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Study of operational requirements in hostile and congested areas with unmanned aerial vehicles (UAV/RPAS)

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Study of operational requirements in hostile and congested areas with unmanned aerial vehicles (UAV/RPAS)

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Report

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Abstract

This study analyses and determines the operational requirements for unmanned aerial vehicles and remotely piloted aircrafts when operating in congested and hostile areas. In order to do so, a study of present regulatory framework from different countries is done and proposals published by regulating authorities from Europe and America as well, concluding this initial approach to unmanned aerial vehicle's regulations with a benchmark of best practices.

Afterwards, a risk analysis and a safe study are done by identifying potential risks, taking into account all possible situations and scenarios that can be produced during an operation in a congested area. Once the risks are adequately identified, an evaluation of them is performed, obtaining as a result a safety level which is acceptable or unacceptable in order to ensure the integrity of people on ground, and consequently developing the operation or not. Finally, for those operations associated to a risk that result in an unacceptable safety level, mitigation measures are proposed to reduce the likelihood of hazard happening and the severity of the consequences. It may be noted that these mitigation measures consist in adding technology to unmanned aircraft systems and establishing operational procedures.

Preface

As the number of operations with unmanned aerial vehicles and remotely piloted aircrafts has shot up in the last years and expectations in a near future say that these kind of aircraft will be increasingly common to observe in the sky, this study has been done to evaluate the situation of regulations regarding their use in congested and hostile areas to this day.

Currently, the lack of regulations regarding the operation of this kind of aircraft over densely populated areas is a real fact, having for every country its own regulatory framework, which in practically all of the cases is prohibited to operate in congested areas. This situation is not suitable since most of the innovative applications using unmanned aircraft are conceived to be performed in urban areas. Thus, present regulations must be adjusted to real needs by establishing operational requirements for these kind of operations so that safety must be ensured for people on ground, because unmanned aircraft have come here to change many things and be sure the will stay for years.

Summary

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Abbreviations

UAV	Unmanned Aerial Vehicle
RPA	Remotely Piloted Aircraft
UAS	Unmanned Aircraft Systems
RPAS	Remotely Piloted Aircraft Systems
NPA	Notice of Proposed Amendment
A-NPA	Advance Notice of Proposed Amendment
EASA	European Aviation Safety Agency
OPS	Operations
ICAO	International Civil Aviation Organisation
AESA	Agencia Estatal de Seguridad Aérea
NOTAM	Notice to Air men
DGAC	Direction Générale de l'Aviation Civile
CAA	Civil Aviation Authority
NAA	National Aviation Authority
FAA	Federal Aviation Administration
VLOS	Visual line of sight
BVLOS	Beyond visual line of sight
MTOM	Maximum take off mass
OA	Operation Authorisation
NAS	National Airspace System
GPS	Global Position System
ESC	Electronic speed controller
RTH	Return to home

1 Aim of the study

The aim of this study is to analyse the operational requirements of UAVs and RPAs when operating in special conditions, specifically in hostile and congested areas. As there are not any regulations yet considering this fact, the current regulatory framework concerning UAVs will be analysed introducing some proposals of operational procedures and technology that guarantee safety, minimising all the risks previously assessed.

2 Scope of the study

The scope of this study is presented below:

- Determination of the tasks and workloads
- Information research
- Development of the project charter
- Introduction and background
- Study of the regulatory framework
- Benchmark of best practices
- Analyse operational conditions
- Risk analysis
- Safety study
- Proposal of operational procedures and technology
- Environmental impact
- Economic impact analysis
- Conclusions
- End of the project
- Defense before the assessment tribunal

3 Justification of usefulness

During the last decade, number of operations concerning the use of UAVs has increased notoriously and it is foreseen that this number will still increase more during the next years. Unmanned aircraft will provide the world with a wide range of applications that once were inconceivable, but the vast majority of them are designed to take place in urban areas.

However, present regulations do not take into account developing these kind of operations in congested and hostile areas because of the high risk they induce. Thus, this study has been done to contemplate this problem and to make some proposals about the issue, in order to be able to operate in urban areas maintaining an adequate safety level.

4 Introduction and background

In this initial section, a brief introduction will be made explaining the history of UAVs from their beginnings until today, and analysing when and why they started to appear. It will also be shown the importance of these kind of aircrafts throughout the 20th century and the relevance they had in technological world.

Once explained the evolution of UAVs in the last century, a global view of the present situation will be given, explaining the recent increase in number of UAVs all over the world and the problem it supposes because of the lack in regulations when operating in congested or hostile areas.

