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An Overview to Unmanned Aerial Vehicles from Perspectives of Quality and Safety Management in Aviation

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Abstract

Aviation is one of the pioneer industries of technology and military aviation has been a big contributor to the technological developments in the industry. The Unmanned Aerial Vehicles (UAVs) have been in the military domain for years; however, their civil applications are fairly new and rapidly expanding. Due to their capabilities and ease of handling, they have been utilized in various operations such as monitoring, surveillance, remote sensing and delivery. Although their engines and avionics have been improved, there have been still major challenges with UAVs in terms of reliability, safety and maintenance. Quality and safety management concepts are inevitable for civil aviation industry and liable to many regulations and standards. These concepts are not yet fully established for UAVs and the regulations and standards are still in progress. The objective of this study is to provide an overview to UAVs from perspectives of quality and safety management in aviation. Additionally, new trends, developments and research areas are discussed as well.

Key Words

"Unmanned aerial vehicle (UAV), Drone, Quality management, Safety management"

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1. Introduction

Quality and safety management of services are more difficult compared to manufacturing because a product or a good is more tangible than a service and circumstances or preferences influence the perception of that service. Additionally, too much is at stake in service operations in terms of customer lives if safety risks present. Due to the increasing demand for air travel, the terms quality and safety have more emphasis in the aviation domain more than ever. In order to satisfy this demand, airline organizations aim to have competitive advantage by focusing on providing high quality and safety with affordable prices.

The aviation industry has an especially critical role for providing fast connections for people by linking the distant parts of the world. Usually, this is a very desired and advantageous quality. However, in some rare occasions, this high-paced and intensely technological service may end up in disastrous situations very quickly. Thus, preventive actions are taken continuously to avoid these unwanted scenarios. The modern aviation organizations today are well-informed about terms such as risk management, hazard identification, and quality engineering and management. These terms create a framework for the organizations to focus on required areas to maintain a safe and reliable working environment. Beside these terms, aviation industry is subject to various regulations and legislations developed by both international and national organizations such as Federal Aviation Administration (FAA) (FAA - AC 120-92B, 2006), European Union Aviation Safety Agency (EASA) (EASA - EU OPS 1.037, 2008) and ICAO (ICAO - Annexes 1 to 18, 2012). These regulations create a base for quality and safety standards for all aviation organizations and their ground and flight operations.

Very recently, the world has been facing such a situation where the airspaces became the main focus of the 2019-2020 global pandemic of COVID-19 outbreak and because people weren't prepared for it, international agents had to act fast and come up with special regulations concerning aviation safety. Especially during the first months of the global disaster, the whole world population was challenged with unprecedented global safety risk against their health or even their lives which mostly spread through all continents via commercial flights and airports. Although the aviation industry is one of the main actors responsible for spreading the virus globally, it is also one of the victims of the global pandemic and its effects. The COVID-19 pandemic has been affecting the aviation industry since the beginning of 2020 and the most severe effect was economical. According to the International Civil Aviation Organization (ICAO), there has been a loss of 74% international and 50% domestic passengers on average and approximately USD 371 billion loss on revenue throughout the entire industry (ICAO, 2021). This downfall was not isolated and impacted on other industries in chain as well. Besides airlines, connected sectors such as airports, aircraft manufacturers, food and retail services, and eventually global tourism and tourism-dependent businesses are all negatively (Gössling, 2020). Overall, this was an eye-opening lesson for all organizations and all human beings in general about how important risk and safety management in today's very global world are, especially in the aviation industry as it is ensuring most of the international connections
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Due to these recent developments and in order to handle the operations advertently, ICAO published a new guidance on COVID-19 safety risks in aviation (ICAO - Doc 10144, 2020). This publication aims to help countries while addressing safety risks arising in aviation and produced for civil aviation authorities and national aviation regulators. The new handbook contains new adjustments to overcome the challenges created by the pandemic.

In the digitalization era, one of the recent focuses is fully autonomous systems supported by artificial intelligence (AI). Self-driving cars, trucks or pilotless aircrafts are developed via AI technology. Among the emerging robotic technologies, Unmanned Aerial Vehicles (UAVs) have powerful flight and movement capabilities in comparison to other non-aerial robotic systems. UAVs are an emerging technology and a new branch in the aviation ecosystem. Their capabilities create new potential business areas, in fact, it is expected to see over 100,000 new UAV-related jobs in the United States alone by the year 2025 (Rana et al., 2016). In recent years, there have has an increasing interest in the studies and applications related to UAVs (Al-Turjman, 2020)(Shakhatreh et al., 2019)(Otto et al., 2018). Due to this recent interest, both international and national aviation authorities such as ICAO and EASA are rushed to establish regulations in order to control and organize the adrift utilization trend of UAVs (ICAO - Circular 328-AN/190, 2011) (EASA - NPA 2017-05 (A), 2017). Beside their popularity in other areas, UAVs are a hot topic in aviation for various operations such as maintenance, inspection and control as well (Sappington et al., 2019). However, the increasing popularity of UAVs will expand their utilization to many other areas in the coming years. The restrictions and limitations caused by COVID-19 also supported this popularity further. Especially in crowded areas, where it is a health risk to be during a pandemic, UAVs are used in many applications with different purposes such as crowd surveillance and screening, public announcements and supply deliveries (Chamola et al., 2020). According to Yatıştıran and Yaz, (Yakıştıran & Yaz, 2020), UAVs have been utilized in various domains like military defense systems, agriculture, transportation, and etc.. Especially in transportation, tech giants such as Amazon and global logistics giants such as UPS and DHL are promoting the utilization of UAVs in this area for almost a decade (Özoğlu et al., 2019). With the help of wireless technologies and the advancement in studies focusing on extending battery life, we will see the transformation in the workplace and operation field as several other of the operations will be taken over and carried out by robotic systems. The first phase of this study is briefly describing the role of quality and safety management from the viewpoint of the aviation industry. The next phases focus on the concepts of reliability, maintenance, resilience engineering and their use in civil aviation. Then, as the main focus, UAV technologies and their fields of applications, especially in the aviation industry, are detailed. Although COVID-19 global pandemic revealed the extra benefits of UAV utilization, there are still both technologic and legal limitations, since their capabilities for aerial operations make them a part of the aviation industry and liable to its regulations. Thus, the aim of this study is to create a framework for UAVs from the perspective of quality and safety management practices in aviation, along with the applications of reliability and maintainability concepts. In addition to UAV technologies, several new trends and developments in aviation are discussed as well. New research areas such as data science, machine learning, augmented and virtual reality, artificial intelligence and mobile technologies and their current and potential application opportunities are presented in the last phase of the study.

2. Quality and Safety Management in Aviation

Quality management concept has been investigated extensively over the past few decades. A few of the pioneer thoughts on quality management concept gather around constant innovation through top management (Deming, 1986), cost cutting via quality improvement (Crosby, 1979), quality improvement to reduce the cost of poor quality (Juran & Gryna, 1993), quality control by involving individually and personal responsibility (Ishikawa, 1985) and customer-oriented quality (Feigenbaum, 1991). Quality management in general, is a tool which ensures the products and/or services of an organization meet the demand of customers and requirements of regulations and organization itself.

The aviation is one of the pioneer industries in terms of technologies, services and operations. Airplane manufacturing, flight procedures and upkeeping measures are all synchronized and policies ensure that the quality standards are met during all these procedures. Business activities in aviation, or airline industry particularly, is mainly consist of flight and ground operations, engineering and maintenance and finally sales and marketing as seen in Figure 1 (Subagyo, 2002).

Figure 1. Framework of aviation operations (Subagyo, 2002)

Ground and flight operations are at the core of the aviation activities. Maintenance and engineering activities support the ground and flight activities while ensuring safety in operations. Marketing and sale activities only apply in civil aviation but it is a major part as well since the aviation industry itself has a constantly growing economy with a rate between 4.6% and 4.9% annually (Schmidt, 2017).

International legislations and regulations enforce aviation organizations to comply their airport, pilot, air traffic controller and aircraft maintenance training programs, as well as their operations to ensure airworthiness and flight safety. In order to meet the regulatory quality standards of civil aviation authorities, aviation procedures, programs and equipment should be monitored by the quality assurance system. International Organization for Standardization (ISO) defines the quality assurance system as systematic actions to provide confidence that the organization will fulfill the quality requirements. In ISO 9001:2015, the systematic actions as the eight quality management principles for all organizations to follow in order to develop an integrated quality management system are defined as below (ISO 9001:2015, 2015):

I. Customer focus: meet the current and future customer requirements,
II. Leadership: create unity of direction and purpose and provide environment for engagement of people,
III. Engagement of people: respect all individuals at all levels and involve them,
IV. Process approach: understand the underlying system properties and analyze the results,
V. System approach to management: understand and manage interconnected processes as one coherent system,
VI. Improvement: create new opportunities and react to changes,
VII. Evidence-based decision making: understand the importance of cause-and-effect connection and unintentional potential consequences,
VIII. Relationship management: optimize the impact of interested parties on organizational performance by managing relationships.

These principles encourage the organizations to meet the requirements while improving the processes continuously, which ultimately constitute the base for Quality Management System for the organizations.

While using a product or a service, injuries, accidents or different adverse consequences may happen. In order to prevent these consequences, some principles, measures, processes and frameworks should be applied. Safety management is mainly utilized to apply these preventive actions and helps design better operational systems while predicting systemic shortcomings before occurrence or identifying and correcting such failures (Hollnagel, 2018).

In aviation, safety management concept covers the processes which structure flight safety such as aerodrome operations management or air navigation. Strategically, aviation safety management mainly relied on reactive risk management guidelines up until the 90s, then reactive strategies evolved into advanced risk management strategies with more preventive precautions (Stolzer & Goglia, 2016). Reactive safety management is based on:

- Minimum safety measures and preventive actions.
- Low level of safety due to reported safety incidents. Furthermore, these reports are limited only to actual failures and no safety trends affect the reports due to insufficient data.
- Measures taken after the incident happens to prevent re-occurrence.

Predictive safety management is based on:

- Forecasting future for potential incident occurrences.
- Identifying potential risk areas by analyzing operations.
- Regular system analysis and reviews.

Proactive safety management on the other hand, is based on the following:

- Upper management's commitment to safety through safety policies,
- Risk management and hazard identification,
- Safety occurrence reporting of safety related data,
- Safety performance assessment and monitoring,
- Training for safety-related personnel,
- Building safety culture throughout the organization(McDonald et al., 2014).

These actions, all as integrated, increase the system preparedness for unsafe conditions and, it is generally referred as Safety Management System to utilize safety strategies in a consistent manner. Safety evaluation and safety enhancement for particular components of UAVs should be taken into account considering failures. As a matter of fact, failure rates of UAVs are higher than the failure rates of manned aircrafts (Bone & Bolkcom, 2003) in which failures face both safety and financial risks (Segal & Bot, 2018).

