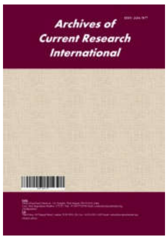

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Risk Assessment and Mitigation for Unmanned Aerial Vehicles

Osman Yazicioglu[1*] and Oguz Borat[1]

[1]*Department of Industrial Engineering, Istanbul Commerce University, Istanbul.*

Authors' contributions

This work was carried out in collaboration between both authors. Authors OY and OB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

UAVs performance is improved, in addition to GPS, they can find routes with artificial intelligence and various techniques, and can fly autonomously. The global UAV market was US$ 25.59 billion in 2018. It is estimated that the market will reach US$70.28 billion by 2029. The first three UAV manufacturers were DCL (USA), Parrot (France) and Yuneec (PRC) and are now being produced in many countries. Aircrafts are exposed to various risks: an aerodynamic stall due to inconsistent sensor readings and inadequate response, hitting a flock of geese or flying objects, pilot being unable to prevent the plane repeatedly nosediving despite following procedures. Therefore, procedures issued by aviation agency for aircraft type certification require an aircraft manufacturer ("applicant") to demonstrate that its design complies with all applicable agency's regulations and requirements. Safety risk management is a key component of a safety management system and involves fundamental activities such as identifying safety hazards, and assessing the risks and mitigation. Risk management is an integral component of safety management and involves some essential steps.Take into account any current mitigation measures and assess the seriousness in terms of the worst possible realistic scenario. The risk assessment considered five operational

**Corresponding author: Email: oyazicioglu@ticaret.edu.tr;*

environments; remote, rural, suburban, urban, and congested. Reliability, availability, maintainability, and safety assessment are important study in the development of UAVs. This kind of study is mandatory to increase the reliability of the UAV, its availability, and to reduce repair and maintenance costs.

Keywords: UAV; UAS; safety risk management.

1. INTRODUCTION

The rapidly growing market of unmanned aeronautical vehicles presents numerous new opportunities with new applications and improvements in vehicle characteristics. People involved in this booming sector to designate these unmanned aerial systems found in more and more areas currently use several names. Manufacturers, public organizations, operators and associations are all referring to some specific terms with slight differences contained in the definitions from one to another. Unmanned Aerial System (UAS) is the entire package needed to operate the system, which includes the Unmanned Aerial Vehicle (UAV) itself, the ground control system, camera, GPS, all the software, skills needed to operate the system and tools required for maintenance.

A UAV herd is a large number of UAV groups that are involved in a self-organizing and self-adapting mannequin to achieve a general mission goal. They proposed a number of models with the inclusion of limited communication in the existing model [1].

The UAV can deliver a floating device to the swimmer safely and quickly. Adding an UAV to rescue operations can improve the quality and speed of first aid while keeping lifeguards away from dangerous marine conditions [2].

Fukushima Daiichi Nuclear Power Plant accident occurred in 2011. A UAV equipped with a small gamma-spectrometer and height normalization system was used to generate maps of the radiation-infected areas [3].

UAV is the acronym of Unmanned Aerial Vehicle. By being the world pioneer in the creation and implementation of regulations for the use of commercial unmanned aerial vehicles, the French Directorate for Civil Aviation (DGAC) is referring to them as drones. The International Civil Aviation Organization (ICAO) employs the acronym RPAS (standing for Remotely Piloted Aircraft System). The definition associated is that these systems as “based on cutting-edge developments in aerospace technologies, offering advancements which are opening new and enhanced civil-commercial applications as well as improvements to the safety and efficiency of the entire civil aviation”. The term RPAS appears to be the preferred terminology used by the international aviation-related agencies like the International Civil Aviation Organization (ICAO). Euro control, the European Aviation Safety Agency (EASA), the Civil Aviation Safety Authority (CASA, Australia), the Civil Aviation Authority (CAA, New Zealand) and the BeUAS are following this trend. Despite the global international agreement on the RPAS (Remotely Piloted Aircraft System) word, some American and British organizations decided to go for the UAS acronym standing for Unmanned Air/Aircraft System. The Civil Aviation Authority (CAA, United Kingdom) provides a complete definition and explanation of this choice: The terms Unmanned Aircraft (UA) or Remotely Piloted Aircraft (RPA). They are used to describe the aircraft itself, whereas the term Unmanned Aircraft System (UAS) is generally used to describe the entire operating equipment including the aircraft, the control station from where the aircraft is operated and the wireless data link.

