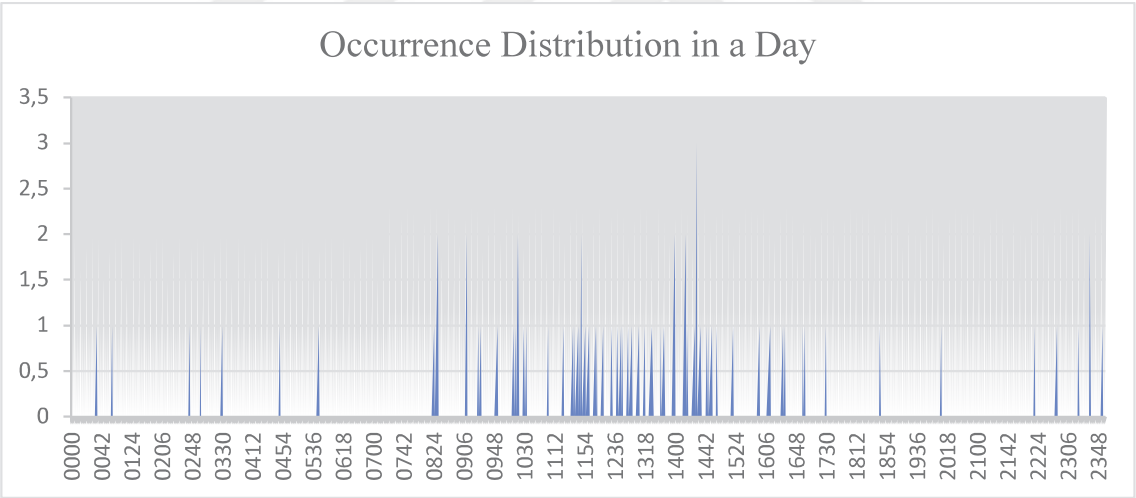
**Figure 4.2.** *Report numbers by year*

Manchester is the most occurrences happened location with four reports. Each one of the listed locations has three investigation reports and those are East Sussex, Essex, London, Somerset, West Sussex, Queensland, and Victoria. Figure 4.3. shows the occurrences' locations on the map with the color series. These locations are limited by the responsibility areas of the authorities.

Furthermore, occurrences mostly happened during the daytime as one might expect. Reports show that between 08:00 and 15:00, the number of occurrences has intensified. All occurrence times united as if they happened in one day and Figure 4.4. shows the distribution for a complete day. Besides that, according to all investigation reports, there are no injuries after the occurrences.



**Figure 4.3.** *Occurrence's locations*



**Figure 4.4.** *Occurrence distribution in a day*

#### 4.4. Aircraft and Flight Details

In this section, the report analysis results are shared under the categories of the type of flights, flight phases, aircraft types, airframe, and engine types, and damage levels of the aircraft.

The flights gather under seven types as shown in Table 4.3. Most flight type in the others is aerial work with a twenty-five flight. The commercial flight with twenty-four flights follows as second and besides that emergency services operation flight follows

with sixteen flights as third. Also, seven private flights, three training flights, one demonstration flight, and one test fly were involved in the investigation reports. Table 4.4. shows that the distribution of occurrences' numbers is examined under seven flight phases. 61% of the occurrences happened during the in-flight phase and 16% during the hover phase.

**Table 4.3.** *Type of involved aircraft flight types*

| Type of flights              | Count of No |
|------------------------------|-------------|
| Aerial Work                  | 25          |
| Commercial                   | 24          |
| Demonstration Flight         | 1           |
| Emergency services operation | 16          |
| Private                      | 7           |
| Test Fly                     | 1           |
| Training                     | 3           |
| <b>Grand Total</b>           | <b>77</b>   |

**Table 4.4.** *Flight phases at the time of occurrence*

| Flight Phase       | Count of No |
|--------------------|-------------|
| Taxi               | 1           |
| Take-off           | 7           |
| Climb              | 5           |
| In-flight          | 47          |
| Hover              | 12          |
| Approach           | 2           |
| Landing            | 3           |
| <b>Grand Total</b> | <b>77</b>   |

Forty-five different UASs have been involved in the occurrence reports. DJI Matrice 210 is involved in the fourteen occurrence reports and is by far the most occurrence-involved system according to the report numbers. Following that, DJI Inspire 2 is involved in five reports, and DJI Phantom 4 is involved in four. A full list of the forty-five UASs has shown in Table 4.5. Also, these UASs are divided into nine categories according to performance metrics. Figure 4.5. shows that 78% of the UASs are categorized as micro or mini. Besides, there are three low-altitude deep penetration category UASs and two medium-range category UASs, and close-range, high-altitude long-endurance, low-altitude low-endurance, medium-range endurance, and short-range categories each have one UAS.



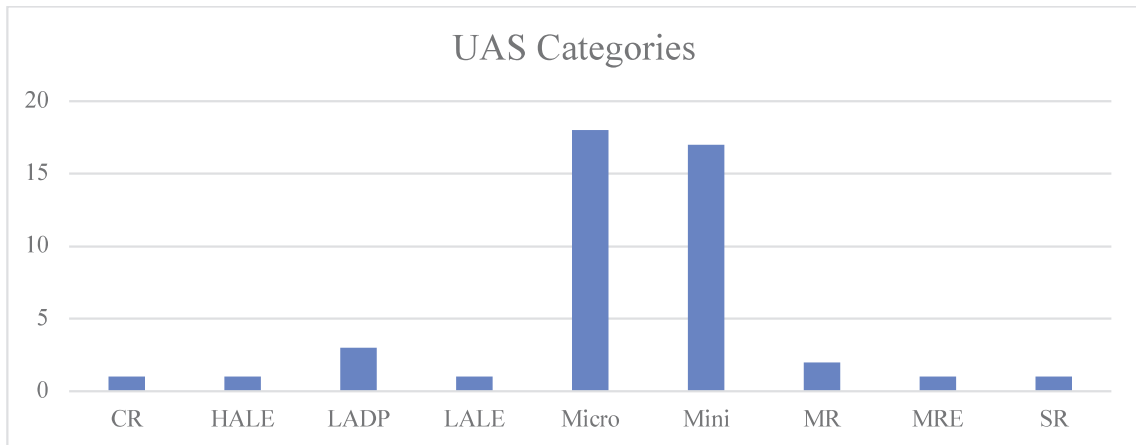
Figure 4.6. shows forty-five UAS distributions by airframe types and engine types. Among the different UASs, dominantly the twenty-eight UASs have multirotor airframes. Following this, eleven UASs have fixed-wing airframe types and another four UASs have rotary-wing airframe types. Just two of them have fixed-wing/ tilt-rotor types also called VTOL airframe types. As for engine types, four different types of engines are used in subject UASs; one doesn't have any engine for flight operation. In fact, electric engines are the most used engine type among the subject UAS and thirty-six of the UASs used this engine type.