Before getting into the subject, it would be pertinent to comment the differences existing between an Unmanned Aerial Vehicle (UAV) and a Remotely Piloted Aircraft (RPA). The main difference is that is that a RPA is piloted by an operator remotely, there is a human presence behind it, whilst in the case of an UAV it is not necessary as seen in Figure 1.

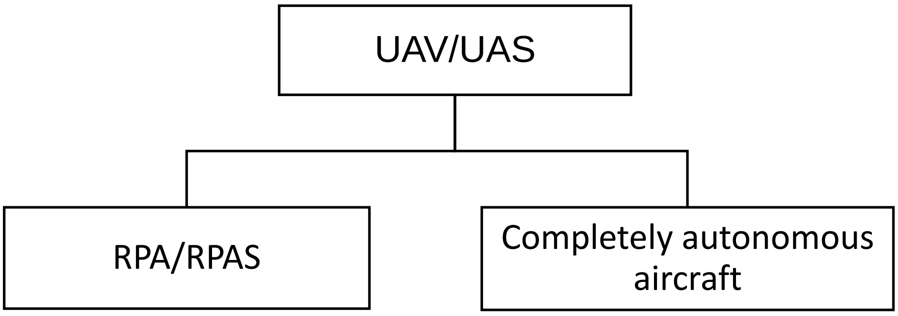

Figure 1 - Unmanned aerial vehicle classification

It should be noted that a RPA is always an UAV as none of them has on-board crew, whereas an UAV can be remotely piloted or just autonomous, previously programmed for a specific mission. RPAS and UAS acronyms are used when talking about the control system and the aircraft as a whole. However, the press and the society frequently use the word "drone" in general to describe any type of them, especially the most commercial ones.

4.1 History of UAVs

Unfortunately, as many other technological advancements in the aeronautical field, UAVs are very connected to military causes and their use has origin in military interests as well. Anyway, it may be highlighted that an unmanned aerial vehicle differs from a cruise missile in that a UAV is thought to be recovered after the mission it has held, while a cruise missile impacts its target, being impossible to recover it.

The first unmanned air vehicle considered in history, as it had no human presence on board, was a hot air balloon that could carry a basket laden with explosives which would be fired by electromagnetism using a timing mechanism. They were used in 1849 by Austria when bombed the city of Venice and in 1863 by the USA during the civil war. It should be observed that it was not until the beginnings of the 20th century that winged aircraft was invented, so these hot air balloons gave the possibility to bomb an objective placed in a larger distance.

During the First and mostly the Second World War, the first pilotless aircraft were built using radio control techniques and common gyroscopes in order to be able to have their control. Initially, they were more like a guided missile rather than one of today's drone. A clear example is the Kettering Bug [1] that, despite it was not fully developed until the end of the war, was able to reach a desired distance where the target was placed once operators had calculated the number of engine revolutions needed for a wind speed and direction given.

After the First World War, some conventional airplanes used in the course of the war were taken to do experimentations and were converted to drones like the Standard E-1s [2]. The two leader countries during that interwar period were the United Stated and the United Kingdom and both armies were plenty concerned about the properly development of unmanned aircraft.

Years later, unmanned aerial vehicles were improved gaining many aptitudes, so they were no longer used just as a way of bombing at larger distances, but for reconnaissance missions, decoy and nuclear tests as well. One of the main reasons that drones have been useful for military operations is that they literally saved lives.

The fact is that they let drones do high-risk flights, despite the probabilities of losing them years ago were also very elevated, while lower-risk operations were carried out by pilots. It resulted doubly positive for army's interests, they were no longer risking human lives when doing reconnaissance and other operations and consequently they had more troops for ground operations as drones acted as a machine, doing tasks that once corresponded to a human being.

In recent history, unmanned aerial vehicles have been much more developed thanks to the incorporation of high quality technology that was not available years before like faster and smaller flight controllers, precise navigation systems and high quality on board cameras. These advancements in technology have allowed using UAVs for a different range of applications rather than just for military purposes as it was decades ago.

4.2 State of the art

Nowadays, the use of UAVs and RPAS has shot up in the last years and expectations in a near future say that these kind of aircraft will be increasingly common to observe in everyday life due to the vast number of operations they are able to carry out. In fact, unmanned aerial vehicles operations can be split into six categories depending on its functionality, some of them still related to military causes but others are already referred to innovation and more commercial purposes. These six categories are the following:

- Target and decoy
- Reconnaissance
- Combat
- Logistics
- Research and development
- Civil and commercial

Commercial and civil applications together with logistics operations are the functionalities that have been introduced later into the market, since others like combat and target have always been established as they were the direct cause of UAV's origin. Therefore, it is possible to affirm that the sudden increase in number of operations of these kind of aircrafts is due to commercial, logistics and civil applications. However, the number of operations concerning combat and target also increases since technology has evolved and allow a larger number of operations. In Figure 2, a forecast for European civil and commercial UAV market per application is showed.