2.1. Quality management systems in aviation

In the early stages of aviation industry, the major aerospace manufacturers adopted the ISO quality standards which covers the requirements of the automotive industry. However, aerospace suppliers had specific requirements which ISO 9001 standards did not address. Thus, AS9000 quality standards, based on ISO 9001, are developed by the International Aerospace Quality Group (IAQG) in order to provide immediate solutions for aviation industry (Barker, 1998). Later on, IAQG expanded these standards into global forms in order to help the original equipment manufacturers to operate globally (IAQG, 2019). The current standards developed by IAQG are listed as below:

- AS9100 - Quality Management Systems - Requirements for Aviation, Space and Defense Organizations
- AS9101 - Quality Management Systems - Audit Requirements for Aviation, Space, and Defense Organizations
- AS9102 - Aerospace First Article Inspection Requirement
- AS9103 - Aerospace Series - Quality Management Systems - Variation Management of Key Characteristics
- AS9104/1 - Requirements for Aviation, Space, and Defense Quality Management System Certification Programs
- AS9104/2 - Requirements for Oversight of Aerospace Quality Management System Registration/certification Programs
- AS9104/3 - Requirements for Aerospace Auditor Competency and Training Courses
- AS9107 - Direct Delivery Authorization Guidance for Aerospace Companies
- AS9110 - Quality Management Systems - Requirements for Aviation Maintenance Organizations
- AS9114 - Direct Ship Guidance for Aerospace Companies
- AS9115 - Quality Management Systems - Requirements for Aviation, Space and Defense Organizations - Deliverable Software
- AS9116 - Aerospace Series - Notification of Change (NOC) Requirements
- AS9117 - Delegated Product Release Verification
- AS9120 - Quality Management Systems - Requirements for Aviation, Space and Defense Distributors
- AS9131 - Aerospace Series - Quality Management Systems - Nonconformance Data Definition and Documentation
- AS9132 - Data Matrix Quality Requirements for Parts Marking
- AS9133 - Qualification Procedure for Aerospace Standard Products
- AS9134 - Supply Chain Risk Management Guideline

- AS9136 - Root Cause Analysis and Problem Solving (9S Methodology)
- AS9137 - Guidance for the Application of AQAP 2110 within a 9100 Quality Management System
- AS9138 - Aerospace Series - Quality Management Systems Statistical Product Acceptance Requirements
- AS9145 - Aerospace Series - Requirements for Advanced Product Quality Planning and Production Part Approval Process
- AS9146 - Foreign Object Damage (FOD) Prevention Program - Requirements for Aviation, Space, and Defense Organizations
- AS9162 - Aerospace Operator Self-Verification Programs

Although AS9100 standards are derived from ISO 9001 series, the main differences rest on the industry-specific requirements. AS9100 series contain additional quality and safety standards and differs from the ISO standards by their scope, term definitions and realization of products.

2.2. Safety management system in aviation

As mentioned earlier, a Safety Management System (SMS) is a systematic approach in order to manage safety risks. It requires planning and organizing, providing directions and communication to fully function and as a result, it continuously improves the overall safety for aviation system (Cacciabue et al., 2015).

According to Advisory Circular 120-92 published by the Federal Aviation Administration (FAA), there are four basic components that the SMSs structured on (FAA - AC 120-92B, 2006):

1. ***Safety policy:*** Defined policies and procedures to accomplish SMS goals. It outlines the steps for accessing acceptable levels of organizational safety.
2. ***Safety planning:*** Implementation of hazard identification and safety risk management procedures to contain operational risks.
3. ***Safety assurance:*** After these controls are determined, operations must be monitored and controls are practiced continuously to achieve predetermined objectives.
4. ***Safety culture:*** Safety must be advocated as a core value and practiced throughout the organization.

2.2.1. SMSs in airline industry

Airline organizations provide the service of air transport for passengers and freightage in a continuously growing industry, as mentioned earlier. In order to cope with this growth in general, extra measures should be considered under the roof of SMSs. However, instead of merely applying regulatory requirements to comply with the authorities, SMSs can be utilized to achieve key goals by enhancing safety performance. There are a number of regulations prepared by different organizations and are expected to be followed by airline businesses. The Convention on International Civil Aviation: Annex 6 prepared by ICAO, divides the aircraft operations in three parts as:

1. International commercial air transport,
2. Aircrafts in international general aviation,
3. Helicopters in international operations,

and suggests a comprehensive safety program on operations of aircraft (ICAO - Annexes 1 to 18, 2012). EASA provides safety requirements under flight safety program (EASA - EU OPS 1.037, 2008). The program suggests that:

1. Flight safety and accident prevention program shall be established and must include:
   - Risk awareness for operation-related personnel,
   - Accident and incident occurrence reporting scheme,
   - Evaluation of accidents and incidents on information base,
   - Flight data monitoring program with safeguards to protect data,
   - Appointment of program manager
2. Program manager shall be responsible for the results of the applied program
3. Quality manager shall monitor the effectiveness of the program.

2.2.2. SMSs in aerodrome operations

Aerodrome safety basically involves the safety of general aviation airfields, military airbases and large commercial airports. Safety at aerodromes includes procedures, responsibilities, organizational structure, provisions and processes and the aerodrome operator provides the safety control and safe use of aerodrome (ICAO - Doc 9774, 2001). Also, Annex 14 defines actions to ensure the safety of the aerodromes as below (ICAO - Annexes 1 to 18, 2012):

- Aerodromes must have obstacle-free airspace to ensure the safety of approaches and departures of aircrafts.
- The volume of the airspace must allow the growth and existence of the aerodrome.
- Safety performance targets must be set for operations such as pavement maintenance, movement area safety and electrical services.
- National regulations and ICAO standards must be complied continuously
- Audit of the aerodrome must be arranged both internally and externally for the inspection of equipment and facilities.
- Operational and maintenance records as well as facilities related to safety must be documented.

- Adequacy of the personnel and their safety-related training must be provided.
- Construction works on aerodrome must have system control measures and relevant procedures must be incorporated to safety-related clauses.

2.2.3. SMSs in air traffic management

Assisting departure, air transit and landing of an aircraft, air traffic services, airspace and air traffic flow and capacity management operations are collected under the roof of Air Traffic Management. ICAO Annex 11 dictates the safety of air traffic services by implementation of a SMS which is acceptable and conducted by and air traffic service provider (ICAO - Annexes 1 to 18, 2012). The main goal here is to prevent aircraft collisions while taking off, landing, maneuvering, in the holding or en route. Maintaining a flow order in air traffic and providing information for efficient and safe flights, alerting the operators for distressed aircrafts are defined as the air traffic safety objectives as well. These services can be maintained by:

- Safety hazards identification.
- Implementation of remedial actions to maintain the safety on an acceptable level.
- Constant monitoring and routine evaluation of the achieved safety level.
- An objective to make consistent enhancements to the overall safety level.

2.3. New trends in quality and safety management in aviation

Although quality management in aviation, having only been introduced at the end of 1990's, is a relatively new concept, at its base the standards to follow have been quite steady with little to no change over the years. However, the notion's starting point coincides with the beginning of a very fast paced development era for the modern technology which also meant new developments for the aviation industry that ultimately caused new trends to appear in aviation generally, creating a certain need for coming up with some updates in standards for the quality and safety management concerning aviation.

In today's world, especially with commercial flights becoming more and more common, more advanced aviation SMS solutions are required for flight operations to ensure safety management in a systematic approach (ARC, 2018). According to the article, because of the quickly evolving SMS technology and best practices, 4 new trends have been recently determined to keep pace with:

- **Mobile safety management:** As we use our mobile devices more and more in our daily routines to take care of our problems and tasks so as the pilots and safety systems because mobile devices make most things quicker and simpler, therefore it is expected for Mobile Safety Management to become progressively relevant in the coming years. It is especially helpful for areas such as immediate reporting of incidents making it effortless to catch the most important details.

- **Data and metrics:** Better and more utilization of data will increase SMS performance since it will reveal risk patterns of incidents and prevent potential disasters.

- **SMS integration:** The trend on Integrated Aviation Management Systems will tie various elements such as security, safety, risk, quality and supplier management into an integrated system with efficient software environment which benefits from data and mobile capabilities.

- **Operational risk management:** Updating regulations and standard on a real-time basis will increase the change response ability and keep the SMS up-to-date.

Data science has become a major topic in various fields and in aviation as well (Chung et al., 2020). Real-time data with substantial amounts are available now regarding flight performance, flight information, airport operation flows and air traffic and weather conditions. Aviation organizations can easily advance operation and service effectiveness, ensure and improve safety in their environment and reduce their cost by analyzing these forms of data.

Airline industry is continuously growing and consequently, airline organizations are forced to expand their fleet due to increasing demand. This increase results in requirement of efficiently planning, organization and allocation of resources and manpower in areas such as maintenance. Using data science and analytics, operators will analyze the real-time and historical flight data of aircrafts, external factors such as weather and will organize their maintenance activities correspondingly (Eltoukhy et al., 2019).

Accurately planning and management of operational capacity is essential for operators to improve service quality, reduce costs and environmental impacts. By using statistical data analysis and forecasting methods effectively, aviation organizations will also be able to calculate the capacity-related stress factors on system which will also affect the flight and aircraft maintenance operations. Reliable and robust forecasting technologies will enable the development of the industry (Xu et al., 2019).

External factors such as weather conditions play a significant role on flight operations. Providing a safe flight mostly depends on the accurate weather activity observations and forecasts. Machine learning techniques will help accurately predicting weather activities which will eventually increase the safety of the operations, and the ability to manage the ground delay program as well

(Yulin Liu et al., 2019). Machine learning techniques will also help improve the runway safety by analyzing runway utilization and factors such as arrival runway occupancy time (Herrema et al., 2019).

Automation in air traffic control seems inevitable with the help of technologies such as Internet of Things (IoT) and artificial intelligence. Virtual air traffic control towers will replace the physical ones in near future and it is believed that it will increase the operation safety while decreasing operational costs drastically (Chung et al., 2020).

Beside VR in maintenance activities, Augmented Reality (AR) is another concept which is gaining traction in aviation maintenance in order to create an environment for human-machine collaboration (Palmarini et al., 2018). AR-supported aircraft and component inspections are encouraged to be implemented since it will definitely improve the fault detection success rate of human workers and the performance of procedures such as ground test instructions (Eschen et al., 2018).

3. Reliability and Maintenance in Aviation

Reliability is generally defined as the probability of a component or system, under some previously stated operational conditions, to operate without a failure for a specific period of time. Reliability engineering is the field of study focused on lifetime performance and dependability of these type of systems and components. Reliability engineering applications plays an important role on the lifecycle of a system or component by both as engineering and services. Engineering part mainly plays a role on design, growth planning and warranty and maintenance parts while services cover the repairable inventory systems, supplying spare parts and end-of-life product recycling and remanufacturing (see Figure 2) (Jin, 2019).

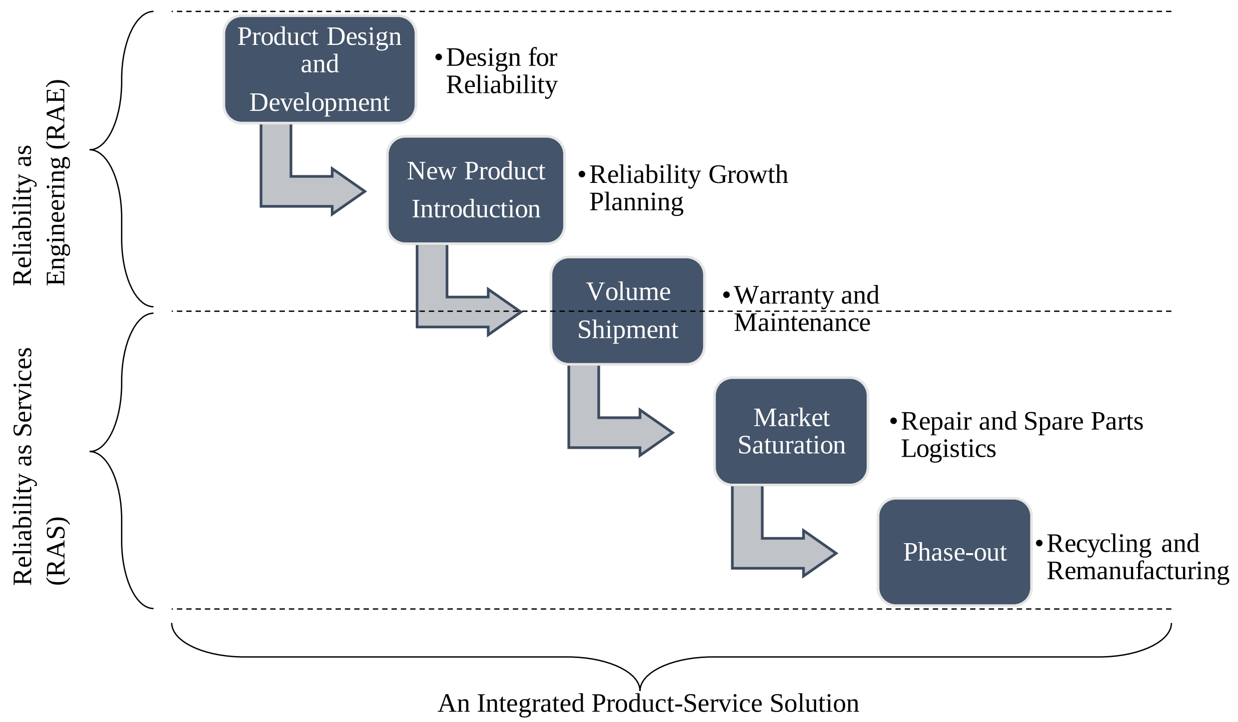

Figure 2. Reliability in product lifecycle management adopted from (Jin, 2019)

In aviation, reliability concept applies mainly on aircrafts during phases such as design, development, manufacturing and operation (Zio et al., 2019). Design solutions for systems and components are determined in order to fulfill design requirements in the design and development stage. Validation and verification are performed after the design and development stage to check the requirements if they are met by the design solution or not. These steps need to be repeated until the design requirements are met. Hereafter, the stage of large-scale manufacturing begins for aircraft production where quality assurance is the key factor to guarantee the fulfillment of production specifications. The manufactured aircrafts are delivered for field operation in the last stage. The reliability of an aircraft must be maintained during the operation stage of the aircraft as well. Increasing rate of using air travel creates safety concerns naturally, thus the term "airworthiness" certification, which will be explained later, is introduced and applied by aviation authorities to check if the aircraft producers follow the reliability requirements (Vieira et al., 2016).