UAV herds are expected to play important role in future military applications. Strategies that form the basis for the measurement and evaluation of robustness have been evaluated (Wang et al. 2019). The Federal Aviation Administration (FAA, United States), the European Aviation Safety Agency (EASA) and the Unmanned Aerial Vehicle Systems Association (UAVSA) also exploit this UAS terminology. A general weight naming classification also exists for unmanned air vehicles UAVs. So, following their mass, different names are used for UAVs: MAV; from Micro Air Vehicle, for UAVs having a mass of less than 0.001 kg. The sUAS is the acronym of small Unmanned Aircraft System, used for UAVs weighting less than 25 kg. The letter “s” is especially written in lowercase, to accentuate the small size of these aircrafts UAV; is then used for unmanned aircraft with a weight of more than 25 kg autonomous flight capabilities of Unmanned Aerial Vehicles (UAVs), which are becoming increasingly common, are also being developed. Their performance is improved, in addition to GPS, they can find routes with artificial intelligence and various techniques, and can fly autonomously. UAVs are unmanned and have a wide range of size and weight values. Of course, drones are unmanned like UAVs, but they do not have autonomous flight [4,5,2,6,7]. Security risk management and definition of seriousness for aviation sector discussed below.

1.1 History of Technology

Drones have been around for more than two decades, but their roots date back to World War I when both the USA and France worked on developing automatic, unmanned airplanes. However, the last few years have been significant in terms of drone adoption, usage expansion across industries, and global awareness.

From technically operating sensitive military areas to luring hobbyists throughout the world, drone technology has developed and prospered in the last few years. Individuals, commercial companies, and governments have come to realize that drones have multiple uses, which include:

a. Aerial photography for film
b. Border control surveillance
c. Building safety inspections
d. Express delivery
e. Geographic mapping of inaccessible locations
f. Precision crop monitoring
g. Thermal sensor drones for rescue operations

Developments of hundreds of more uses of drones are underway due to the multiple investments pouring into this promising industry every day [8].

2. SAFETY RISK

The first three UAV manufacturers were DCL (USA), Parrot (France) and Yuneec (PRC) and are now being produced in many countries. The global UAV market was US$ 25.59 billion in 2018. It is estimated that the market will reach $70.28 billion by 2029 (www.einconnect007.com, 2019). The number of UAV consumers is expected to increase from 1.1 million to 3.55 million between 2016 and 2021 [10]. The figs. in the aviation sector are much larger. Nevertheless, there are accidents with different reasons for safety reasons. Some of these are given below [11].

A passenger plane crashed into an apartment building in downtown Sao Paolo, Brazil, and died on the entire ship and several apartment buildings. France Concorde was one of the worst aircraft-type safety records (due to low flight frequency), killing 100 passengers and 9 crew members in a single accident in July 2000 from a 27-year zero accident record.

In June 2009, the new Airbus A330, flying from South America to Europe, killed 228, the highest death of all aircraft types crushed in the Atlantic Ocean due to inconsistent sensor readings and inadequate response on board.

After hitting a flock of geese, a commercial airplane miraculously landed safely on the Hudson River in Manhattan, New York. The crash of the Polish Air Force Tu-154 in April 2010 probably killed the passengers due to human error.

Similarly, accident registrations have begun for increasingly popular UAVs: in July 2019, the RQ-7 Shadow drone crashed into the mountains from Wheeler Army Airport near Honolulu [12].
People faced with the immediate challenge of the wide range of risk assessment implementation, with different objectives, terminologies and technical demands. There are four basic ideas common to all risk assessments:

1. Strict discipline needed
2. The development of a risk assessment is cyclical
3. The process is a teamwork
4. There are many tasks common to most assessments.

Reliability is a statistical measure of the probability that a machine element will not break. Some researchers considered reliability of UAVs [13]. Since reliability will never reach 100%, there is a risk in any case. The reliability factor for the 0.999 reliability is 0.753. Risk assessment is a tool used to assess operational risks, so that an organization can effectively mitigate and manage risks to an acceptable level. Some pitfalls in risk assessment relate to lack of communication, UAV design process, hierarchy of controls, hazard identification, risk assessment techniques, acceptable risk level of the organization, risk assessment and risk management framework [14].

Education is important in assessing risk. National qualifications frameworks are gaining importance in countries and awareness of related sectors is increasing. It is very important for the individual and the society to determine the personal gains through qualifications and to ensure that qualifications are accepted and validated among countries. Turkey develops educational policy that comply with EU standards. In the upcoming period, the Turkish Qualification Framework will be actively implemented and expanded by enhancing the quality of the education and training system and strengthening the relations between education and employment [15,16].