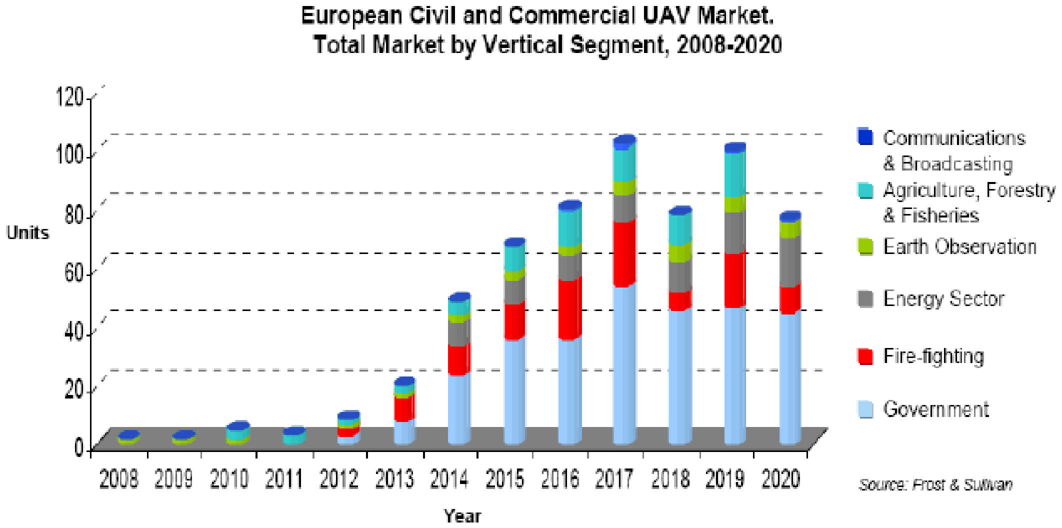

Figure 2 - Forecast European civil UAV market per application **[3]**

As this rise in number of UAVs has been very pronounced during recent years, the present situation is that there are few regulations related to their use. This fact evidences a lack in norms for operational procedures and consequently bad levels of safety with the risks that this supposes. It should be noted that regulating authorities have delegated to each country the establishment of their own regulations concerning the use of UAVs and RPAS, giving as a result as many different regulations as countries are interested in establishing limitations and restrictions to ensure safety and no risks when operating.

Observing the different countries with developed regulations about this issue, France, United Kingdom, Spain and the United States of America, it has been observed that hardly any of them takes into account the use of unmanned aerial vehicles in hostile and congested areas, in fact, they have just prohibited it by now.

Nevertheless, future on this field involves operating in congested and hostile areas rather than deserted areas where it is already allowed. Therefore, despite of country regulations treating the use of UAVs, some competent authorities have already published documents trying to solve this global problem like the A-NPA 2015-10, an advance notice of proposed amendment published by the European Aviation Safety Agency in 2015.

5 Regulatory framework

5.1 Definition of the environment

The study is about operational requirements of unmanned aerial vehicles in hostile and congested areas, therefore these areas must be clearly defined in order to make the most accurate possible study.

The strict definitions of hostile and congested can be found in Cambridge dictionary and are the following:

- Hostile: unfriendly and not liking something; difficult, not suitable or not hospitable.
- Congested: too crowded or blocked, causing difficulties.

Furthermore, in the EASA's Annex I of the Annexes to the draft Commission Regulation on 'Air Operations – OPS' [4], some manned air operations are regarded in congested and hostile areas. Thus, the definitions of congested area and hostile area are present in this annex and are the following:

- 'Congested area' means in relation to a city, town or settlement, any area which is substantially used for residential, commercial or recreational purposes.

- 'Hostile environment' means:

a) an environment in which:
    - a safe forced landing cannot be accomplished because the surface is inadequate;
    - the occupants cannot be adequately protected from the elements; (it has no sense in the case of UAVs as they do not have occupants)
    - search and rescue response/capability is not provided consistent with anticipated exposure;
    - there is an unacceptable risk of endangering people or property on ground.

b) In any case, the following areas shall be considered hostile:
   - for overwater operations, the open sea areas North of 45N and South of 45S designated by the authority of the State concerned;
   - parts of a congested area without adequate safe forced landing areas.

Many times, the term non-hostile environment is also employed to describe an area, it is obvious that it means the opposite of a hostile zone but it may be detailed, especially when coinciding with a congested one.

- 'Non-hostile environment' means an environment in which:

  - a safe forced landing can be accomplished;
  - the occupants can be protected from the elements; (no sense in UAV's case)
  - search and rescue response/capability is provided consistent with the anticipated exposure.