The reliability of a UAV on the other hand, is correlated with the maintenance intervals. That is to say; there is a higher failure rate leading to very expensive repairs. It is important to enhance required reliability level by using high quality, derated components with a very detailed selection of a redundant subsystem during the design phase. For further directions, a very large number of variables for all systems and subsystems may be considered to minimize uncertainty (Petritoli et al., 2018).

3.1. Reliability in aviation

Reliability and safety are directly connected and both of them are high priority items on the agenda of aviation operators. Especially safety and reliability of the flight operations must be retained continuously by maintaining aircraft operability since the fragility and possible disastrous consequences of those operations. In order to maintain aircraft operability, operational requirements in respect to operational reliability must be met. Reliability in design must be allocated in component-level as well, in three main sub-group: hardware, software and human elements (Zio et al., 2019). Human reliability is especially important due to the high contribution of human error to accidents in aviation (ICAO, 2019).

Concepts of reliability are generally based on mathematical explanations and they may not be easily explained by only telling (Levin & Kalal, 2005). However, the importance of the subject dictates that a brief explanation for some of the basic concepts of reliability commonly used in aviation is to be given as follows:

The bathtub curve: It is one of the most fundamental concepts and it corresponds to displaying a way of failures in a product population as a cumulative number and represent as rate of failure instead of number of failures. As seen in Figure 3, it consists of three stages, namely infant mortality, useful life and wear-out phase.

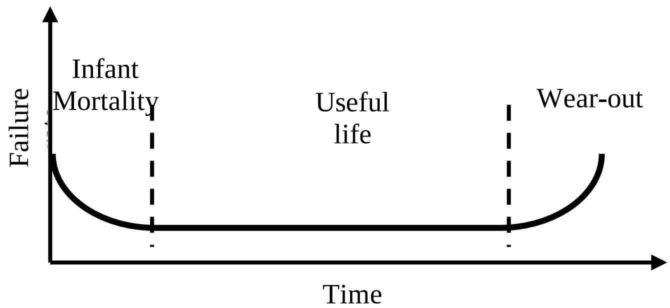

Figure 3. The bathtub curve

"Infant mortality" stands for quality related early phase failures or failures occur during initial product introduction. The steady line in the graph represents "Useful life" of a product where the failure rate is stabilized for a period of time. "Wear-out" phase means that the product has reached the end of its useful life and degradation failures are beginning.

Essential and Common Reliability Concepts Used in Aviation are explained as follows:

- **Mean residual life:** It represents the remaining life of a component or system, given that it has reached a certain time of its life.
- **Mean time between failure:** It measures the failure rate of a component or system during normal life period.
- **Mean time between repair:** It measures the time between repairs in average for a component or system.
- **Mean time between maintenances:** It measures the time between maintenance (both repair and preventive maintenance) in average for a component or system.
- **Mean time to failure:** It measures the average time until next failure for a non-repairable component or system.
- **Mean time to repair:** It measures the average time to repair and also represents the unavailability of a component or system during a repair.
- **Mean time to restore system:** It is similar to mean repair time, though with additional time spent during obtaining the needed parts to restore the component or system.
- **Reliability growth:** It measures the improvement of component or system reliability after removing the failure mechanisms. As a result, it is expected for mean time between failures to increase for each eliminated defect.
- **Reliability demonstration testing:** It is often confused with reliability growth; however, it is a process to ensure statistically that the predetermined reliability goal is reached. It starts just after the design is finalized the final product or state of the system is tested in the end. While reliability growth improves the mean time between failures of a component or system, reliability demonstration testing is utilized to verify the outcomes of that improvement.

Beside the general terms, there are also specific reliability performance indicators for aircraft operations as listed below (Zio et al., 2019):

- **In-flight shutdown rate:** The number of shutdowns or power losses on an engine during flight hours.
- **Mean time between unscheduled removal:** It is the ratio of total number of flight hours to the number of unscheduled removals of a component in a given period.
- **Mean flight hour between failure:** Failure rate of a component in terms of number of flight hours.
- **Engine shop visit rate (Time on wing):** It is obtained by dividing total number of visits occurred to the engine shop by the total number of flight hours in a given period.

3.2. Maintenance in aviation

The degradation and failure of objects vary due to their environment, design or usage intensity; however, effective maintenance controls these factors and helps maintaining a desired performance. In aviation, this is also valid for aircraft maintenance, since no aircraft is tolerant to corrosion, wear, fatigue or operational failures. Maintenance in aviation is a process to ensure that intended functioning of safety and reliability of the system continues to perform at designed-in level (Kinnison & Siddiqui, 2012). Aircraft maintenance is the most problematic part of maintenance in aviation due to its complex structure as it requires coordination and cooperation of the service groups such as engine, airframe, instrument, electrical and electronic (Kim & Song, 2016).

Airworthy is a term to define an aircraft or a component part belong to the aircraft which meets the corresponding type design and the condition of the aircraft or the component part is sufficient for safe operation (FAA - AC 43.13-1B, 1998). An aircraft must certify airworthiness by meeting certification codes prior to beginning service. It guarantees aircrafts or other airborne systems to avoid significant hazard to passengers, ground crew and air crew or other parties during operation and throughout its lifecycle. According to ICAO Annex 8, when an aircraft exceeds its limits specified in flight manual during operation may cause airworthiness invalidation (ICAO - Annexes 1 to 18, 2012). Also, in order to remain airworthy, continuous airworthiness is a key point in aviation and in a maintenance program to guarantee such permanence, maintenance needs must be fulfilled by both inspection functions and individual maintenance utilized by operators.

3.3. Reliability-Centered maintenance

The first industry to acknowledge the approach of Reliability-Centered Maintenance (RCM) is the aircraft industry and the term first used by F. Stanley Nowlan and Howard F. Heap for designing new and economically viable aircraft maintenance activities (Nowlan & Heap, 1978). It aims to identify preventive maintenance tasks in order to provide equipment reliability by exerting minimum resources. The focus here is to maintain the system function instead of returning the equipment to its ideal status. In aviation, each aircraft component is assessed for potential functional failures as well as failure modes and their effects and consequences. Next, a maintenance plan, which even lets the components to fail, is formed with the aim of increased reliability and lowered maintenance costs.

The main approach in RCM is the component and system prioritization considering the aftermaths of the failure. Preventable failures and their dominant causes are prioritized and appropriate maintenance policies are selected accordingly. In civil aviation, Maintenance Steering Group handbooks, MSG-1, MSG-2 and MSG-3, are developed by Boeing first for the Air Transport Association (ATA), known as Airlines For America (A4A) today. These documents provide the methodology to develop maintenance tasks and scheduled intervals for the manufacturers and the operators. The first handbook was published in 1968 and it was used for maintenance of Boeing 747 aircrafts. The latest updated version is the MSG-3 and it has two different volumes for fixed-wing aircrafts (A4A, 2018a) and rotorcrafts (A4A, 2018b). For modern commercial aircrafts, these documents provide methods to be used in development of initial maintenance requirements.

3.4. Maintenance applications in aviation

Maintenance applications in aviation are usually grouped as below (Hinsch, 2018):

Line maintenance: Maintenance activities performed before the flight to check the fitness of the aircraft for intended flight. It is also called Light maintenance and consist of limited and routine maintenance activities. It aims to modify defects on the aircraft which occur during flight and make the aircraft departure-ready to maintain the punctuality and steadiness of flight operations. Typical Line maintenance activities are:

- Troubleshooting and visual inspections.
- Defect rectification.
- Replacement of components which may include engines or propellers.
- Scheduled maintenance via superficial visual inspection to detect obvious failures.

Base maintenance: Also called the Heavy maintenance activities, they are performed less frequently than Line maintenance, however, contain more long-lasting and in-depth tasks. It aims to fix the faults occurred during Line maintenance and flight, to apply preventive maintenance and to verify airworthiness. Typical Base maintenance activities are:

- Periodic controls for deterioration of the engines, systems and airframe
- Defect rectification (may be performed during Line maintenance)
- Modifications and technology upgrades
- Cabin reconfiguration, aircraft painting

Technical support: Inspection and engineering services are part of the technical support where engineering services supports the field mechanic by providing technical resources and inspection checks the appropriateness of the maintenance process (Kim & Song, 2016). Beside the maintenance activities in the hangar or directly on the aircraft, various aircraft components such as navigational instruments, landing gears, hydraulic pumps and galleys are removed and delivered to specialized workshops with appropriate equipment and qualified staff for overhaul.

Virtual inspection and maintenance: Virtual Reality (VR) concept has been around for quite some time and it has a wide range of applications. In aviation, VR technologies are mainly adopted in maintenance design and operations in order to fix design faults which eventually affects maintainability or to inspect components of the aircraft for cracks or deformations. There are many applications of VR in aircraft maintenance such as disassembly processes (Zhou et al., 2010)(Z. Liu et al., 2014), engine component replacement (Amundarain et al., 2004), cargo bay inspection (Bowling et al., 2008). Virtual maintenance training is another aspect of VR applications in aviation which is evidently makes the environment safer and more economic for both technicians and operators (Vander Weide & Secretan, 2009).

3.5. Resilient systems in aviation

Safety always is the main issue in aviation given that the effects of an air disaster would be excruciating. Traditional risk assessment methods mainly concentrates on functional failures, however, the role of human and software are increasing in supervisory control, causing the dysfunctional interactions (Chialastri & Pozzi, 2008). A solution to this problem is by enhancing the ability of as system to create both robust and flexible processes through resilience engineering to endure for internal and external disruptions. As the accidents in a system are considered combination of unexpected events leading to disaster, resilience corresponds to the ability of the system to cope with these unexpected situations to avoid jeopardizing the whole system.

Resilience in aviation is a complex notion and has many shareholders. First, international authorities set the rules for air transport. For civil aviation in global, airlines must follow the criteria for Airworthiness of operation certificate and flight procedures which ICAO designed, and the national regulations as well (ICAO - Doc 9906, 2009). Then the responsibility falls to the actors of airline industry (Chialastri & Pozzi, 2008):

Manufacturers: Building the aircraft according to the regulations, selling after flight tests with operation manual.

Operators: Buying the aircraft from manufacturer and planning the operating schedule, providing crew with conduction rules beside the manual from manufacturer.

Crews: Flying the aircraft according to the international and national laws and regulations while following the procedures from manuals both from manufacturer and operator.

Auxiliary services: Airport services, maintenance, air traffic management and marketing services.

Besides autopilot features, which was still guided by pilots, automation in flight management is not an old concept and has been around thirty years. This concept is created in order to provide a strategic approach to automation. With the introduction of Flight Management System, input of a pilot is minimized by transferring management and computation of various flight aspect to the system and protection against issues caused by flying skills is provided. However, this might shift the risk factor as over-redundancy might keep the pilot from taking control when needed (Kongoli, 2012).