**Table 4.5.** *Full list of related UASs*

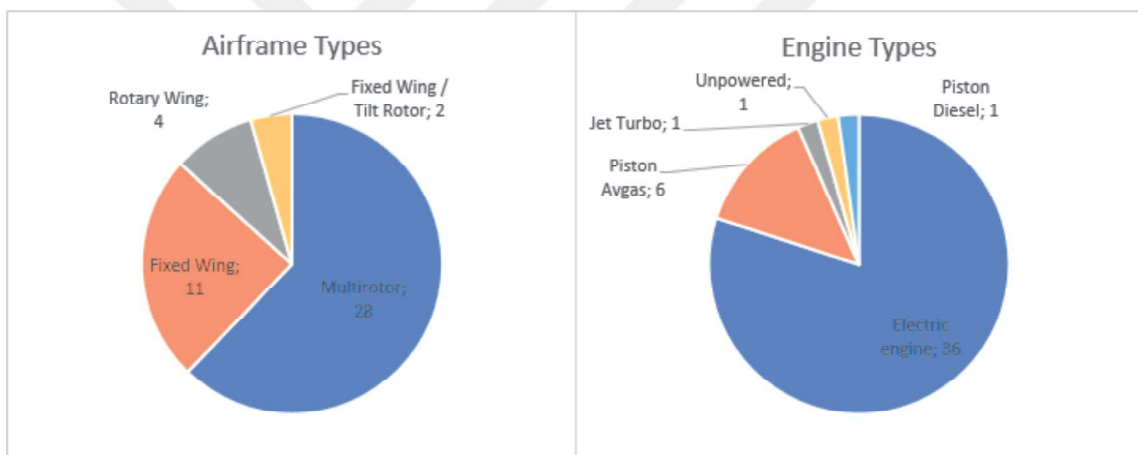
| UAS                              | Count of No | UAS                             | Count of No |
|----------------------------------|-------------|---------------------------------|-------------|
| 3DR Solo                         | 1           | Insitu ScanEagle X200           | 1           |
| Aerialtronics Altura Zenith ATX8 | 1           | Lockheed Martin Stalker XE      | 1           |
| Aeronavics SkyJib 8              | 1           | Lockheed Martin Stalker XE VTOL | 1           |
| Aeryon Skyranger R60             | 2           | MA Scale F4 Phantom             | 1           |
| Airbus Zephyr                    | 1           | Parrot Anafi                    | 3           |
| Alauda Airspeeder Mk II          | 1           | Parrot Anafi Thermal            | 1           |
| Believer                         | 1           | Parrot Anafi USA                | 2           |
| Brian Taylor AT6                 | 1           | Pulse Aerospace Vapor 55        | 1           |
| DJI Air 2S                       | 1           | RF Designs Mephisto             | 1           |
| DJI Inspire 2                    | 5           | SAS Wildthing                   | 1           |
| DJI M600 Pro                     | 1           | Schiebel Camcopter S-100        | 1           |
| DJI Matrice 100                  | 1           | UAVE Prion Mk 3                 | 2           |
| DJI Matrice 200 V1               | 3           | Valenta Ray X                   | 1           |
| DJI Matrice 210                  | 15          | Velos Single Rotor              | 1           |
| DJI Matrice 210 RTK              | 3           | Yamaha RMAX                     | 1           |
| DJI Matrice 300                  | 2           | Yuneec H520                     | 1           |
| DJI Matrice 300 RTK              | 1           | Yuneec Typhoon H480             | 1           |
| DJI Mavic Pro 2                  | 1           | Quest Q-200                     | 1           |
| DJI Phantom 3 Pro                | 2           | DJI Matrice 210 V2              | 1           |
| DJI Phantom 4 Pro                | 4           | Wingcopter 178                  | 1           |
| DJI Phantom 4 RTK                | 1           | Tekever AR5 Evolution Mk2       | 1           |
| Evolve Dynamics Sky Mantis       | 1           | DJI Spreading Wings S900        | 1           |
| Falcon 8 Trinity Asctec          | 1           |                                 |             |

The damage on the UASs is evaluated under eight categories according to investigation reports. Table 4.6. shows that twenty-six UASs were destroyed after the occurrence. This indicates that 34% of the occurrences render completely unusable to UASs. Also, twenty-one occurrence reports do not contain specific content about the extent and cost of the damage. Therefore, these contents are evaluated under the

“Damaged” category. On the other hand, six occurrences are evaluated as financially unreasonable to repair and use again and two UASs cannot be found and located after the occurrence.



**Figure 4.5.** *UAS categories*



**Figure 4.6.** *Distribution of the fifty-one UAS systems by airframe and engine*

**Table 4.6.** *Damage levels of UAS after the occurrence happened*

| Damage Categories                | Count of No |
|----------------------------------|-------------|
| Damaged                          | 21          |
| Damaged beyond economical repair | 6           |
| Destroyed                        | 26          |
| Extensively damaged              | 9           |
| Minor Damage                     | 3           |
| None                             | 5           |
| Substantial                      | 5           |
| Unknown (Missing)                | 2           |
| <b>Grand Total</b>               | <b>77</b>   |

#### 4.5. Occurrence Categories

Seventy-seven investigation reports are evaluated and categorized according to ECCAIRS Aviation 1.3.0.12 Data Definition Standards. This section shares evaluation results and combination with UASs general and aircraft information. Due to some events with multiple factors affecting the UASs, the results are not equal to the number of investigation reports. Therefore, although there are seventy-seven investigation reports, eighty-five accidents have been determined according to data definition standards.

Analysis shows that occurrences are categorized under ten categories, which are divided according to occurrence classes in Table 4.7. Firstly, accidents mostly occurred under the SCF-NP category which means 39% of all accidents and thirty accidents. Following that, LOC-I accidents occurred twenty-three times, meaning 30% of all accidents. Respectively, from more to less, SCF-PP accidents occurred 13 times, CFIT accidents 4 times, LALT accidents 3 times, and BIRD, LOC-G, USOS, and UNK accidents each occurred once. Secondly, serious incidents occurred under 4 categories. The most serious incident occurred 3 times as LOC-I. Subsequent to that, MAC incidents occurred 2 times, and LALT and SCF-PP each occurred once. Lastly, incidents only occurred once as CFIT.

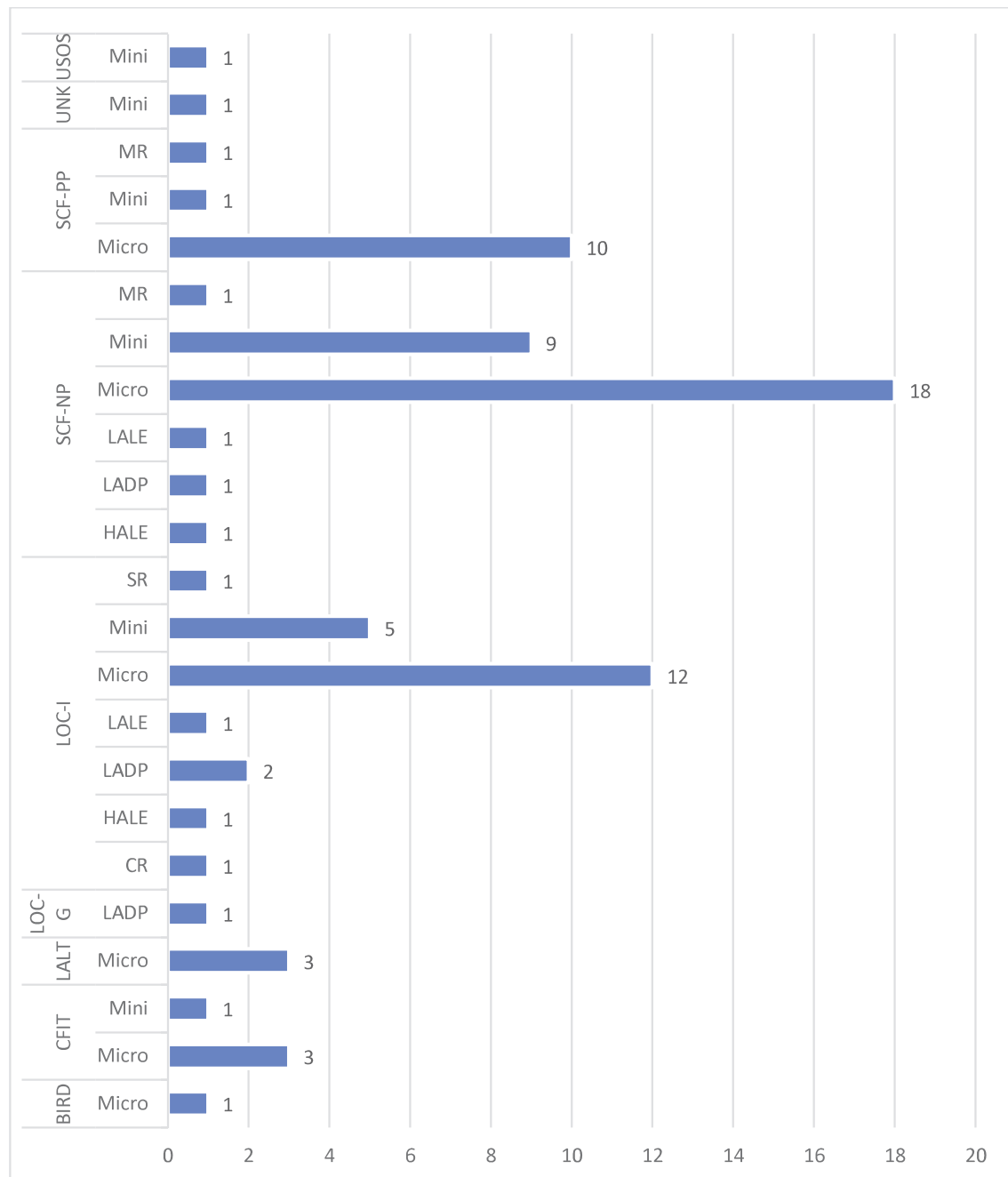
**Table 4.7.** Occurrence categories by occurrence classes