In any case, those parts of a congested area with adequate safe forced landing areas shall be considered non-hostile.

5.2 Study of present regulations

In this section, the different current regulations of the main leading countries that take into account the use of UAVs and RPAS are studied and analysed. Contrasting some different regulations permits to observe differences between them as well as some points in common that can be the base of a unified normative.

There are many countries with normative related to drones and it is obvious to observe that a study including all of them would be not practical, regulations chosen for the study are those that are more representative due to country's influence on the world and those that have been innovative in this field.

Countries chosen for the study are the United Kingdom, Spain, France and the United States of America. Other related organisms like the International Civil Aviation Organisation (ICAO) that already have some publications considering unmanned aircraft vehicles, are also brought in the study.

5.2.1 Spain's regulations

At present, Spanish regulatory framework is based on Law 18/2014 [5] published in BOE on 17th October 2014 by AESA. This new law, which has been rapidly developed due to fast growth in the use of drones, establishes exploitation conditions for drone operations related to technical and scientific works with a mass always lower than 150 kg. In fact, this regulation considers the different scenarios in which it will be possible to do aerial works depending on the aircraft's weight.

The law states:

Remotely piloted civilian aircrafts will only be able to operate in daylight hours in zones out of building agglomeration in cities, towns, inhabited places or people meetings outdoors and in uncontrolled airspace:

- maintaining visual line of sight with the pilot at a distance not larger than 500 m and at an altitude not greater than 400 ft or 120 m above ground, when their maximum take off mass do not exceed 25 kg
- beyond visual line of sight of the pilot, in the range of the radio emissions of the control station at an altitude not greater than 400 ft or 120m above ground, when their maximum take off mass do not exceed 2 kg. They must always have a functionality to make the pilot know where the aircraft is at any moment. The operation is also conditioned to a NOTAM emission by the provider of aeronautical information services to inform the rest of airspace users about the operation.

Those remotely piloted civilian aircrafts whose maximum take off mass exceeds 25 kg but is lower than 150 kg and those destined to firefighting, search and rescue activities, whose maximum take off mass exceeds or is equal to 150 kg, will only be able to operate in uncontrolled airspace with the conditions and limitations established in their airworthiness certificate issued by AESA.

Moreover, for all kind of operations previously cited it will be required:

- Documentation related to the aircraft characteristics and configuration provided by the operator
- Handbook of operations by the operator establishing operational procedures
- Safety aeronautical study in which it is concluded that the operation is safe
- Satisfactory test flights to prove the safeness of the operation
- Insurance policy or other financial guarantee that covers civilian responsibility in case any damaged is produced to third parties.
- Adequate measures adopted to protect the aircraft from acts of unlawful interference during an operation, as well as additional measures in order to ensure safety of the operation and of underlying people or goods
- Minimum distance of 8 km to any airport or aerodrome and for instrumental flights where the operation can be performed beyond visual line of the pilot, a maximum distance of 15 km from the reference point is allowed

Pilots have a key role in the operation, as they are the maximum responsible of all manoeuvres and have control of the aircraft. Therefore, in order to guarantee the safety of the operation, pilots are required to have adequate knowledge in aeronautical concepts concerning different subjects like aeronautical rules, general aircraft knowledge, aircraft performance, meteorology, airworthiness, maps interpretation, operational procedures and communications. This knowledge must be proved through any pilot license for operations with maximum take off mass greater than 25 kg and a basic certificate or advanced certificate for piloting RPAs depending if the operation is in the visual line of the pilot or not respectively, for operation with maximum take off mass lower than 25 kg. A health certificate for the pilot will also be needed for all kind of operations, but with higher exigence for the heavier drone operations. Being older than 18 years old, will be a requirement for the pilots as well.

5.2.2 France's regulations

France has clearly noticed the quick development of drone industry, having at first 90 registered operators in November 2012 and just in three years, this number has increased to 2200 approximately. Therefore, in close consultation with users and other state services, work on the desirable regulatory changes helped to revise the regulations to make them more readable, more adapted to the needs, simplifying certain administrative formalities and taking into account the improvements in unmanned aircraft with the operations of aircraft in low and very low altitudes to guarantee safety of other users.

The current regulation in France [6][7] has been published by Direction Générale de l'Aviation Civile (DGAC) on 17th December 2015 and is applied on unmanned aircraft with maximum take off mass lower than 150 kg operating in outdoor areas.

This regulation identifies four operational scenarios for which conditions of authorization have been defined with detail. Any operation out of these four scenarios or in deviation from the conditions stablished cannot be performed unless a specific authorization is made, after a study of the operation justifying that the safety is maintained at an acceptable level.