As any action has an effect on the final result, each operator in aviation shares the basic approach to safety since each individual working with aircrafts has the role of assuring safety. Thus in aviation, a knowledge-based approach is adopted on level of performance of a single operator to ensure the system resilience (Chialastri, 2011).

4. Unmanned Aerial Vehicles (UAVs)

UAVs or drones, as commonly referred to, are remotely controlled aircrafts with a degree of autonomy. UAVs are generally a part of a system called Unmanned Aircraft System (UAS) which consist of a ground-based control mechanism, an UAV and a communication system to link these two sub-systems (N. Singh et al., 2019). However, according to Joint Air Power Competence Centre (JAPCC), principally the structure of UASs have many components such as support elements, payload or data links, as displayed in Figure 4 (JAPCC - UAS CONEMP, 2010).

The first examples of UAVs were used in 1916 during American Civil War as attack balloons with explosives and the interest in UAVs began to rise during World War II and still continues to grow today (Demir et al., 2015). Although the initial purpose of using UAVs is purely military, several different types of UAVs are designed and developed since the beginning of the 21st century for various functions.

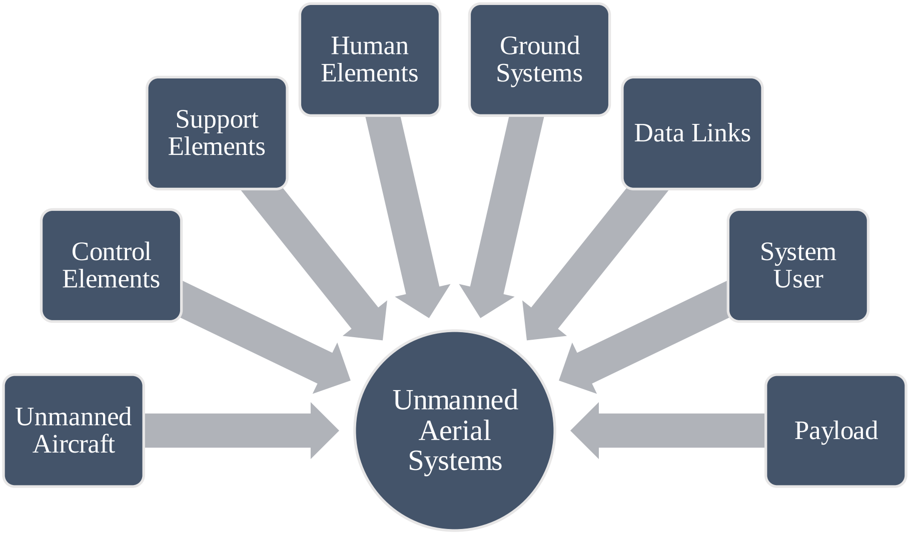

Figure 4. Fundamental elements of unmanned aerial systems (JAPCC - UAS CONEMP, 2010)

4.1. UAV types and applications

As previously mentioned, various types of UAVs can be listed according to their intended usage but can be grouped under three different categories such as military, industrial and commercial.

In military, UAVs are mainly utilized for surveillance and intelligence gathering, anti-aircraft target practices and aerial operations as attack aircrafts with weapon platforms. After civil applications of UAVs are allowed, numerous of them for industrial purposes are performed such as monitoring crops and lands, surveying power grids and lines, delivering small packages by companies working in agriculture, energy and logistic sectors, respectively. These features expanded the utilization areas of UAVs to capturing images or videos for movie industry and commercial agencies as well (N. Singh et al., 2019). Their ease of use and deployment, hovering ability and low cost of maintenance make them attractive for civil applications (Shakhatreh et al., 2019).Table 1 shows literature review of civil application areas for UAVs.

Table 1. Civil application areas for UAVs

Author (Year)	**Focus of Application**	**Contribution Area**
Vrba et al., (2022) Canisius et al., (2019)	• Active sensing systems • Passive sensing systems	Remote Sensing
N. A. Khan et al., (2020) Mliki et al., (2020) Outay et al., (2020)	• Traffic control • Behavior recognition • Roadside assistance	Real-Time Monitoring
Du et al., (2019) Patil et al., (2022) Schweizer et al., (2018)	• Locating missing individuals • Delivering medicine, food and water to the injured • Taking images of areas or infrastructures for damage assessment after disasters	Search and Rescue
Yanchao Liu, (2019) Bhatt et al., (2018) Sumanth Reddy et al., (2019)	• Food delivery • Medicine and blood samples delivery • Lightweight commercial products delivery	Delivery of Goods
Ghazali et al., (2021) Wu et al., (2021) Tazibt et al., (2022) S. K. Khan et al., (2021) Marchese et al., (2019)	• Network gateways • Omnipresent coverage • Data collection • Relay nodes between wireless devices • Worldwide coverage via satellites	Providing Wireless Coverage

Table 1 *(cont)*. Civil application areas for UAVs

Author (Year)	Focus of Application	Contribution Area
Fu et al., (2020) Christiansen et al., (2017) Romero et al., (2018) Faiçal et al., (2017) Kerkech et al., (2020) Stroppiana et al., (2018) Huuskonen & Oksanen, (2018) Kavoosi et al., (2020)	• Crop maturity and yield mapping • Field tile mapping • Irrigation scheduling • Pesticide spraying • Disease detection • Weed detection • Soil texture mapping • Residue cover and tillage mapping	Precision Agriculture
Kas & Johnson, (2020) Gopalakrishnan et al., (2018) Tan et al., (2021) Jalil et al., (2019) Gu et al., (2020) Nordin et al., (2022)	• Infrastructure internal inspection • Surface degradation assessment and crack detection • Vertical inspection for towers and high rise • Power transmission lines inspection • Wind and oil/gas turbine inspection • Onshore and offshore asset inspection	Infrastructure Inspection

Other than their operational purposes, the types of UAVs also differ according to their design features which affect their flying principles. In Figure 5, UAV types are classified first according to their vehicle mass, then the heavy types are further classified to rotor and wing types (Liew et al., 2017). Being wing-type, rotor-type or hybrid and vehicle mass determines their leveling, position holding, landing and take-off, flight time and distance functions as well (Hassanalian & Abdelkefi, 2017).

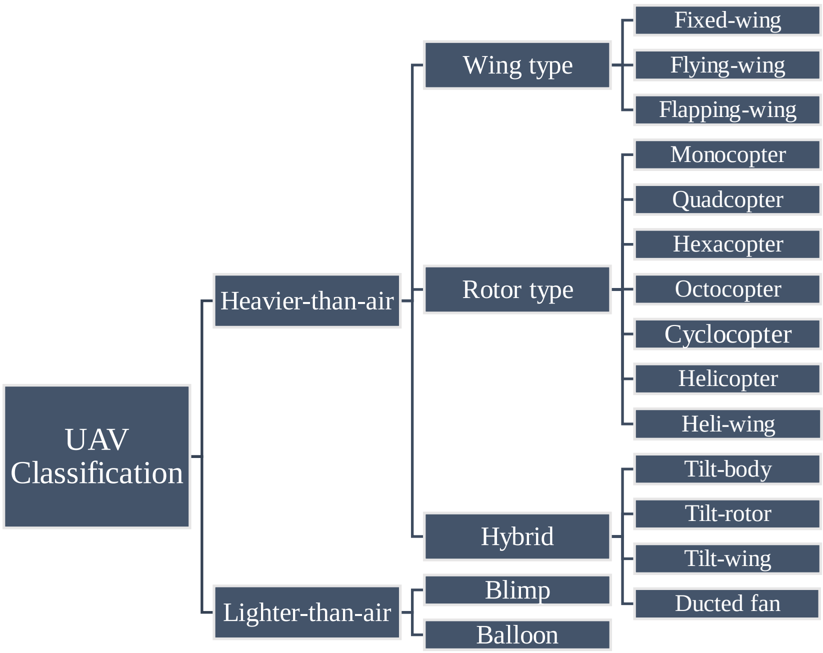

Figure 5. Classification of UAV types according to their flying principles adopted from (Liew et al., 2017) and (Hassanalian & Abdelkefi, 2017).

4.2. Limitations of UAVs in military and civil aviation

Being a fairly new element of the airspace, UAVs may pose potential risks to other elements in the sky or on the ground. Aviation authorities consider these risk factors to be minimized and as a result, certain regulations are established. These regulations mainly focus on minimizing the danger which UAVs pose to the manned aircrafts by regulating the airspace, securing appropriate flights with operational limitations and procedures such as pilot licenses flight permissions and data collection permissions (Stöcker et al., 2017).

The efforts to regulate UAV utilization in aviation was at national level starting from World War II until 2002 when a UAV task force was established by European Organization for the Safety of Air Navigation (EUROCONTROL) for the integration of UAVs into European Airspace via updating civil aviation regulations for UAVs (Stöcker et al., 2017). Until then, various standards and procedures are recommended by international civil aviation authorities for UAVs integration into national airspaces. Initially, ICAO published an international framework as a first step in global regulations (ICAO - Circular 328-AN/190, 2011), then published a toolkit with the purpose of establishing a global framework and declaring UAVs as equal partners of civil aviation as other aircrafts which also interacts with air traffic control on real-time (ICAO - Doc 10019, 2015). The Riga Declaration on Remotely Piloted Aircrafts was published in European Union for future UAV regulations (EASA, 2015c). This framework highlights five key points:

I. UAVs are defined as a new type of aircraft and treated by new rules,
II. UAV service safety rules are urged to be developed,
III. For full integration of UAVs into European Airspace, development of technologies and standards are requested,
IV. UAV services can grow further by public acknowledgment,
V. Operator is the responsible figure for the use of UAV.

EASA also proposed common rules for operating UAVs (EASA, 2015a), regulatory framework for UAVs (EASA - NPA 2017-05 (A), 2017), and concept of UAV operations (EASA, 2015b) as regulatory frameworks. The State Airport Administration of Turkey (SAMA) is in the process of establishing new regulations for operating UAVs in Turkish national airspace (SAMA, 2022). According to these regulations, any individual or establishment must register their UAVs to the system before using and piloting certificate can be obtained as well through Directorate General of Civil Aviation website.

Utilization of UAVs brought vitally important ethical questions about their use. For utilization of UAVs, ethical issues regarding responsibilities for unintentional harm should be delicately anticipated. As a matter of fact, ethical principle of autonomy should be taken into account considering the humanitarian values, responsibilites and trusts.

UAVs are called as "Remotely Piloted Aircraft" by military and aviation authorities due to the fact that they fly under direct control of human operators. However, military requires greater autonomy in UAVs for reducing operating costs. For this reason, the responsibility for the actions of the UAV becomes ambiguous. For military utilizations of UAVs, when and where the law requires human presence in the decision cycle should be planned with respect to human interference with the weapon or weapon system. For further challenges, the vision of a world where decisions about life and death will be made by machines rather than human direct control must be considered urgently.

UAVs along with autonomous UAVs are facing challenges for the judiciary and ethics related to liability for damage. There are potential liability gaps in the moral and legal responsibility system which must be properly handled via technical solutions as well as official regulations. In the literature for UAVs, risk analyses, which have been handled considering mainly commercial systems through data from civil aviation, are based on probabilistic approaches without proposing hazards and respective requirements (Plioutsias et al., 2018).

4.3. Reliability, availability, maintenance and safety assessment

During the design phase of UAVs, critical parts which would increase the rate of failure can be detected through Reliability, Availability, Maintenance and Safety (RAMS) assessment (Petritoli et al., 2018). RAMS assessment guarantees the ability of UAVs to perform a function given in design phase, to keep functioning in a particular environment, to be maintained easily and on time, and to not pose any harm during operations to those around the UAV. Considering the costs and limitations, RAMS predictions can distinguish a problematic element and estimate the value of a failure by finding the corresponding failure rate (Hao et al., 2009). The failure rate here helps finding the problematic area by considering all components and their failure rates.