| Occurrence Category (Abbreviation)                                                   | Accident  | Serious Incident | Incident | Grand Total |
|--------------------------------------------------------------------------------------|-----------|------------------|----------|-------------|
| BIRD (BIRD)                                                                          | 1         |                  |          | 1           |
| Controlled Flight into or Toward Terrain (CFIT)                                      | 4         |                  | 1        | 5           |
| Loss of Control – Ground (LOC-G)                                                     | 1         |                  |          | 1           |
| Loss of Control – Inflight (LOC-I)                                                   | 23        | 3                |          | 26          |
| Low Altitude Operations (LALT)                                                       | 3         | 1                |          | 4           |
| Airprox/TCAS Alert/Loss of Separation/Near Midair Collisions/Midair Collisions (MAC) |           | 2                |          | 2           |
| System/Component Failure or Malfunction (Non-Powerplant) (SCF-NP)                    | 31        |                  |          | 31          |
| System/Component Failure or Malfunction (Powerplant) (SCF-PP)                        | 12        | 1                |          | 13          |
| Undershoot/Overshoot (USOS)                                                          | 1         |                  |          | 1           |
| Unknown or Undetermined (UNK)                                                        | 1         |                  |          | 1           |
| <b>Grand Total</b>                                                                   | <b>77</b> | <b>7</b>         | <b>1</b> | <b>85*</b>  |

Each one of the occurrence classes has been analyzed according to related UAS with information about UAS category, flight phase, damage level, airframe and engine types, and occurrence category.

#### 4.5.1. Accident class occurrences analysis

Accident class investigation reports have been analyzed to determine the related occurrence category. This analysis also discovers detailed information about related UASs and their combination with occurrence classes. Table 4.7. shows seventy-seven accidents by occurrence categories. Nine of the ten occurrence categories within the scope of the study involved accident class occurrences. Figure 4.7. shows the accident class occurrence categories by UAS performance metric categories.

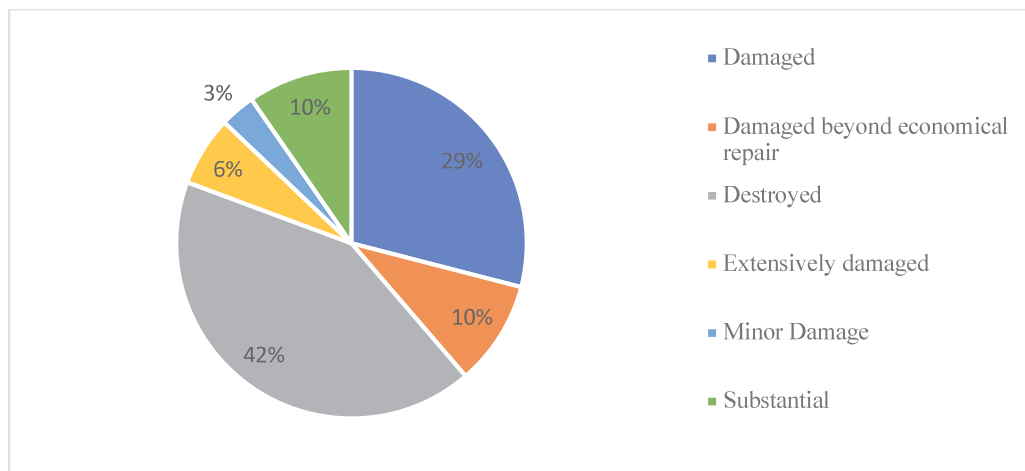


**Figure 4.7.** Accident classes occurrence categories by UAS performance metric categories

#### 4.5.1.1. System/component failure or malfunction – non-powerplant

SCF-NP accidents, the category with the highest number of accidents, are related to thirty-one UASs, and these UASs are evaluated under six performance metric categories. Eighteen of the UASs related to SCF-NP accidents are micro-category systems and this category UASs are more than all the others combined related to SCF-NP accidents. The other UAS categories related to these accidents are evaluated in nine mini-category UAS, one medium-range, one low-altitude long-endurance, one low-altitude deep penetration, and one high-altitude long-endurance category. According to the investigation reports, the main causes of these SC-NP accidents are:

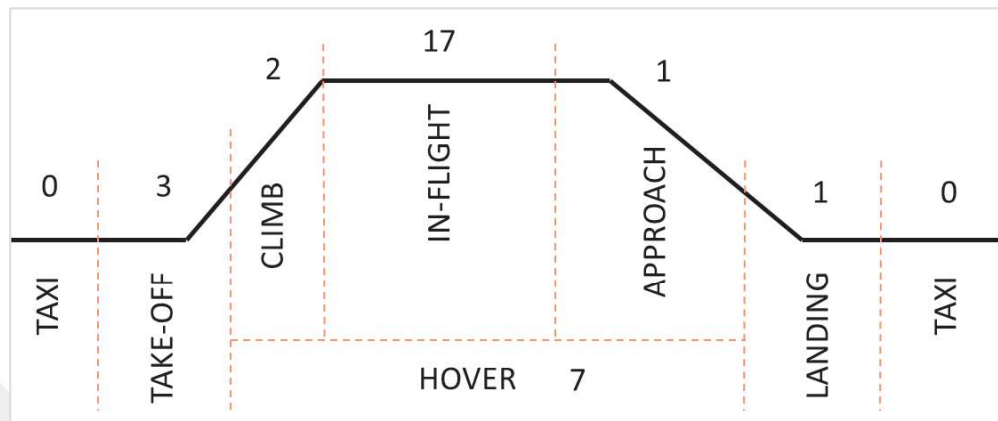
- Engine failure,
- Flight control surface failure,
- Structural abnormalities,
- Communication or datalinks system failures,
- Malfunctions with the lock mechanism on foldable systems,
- Malfunctions of recovery systems,
- Propeller blade failures,
- Miscalculation limits or exceeding limits of the system.



**Figure 4.8.** Damage level of the SCF-NP accidents on the UASs

As a result of the analysis, in Figure 4.8., only 3% of the SCF-NP accidents inflicted minor damage on the related UAS. 42% of the related UASs are destroyed and another 10% exceeds the limit of the economical repair. There are no SCF-NP accidents without any damage. The accidents that occurred during the In-flight phase account for more than half of the SCF-NP accidents. Seventeen accidents happened during the in-flight phase.

Figure 4.9. shows that besides the in-flight phase SCF-NP accidents, there are seven accidents during hover, three accidents during take-off, two accidents during the climb, and one of each phase as approach, and landing.



**Figure 4.9.** Phases in which SCF-NP accidents occur by the number

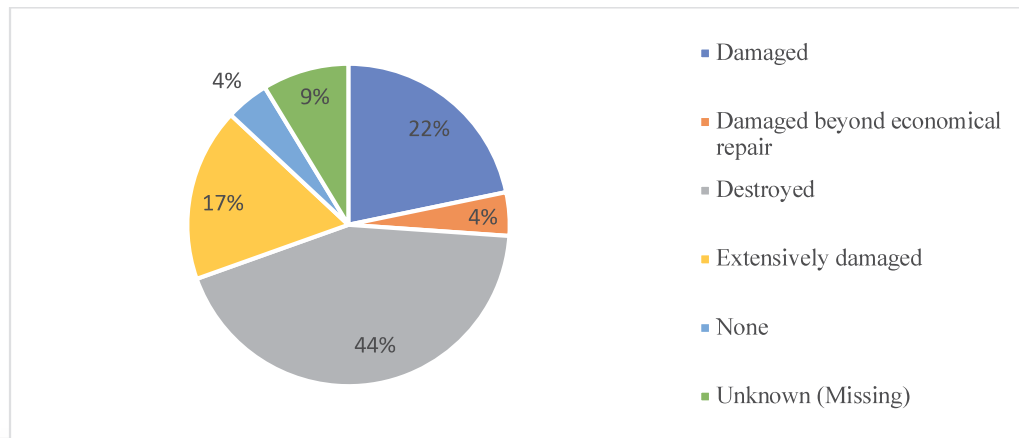
#### 4.5.1.2. Loss of control – in-flight