The four defined scenarios are the following:

- **S1:** operation out of populated areas maintaining 50 m of distance with urban areas or 150 m with people meetings, without overflying third parties, in visual line of sight with the pilot and in a maximum horizontal distance of 200 m from him. This scenario can be operated for all drones with lower maximum take off mass than 25 kg. Maximum altitude above ground allowed is 150 m. Main characteristics of scenario S1, as well as limitations of mass, altitude and distance are represented in Figure 3.

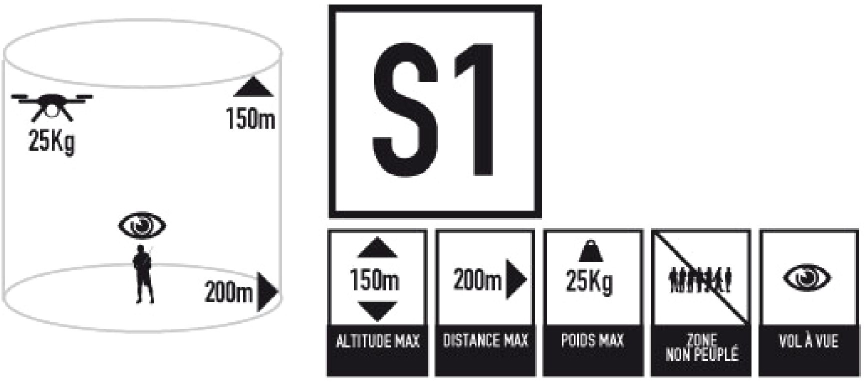

Figure 3 - Scenario 1 specifications **[8]**

- **S2:** operation out of populated areas maintaining 50 m of distance with urban areas or 150 m with people meetings, without third parties on ground, beyond visual line of sight with the pilot and in a maximum horizontal distance of 1000 m from him. Mass is limited at 2 kg in this scenario above 50 m of altitude, below this altitude until 25 kg drones are allowed. Main characteristics of scenario S2, as well as limitations of mass, altitude and distance are represented in Figure 4.

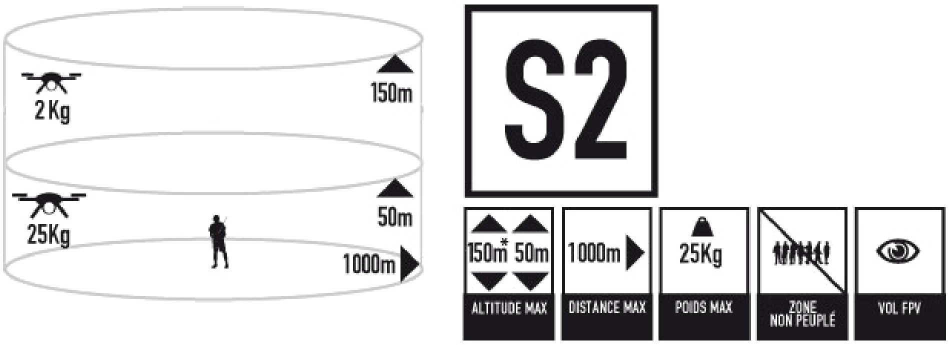

Figure 4 - Scenario 2 specifications **[8]**

- **S3:** operations in populated areas are allowed, in visual line of sight with the pilot and in a maximum horizontal distance of 100 m from him. Captive aircraft, those affixed in the ground in some way, are limited at 25 kg, but the drones commonly used, which are non-captive drones, are restricted to a maximum take off mass of 8 kg. Those drones with mass greater than 2 kg must have a third parties protection device, normally a parachute, to preserve the safety of the operation. Maximum altitude above ground allowed is 150 m. Main characteristics of scenario S3, as well as limitations of mass, altitude and distance are represented in Figure 5.