Table 2. Classification of common UAV maintenance tasks (Hobbs & Herwitz, 2008)

	Scheduled	Unscheduled
Aircraft	• Verification of secure connections during assembly • Checking control actuators movement • Deflection measuring on control surfaces • Testing flight termination system • Balance and weight check for aircraft, placing balance weights if required • Battery charging • Aircraft fueling with accurate measurement	• Correcting gasoline engine and fuel system problems • Repairing electrical connectors, airframe, landing skids and wheels • Tightening fasteners and screws loosened after flight vibrations • Responding to overheating avionics • Failed servo replacement • Repairing structural damages due to transport, packing and flight • Responding to payload changes

Table 2 *(cont)*. Classification of common UAV maintenance tasks (Hobbs & Herwitz, 2008)

	Scheduled	Unscheduled
Ground Systems	• Computer battery charge verification • Checking for latest flight software and virus protection update • Confirming no background program or extraneous utilities running • Routine computer maintenance • Checking antennas and verifying connections, performing range checks	• Responding to computer performance problems or software faults • Required software patch installation • Responding to viruses • If signal is interrupted, diagnosing and correcting the problem

4.4. UAV reliability

The reliability of a UAV can be ensured by first defining the failures which the UAV must be reliable for. The seriousness of a failure mainly depends on the outcome. When the type of the failure is defined, their criticality levels will be defined as well and it will be clearer to link them with the minimum acceptable reliability level (Blom, 2010). According to De Francesco et al. (De Francesco et al., 2014), for UAVs, there are four types of failures, which are described as follows: Catastrophic failures, where the UAV crashes with the possibility of injuries or death on the ground; Severe failures, where there is expectation of heavy damage and low probability of repair; Moderate failures, where there is no severe damage but moderate function degradation with the possibility of aborting mission; and Soft failures, where there is light damage on UAV but no mission cancellation.

The design phase and the completed design of an UAV is the main focus of reliability studies. The outputs of a reliability analysis, a list of recommendations and criticality points, provides feedback to the designers to fix the original design. This way, it is likely to achieve a higher level of reliability by taking measures and upgrading the system during the design phase of the UAV (Beard & McLain, 2012).

4.5. Maintenance for UAVs

As briefly described in Section 7.2, rapid growth in utilization of UAVs arise many concerns about operating these aircrafts safely. In this context, maintenance for UAVs generally aims to avoid outcomes of hazardous incidents such as damaging humans or assets on the ground by collision or damaging other airspace users while airborne. While having similarities with conventional maintenance in aviation, UAV maintenance has its own specific actions and procedures.

Airworthiness is also applicable for UAVs yet airworthiness certification is not required. According to the Title 14 Part 107 of Code of Federal Regulations, a civil UAV can only be operated by a person if it is in safe operation condition. The remote pilot must check the condition of UAV for safe operation before each flight (Electronic Code of Federal Regulations, 2016).

In general, maintenance activities for UAVs can be divided into two categories as scheduled and unscheduled maintenance (Hobbs & Herwitz, 2008). Scheduled tasks mainly consist of replacement of components, adjustments and routine inspections. Pre-flight functional tests, battery charging, fuel mixing and system assembly are included in scheduled tasks as well. In other respect, unscheduled tasks consist of damage identification and repair or replacement of components. Typical maintenance tasks for UAVs for the aircraft itself and ground control systems are shown in Table 2.

Beside the commonalities between conventional aviation and UASs, manufacturing standards and maintenance requirements are clearly different (Mrusek et al., 2018). Soydan et al. emphasized that surface quality of materials with high corrosion and high heat resistance are preferably considered in aviation (Soydan et al., 2020). Since UAV design and manufacturing processes have no standards, unlike manned aircrafts, various materials used on the UAS generally have no existing history of failure rates and maintenance issues. Links of data and communication and ground control units are critical systems, thus , safety of operations depends on continued airworthiness of these systems (Ley, 2016). UAVs are generally powered by consumer grade lithium batteries which are sensitive to deformation and heat and they require maintenance, inspection and extra care. Additionally, assembly and disassembly before and after each flight is not a standard procedure for most manned aircrafts, however for UAVs, this process has possible effects on the life expectancy of hardware components.

Along with hardware maintenance in UASs, the software and firmware are subject to maintenance as well (Mrusek et al., 2018). As part of the maintenance, these software and firmware are often updated and the update processes follow different paths from software update for manned aircraft avionics. For instance, one of the vital requirements of UAV relay networks is to preserve the connectivity between nodes in the network for providing reliable data communication. Connectivity maintenance in a UAV network can be a complicated task due to the fact that moving any node can affect the existing links between other nodes. Also, the software and firmware update management may require different skill set than the one which hardware maintenance needs.

4.6. UAV as a quality and safety assessment tool

The gradual shift in the commercial use of UAVs has emerged new utilization areas and opportunities. Remote sensing and high mobility capabilities allow them to inspect and analyze their environment more effectively than humans. In fact, 45% share of the UAV market belong to applications of infrastructure and construction inspection (Shakhatreh et al., 2019). As the awareness of resource-efficiency and sustainability increases, requirement for efficient methods in construction and infrastructure applications increases as well.

Structure inspections is conventionally based on visual analysis and inspection of plants and large structures are expensive and technically demanding. Special equipment such as scaffolding or access units are required for hard-to-reach structural components (Morgenthal & Hallermann, 2014). Thus, UAVs appeal for quality and safety inspections by their virtues such as remotely controlled or autonomous operation ability, ease of flight and great maneuverability. Inspections are performed with UAVs by mounting digital equipment which are able to acquire and transmit information, namely, thermal, color or infrared cameras, ultrasonic sensors or laser range finders (Máthé & Buşoniu, 2015). Sensor types can be classified as (Giacobbe & Biancuzzo, 2018):

- Proprioceptor: compass, gyroscope, altimeter, accelerometer, payload measurement, GPS module
- Interoceptive: CMOS camera, infrared camera, gamma sensors (sonar, radar, lidar)
- Exteroceptive: camera with gimbal, internal / external thermometer.

4.6.1. Quality assessment with UAVs

Inspection and analysis for quality assessment using UAV has been applied to many areas. Usual tasks related to construction such as project monitoring, quality control or defect detection are some of the examples of UAV utilization, however, a detailed list of examples according to their application area are given below (Jordan et al., 2018):

- Construction quality control assessment is applied using UAVs with integration of Building Information Modeling (Wang et al., 2015).
- Image processing methods are used for crack detection on structure surfaces to assess surface quality (Sankarasrinivasan et al., 2015).
- Vertical inspection is performed for high structures such as electricity poles, streetlights and cell towers to inspect the general condition of the structure (Sa & Corke, 2014).
- High voltage power transmission lines are inspected and:
  - the real temperature of joints on power lines are estimated (Luque-Vega et al., 2014),
  - multi UAV cooperation efficiency for inspections is proposed (Deng et al., 2014).
- Oil and gas pipelines are inspected to detect leakages (Gómez & Green, 2017)(Barchyn et al., 2017).

4.6.2. Safety assessment with UAVs

Safety inspections in the work environment generally includes monitoring employees and the working site by regular direct observations. Safety inspections on work sites generally has three main requirements (Gheisari et al., 2014):

1. Work site monitoring, identification of hazards and application of safe practices must be maintained by daily inspections.
2. Real-time data must be collected through personal examination by safety inspectors during routine activities and for observation and reporting in case of an accident.
3. Workplace safety practices must be encouraged by direct contact with the employees for immediate feedback.

These three requirements can easily be fulfilled by UAVs and in fact, applications are already present for some aspect such as real-time monitoring of a construction site (P. Liu et al., 2014) and inspection of employees on a work site to check if they are wearing hard hats (Gheisari et al., 2014).

4.6.3. Airport safety and aircraft inspections with UAVs

UAV-aided inspection applications emerge in the aviation among other examples as well. Since safety and maintenance are extremely vital in this domain, transferring some of the task to UAVs gives more safe, efficient and economical solutions (Sappington et al., 2019). Thus, proper utilization of UAVs in airports would be beneficial in numerous ways:

- Pictures of runways and pavement can be taken by performing hovering flights to detect cracks and obstacles.
- Take-off and landing operations can be coordinated to reduce human labor and increase safety.
- Periodic inspection and calibration of lightening systems requires photometric calibration equipment which requires different heights and adjustments. UAVs can easily hover at desired height and relieve the operator of time-consuming adjustments.
- Pre-flight and post-flight inspections of aircrafts which performed for every flight and requires visual inspection can be carried out in much less duration.
- Bird strikes create major problems for airports which may cause critical damages to aircrafts. UAVs can be used to scare and control the bird population around airports.

4.7. UAV Utilization During COVID-19 Global Pandemic

The COVID 19 global pandemic has forced people to stay distant with each other and be cautious when making a contact with other people or materials and surfaces. This situation provided an opportunity for robotic technologies to utilize them in various areas in order to decrease human contact as much as possible. A private company in India has provided UAVs to the local police forces to monitor areas for surveillance and handling unwarranted situations (Cyient, 2020). In many cities in China, UAVs equipped with speakers are deployed to observe and instruct crowds during the pandemic (Marr, 2020). In order to inform people about the state of emergency guidelines and social distancing rules, UAVs with speakers are used in Spain and other European countries as well (Gascueña, 2020)(Sharma, 2020)(Carassava, 2021). While UAVs are utilized for crowd surveillance, there are many applications of surveillance performed by sensors rather than security cameras such as infrared thermometers which can check individuals or groups of people simultaneously for body temperature (NDTV, 2020)(P. Singh, 2020)(UniSa, 2020)(Ratcliffe, 2021). Disinfecting public areas has become one of the common priorities during the pandemic and agricultural UAVs are adopted to spray disinfecting chemicals on these areas (Pan, 2020). Aside from these examples, the majority of the UAV applications are focused on collecting blood samples, transporting medicine, vaccines, food and other supplies before and during the global pandemic (Nui Galway, 2019)(Ackerman, 2020)(Dash, 2020)(Bateman, 2021). Their speed and agility provide quick solutions for delivering supplies between facilities or to rural areas where it would take too long to reach with conventional methods (Yang, 2020)(Adwibowo, 2021).

In the light of recent events, it can easily be observed that there will be various new utilization areas for UAVs. The developments in UAV manufacturing technologies will minimize their current weaknesses to malicious attacks and new regulations will provide a suitable environment to utilize their full potential while preventing unauthorized applications.

5. Conclusion

Aviation management is a highly complex process that requires an excessive amount of concentration to detail. A minor fault or an accident has the constant possibility of causing a disaster. Aviation operators always have to consider these matters and act on predicting or preventing such issues. Considerations about quality and safety of the operations and services are at the core of all processes throughout the organization. In this paper, the ideas of quality and safety in aviation and how they are applied to the organizations and their operations are explained. These quality and safety standards, established by international authorities, ensure the organization is eligible to provide safe operations and services which are able to fulfill customer needs. Reliability in aviation ensures the operations are safe and uninterrupted by shaping the maintenance and support mechanisms. Resilience on the other hand, attempts to minimize the probability of system failure by making the system robust and flexible. These concepts and their effects on quality and safety of operations are shown and explained with examples.

UASs have been implemented in various parts of many industries since the beginning of the Industry 4.0 revolution and will be in many different forms and many other industries and our daily lives. As seen in Table 1, the integration of UAVs in civil area of applications such as agriculture, construction, logistics and network technologies are emerging in an exponential fashion. Beside the commercial usefulness, UAVs provide safety and minimize risk factors by taking over dangerous tasks and perform these tasks faster than the conventional methods. Post-disaster, post-accident management or potentially risky inspection missions require intense focus and prompt action which UAVs can carry out with ease considering the human factor. Autonomous systems and robotics applications will continue to expand and the aviation industry will be a vital part of this course. There have been innovative challenges in avionics. However, there have been still major problems of UAVs such as reliability, safety and maintenance although their engines have become more robust. For UAVs, efficient maintenance and logistics management should be performed considering optimization regarding system availability at lowest possible Life-Cycle cost.

Although the utilization of UAVs in the aviation industry is not new and there are numerous applications, potential areas for UAVs and other technologies such as AR, machine learning, data science and mobile technologies will emerge. The industry should be in an adaptive and embracing position for these renovations and should prepare mental and infrastructural states of the organization and its entities. During extraordinary events such as COVID-19 pandemic, UAVs ensure the safety of the customers and personnel by taking over some of the workload and decreasing the human contact level to minimum. It is a recent example for all organizations to emphasize the importance and advantages of fast adaptation to utilization of UAVs in operations.