LOC-I category which is the category that has the second-highest accident number is related to twenty-three accidents. Seven UAS categories cover involved UASs. As in the other occurrence categories, micro UASs are the most involved in this one with twelve accidents and mini UASs follow that as second with five accidents. The other UAS categories related to these accidents are evaluated in two low-altitude deep penetration, one short range, one low-altitude long endurance, one high-altitude long endurance, and one close range category UAS. When all investigation reports are evaluated, the causes of accidents, in general, are given below:

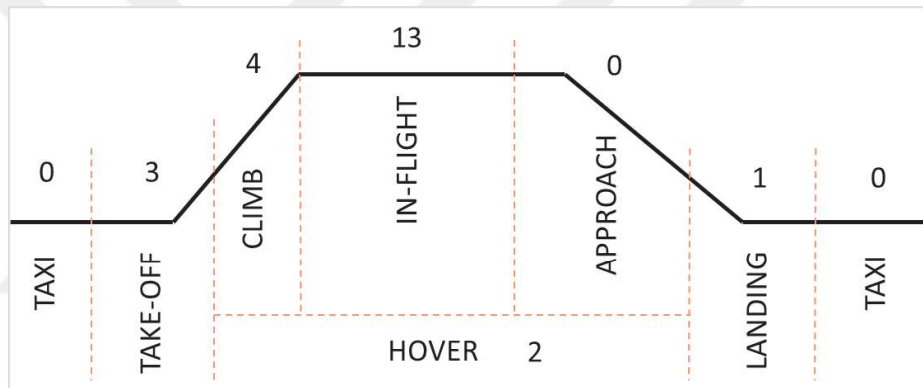
- Non-procedural operations,
- Exceeding limits,
- Miscalculating center of gravity,
- Linkloss,
- Magnetic interference or GPS-Compass error,
- Structural abnormalities,
- Collision with obstacles.

Figure 4.10 shows that 44% of the LOC-I accidents, that is 10 accidents, resulted in the destruction of the UAS, and only one accident take damage beyond economical repair. Also, one UAS take no damage and two accidents resulted in the disappearance of

the UAS. Most of these accidents occurred when aircraft fly in the in-flight phase. Figure 4.11. shows these LOC-I accidents in the take-off, climb, hover, and landing phases.



**Figure 4.10.** Damage level of the LOC-I accidents on the UASs



**Figure 4.11.** Chemical formula of paracetamol

#### 4.5.1.3. System/component failure or malfunction (powerplant)

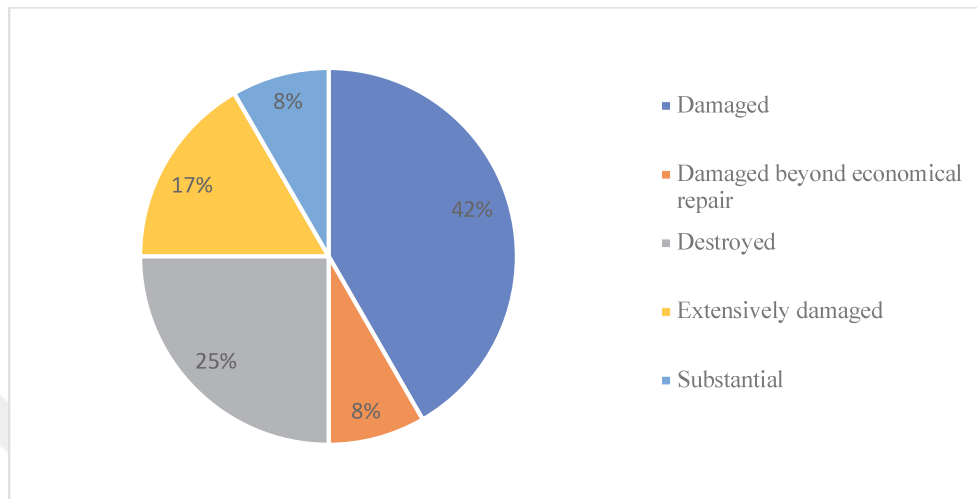
SCF-PP category is the third category according to accident number and is related to thirteen accidents. three UAS categories according to performance metrics are involved in these accidents: ten micro categories, two mini categories, and one medium-range category aircraft. The causes of the SCF-PP accidents mainly occurred:

- Battery anomaly,
- Not seated or fitted battery,
- Engine failure,
- Exceeding limits.

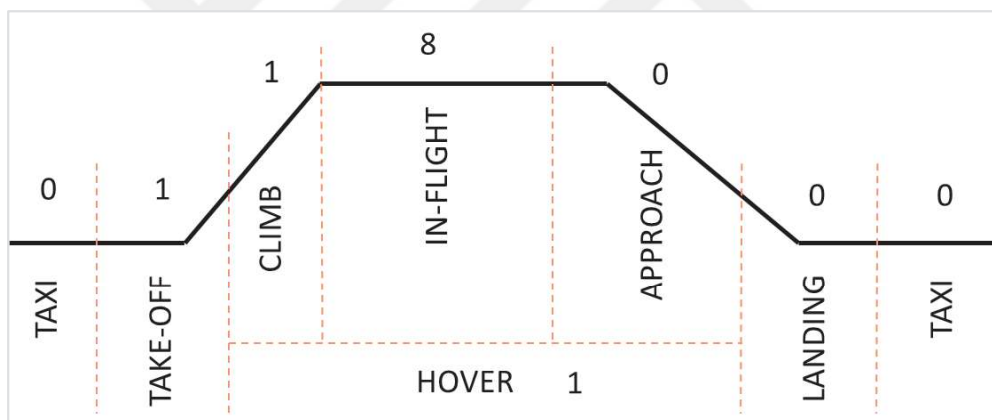
SCF-PP accidents caused three UASs destruction and one UAS to be damaged beyond economic repair. Figure 4.12. shows the distribution of other damage categories



and there is no undamaged SCF-PP accident. Eight of the accidents occurred when UAS fly in the in-flight phase, and one of the each occurred take-off phase, climb phase, and hover phase. None aircraft was able to fly until the approach or landing phases.



**Figure 4.12.** *Damage level of the SCF-PP accidents on the UASs*



**Figure 4.13.** *Phases in which SCF-PP accidents occur by the number*

#### **4.5.1.4. Controlled flight into or toward terrain**

Four accidents are related to the CFIT category. Only two different UAS categories involved this accident category. Three mini UASs and one micro UAS are evaluated as CFIT accidents. All the accidents mainly occurred due to:

- Poor flight planning,
- BLOS conditions,
- Insufficient operational procedures.

CFIT accidents caused the 3 systems to be damaged and 1 system to be extensively damaged. Also, all the accidents occurred during the in-flight phase and resulted in an impact with obstacles.

#### ***4.5.1.5. Low altitude operations***

Three accidents are related to the low-altitude operation category. These three accidents occurred with micro UASs and all of them resulted in an impact with obstacles and mainly occurred due to:

- Flight below the planned altitude,
- Inadequate or incorrect assessment of flight area.

LALT accidents caused one system to be destroyed, one system to be extensively damaged, and one system to be damaged and all the accidents occurred during the in-flight phase.

#### ***4.5.1.6. Bird***

Bird category accident occurred only one time by micro UAS due to a bird strike. It caused substantial damage to the UAS and occurred during the in-flight phase.

#### ***4.5.1.7. Loss of control – ground***

LOC-G accident occurred only one time by LADP category UAS during the taxi phase. It caused minor damage to the UAS and occurred due to a change in the automation mode of the aircraft and loss of control on the throttle level.

#### ***4.5.1.8. Undershoot/overshoot***

USOS accident occurred by mini category UAS during landing only one time. It caused damage beyond economic repair and occurred due to insufficient autopilot limits.