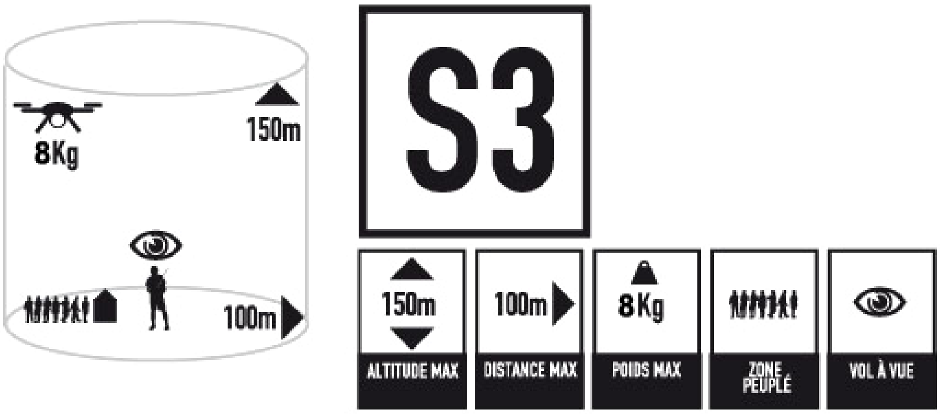

Figure 5 - Scenario 3 specifications **[8]**

- **S4:** operation out of populated areas, beyond visual line of sight with the pilot and no responding to criteria established in scenarios S1 and S2. Unlimited horizontal distance from the pilot with the authorization of overflying isolated individual but maintaining a distance of 50 m form any people meeting and mass is limited at 2 kg. Maximum altitude above ground allowed is 150 m. In this scenario, pilots must have a pilot license for some kind of manned aviation, having at least the knowledge of private plane pilot or helicopter pilot. Main characteristics of scenario S3, as well as limitations of mass, altitude and distance are represented in Figure 6.

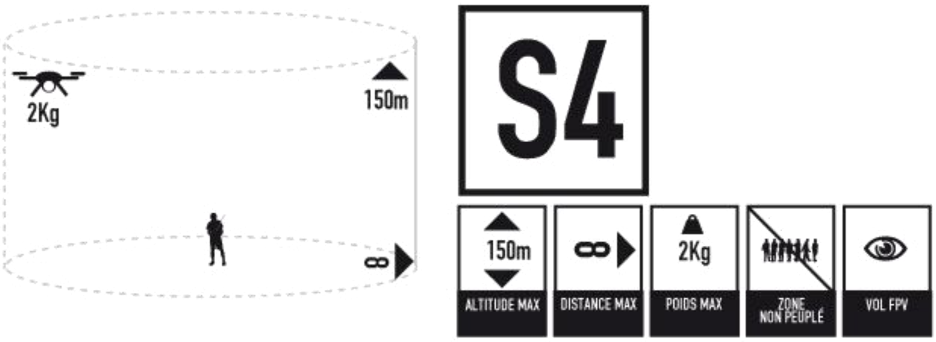

Figure 6 - Scenario 4 specifications **[8]**

Motorways and railways are considered as a special case since they cannot be treated strictly like populated areas. Therefore, it is concluded that any operation is allowed to perform at a minimum horizontal distance of 30 m of a motorway or a railway unless a permission is given by the exploiter of the track. This norm is not applied to operations that fit scenario S4 if there is a punctual crossing of them during the operation.

It should be remarked that third parties protection, concretely of people on ground, is the main interest of regulating the use of drones. This is the reason why the maximum energy of impact has been limited by French authorities at 69 J, therefore flight altitude and aircraft speed must be monitored or taken into account depending on the mass of the drone as well.

5.2.3 United Kingdom's regulations

Present regulations in the United Kingdom are established by the Civil Aviation Authority in several publications, but it is in the Air Navigation Order CAP 393 [9] where the current basic requirements for unmanned aircraft operations are detailed. In CAP 722 [10], the use of drones is also treated but as a guidance way for future regulatory framework, which is going to be analysed in the section of best practices.

First of all, the regulation of drones in the United Kingdom divides all unmanned aircraft in three categories depending on the mass, which is considered too basic for many regulating organisations:

Type	Mass range	Regulatory body
Small unmanned aircraft	0 – 20 kg	National Aviation Authority
Light unmanned aircraft	>20 – 150 kg	National Aviation Authority
Large unmanned aircraft	>150 kg	EASA

Table 1 - Mass categorisation

For small unmanned aircraft, the regulation states the following:

The person in charge of a small unmanned aircraft should only fly it only if is convinced that the flight can be safely made. The pilot must also maintain direct, unaided visual contact with the aircraft that enables him to monitor its flight path in relation to other aircraft, persons, vehicles, vessels and structures for the purpose of avoiding collisions.

An operation cannot be performed if the aircraft has a mass of more than 7 kg, excluding its fuel but including all the equipment attached to it, for the next conditions:

- in class A, C, D or E airspace unless a permission is obtained from the corresponding air traffic control unit
- within an aerodrome traffic zone unless an authorisation from the appropriate air traffic control unit is obtained
- at an altitude of more than 400 ft above the ground unless it is flying in an airspace described in the previous points, following the requirements of the corresponding airspace

The pilot in charge of a small unmanned aircraft must not fly the aircraft unless a permission is obtained by the Civil Aviation Authority in any of the following situations:

- over or within 150 meters of any congested area
- over or within 150 meters of an organised open-air assembly of more than 1000 persons
- within 50 meters of any vessel, vehicle or structure which is not under the responsibility of the pilot of the aircraft
- within 50 meters of any person, but during take off and landing, this distance is reduced to 30 meters. In both cases, the pilot is exempted from this norm.