Additionally, the quality and safety regulations regarding the UAVs are still in progress. Implementation of new UAV regulations into the current international and national aviation domain will cause a necessity for the present regulations of civil aviation to be updated considering possible effects.

For further directions, there are challenges and the new directions to be considered for airport management and airlines management in a post COVID-19 era: Security and privacy are serious challenges for utilization of UAVs. Moreover, autonomous operation of UAVs is another challenge that should be taken into account because sensing of humans is required to avoid collisions. There should be a balance between supervisor interventions and autonomous operations of UAVs.

Future challenges should be toward effective integration of UAVs considering future passengers' transportation services in a post COVID-19 era.

References

A4A. (2018a). *MSG-3: Operator/Manufacturer Scheduled Maintenance Development, Volume 1 - Fixed wing aircraft*. Airlines For America. https://publications.airlines.org/CommerceProductDetail.aspx?Product=278

A4A. (2018b). *MSG-3: Operator/Manufacturer Scheduled Maintenance Development, Volume 2 - Rotorcraft*. Airlines For America. https://publications.airlines.org/CommerceProductDetail.aspx?Product=279

Ackerman, E. (2020, April 3). *Zipline Wants to Bring Medical Drone Delivery to U.S. to Fight COVID-19*. https://spectrum.ieee.org/automaton/robotics/drones/zipline-medical-drone-delivery-covid19

Adwibowo, A. (2021). Assessments of heavy lift UAV quadcopter drone to support COVID 19 vaccine cold chain delivery for indigenous people in remote areas in South East Asia. *MedRxiv*, 2021.01.09.21249494. https://doi.org/10.1101/2021.01.09.21249494

Al-Turjman, F. (Ed.). (2020). *Unmanned Aerial Vehicles in Smart Cities*. Springer International Publishing. https://doi.org/10.1007/978-3-030-38712-9

Amundarain, A., Borro, D., García-Alonso, A., Gil, J. J., Matey, L., & Savall, J. (2004). Virtual reality for aircraft engines maintainability. *Mécanique & Industries*, *5*(2), 121–127. https://doi.org/10.1051/meca:2004076

ARC. (2018). *Four SMS Trends To Watch For In 2018*. ARC Safety Management. https://arcsky.com/arc_blog/four-sms-trends-2018/

Barchyn, T., Hugenholtz, C. H., Myshak, S., & Bauer, J. (2017). A UAV-based system for detecting natural gas leaks. *Journal of Unmanned Vehicle Systems*, juvs-2017-0018. https://doi.org/10.1139/juvs-2017-0018

Barker, E. M. (1998). Aerospace Basic Quality System Standard SAE AS9000. *Quality Congress. ASQ's ... Annual Quality Congress Proceedings; Milwaukee*, 595.

Bateman, T. (2021, June 4). *Drone delivery of vaccine doses speeds up COVID-19 vaccinations in remote areas of Ghana*. https://www.euronews.com/next/2021/06/04/drone-delivery-of-vaccine-doses-speeds-up-covid-19-vaccinations-in-remote-areas-of-ghana

Beard, R. W., & McLain, T. W. (2012). *Small Unmanned Aircraft: Theory and Practice*. Princeton University Press.

Bhatt, K., Pourmand, A., & Sikka, N. (2018). Targeted Applications of Unmanned Aerial Vehicles (Drones) in Telemedicine. *Telemedicine and E-Health*, *24*(11), 833–838. https://doi.org/10.1089/tmj.2017.0289

Blom, J. D. (2010). *Unmanned Aerial Systems: A Historical Perspective*. Combat Studies Institute Press.

Bone, E., & Bolkcom, C. (2003). *Unmanned Aerial Vehicles: Background and Issues for Congress*. https://digital.library.unt.edu/ark:/67531/metacrs5693/m1/1/high_res_d/RL31872_2003Apr25.pdf

Bowling, S. R., Khasawneh, M. T., Kaewkuekool, S., Jiang, X., & Gramopadhye, A. K. (2008). Evaluating the Effects of Virtual Training in an Aircraft Maintenance Task. *The International Journal of Aviation Psychology*, *18*(1), 104–116. https://doi.org/10.1080/10508410701749506

Cacciabue, P. C., Cassani, M., Licata, V., Oddone, I., & Ottomaniello, A. (2015). A practical approach to assess risk in aviation domains for safety management systems. *Cognition, Technology & Work*, *17*(2), 249–267. https://doi.org/10.1007/s10111-014-0294-y

Canisius, F., Wang, S., Croft, H., Leblanc, S. G., Russell, H. A. J., Chen, J., & Wang, R. (2019). A UAV-Based Sensor System for Measuring Land Surface Albedo: Tested over a Boreal Peatland Ecosystem. *Drones*, *3*(1), 27. https://doi.org/10.3390/drones3010027

Carassava, A. (2021, June 7). *Greece Deploys Drones to Stop Partygoers From Breaching COVID Rules*. https://www.voanews.com/europe/greece-deploys-drones-stop-partygoers-breaching-covid-rules

Chamola, V., Hassija, V., Gupta, V., & Guizani, M. (2020). A Comprehensive Review of the COVID-19 Pandemic and the Role of IoT, Drones, AI, Blockchain, and 5G in Managing its Impact. *IEEE Access*, *8*, 90225–90265. https://doi.org/10.1109/ACCESS.2020.2992341

Chialastri, A. (2011). Resilience and Ergonomics in aviation. In *Proceedings of the fourth Resilience Engineering Symposium* (pp. 65–71). Presses des Mines. https://doi.org/10.4000/books.pressesmines.980

Chialastri, A., & Pozzi, S. (2008). Resilience in the Aviation System. In M. D. Harrison & M.-A. Sujan (Eds.), *International Conference on Computer Safety, Reliability, and Security* (pp. 86–98). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-87698-4_10

Christiansen, M., Laursen, M., Jørgensen, R., Skovsen, S., & Gislum, R. (2017). Designing and Testing a UAV Mapping System for Agricultural Field Surveying. *Sensors*, *17*(12), 2703. https://doi.org/10.3390/s17122703

Chung, S.-H., Ma, H.-L., Hansen, M., & Choi, T.-M. (2020). Data science and analytics in aviation. *Transportation Research Part E: Logistics and Transportation Review*, *134*, 101837. https://doi.org/https://doi.org/10.1016/j.tre.2020.101837

Crosby, P. B. (1979). *Quality is free: the art of making quality certain*. McGraw-Hill. https://books.google.com.tr/books?id=0RxtAAAAMAAJ

Cyient. (2020, April 2). *Cyient Provides Drone-Based Surveillance Technology to Support Telangana State Police in Implementing COVID-19 Lockdown*. https://www.cyient.com/prlisting/corporate/cyient-provides-drone-based-surveillance-technology-to-support-telangana-state-police-in-implementing-covid-19-lockdown

Dash, S. (2020, March 31). *This drone is delivering medicines, collecting blood samples and spraying sanitizers in Telangana*. https://www.businessinsider.in/business/startups/news/coronavirus-innovation-this-drone-is-delivering-medicines-collecting-blood-samples-and-spraying-sanitizers-in-telangana/articleshow/74882886.cms

De Francesco, E., De Francesco, R., Leccese, F., & Cagnetti, M. (2014). Risk analysis in aviation: The forensic point of view. *In Proceedings of the 20th IMEKO TC4 Symposium on Measurements of Electrical Quantities, Research on Electrical and Electronic Measurement for the Economic Upturn, Together with 18th TC4 International Workshop on ADC and DCA Modeling and Testing*, 563–568.

Deming, W. E. (1986). *Out of the crisis / W. Edwards Deming*. Massachusetts Institute of Technology, Center for Advanced Engineering Study ; Cambridge University Press.

Demir, K. A., Cicibas, H., & Arica, N. (2015). Unmanned Aerial Vehicle Domain: Areas of Research. *Defence Science Journal*, *65*(4), 319. https://doi.org/10.14429/dsj.65.8631

Deng, C., Wang, S., Huang, Z., Tan, Z., & Liu, J. (2014). Unmanned Aerial Vehicles for Power Line Inspection: A Cooperative Way in Platforms and Communications. *Journal of Communications*, *9*(9), 687–692. https://doi.org/10.12720/jcm.9.9.687-692

Du, Y.-C., Zhang, M.-X., Ling, H.-F., & Zheng, Y.-J. (2019). Evolutionary Planning of Multi-UAV Search for Missing Tourists. *IEEE Access*, *7*, 73480–73492. https://doi.org/10.1109/ACCESS.2019.2920623

EASA. (2015a). A Proposal to Create Common Rules For operating Drones in Europe. *European Aviation Safety Agency*.

EASA. (2015b). Concept of Operations for Drones: A Risk Based Approach to Regulation of unmanned Aircraft. *European Aviation Safety Agency*.

EASA. (2015c). Riga Declaration on Remotely Piloted Aircraft (Drones). *European Aviation Safety Agency*.

EASA - EU OPS 1.037. (2008). Regulations. *Official Journal of the European Union*, 238.

EASA - NPA 2017-05 (A). (2017). Introduction of a regulatory framework for the operation of drones—Explanatory Note. *European Aviation Safety Agency*. https://www.easa.europa.eu/sites/default/files/dfu/NPA 2017-05 %28A%29_0.pdf

Electronic Code of Federal Regulations. (2016). *Title 14 Part 107*.

Eltoukhy, A. E. E., Wang, Z. X., Chan, F. T. S., & Fu, X. (2019). Data analytics in managing aircraft routing and maintenance staffing with price competition by a Stackelberg-Nash game model. *Transportation Research Part E: Logistics and Transportation Review*, *122*, 143–168. https://doi.org/https://doi.org/10.1016/j.tre.2018.12.002

Eschen, H., Kötter, T., Rodeck, R., Harnisch, M., & Schüppstuhl, T. (2018). Augmented and Virtual Reality for Inspection and Maintenance Processes in the Aviation Industry. *Procedia Manufacturing*, *19*, 156–163. https://doi.org/10.1016/j.promfg.2018.01.022

FAA - AC 120-92B. (2006). Safety Management Systems for Aviation Service Providers. *Federal Aviation Administration:*

Advisory Circular 120-92. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_120-92B.pdf

FAA - AC 43.13-1B. (1998). *Acceptable Methods, Techniques, and Practices - Aircraft Inspection and Repair*. federal Aviation Administration.

Faiçal, B. S., Freitas, H., Gomes, P. H., Mano, L. Y., Pessin, G., de Carvalho, A. C. P. L. F., Krishnamachari, B., & Ueyama, J. (2017). An adaptive approach for UAV-based pesticide spraying in dynamic environments. *Computers and Electronics in Agriculture*, *138*, 210–223. https://doi.org/10.1016/j.compag.2017.04.011

Feigenbaum, A. V. (1991). *Total Quality Control, Revised*. McGraw-Hill Companies. https://books.google.com.tr/books?id=kkFoPgAACAAJ

Fu, Z., Jiang, J., Gao, Y., Krienke, B., Wang, M., Zhong, K., Cao, Q., Tian, Y., Zhu, Y., Cao, W., & Liu, X. (2020). Wheat Growth Monitoring and Yield Estimation based on Multi-Rotor Unmanned Aerial Vehicle. *Remote Sensing*, *12*(3), 508. https://doi.org/10.3390/rs12030508

Gascueña, D. (2020, April 16). *Drones to stop the COVID-19 epidemic*. https://www.bbva.com/en/drones-to-stop-the-covid-19-epidemic/

Ghazali, M. H. M., Teoh, K., & Rahiman, W. (2021). A Systematic Review of Real-Time Deployments of UAV-Based LoRa Communication Network. *IEEE Access*, *9*, 124817–124830. https://doi.org/10.1109/ACCESS.2021.3110872

Gheisari, M., Irizarry, J., & Walker, B. N. (2014). UAS4SAFETY: The Potential of Unmanned Aerial Systems for Construction Safety Applications. *Construction Research Congress 2014*, 1801–1810. https://doi.org/10.1061/9780784413517.184

Giacobbe, F., & Biancuzzo, E. (2018). Inspection of Components with the Support of the Drones. *International Research Journal of Engineering and Technology (IRJET)*, *5*(12), 1784–1789.