#### ***4.5.1.9. Unknown or undetermined***

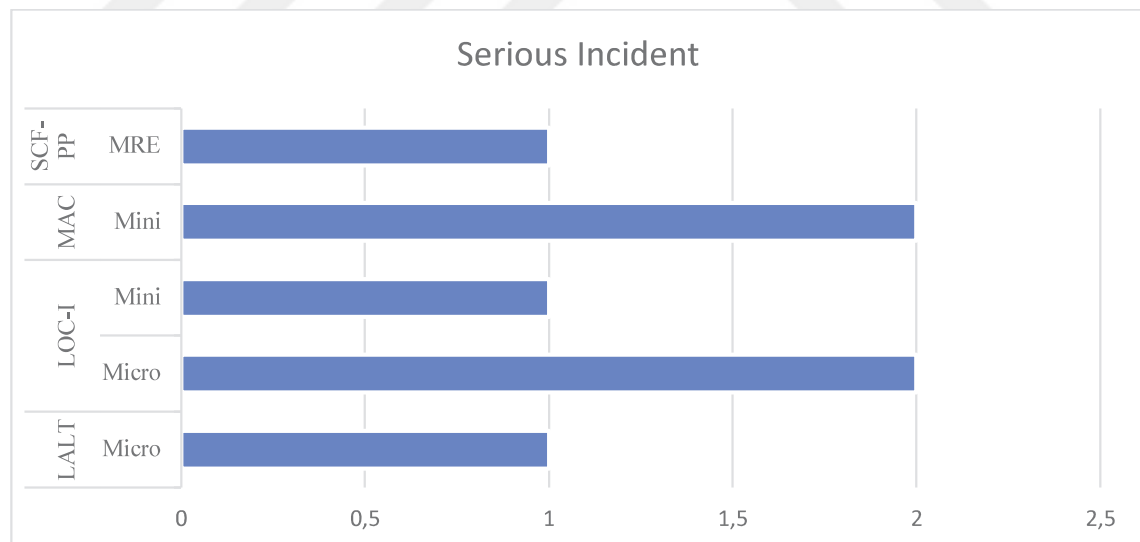
A mini UAS category involved accident could not be evaluated in any accident category other than Unknown. The accident caused damage to the aircraft and occurred during the approach phase but the findings and evidence about the accident were found to be insufficient, therefore, the cause of the accident cannot be confirmed.

#### 4.5.2. Serious incident class occurrences analysis

Serious incident class investigation reports have been analyzed to determine the related occurrence category. Table 4.7. shows that seven serious incident reports are evaluated under four occurrence categories. These occurrence categories are analyzed according to performance metric categories of the relevant UASs in Figure 4.14. These serious incidents caused two of the UAS to be destroyed and one of the UAS to be minor damage. The other four UAS are not damaged after the occurrence. Besides, that five serious incidents occurred during the in-flight phase and the other two occurred during the hover phase.

##### 4.5.2.1. Loss of control – inflight

LOC-I serious incidents, the most serious incidents that occurred category, are related to three occurrences. Two micro UASs and one mini UAS have been involved in these incidents. LOC-I serious incidents caused one of the UAS to be destroyed, one of the UAS to be extensively damaged, and the last one to be damaged. Also, these serious incidents occurred during the in-flight phase two times, and one time during the hover phase.



**Figure 4.14.** Serious incident classes occurrence categories by UAS performance metric categories

##### 4.5.2.2. Airprox/TCAS alert/loss of separation/near midair collisions/midair collisions

MAC serious incidents occurred two times according to investigation reports and involved two mini UASs. One of the UAS is destroyed and the other survived the serious incident with minor damage. All MAC serious incidents occurred during in-flight phases.

#### ***4.5.2.3. Low altitude operations***

LALT serious incidents occurred only one time by micro UAS during the hover phase. This serious incident caused no damage to the system.

#### ***4.5.2.4. System/component failure or malfunction (powerplant)***

SCF-PP serious incidents occurred only one time by medium-range endurance UAS during the in-flight phase. This serious incident caused no damage to the system.

#### **4.5.3. Incident class occurrences analysis**

As a result of the analysis, only one incident class investigation report has been founded. One micro category UAS involved CFIT occurrence during the in-flight phase. This incident caused damage to the system.

## **5. CONCLUSION, DISCUSSIONS AND RECOMMENDATION**

### **5.1. Conclusion**

The areas of use of UASs are expanding and becoming more widespread, as a result of which there is an increase in occurrences from year to year. As in every part of aviation, the safety management system is one of the most important factors in unmanned aviation. This situation should not be ignored in the development of UASs. With the establishment of the reporting culture and system on solid foundations, the identification of hazards and risks is important for the development and future of the system. As a result of the examinations, 2 authorities with accessible reports were found. The reports published by these authorities were examined according to the qualitative research method and classified according to their general information, system information, and occurrence information. Under these classes, the main causes of occurrences are determined.

As a result of the analysis, a total of 77 occurrence reports were examined and a total of 85 related occurrence categories were identified. Of these occurrence reports, 48% were submitted by the pilot, and the rest were submitted as a result of the investigation. It has been determined that the majority of the occurrences were experienced in the in-flight phase and hover phase. At the same time, when looking at the highest number of flight types, 25 occurrences were experienced during aerial work, 24 occurrences during commercial operations, and 16 occurrences during emergency services operations. The majority of these incidents have occurred in multirotor and electric-powered UASs. When classified according to performance parameters, 18 occurrences were Micro-UA systems, and 17 occurrences were Mini-UA systems. As a result, 26 systems were destroyed. When the events were categorized, 31 SCF-NP, 26 LOC-I, and 13 SCF-PP category occurrences were experienced as the first three.

SCF-NP occurrences are generally caused by engine failure, flight control surface failure, structural abnormalities, communication or datalinks system failures, malfunctions with the lock mechanism on foldable systems, malfunctions of recovery systems, propeller blade failures, miscalculation limits or exceeding limits of the system detected. While the majority of these occurrences were experienced in the in-flight and hover phases, 42% of the systems were destroyed afterward. LOC-I events are generally caused by non-procedural operations, Exceeding limits, miscalculating center of gravity,

linkloss, Magnetic interference or GPS-Compass error, Structural abnormalities, and collision with obstacles. While these occurrences were experienced mostly in the in-flight phase, they also occurred in the climb and take-off phases and destroyed 44% of the systems. SCF-PP occurrences were experienced due to battery anomaly, not seated or fitted battery, engine failure, exceeding limits, and destroyed 25% of the systems. It caused less damage than the first two occurrence categories, and similarly, it was usually experienced in the in-flight phase. Other category occurrences were less frequently experienced or reported.

All of the evaluations were made in line with the objectives. These evaluations:

- A total of 77 occurrence reports were examined.
- Among the ICAO-approved authorities, UAS reports could be accessed in only AAIB (UK) and ATSB (Australia) data banks.
- The highest rate among these is the accident class with 69 reports.
- The highest rate of 37 of the reviewed reports was reported by the pilots.
- On a yearly basis, occurrences were reported at most in 2019, at least in 2015 and 2016. Since the study was conducted in 2022, all reports during the year are not included in this study. For this reason, only 1 report is seen during the year.
- Occurrences were reported in 7 regions with a maximum of 3 reports.
- As unmanned aerial vehicles perform VFR flights, occurrences usually took place between 08:00 and 17:30.
- The highest number of occurrences experienced between 14:00 and 15:00 during the day.
- No occurrence was reported between 05:00 and 08:00 in the morning.
- Among the reports examined, the occurrence experienced during the most aerial work, with 25 reports.
- With 1 report each, occurrences were experienced at least in test fly and demonstration flight.
- The highest number of occurrences was experienced in the In-flight phase with 47 occurrences, and the least in the taxi phase with 1 occurrence.
- The DJI company, which has the largest market share, has also been involved in the most occurrences.