3. SAFETY RISK MANAGEMENT

Aircrafts are exposed to various risks: an aerodynamic stall due to inconsistent sensor readings and inadequate response, hitting a flock of geese or flying objects, pilot being unable to prevent the plane repeatedly nosediving despite following procedures [11]. Therefore, procedures issued by aviation agency for aircraft type certification require an aircraft manufacturer (“applicant”) to demonstrate that its design complies with all applicable agency’s regulations and requirements. For transport-category airplanes, as part of this process, applicants must demonstrate through analysis, test, or both that their design meets the applicable requirements under certain code of related regulations. Specifically, some of define the requirements for control systems in general and stability augmentation and automatic and power-operated systems, respectively.

UAVs and UASs are used in a wide variety of environments for a wide range of purposes (Table 1).

As can be seen, the function and working environments are very different. Therefore, very different details need to be taken into consideration in terms of risk assessment.

Speed, bearing capacity, altitude, comfort and technological developments in aviation sector requires re-examination of risk factors. Similar factors and their risks apply to ground-controlled unmanned aerial vehicles. Safety risk management is a key component of a safety management system and involves fundamental activities:

- Identifying safety hazards,
- Assessing the risks and mitigation.

There are several methods of identifying hazards:

- Brainstorming
- Formal review of standard
- Questionnaires
- One person standing back from the operation and monitoring it critically
- Safety assessments
- Hazard reporting systems.

Table 1. UAV application areas

1.	Agriculture	11.	Mapping
2.	Aviation	12.	Maritime
3.	City/Government	13.	Marketing
4.	Construction / Pre-Construction	14.	Meteorology
5.	Disaster Response	15.	Mining / Oil & Gas
6.	Education	16.	Natural History Surveys
7.	Engineering	17.	Real Estate
8.	Environment &AM; Climate	18.	Tourism
9.	Inspections	19.	Utilities
10.	Insurance		

Early warning safety system suggested steps:

- Identify safety hazards
- Rank the probability and severity of these hazards
- Identify the current defenses in place to manage them
- Evaluate the effectiveness of these hazards
- Identify additional defenses where required
- Record all this information in hazard register

Risk management is an integral component of safety management and involves some essential steps as shown in Fig. 1. First step is hazard identification, second step is risk analysis probability, third step is risk analysis severity and fourth one is risk assessment. Yes, mean risk acceptable, no mean requirement to reduce the risk to an acceptable level.

1st Step: Equipment, procedures

2nd Step: Analysis the likely hood of the consequence occuring procedures

3rd Step: Evaluate the seriousness of the consequence procedures

4th Step: Is the assessed risk acceptable?

Fig. 1. Safety risk management [17].

4. IDENTIFICATION OF THE SEVERITY

Take into account any current mitigation measures and assess the seriousness in terms of the worst possible realistic scenario. Seriousness level is shown in Table 2 [17].

Table 2. Seriousness levels

Level	Seriousness	Descriptor
1	Negligible	Insignificant
2	Minor	First aid treatment in the workplace
3	Moderate	Medical treatment required
4	Major	Extensive injuries
5	Severe	Catastrophic

5. LIKELY HOOD OF OCCURRENCE

Take into account any current mitigation measures and assess the likelihood of the risk. Likelihood level is shown in Table 3 [17].

Table 3. Likelihood level

Level	Likelihood	Descriptor
1	Rare	Once in the next 10 years may ocur
2	Unlikely	Once in the next 1-5 years may occur
3	Possible	Once in the next 12 months may occur
4	Likely	Once in the next month may occur
5	Almost certain	Imminent-is expected to occur in most circumstances

6. QUALITATIVE RISK ASSESSMENT

A qualitative risk assessment of the hazards listed in Table 4 was conducted. Each hazard was considered in terms of all three dimensions of the problem space illustrated in Fig. 1, operational complexity, population density, and vehicle weight and configuration. In addition, each hazard was described in terms of possible causes and considered in terms of credible outcomes [18].

Table 4. Vehicle level hazards set

Hazard Number	Hazard
VH-1	Aircraft loss of control
VH-2	Aircraft fly-away
VH-3	Aircraft loss communication
VH-4	Aircraft loss of navigation capability
VH-5	Unsuccessful landing
VH-6	Unsuccessful flight termination
VH-7	Failure

Table 5. UAV classes

UAV Classes	Maximum mass, kg	Maximum velocity, km/h	Maximum kinetic energy, N.m
Micro - UAS	2	111	957
Mini – UAS	9	161	9149
Small – UAS	25	161	25157

The risk assessment considered five operational environments: Remote, rural, suburban, urban, and congested. Additionally, we analyzed the risks associated with three vehicle weight classes as shown in Table 4. Micro UAS (W ≤ 2 kg), Mini UAS (2 < W ≤ 9 kg), and Small UAS (9 < W ≤ 25 kg), and finally three sUAS vehicle configurations were evaluated: fixed wing (FW), multirotor (MR), and unmanned helicopter (UH). Five items must be considered such as sUAS classification, severity classes, likelihood classes, risk matrix, and results [18].