Gómez, C., & Green, D. R. (2017). Small unmanned airborne systems to support oil and gas pipeline monitoring and mapping. *Arabian Journal of Geosciences*, *10*(9), 202. https://doi.org/10.1007/s12517-017-2989-x

Gopalakrishnan, K., Gholam, H., Vidyadharan, A., Choudhary, A., & Agrawal, A. (2018). Crack damage detection in unmanned aerial vehicle images of civil infrastructure using pre-trained deep learning model. *International Journal for Traffic And Transport Engineering*, *8*(1), 1–14. https://doi.org/10.7708/ijtte.2018.8(1).01

Gössling, S. (2020). Risks, resilience, and pathways to sustainable aviation: A COVID-19 perspective. *Journal of Air Transport Management*, *89*, 101933. https://doi.org/10.1016/j.jairtraman.2020.101933

Gu, W., Hu, D., Cheng, L., Cao, Y., Rizzo, A., & Valavanis, K. P. (2020). Autonomous Wind Turbine Inspection using a Quadrotor. *2020 International Conference on Unmanned Aircraft Systems (ICUAS)*, 709–715. https://doi.org/10.1109/ICUAS48674.2020.9214066

Hao, L., Jinsong, Y., Ping, Z., & Xingshan, L. (2009). A review on fault prognostics in integrated health management. *2009 9th International Conference on Electronic Measurement & Instruments*, 4-267-4–270. https://doi.org/10.1109/ICEMI.2009.5274082

Hassanalian, M., & Abdelkefi, A. (2017). Classifications, applications, and design challenges of drones: A review. *Progress in Aerospace Sciences*, *91*, 99–131. https://doi.org/10.1016/j.paerosci.2017.04.003

Herrema, F., Curran, R., Hartjes, S., Ellejmi, M., Bancroft, S., & Schultz, M. (2019). A machine learning model to predict runway exit at Vienna airport. *Transportation Research Part E: Logistics and Transportation Review*, *131*, 329–342. https://doi.org/https://doi.org/10.1016/j.tre.2019.10.002

Hinsch, M. (2018). *Industrial Aviation Management: A Primer in European Design, Production and Maintenance Organisations*. Springer Berlin Heidelberg. https://books.google.com.tr/books?id=oVptDwAAQBAJ

Hobbs, A., & Herwitz, S. R. (2008). *Maintenance Challenges of Small Unmanned Aircraft Systems - A Human Factors Perspective*. https://doi.org/10.13140/RG.2.1.1858.8647

Hollnagel, E. (2018). *Safety-I and Safety-II: The Past and Future of Safety Management*. CRC Press.

Huuskonen, J., & Oksanen, T. (2018). Soil sampling with drones and augmented reality in precision agriculture. *Computers and Electronics in Agriculture, 154,* 25–35. https://doi.org/10.1016/j.compag.2018.08.039

IAQG. (2019). *Published Standards*. https://iaqg.org/standards/

ICAO. (2019). *State of Global Aviation Safety*. International Civil Aviation Organization. https://www.icao.int/safety/Documents/ICAO_SR_2019_final_web.pdf

ICAO. (2021). *First two weeks ADS-B data indicates improvement in overall international and domestic traffic*. https://www.icao.int/sustainability/Documents/COVID-19/ICAO_COVID 2021_03_17_Economic_Impact_TH_Toru.pdf

ICAO - Annexes 1 to 18. (2012). *The Convention on International Civil Aviation*.

ICAO - Circular 328-AN/190. (2011). Unmanned Aircraft Systems (UAS). *International Civil Aviation Organization*.

ICAO - Doc 10019. (2015). Manual on Remotely Piloted Aircraft Systems (RPAS). *International Civil Aviation Organization*.

ICAO - Doc 10144. (2020). *Handbook for CAAs on the Management of Aviation Safety Risks related to COVID-19*. https://www.icao.int/safety/SafetyManagement/Doc10144/Doc 10144.pdf

ICAO - Doc 9774. (2001). Manual on Certification of Aerodomes. *International Civil Aviation Organization*.

ICAO - Doc 9906. (2009). Quality Assurance Manual for Flight Procedure Design. *International Civil Aviation Organization, Volume 1*. https://www.icao.int/Meetings/PBN-Symposium/Documents/9906_v1_cons_en.pdf

Ishikawa, K. (1985). *What is total quality control? The Japanese way*. Prentice-Hall. https://books.google.com.tr/books?id=59hTAAAAMAAJ

ISO 9001:2015. (2015). Quality Management Principles. *International Organization for Standardization*. https://www.iso.org/publication/PUB100080.html

Jalil, B., Leone, G. R., Martinelli, M., Moroni, D., Pascali, M. A., & Berton, A. (2019). Fault Detection in Power Equipment via an Unmanned Aerial System Using Multi Modal Data. *Sensors*, *19*(13), 3014. https://doi.org/10.3390/s19133014

JAPCC - UAS CONEMP. (2010). Strategic concept of employment for unmanned aircraft systems in NATO. *Joint Air Power Competence Centre UAS Conemp Report*. http://www.japcc.org/wp-content/uploads/UAS_CONEMP.pdf

Jin, T. (2019). *Reliability Engineering and Services*. Wiley, 1st Edition. https://books.google.com.tr/books?id=Nlh-DwAAQBAJ

Jordan, S., Moore, J., Hovet, S., Box, J., Perry, J., Kirsche, K., Lewis, D., & Tse, Z. T. H. (2018). State-of-the-art technologies for UAV inspections. *IET Radar, Sonar & Navigation*, *12*(2), 151–164. https://doi.org/10.1049/iet-rsn.2017.0251

Juran, J. M., & Gryna, F. M. (1993). *Quality Planning and Analysis: From Product Development Through Use*. McGraw-Hill. https://books.google.com.tr/books?id=w95TAAAAMAAJ

Kas, K. A., & Johnson, G. K. (2020). Using unmanned aerial vehicles and robotics in hazardous locations safely. *Process Safety Progress*, *39*(1). https://doi.org/10.1002/prs.12066

Kavoosi, Z., Raoufat, M. H., Dehghani, M., Abdolabbas, J., Kazemeini, S. A., & Nazemossadat, M. J. (2020). Feasibility of satellite and drone images for monitoring soil residue cover. *Journal of the Saudi Society of Agricultural Sciences*, *19*(1), 56–64. https://doi.org/10.1016/j.jssas.2018.06.001

Kerkech, M., Hafiane, A., & Canals, R. (2020). Vine disease detection in UAV multispectral images using optimized image registration and deep learning segmentation approach. *Computers and Electronics in Agriculture*, *174*, 105446. https://doi.org/10.1016/j.compag.2020.105446

Khan, N. A., Jhanjhi, N. Z., Brohi, S. N., Usmani, R. S. A., & Nayyar, A. (2020). Smart traffic monitoring system using Unmanned Aerial Vehicles (UAVs). *Computer Communications*, *157*, 434–443. https://doi.org/10.1016/j.comcom.2020.04.049

Khan, S. K., Naseem, U., Siraj, H., Razzak, I., & Imran, M. (2021). The role of unmanned aerial vehicles and mmWave in 5G: Recent advances and challenges. *Transactions on Emerging Telecommunications Technologies*, *32*(7). https://doi.org/10.1002/ett.4241

Kim, C.-Y., & Song, B.-H. (2016). An Empirical Study on Safety Culture in Aviation Maintenance Organization. *International Journal of U- and e- Service, Science and Technology*, *9*(6), 333–344. https://doi.org/10.14257/ijunesst.2016.9.6.30

Kinnison, H. A., & Siddiqui, T. (2012). *Aviation Maintenance Management, Second Edition*. McGraw-Hill Education. https://books.google.com.tr/books?id=dsmNupJXlLYC

Kongoli, F. (2012). Automation in aviation. In *Automation* (pp. 79–102). IntechOpen. https://doi.org/10.5772/49949

Levin, M., & Kalal, T. (2005). Reliability Concepts. In *Improving Product Reliability: Strategies and Implementation* (pp. 47–63). https://doi.org/10.1002/0470014024.ch6

Ley, S. C. (2016). *UAS Maintenance, modification, repair, inspection, training, and certification considerations: A review of existing UAS maintenance data*. Alliance for System Safety of UAS Through Research Excellence (ASSURE). http://www.assureuas.org/projects/deliverables/a5/Deliverable 1 - Task 1 Review of UAS Maint Data.pdf

Liew, C. F., DeLatte, D., Takeishi, N., & Yairi, T. (2017). Recent Developments in Aerial Robotics: A Survey and Prototypes Overview. *Arvix*. http://arxiv.org/abs/1711.10085

Liu, P., Chen, A. Y., Huang, Y.-N., Han, J.-Y., Lai, J.-S., Kang, S.-C., Wu, T.-H., Wen, M.-C., & Tsai, M.-H. (2014). A review of rotorcraft Unmanned Aerial Vehicle (UAV) developments and applications in civil engineering. *Smart Structures and Systems*, *13*(6), 1065–1094. https://doi.org/10.12989/sss.2014.13.6.1065

Liu, Yanchao. (2019). An optimization-driven dynamic vehicle routing algorithm for on-demand meal delivery using drones. *Computers & Operations Research*, *111*, 1–20. https://doi.org/10.1016/j.cor.2019.05.024

Liu, Yulin, Liu, Y., Hansen, M., Pozdnukhov, A., & Zhang, D. (2019). Using machine learning to analyze air traffic management actions: Ground delay program case study. *Transportation Research Part E: Logistics and Transportation Review*, *131*, 80–95. https://doi.org/https://doi.org/10.1016/j.tre.2019.09.012

Liu, Z., Xie, C., Yan, M., Bu, S., & Zhang, C. (2014). Maintenance Path Planning for Aircraft Virtual Maintenance. *Lecture Notes in Electrical Engineering*, *296*, 587–597. https://doi.org/10.1007/978-3-642-54236-7_64

Luque-Vega, L. F., Castillo-Toledo, B., Loukianov, A., & Gonzalez-Jimenez, L. E. (2014). Power line inspection via an unmanned aerial system based on the quadrotor helicopter. *MELECON 2014 - 2014 17th IEEE Mediterranean Electrotechnical Conference*, 393–397. https://doi.org/10.1109/MELCON.2014.6820566

Marchese, M., Moheddine, A., & Patrone, F. (2019). IoT and UAV Integration in 5G Hybrid Terrestrial-Satellite Networks. *Sensors*, *19*(17), 3704. https://doi.org/10.3390/s19173704

Marr, B. (2020, March 18). *Robots And Drones Are Now Used To Fight COVID-19*. https://www.forbes.com/sites/bernardmarr/2020/03/18/how-robots-and-drones-are-helping-to-fight-coronavirus/#2a8bfbca2a12

Máthé, K., & Buşoniu, L. (2015). Vision and Control for UAVs: A Survey of General Methods and of Inexpensive Platforms for Infrastructure Inspection. *Sensors*, *15*(7), 14887–14916. https://doi.org/10.3390/s150714887

McDonald, N., Corrigan, S., Ulfvengren, P., & Baranzini, D. (2014). Proactive Safety Performance for Aviation Operations. In D. Harris (Ed.), *International Conference on Engineering Psychology and Cognitive Ergonomics* (pp. 351–362). Springer International Publishing.

Mliki, H., Bouhlel, F., & Hammami, M. (2020). Human activity recognition from UAV-captured video sequences. *Pattern Recognition*, *100*, 107140. https://doi.org/10.1016/j.patcog.2019.107140

Morgenthal, G., & Hallermann, N. (2014). Quality Assessment of Unmanned Aerial Vehicle (UAV) Based Visual Inspection of Structures. *Advances in Structural Engineering*, *17*(3), 289–302. https://doi.org/10.1260/1369-4332.17.3.289

Mrusek, B. M., Kiernan, K. W., & Clark, P. J. (2018). UAS Maintenance: A Critical Component in Maintaining Airworthiness. *International Journal of Aviation, Aeronautics, and Aerospace*, *5*(5).