5.2.4 USA's regulations

The American regulatory framework it is maybe the most complex and complicated one, probably because of the wide extension of national airspace and the problems and incidents that causes. Therefore, conflict is present nowadays for the lack of regulations concerning different types of activities with different type of drones.

Federal Aviation Administration (FAA) is the regulating authority in the United States of America, but it may be highlighted that the FAA cannot make laws, its mission is to develop guidelines and regulations. It is also noted that the FAA does not actually define or even talk about unmanned aerial systems in any of its regulatory documents. All mention of unmanned aerial systems is only in circular advisories, primarily written for internal FAA guidance, and as the documents themselves state, are not intended to be regulatory.

Nowadays, the document that concerns the use of drones in the United States of America is the special rule for model aircraft found in section 336 of FAA Modernization and Reform Act of 2012 and its posterior interpretation of the rule published on June 18, 2014.

In fact, this document talks about model aircraft instead of employing words like drone or unmanned aerial vehicles. A model aircraft is defined as an unmanned aircraft that is capable of sustained flight in the atmosphere, flown within visual line of sight of the person operating the aircraft and flown for hobby or recreational purposes. The special rule for model aircraft finally concludes that a model aircraft or any other aircraft being developed as a model aircraft would be exempt from any future FAA rulemaking process and is able to be flown if:

- it is flown strictly for hobby or recreational use
- it is operated in accordance with a community-based set of safety guidelines
- it is limited to no more than 55 lb (25 kg) unless a recognised organization certifies the aircraft's design, construction, flight test and operational safety program
- it is operated in a way that does not interfere with and gives way to any manned aircraft
- when flown within 5 miles (8 km) of an airport, the operator of the aircraft provides the airport operator and the airport air traffic control tower with prior notice of the operation

The conflict has appeared when distinguishing between recreational and commercial operations, because sometimes the aircraft used in an operation is the same but depending on the activity, the requirements are stronger for commercial activities. In fact, commercial operators have to be registered by FAA while those that do a recreational use do not. What is more, commercial operators are more concerned of risks and work very hard in order to guarantee the safety of people on ground, while hobby operations usually performed by non-professional pilots, that are maybe not as concerned of all dangers that can occur during an operation, can be operated without any registration on FAA.

After all, it is observed that regulatory framework is not fully developed and its lack of regulations is evident. This is the reason why it have been existing during the last years a rulemaking process leaded by the Department of Transportation of

FAA, which final proposed rules of using small unmanned aircraft systems in today's aviation system are presented in the section *5.3 Study of current* proposals*.*

5.2.5 Other European countries

Other European countries have also a regulatory framework concerning the use of drones but not as detailed like leading countries, which have been studied before in this section. In Table 2 - Summary of some European country characteristics of regulations, it can be observed the mass categorization, permitted operations and areas allowed to be overflown for five European countries.

Country	Drone mass categories	Permitted operations	Areas allowed
Denmark	- Below 7 kg - Between 7-25 kg - Between 25-150 kg	- VLOS only - altitude <100 m	- 150 m from road and buildings - Never over densely built areas
Germany	- Below 5 kg - Above 5 kg	- VLOS only - altitude <100 m	- Not defined
Austria	- Below 5 kg - Between 5-25 kg - Between 25-150 kg	- VLOS only	- Undeveloped - Unpopulated - Populated - Densely populated

Sweden	- Below 1,5 kg or <150 J - Between 1,5-7kg or <1000 J - Between 7-150 kg	- VLOS - BLOS - altitude <120 m	- 50 m from any person or property
Italy	- Below 25 kg - Above 25 kg	- altitude <70 m radius <200 m - altitude <150 m radius <500 m	- 150 m from any congested area - 50 m from any person or property

Table 2 - Summary of some European country characteristics of regulations

Despite each country has its own normative and establishes different subcategorization as well as different operational limitations, these five countries together with Spain, France and United Kingdom previously studied, it possible to say that all have the same tendency.

5.3 Study of current proposals

5.3.1 European proposals

As number of operations with UAVs and RPAs is increasing and technology involving them is continuously being developed and improved, there is the need to have a rulemaking process constantly in operation.

The European Aviation Safety Agency is in charge of this complex rulemaking process, and through it, they contribute to the production of EU legislation and implementation material related to civil aviation safety and environmental compatibility. The aim of this process is also to have regulations as updated as possible, modifying and adapting them to changes and improvements in the air navigation.