6.1 SUAS Classification

It is likely that any unmanned aircraft classification will be centered on the UAS's mass and speed (i.e., on its kinetic energy). We have chosen maximum speeds proposed by the Small Unmanned Aircraft System Aviation Rulemaking Committee (sUAS ARC) for UAVs up to 25 kg. The specific groupings are given in Table 4.-It is likely that any unmanned aircraft classification will be centered on the UAS's mass and speed. The specific groupings are shown in Table 5.

6.2 Severity Classes

Manned aircraft system failures are defined in terms of their effect on both the aircraft and on persons. Catastrophic hazardous effects involve multiple fatalities, loss of the aircraft, or incapacitation of the flight crew [18].

6.3 Likelihood Classes

Likelihood is defined as the estimated probability or frequency of a hazard's effect or outcome. Quantitative allowable probabilities for manned airplane hazards are taken from the various FAA system safety Advisory Circulars.

6.4 Risk Matrix Classification

Likelihood is defined as the estimated probability or frequency of a hazard's effect or outcome.

6.5 Results Classification

A discussion of how we applied the standard risk assessment process to the evaluation of the aircraft loss of control hazard.

7. UNMANNED AERIAL VEHICLE DESIGN

Male and female molds of a UAV are produced with glass fiber fabric and special mold resin. Manufacturing accomplished using parts, glass, carbon and aramid fiber material and epoxy resin, wet laying and vacuum bagging technique. Wing, tail and body shells are produced primarily and the reinforcing structures are then integrated into the shells and cured. The shells were then combined and separate components were obtained. Rear landing gear and tail pipes are also made of carbon fiber composite material. All components are assembled in alignment molds and UAV production is completed [19]. Reliability, availability, maintainability, and safety assessment are important study in the development of UAVs. This kind of study is mandatory to increase the reliability of the UAV, its availability, and to reduce repair and maintenance costs. The CoDeF structure: A way to evaluate Ai including failures caused by multiple minor degradations [20].

An unmanned aerial vehicle designed with the following values; maximum payload = 300 kg, maximum cruise velocity = 900 km/h, and duration time = 50 h. A paper is addressed to develop a conceptual design process of high-performance UAV, which carries a maximum payload of about 300 kg and can travel for the maximum range 900 km/hrs. For about 50 hours of maximum endurance [21].

A research on the development of a new logistic approach, based on reliability and maintenance assessment, with the final aim of establishing a more efficient interval for the maintenance activities for Unmanned Aerial Vehicles [13].

Modern turbofan engines, powered by most large transport aircraft, have unmatched reliability and rarely demand constant attention from the flight crew. Using control task analysis, they analyzed the flight crew response to a flight power plant system failure [22]. A multi-body system model of a particular collision was found. Verification shows that the multibody system model is closely compatible with experimental UA system release tests on a crush dummy. It was found that a 1.2 kg mass UA system could cause severe head trauma in humans [23]. Fail-safe and damage-tolerant principles can be used in UAV design. The design principle is important for mitigation. A balanced combination of these principles can be proposed.

8. CONCLUSION

UAVs can be classified according to their weight. UAV weighs more than 25 kg. Smaller ones are called micro UAV, mini UAV, and small UAV. The largest UAV manufacturers in the world are the USA, PRC and France. The number of UAVs and UASs whose usage areas are rapidly increasing are examined. It has been shown that UAV and UAS are used in very different areas for different purposes and the number of usage areas more than a hundred. Therefore, as in conventional aircraft, the need for a systematic structure of risk safety, risk safety management, identification, likelihood, occurrence and qualitative risk assessment is emphasized. Speed, bearing capacity, altitude, comfort and technological developments in aviation sector requires re-examination of risk factors. Similar factors and their risks apply to ground-controlled unmanned aerial vehicles. There are four basic ideas common to all risk assessments such as strict discipline.

Safety risk management is a key component of a safety management system and involves fundamental activities; identifying safety hazards and assessing the risks and mitigation. There are several methods of identifying hazards. Among these brainstorming, formal review of standards, questionnaires, safety assessments, and hazard reporting systems may be considered. The safety principle must be taken into account in the initial design of UAV for risk mitigation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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