NDTV. (2020, April 11). *Delhi Civic Body Begins Thermal Screening People On Balconies With Drones*. https://www.ndtv.com/delhi-news/coronavirus-delhi-civic-body-using-drones-to-check-temperature-of-people-on-balconies-2209832

Nordin, M. H., Sharma, S., Khan, A., Gianni, M., Rajendran, S., & Sutton, R. (2022). Collaborative Unmanned Vehicles for Inspection, Maintenance, and Repairs of Offshore Wind Turbines. *Drones*, *6*(6), 137. https://doi.org/10.3390/drones6060137

Nowlan, F. S., & Heap, H. F. (1978). Reliability-Centered Maintenance. In *United Airline Publications*. Dolby Access Press.

Nui Galway. (2019, September 16). *NUI Galway makes Aviation History by Completing the World's First Diabetes Drone Mission from Mainland to Aran Islands*. https://www.nuigalway.ie/about-us/news-and-events/news-archive/2019/september/nui-galway-makes-aviation-history-by-completing-the-worlds-first-diabetes-drone-mission-from-mainland-to-aran-islands.html

Otto, A., Agatz, N., Campbell, J., Golden, B., & Pesch, E. (2018). Optimization approaches for civil applications of unmanned aerial vehicles (UAVs) or aerial drones: A survey. *Networks*, *72*(4), 411–458. https://doi.org/10.1002/net.21818

Outay, F., Mengash, H. A., & Adnan, M. (2020). Applications of unmanned aerial vehicle (UAV) in road safety, traffic and highway infrastructure management: Recent advances and challenges. *Transportation Research Part A: Policy and Practice*, *141*, 116–129. https://doi.org/10.1016/j.tra.2020.09.018

Özoğlu, B., Çakmak, E., & Koç, T. (2019). Clarke & Wright's Savings Algorithm and Genetic Algorithms Based Hybrid Approach for Flying Sidekick Traveling Salesman Problem. *European Journal of Science and Technology*, 185–192. https://doi.org/10.31590/ejosat.637816

Palmarini, R., Erkoyuncu, J. A., Roy, R., & Torabmostaedi, H. (2018). A systematic review of augmented reality applications in maintenance. *Robotics and Computer-Integrated Manufacturing*, *49*, 215–228. https://doi.org/10.1016/j.rcim.2017.06.002

Pan, C. (2020, April 1). *Spain's military uses DJI agricultural drones to spray disinfectant in fight against Covid-19*. https://www.scmp.com/tech/gear/article/3077945/spains-military-uses-dji-agricultural-drones-spray-disinfectant-fight

Petritoli, E., Leccese, F., & Ciani, L. (2018). Reliability and Maintenance Analysis of Unmanned Aerial Vehicles. *Sensors*, *18*(9), 3171. https://doi.org/10.3390/s18093171

Plioutsias, A., Karanikas, N., & Chatzimihailidou, M. M. (2018). Hazard Analysis and Safety Requirements for Small Drone Operations: To What Extent Do Popular Drones Embed Safety? *Risk Analysis*, *38*(3), 562–584. https://doi.org/10.1111/risa.12867

Rana, K., Praharaj, S., & Nanda, T. (2016). Unmanned Aerial Vehicles (UAVs): An Emerging Technology for Logistics. *International Journal of Business and Management Invention*, *5*(5), 86–92.

Ratcliffe, R. (2021, June 7). *Police in Malaysia use drones to detect high temperatures amid Covid surge*. https://www.theguardian.com/world/2021/jun/07/police-in-malaysia-use-drones-to-detect-high-temperatures-amid-covid-surge

Romero, M., Luo, Y., Su, B., & Fuentes, S. (2018). Vineyard water status estimation using multispectral imagery from an UAV platform and machine learning algorithms for irrigation scheduling management. *Computers and Electronics in Agriculture*, *147*, 109–117. https://doi.org/10.1016/j.compag.2018.02.013

Sa, I., & Corke, P. (2014). Vertical Infrastructure Inspection Using a Quadcopter and Shared Autonomy Control. In *Field and Service Robotics* (pp. 219–232). https://doi.org/10.1007/978-3-642-40686-7_15

SAMA. (2022). *Regulations on Unmanned Aerial Vehicles (SYH-IHAS)*. The State Airport Administration of Turkey. https://web.shgm.gov.tr/documents/sivilhavacilik/files/mevzuat/sektorel/taslaklar/2022/SHY-IHAS.pdf

Sankarasrinivasan, S., Balasubramanian, E., Karthik, K., Chandrasekar, U., & Gupta, R. (2015). Health Monitoring of Civil Structures with Integrated UAV and Image Processing System. *Procedia Computer Science*, *54*, 508–515. https://doi.org/https://doi.org/10.1016/j.procs.2015.06.058

Sappington, R. N., Acosta, G. A., Hassanalian, M., Lee, K., & Morelli, R. (2019, June 17). Drone Stations in Airports for Runway and Airplane Inspection Using Image Processing Techniques. *AIAA Aviation 2019 Forum*. https://doi.org/10.2514/6.2019-3316

Schmidt, M. (2017). A review of aircraft turnaround operations and simulations. *Progress in Aerospace Sciences*, *92*, 25–38. https://doi.org/https://doi.org/10.1016/j.paerosci.2017.05.002

Schweizer, E. A., Stow, D. A., & Coulter, L. L. (2018). Automating Near Real-Time, Post-Hazard Detection of Crack Damage to Critical Infrastructure. *Photogrammetric Engineering & Remote Sensing*, *84*(2), 75–86. https://doi.org/10.14358/PERS.84.2.75

Segal, A., & Bot, Y. (2018). Maintenance of a Drone Fleet. *2018 Annual Reliability and Maintainability Symposium (RAMS)*, 1–3. https://doi.org/10.1109/RAM.2018.8463142

Shakhatreh, H., Sawalmeh, A. H., Al-Fuqaha, A., Dou, Z., Almaita, E., Khalil, I., Othman, N. S., Khreishah, A., & Guizani, M. (2019). Unmanned Aerial Vehicles (UAVs): A Survey on Civil Applications and Key Research Challenges. *IEEE Access*, *7*, 48572–48634. https://doi.org/10.1109/ACCESS.2019.2909530

Sharma, M. (2020, April 20). *How drones are being used to combat COVID-19*. https://www.geospatialworld.net/blogs/how-drones-are-being-used-to-combat-covid-19/

Singh, N., Muthukrishnan, P., & Sanpini, S. (2019). *Industrial System Engineering for Drones: A Guide with Best Practices for Designing*. Apress, Berkeley, CA. https://doi.org/10.1007/978-1-4842-3534-8

Singh, P. (2020, April 11). *Thermal scan: Drones check people for fever in Delhi*. https://timesofindia.indiatimes.com/city/delhi/thermal-scan-drones-check-people-for-fever/articleshow/75088774.cms

Soydan, O., Göv, K., & Eyercioğlu, Ö. (2020). Surface Finishing of Aerospace Materials. *El-Cezerî Journal of Science and Engineering*, *7*(2), 700–709. https://doi.org/10.31202/ecjse.691548

Stöcker, C., Bennett, R., Nex, F., Gerke, M., & Zevenbergen, J. (2017). Review of the Current State of UAV Regulations. *Remote Sensing*, *9*(5), 459. https://doi.org/10.3390/rs9050459

Stolzer, A. J., & Goglia, J. J. (2016). *Safety Management Systems in Aviation*. CRC Press. https://books.google.com.tr/books?id=Qk6rCwAAQBAJ

Stroppiana, D., Villa, P., Sona, G., Ronchetti, G., Candiani, G., Pepe, M., Busetto, L., Migliazzi, M., & Boschetti, M. (2018). Early season weed mapping in rice crops using multi-spectral UAV data. *International Journal of Remote Sensing*, *39*(15–16), 5432–5452. https://doi.org/10.1080/01431161.2018.1441569

Subagyo, T. H. (2002). *Quality management practices in the South East Asian airlines'operations function*. PhD Thesis, Cranfield University, College of Aeronautics.

Sumanth Reddy, T. B., Harsha Teja, P., Pavan Teja, R., & Praneeth, T. (2019). Adaptive Autonomous Technology in Unmanned Aerial Vehicles for Parcel Delivery. *International Journal of Scientific Research in Computer Science, Engineering and Information Technology*, 07–12. https://doi.org/10.32628/CSEIT1951138

Tan, Y., Li, S., Liu, H., Chen, P., & Zhou, Z. (2021). Automatic inspection data collection of building surface based on BIM and UAV. *Automation in Construction*, *131*, 103881. https://doi.org/10.1016/j.autcon.2021.103881

Tazibt, C. Y., Achir, N., & Djamah, T. (2022). Online drone-based data gathering strategies for ground sensor networks. *International Journal of Sensor Networks*, *38*(3), 177. https://doi.org/10.1504/IJSNET.2022.121702

UniSa. (2020, March 26). *UniSA working on 'pandemic drone' to detect coronavirus*. https://www.unisa.edu.au/Media-Centre/Releases/2020/unisa-working-on-pandemic-drone-to-detect-coronavirus/

Vander Weide, S. A., & Secretan, J. (2009). The Potential for Improving Maintainer, Equipment and Flight Safety through Virtual Maintenance Training. *SAE Technical Paper 2009-01-3225*. https://doi.org/10.4271/2009-01-3225

Vieira, D. R., Rebaiaia, M.-L., & Chain, M. C. (2016). The Application of Reliability Methods for Aircraft Design Project Management. *American Journal of Industrial and Business Management*, *6*, 967–992. https://doi.org/10.4236/ajibm.2016.69094

Vrba, M., Stasinchuk, Y., Báča, T., Spurný, V., Petrlík, M., Heřt, D., Žaitlík, D., & Saska, M. (2022). Autonomous capture of agile flying objects using UAVs: The MBZIRC 2020 challenge. *Robotics and Autonomous Systems*, *149*, 103970. https://doi.org/10.1016/j.robot.2021.103970

Wang, J., Sun, W., Shou, W., Wang, X., Wu, C., Chong, H.-Y., Liu, Y., & Sun, C. (2015). Integrating BIM and LiDAR for Real-Time Construction Quality Control. *Journal of Intelligent & Robotic Systems*, *79*(3), 417–432. https://doi.org/10.1007/s10846-014-0116-8

Wu, Q., Xu, J., Zeng, Y., Ng, D. W. K., Al-Dhahir, N., Schober, R., & Swindlehurst, A. L. (2021). A Comprehensive Overview on 5G-and-Beyond Networks With UAVs: From Communications to Sensing and Intelligence. *IEEE Journal on Selected Areas in Communications*, *39*(10), 2912–2945. https://doi.org/10.1109/JSAC.2021.3088681

Xu, S., Chan, H. K., & Zhang, T. (2019). Forecasting the demand of the aviation industry using hybrid time series SARIMA-SVR approach. *Transportation Research Part E: Logistics and Transportation Review*, *122*, 169–180. https://doi.org/https://doi.org/10.1016/j.tre.2018.12.005

Yakıştıran, Ö., & Yaz, M. (2020). Fuzzy Logic Positioning of a Vehicle in the Movement Direction. *El-Cezerî Journal of Science and Engineering*, *7*(1), 1–8. https://doi.org/10.31202/ecjse.581440

Yang, J. (2020, March 16). *3 ways China is using drones to fight coronavirus*. https://www.weforum.org/agenda/2020/03/three-ways-china-is-using-drones-to-fight-coronavirus/

Zhou, D., Shi, J. M., Geng, J., & Lv, C. (2010). Virtual Maintenance Concepts and Methods. *Applied Mechanics and Materials*, *26–28*, 714–719. https://doi.org/10.4028/www.scientific.net/AMM.26-28.714

Zio, E., Fan, M., Zeng, Z., & Kang, R. (2019). Application of reliability technologies in civil aviation: Lessons learnt and perspectives. *Chinese Journal of Aeronautics*, *32*(1), 143–158. https://doi.org/https://doi.org/10.1016/j.cja.2018.05.014