- According to the UAS classification, micro and mini UASs experienced the most occurrences.
- Multirotor UASs experienced the most occurrences according to airframe types, and UASs with the most electric motors according to engine types.
- 26 UASs were destroyed with the highest rate among the UASs involved in the occurrences.
- According to the occurrence category, the highest number of SCF-NP-related accidents occurred.
- Serious incidents occurred in the LOC-I category the most.
- The incident report, which is the only one among the reports, is in the CFIT category.
- In the accidents in the SCF-NP category, the micro category has the highest number of accidents among the UAS categories.
- UASs included in the SCF-NP category with a rate of 42% were destroyed. Most of the accidents occurred during the in-flight phase.
- UASs included in the LOC-I category with a rate of 44% were destroyed. Most of the accidents occurred during the in-flight phase.
- UASs included in the SCF-PP category with a rate of 42% were damaged. Most of the accidents occurred during the in-flight phase.
- In the CFIT category, 3 systems were damaged with the highest rate. At the same time, all accidents occurred during the in-flight phase.
- All LALT category accidents occurred during the in-flight phase, with one destroyed, one extensively damaged, and one damaged.
- In the BIRD category, the accident occurred once in the in-flight category and received substantial damage.
- In the LOC-G category, the accident occurred once in the taxi phase. The aircraft received minor damage in the accident that occurred due to an automation failure.
- The USOS category accident occurred during the landing phase. It was damaged beyond economical repair.
- An accident that occurred during the approach phase was evaluated in the UNK category because there was no finding or evidence.



- In the LOC-I serious incidents, there were 3 incidents, one destroyed, one extensively damaged, and the other damaged. Most incidents occurred in the in-flight phase.
- The MAC serious event occurred twice during the in-flight phase. One of the systems was destroyed, while the other received minor damage.
- The LALT serious incident occurred once during the hover phase and the system was undamaged.
- The SCF-PP serious incident occurred once during the in-flight phase and the system was undamaged.
- Only one incident report occurred during the in-flight phase, in the CFIT category. Damage has occurred to the system.

As a result, it has been seen that UASs should continue to be evaluated with safety management systems and more resources and data should be created for future studies. At the same time, it was aimed to lay the foundations of the classification standards for future studies, and a source was created for further studies.

## **5.2. Discussions**

According to the findings obtained in this study, it has been determined that the number of reports regarding Micro and Mini UASs is higher than that of other-category UASs. This is thought to be due to the ease of use and access of Mini and Micro UASs.

During the data collection process for the thesis, it was determined that only 2 ICAO-approved authorities regulated the reporting of UASs and published them with open access to everyone. The spread of this situation, the sharing, and publication of incidents and accidents with cause-effect relationships will increase the development of unmanned aviation and will ensure that risk and danger analyses are made proactively.

In addition, the flight phase data of the occurrences obtained are in contrast with manned aviation. A report by Airbus revealed that more than 55% of the occurrences between 2001 and 2020 were experienced during the landing phase. This is followed by the take-off and approach phases, respectively (AIRBUS, 2021). In the UAS data obtained as a result of this thesis, it was observed that approximately 61% of the occurrences were experienced during the in-flight phase. In Airbus data, this is about 8%. In the 1950s, when aviation first became widespread, it is seen that the occurrences

experienced in the in-flight phase were more than in the other phases with a similar situation (Our World in Data, 2023). A similar process may occur in the coming years with the development of UASs.

When the occurrence categories are examined in general, it is seen that the number of malfunction or failure-related occurrences on the system is higher. This is one of the main signs that unmanned aviation is still a developing system and has not reached its absolute form. In another study conducted on safety in UASs, when the causes of accidents and incidents are based on the number of occurrences, the first three reasons were determined as LOC, SCF-NP, and SCF-PP incidents according to ICAO categories. These three categories account for 66% of the total incidents and accidents (Ghasri & Maghrebi, 2021). According to the findings of this thesis, the first three categories of accidents and incidents based on the number of occurrences are the same, and they constitute 82% of the total number of incidents and accidents. Similarities were found between the findings of the two studies.

When the air traffic in the world is evaluated, according to ICAO data, there were 24.92 million flights in commercial flights in 2021, and due to pandemic conditions, this traffic number has decreased by 49% compared to the pre-pandemic conditions (ICAO, 2022). There is no data for UASs from this safety report. Looking at the AAIB data for commercial aviation, 310 reports were published between 2015 and 2022, and 67 reports were published for UASs in the same time period (AAIB, 2023). According to other data shared by CAA, while there were 114,732 registered operators on March 31, 2020, this number increased to 183,925 until March 31, 2022 (CAA, 2022). In 2030, it is predicted that 76,000 UAS will be used in the UK airspace, 36% of which will be for public services (Leslie, 2023). In this way, it can be predicted that the increase in the UAS sector will be not only in the UK but also all over the world. With this increase, the spread of the reporting culture around the world, the sharing of the results of the reports obtained, and the mention of unmanned aviation while sharing aviation data will facilitate standardization and create similarity between systems. Considering these, there is a lack of reporting the UASs related occurrences, classifying them, and interpreting them from the SMS point of view. Therefore, more academic studies should be done on this subject.

### **5.3. Recommendations**

In line with the findings obtained, safety gaps in UASs should be identified and improved. For these gaps, studies should be carried out according to the occurrence categories, and hazards and risks should be determined and mitigated.

Safety promotion studies should be conducted with the identified occurrence categories and their causes, and pilots and air traffic controllers should be familiar with what they might encounter.

In future studies, the ideal report format that can be created for increasing the reporting culture, protecting and using the data should be investigated.



## REFERENCES

- AAIB. (2023). *Air Accidents Investigation Branch reports*. Retrived June 28, 2023, from GOV.UK: <https://www.gov.uk/aaib-reports?>
- AIRBUS. (2021). *A Statistical Analysis of Commercial Aviation Accidents 1958-2020*. Blagnac Cedex: AIRBUS S.A.S.
- Alexpl. (2020). Bayraktar TB2 draw. Wikimedia. <https://commons.wikimedia.org/wiki/File:Bayraktar-TB2-draw.svg>
- Altawy, R., & Youssef, A. M. (2016). Security, Privacy, and Safety Aspects of Civilian Drones: A Survey. *ACM Transactions on Cyber-Physical Systems*, 1(2), 1-25.
- ATSB. (2022). *Loss of control and collision with terrain involving DJI Inspire 2 remotely piloted aircraft*. Australian Transport Safety Bureau. [https://www.atsb.gov.au/publications/investigation\\_reports/2021/aaib/ao-2021-001](https://www.atsb.gov.au/publications/investigation_reports/2021/aaib/ao-2021-001)
- Ayers, S. M., & Crawley, D. (2018). Safety assurance: Making safety data work for you. *Journal of Airport Management*, 12(3), 257-271.
- Barnhart, R. K., Marshall, D. M., & Shappe, E. (2021). *Introduction to Unmanned Aircraft Systems*. Oxon: CRC Press.
- Blyenburgh, P. v. (2021, June 14). *RPAS The Global Perspective Volume 1*. Remotely Piloted Systems The International Information & Reference Source: [https://rps-info.com/publications/rpas-the-global-perspective\\_volume-1\\_2021\\_flipbook/](https://rps-info.com/publications/rpas-the-global-perspective_volume-1_2021_flipbook/)
- Blyenburgh, P. v. (2022). *The Professional Drone Operations Market*. Paris: Blyenburgh & Co.
- Brungardt, J., & Carraway, K. (2021). The "System" in UAS. R. K. Barnhart, D. M. Marshall, & E. Shappee içinde, *Introduction to Unmanned Aircraft Systems* (s. 57-70). Oxon: CRC Press.
- CAA. (2022, June 9). *Request on the number of drones registered annually 2017-2022*. Retrived June 28, 2023, from WhatDoTheyKnow: [https://www.whatdotheyknow.com/request/request\\_on\\_the\\_number\\_of\\_drones#incoming-2056871](https://www.whatdotheyknow.com/request/request_on_the_number_of_drones#incoming-2056871)
- Carr, E. B. (2013). *Unmanned Aerial Vehicles: Examining the Safety, Security, Privacy and Regulatory Issues of Integration into U.S. Airspace*. National Centre for Policy Analysis (NCPA).
- CASA. (2022). *SMS 9: Safety management systems for RPAS* (1st b.). Civil Aviation Safety Authority.
- Chatzi, A. V. (2018). Safety Management Systems: An opportunity and a challenge for millitary aviation organizasitons. *Aircraft Engineering and Aerospace Technology*, 91(1), 190-196.

- Chen, W., & Li, J. (2016). Safety performance monitoring and measurement of civil aviation unit. *Journal of Air Transport Management*, 57, 228-233.
- Clothier, R., & Walker, R. (2006). Determination and evaluation of UAV safety objectives. *Proceedings of the 21st International Conference on Unmanned Air Vehicle Systems* (s. 3-13). United Kingdom: University of Bristol.
- Clothier, R., Williams, B., Fulton, N., & Lin, X. (2013). ALARP and the risk management of civil unmanned aircraft systems. *Proceedings of 2013 Australian System Safety Conference* (s. 3-13). Adelaide, Australia: Australian Computer Society.
- Cromwell, C., Giampaolo, J., Hupy, J., Miller, Z., & Chandrasekaran, A. (2021). A Systematic Review of Best Practices for UAS Data Collection in Forestry-Related Applications. *Forests*, 12(7), 957.
- Dalamagkidis, K. (2015). Classification of UAVs. K. P. Valavanis, & G. J. Vachtsevanos içinde, *Handbook of Unmanned Aerial Vehicles* (s. 83-91). Dordrecht: Springer Science+Business Media.
- Dalamagkidis, K. (2015). Definitions and Terminology. K. P. Valavanis, & G. J. Vachtsevanos içinde, *Handbook of Unmanned Aerial Vehicles* (s. 43-55). Dordrecht: Springer Science+Business Media.
- Dalziell, E., & Nicholson, A. (2001). Risk and Impact of Natural Hazards on a Road Network. *Journal of Transportation Engineering*, 91(1), 159-166.
- DARPA. (2017, 2 6). *SideArm Prototype Catches Full-Size Unmanned Aerial System Flying at Full Speed*. Defense Advanced Research Projects Agency: <https://www.darpa.mil/news-events/2017-02-06>
- Dekker, S. (2012). *Just culture: Balancing Safety and Accountability*. Ashgate Publishing Company.
- EASA. (2021). *Drone Incident Management at Aerodromes Part 1: The challenge of unauthorised drones in the surroundings of aerodromes*. Cologne: European Union Aviation Safety Agency.
- EASA. (2022). *Drones - regulatory framework*. European Union Aviation Safety Agency: <https://www.easa.europa.eu/domains/civil-drones/drones-regulatory-framework-background>
- EASA. (2022). *Open Category - Civil Drones*. European Union Aviation Safety Agency: <https://www.easa.europa.eu/domains/civil-drones/drones-regulatory-framework-background/open-category-civil-drones>
- EASA. (2023, June 8). *Civil drones (unmanned aircraft)*. European Union Aviation Safety Agency: <https://www.easa.europa.eu/en/domains/civil-drones>
- FAA. (2009). *Risk Management Handbook (FAA-H-8083-2)*. U.S. Department of Transportation Federal Aviation Administration.

- Fahlstrom, P. G., & Gleason, T. J. (2012). *Introduction to UAV Systems, Fourth Edition*. West Sussex: A John Wiley & Sons, Ltd., Publication.
- Ferrell, U. D., & Anderegg, A. H. (2020). Applicability of UL 4600 to Unmanned Aircraft Systems (UAS) and Urban Air Mobility. *2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC)* (s. 1-7). San Antonio: IEEE.
- Garg, P. K. (2021). *Unmanned Aerial Vehicles: An Introduction*. Dullas: Mercury Learning and Information.
- Gérard, M. (2022). Remote Pilot Training, Qualification & Examination. P. v. Blyenburg içinde, *The Professional Drone Operations Market* (s. 26-27). Paris: France.
- Ghasri, M., & Maghrebi, M. (2021). Factors affecting unmanned aerial vehicles' safety: A post-occurrence exploratory data analysis of drones' accidents and incidents in Australia. *Safety Science*, 139.
- Guerin, J., Delmas, K., & Guiochet, J. (2021). Certifying Emergency Landing for Safe Urban UAV. *2021 51st Annual IEEE/IFIP International Conference on Dependable Systems and Networks Workshops (DSN-W)*. Taipei, Taiwan: IEEE. doi:10.1109/DSN-W52860.2021.00020
- Hsu, Y.-L., Li, W.-C., & Chen, K.-W. (2010). Structuring critical success factors of airline safety management system using a hybrid model. *Transportation Research Part E: Logistics and Transportation Review*, 46(2), 222-235.
- ICAO. (2011). *Cir 328, Unmanned Aircraft Systems (UAS)*. Montréal: International Civil Aviation Organization.
- ICAO. (2013, April 29). *ECCAIRS Aviation 1.3.0.12 Damage Aircraft*. Retrived January 3, 2023, from ICAO ADREP Taxonomy: [https://www.icao.int/safety/airnavigation/AIG/Documents/ADREP%20Taxonomy/ECCAIRS%20Aviation%201.3.0.12%20\(V4%20CD%20Damage%20aircraft\).pdf](https://www.icao.int/safety/airnavigation/AIG/Documents/ADREP%20Taxonomy/ECCAIRS%20Aviation%201.3.0.12%20(V4%20CD%20Damage%20aircraft).pdf)
- ICAO. (2013, April 29). *ECCAIRS Aviation 1.3.0.12 Occurrence Category*. Retrived January 5, 2023, from ICAO ADREP Taxonomy: [https://www.icao.int/safety/airnavigation/AIG/Documents/ADREP%20Taxonomy/ECCAIRS%20Aviation%201.3.0.12%20\(VL%20for%20AttrID%20%20430%20-%20Occurrence%20category\).pdf](https://www.icao.int/safety/airnavigation/AIG/Documents/ADREP%20Taxonomy/ECCAIRS%20Aviation%201.3.0.12%20(VL%20for%20AttrID%20%20430%20-%20Occurrence%20category).pdf)
- ICAO. (2013, April 29). *ECCAIRS Aviation 1.3.0.12 Occurrence Classes*. Retrived January 4, 2023, from ICAO Adrep Taxonomy: [https://www.icao.int/safety/airnavigation/AIG/Documents/ADREP%20Taxonomy/ECCAIRS%20Aviation%201.3.0.12%20\(VL%20for%20AttrID%20%20431%20-%20Occurrence%20Classes\).pdf](https://www.icao.int/safety/airnavigation/AIG/Documents/ADREP%20Taxonomy/ECCAIRS%20Aviation%201.3.0.12%20(VL%20for%20AttrID%20%20431%20-%20Occurrence%20Classes).pdf)
- ICAO. (2013, April 29). *Event Phases*. Retrived December 31, 2022, from ADREP Taxonomy: <https://www.icao.int/safety/airnavigation/AIG/Documents/ADREP%20Taxonomy>



my/ECCAIRS%20Aviation%201.3.0.12%20(VL%20for%20AttrID%20%20391%20-%20Event%20Phases).pdf

- ICAO. (2018). *Safety Management Manual, 4. Edition*. Montréal: International Civil Aviation Organization.
- ICAO. (2020). *Annex 13 Aircraft Accident and Incident Investigation* (20 b.). Montreal: International Civil Aviation Organization.
- ICAO. (2022, November 26). *Accident Investigation Authorities Addresses*. ICAO: <https://www.icao.int/safety/aia/Pages/default.aspx#InplviewHash6263f282-925e-4cb8-b829-bf66db2a176f=FolderCTID%3D0x012001>
- ICAO. (2022). *Safety Report*. Montréal: International Civil Aviation Organization.
- ICAO. (2023). *Development of UAS Regulation*. Retrived June 17, 2023 from International Civil Aviation Organization: <https://www.icao.int/safety/UA/UAStoolkit/Pages/Narrative-Regulation.aspx>
- Janic, M. (2000). An assessment of risk and safety in civil aviation. *Journal of Air Transport Management*, 6(1), 43-50.
- JAPCC. (2010). *JAPCC Strategic Concept of Employment for UAS in NATO*. Kalkar: The Executive Director of the Joint Air Power Competence Centre.
- Jeelani, I., & Gheisari, M. (2021). Safety challenges of UAV integration in construction: Conceptual analysis and future research roadmap. *Safety Science*, 144.
- Jensen, W. (2021). Human Factors in Unmanned Aerial Systems. R. K. Barnhart, D. M. Marshall, & E. Shappee içinde, *Introduction to Unmanned Aircraft Systems* (3rd b., s. 137-152). Oxon: CRC Press.
- Kaliardos, B., & Lyall, B. (2015). Human Factors of Unmanned Aircraft System Integration in the National Airspace System. K. P. Valavanis, & G. J. Vachtsevanos içinde, *Handbook of Unmanned Aerial Vehicles* (s. 2135-2158). Dordrecht: Springer Science+Business Media.
- Konert, A., & Kasprzyk, P. (2021). UAS Safety Operation – Legal Issues on Reporting UAS Incidents. *Journal of Intelligent & Robotic Systems*, 103(3).
- Kontogiannis, T., Leva, M. C., & Balfe, N. (2017). Total Safety Management: Principles, processes and methods. *Safety Science*, 100, 128-142.
- Krivosos, P. D. (2007). Communication in Aviation Safety: Lessons learned and lessons required. *Regional Seminar of the Australia New Zealand Societies of Air Safety Investigators*, 4, s. 1-35.
- Law Insider. (2023, January 3). *Extensively damaged definition*. Law Insider: <https://www.lawinsider.com/dictionary/extensively-damaged>



- Leslie, J. (2023, April 4). *Drone Statistics UK: A Comprehensive Analysis*. Retrived June 28, 2023, from Drone Surveys: <https://dronesurveyservices.com/drone-statistics-uk/#:~:text=Recreational%20Drone%20Usage%3A%20Over%20500%2C000,as%20technology%20becomes%20more%20affordable>.
- Maurino, D. E., Reason, J., Jonston, N., & Lee, R. B. (2017). *Beyond Aviation Human Factors: Safety in High Technology Systems*. Routledge.
- Mazur, D. G. (2002). The X-47A Pegasus: From Design to Flight. *1st UAV Conference* (s. 3426). Portsmouth, Virginia: AIAA.
- Melnyk, R. (2021). A Program for Managing Unmanned Aircraft Systems in Engineering Education. *2021 ASEE Virtual Annual Conference Content Access*. Virtual Conference. doi:10.18260/1-2--36602
- Mendes de Leon, P., & Scott, B. I. (2016). An Analysis of Unmanned Aircraft Systems Under Air Law. A. Završnik (Dü.) , *Drones and Unmanned Aerial Systems* (s. 185-213). Ljubljana: Springer.
- Mendonca, F. A., & Carney, T. Q. (2017). A safety management model for FAR 141 approved flight schools. *Journal of Aviation Technology and Engineering*, 6(2), 3.
- Müller, R., & Drax, C. (2014). Essential Basics and Limitations of Safety and Risk Management. *Aviation Risk and Safety Management*, 7-17.
- NAI2O. (2022, June). *UAS Categories*. Retrived May 3, 2023 from National Aviation Intelligence Integration Office: <https://www.airdomainintelligence.mil/Global-Air-Hub/Unmanned-Aircraft-System-UAS/UAS-Categories/>
- Namian, M., Khalid, M., Wang, G., & Turkan, Y. (2021). Revealing safety risks of unmanned aerial vehicles in construction. *Transportation research record*, 2675(11), 334-347.
- Namuduri, K., Chaumette, S., Kim, J. H., & Sterbenz, J. P. (2018). *UAV Networks and Communications*. Cambridge: Cambridge University Press.
- Our World in Data. (2023). *Global aviation accidents by flight phase*. Retrived June 20, 2023, from Our World in Data: <https://ourworldindata.org/grapher/aviation-accidents-by-flight-phase?facet=metric>
- Piers, M., Montijn, C., & Balk, A. (2009). Safety culture framework for the ECAST SMS-WG. *European Commercial Aviation Safety Team (ECAST)*, 1-14.
- Roelen, A., & Klompstra, M. (2012). The challenges in defining aviation safety performance indicators. In *11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference* (s. 25-29). Helsinki: Curran Associates.
- Sadraey, M. H. (2020). *Design of Unmanned Aerial System*. West Sussex: John Wiley & Sons.

- Santos-Reyes, J., & Beard, A. N. (2002). Assessing safety management systems. *Journal of Loss Prevention in the Process Industries*, 15(2), 77-95.
- SHGM. (2020). *İNSANSIZ HAVA ARACI SİSTEMLERİ TALİMATI (SHT-İHA)* (4th b.). Ankara: Sivil Havacılık Genel Müdürlüğü. [https://web.shgm.gov.tr/documents/sivilhavacilik/files/mevzuat/sektorel/talimatlar/2020/SHT-IHA\\_Rev-04.pdf](https://web.shgm.gov.tr/documents/sivilhavacilik/files/mevzuat/sektorel/talimatlar/2020/SHT-IHA_Rev-04.pdf)
- Skitmore, A. (2021). Launch and Recovery System for Improved Fixed-Wing UAV Deployments in Complex Environments. R. D. Green, B. J. Gregory, & A. R. Karachok içinde, *Unmanned Aerial Remote Sensing UAS for Environmental Applications* (s. 303-316). Oxon: CRC Press.
- Small Unmanned Aircraft Systems. (2022). 14 C.F.R. § 107.
- Stefana, E., Ustolin, F., & Paltrinieri, N. (2022). IMPROSafety: A risk-based framework to integrate occupational and process safety. *Journal of Loss Prevention in the Process Industries*, 75.
- Stolzer, A. J., Halford, C. D., & Goglia, J. J. (Dü). (2011). *Implementing safety management systems in aviation*. London: Routledge.
- Strong, R. L. (2020). Safety Performance Management. M. A. Friend, A. J. Stolzer, & M. D. Aguiar içinde, *Safety Management Systems: Applications for the Aviation Industry* (s. 83-94). London: The Rowman & Littlefield Publishing Group.
- Sukamolson, S. (2007). Fundamentals of quantitative research. *Language Institute Chulalongkorn University*, 1(3), 1-20.
- Szabo, S., & Koblen, I. (2020). Safety Performance Indicators as Important Part of Safety Management System Implementation in Production Organizations of the Aviation Industry. *2020 New Trends in Aviation Development (NTAD)* (s. 229-235). Starý Smokovec, Slovakia: IEEE.
- Torretta, V., Rada, E. C., Schiavon, M., & Viotti, P. (2017). Decision Support Systems for Assessing Risks Involved in Transporting Hazardous Materials: A review. *Safety Science*, 92, 1-9.
- TxDOT Flight Services. (2018). *Unmanned Aircraft System (UAS) Flight Operations and User's Manual*. Austin: Texas Department of Transportation.
- Valvanis, K. P., & Vachtsevanos, G. J. (2015). *Handbook of Unmanned Aerial Vehicles*. Dordrecht: Springer Science+Business Media.
- Wackwitz, K., & Boedecker, H. (2015). *Safety Risk Assessment for UAV Operation*. Hamburg: Drone Industry Insights.
- Weibel, R. E., & Hansman, R. J. (2005). *Safety Considerations for Operation of Unmanned Aerial Vehicles in the National Airspace System*. Cambridge: Massachusetts Institute of Technology.

- Williams, C. (2007). Research Methods. *Journal of Business & Economic Research*, 5(3).
- Williams, K. W. (2006). *Human Factors Implications of Unmanned Aircraft Accidents: Flight-Control Problems*. Washington: Office of Aerospace Medicine.
- Wincek, J., Sousa, L. S., Myers, M. R., & Ozog, H. (2015). Organizational Change Management for Process Safety. *Process Safety Progress*, 34(1), 89-93.
- Winston-Salem State University. (tarih yok). *Key Elements of a Research Proposal - Quantitative Design*. Retrived March 20, 2023, from Winston-Salem State University: [https://www.wssu.edu/about/offices-and-departments/office-of-sponsored-programs/pre-award/\\_Files/documents/develop-quantitative.pdf](https://www.wssu.edu/about/offices-and-departments/office-of-sponsored-programs/pre-award/_Files/documents/develop-quantitative.pdf)
- Wright, J. F. (2018). Risk Management: a behavioural perspective. *Journal of Risk Research*, 21(6), 710-724.
- Yang, H.-H., Chang, Y.-H., & Lin, C.-H. (2022). A combined approach for selecting drone management strategies based on the ICAO Safety Management System (SMS) components. *Journal of Air Transport Management*, 104.
- Zariouh, A., Haddout, A., & Benhadou, M. (2022). A critical review of African aviation safety management system GAP analysis. *Journal of Operations Management, Optimization, and Decision Support*, 2(2), 1-5.

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