These modifications and improvements in regulations done by EASA are called NPA (Notice of Proposed Amendment) and in some cases, it is possible to find what is called an A-NPA, which is an advance of the corresponding NPA. It is calculated that an average of 25 NPA approximately are published every year by EASA.

In order to assure the exceptional quality of these documents, EASA counts on a large group of professionals and experts. In addition, the agency enables users to give feedback of the published documents and make comments about any possible ambiguity present in the regulations, so that they can rectify them as soon as possible. Therefore, the complexity and perfection of the process requires a considerably amount of time, lasting about 22 months minimum to be published since the need of regulating or modifying something appeared.

The rulemaking process that the agency follows for notices of proposed amendment can be seen in Table 3 - Complete process of a NPA, where each task's period can be observed as well.

Process of a Notice of Proposed Amendment		
1	Drafting and adoption of the Rulemaking Programme	12 Months
2	Initiation of the rule development by defining the Terms of Reference	2-6 Months
3	The drafting of the rule	3-18 Months
4	Consultation phase	1-3 Months
5	Analysis of comments and final review	2-6 Months
6	Adoption and Publication	2 Months

Table 3 - Complete process of a NPA [11]

Concerning the use of unmanned aerial vehicles, EASA has already published two NPA and an A-NPA, which are the following:

- NPA 2012-10 [3]
- NPA 2014-09 [12]
- A-NPA 2015-10 [13]

A description of the contents of the documents previously cited is given below following chronological order, so that it is possible to observe the evolution of regulations that take into account unmanned aerial vehicles operations.

NPA 2012-10

As amendment 43 to ICAO Annex 2, that mainly talk about remotely piloted aircraft systems (RPAS), was going to become applicable on 15 November 2012, EASA found it necessary to publish this NPA in August of the same year in order to transpose these new concept into common rules of the air.

The main aspects covered in this NPA are the following:

- certification of the remotely piloted aircraft system (RPAS), including the airworthiness of the remotely piloted aircraft (RPA);
- certification of RPAS operators involved in commercial air transport and/or specialised operations (SPO);
- licensing of remote pilots;
- provisions to facilitate the 'special authorisation' mandated by Article 8 of the Chicago Convention for international RPAS operations;
- improvement of air traffic control planning in oceanic and remote airspace through more accurate position reporting and estimating by flight crews of 'manned' aircraft.

NPA 2014-09

This NPA is on the same matter as NPA 2012-10, in fact, it is a correction and revision of it. NPA 2012-10 received more than 200 adverse comments questioning and criticizing the proposed rules, so the Agency decided to withdraw it and to publish the NPA 2014-09.

On the one hand, this NPA tries to solve the errors or ambiguities published in the previous proposed rules concerning the use of RPAS. On the other hand, this NPA also proposes rules of the air applicable to RPAS of any mass, when flown under General Air Traffic rules. In other words, this notice of proposed amendment tries to integrate the operations of remotely piloted aircraft into the global airspace.

A-NPA 2015-10

In this case, it is an advance notice of proposed amendment and it has been published because the European Commission has delegated to EASA the responsibility to develop a regulatory framework for drone operations and concrete proposals taking into account the regulation of low-risk drone operations as well, as it has been agreed in the Riga Conference that took place on 6th March 2015 [14]. Despite being an advance of NPA, it is the most developed regulation concerning several current incidents to this day.

It is possible to observe that only with a year of difference since the last NPA was published, the intentions of both amendments are completely different. In fact, this obvious change of direction in such a short period demonstrates that the use of drones is exponentially increasing at it is already a problem for the regulating authorities who had not expected it before.

The particularity of this regulatory framework, which proposes all drones to be regulated at EU level, is that it is based on the risk posed by drone operations following an operation-centric approach. The reason why an operation-centric approach is employed is due to the high dependence of consequences if a loss of control occurred as there is nobody on board a drone. It is easy to exemplify why operation's risks have been taken into account just imagining, how different the consequences would be if a crash happened in the middle of Sahara desert or in a city like Barcelona or London.

Depending on the risk that represent a drone operation, EASA together with member states has proposed to divide operations into three groups, from lower to higher risks. These three categories together with the description of their main characteristics are defined in Table 4 - EASA category classification for drone operations:

Category	**Risk**	**Description**
Open	Low	- Limitations in operations - Compliance with industry standards - Requirement to have certain functionalities - Minimum set of operational rules - Enforcement mainly by the police
Specific	Medium	- Authorization by a National Aviation Authority - Qualified entity assists the National Authority following a risk assessment performed by the operator - Manual of operations listing risk mitigation measures
Certified	Higher	- Requirements similar to those for manned aviation - Supervision of licences, approval of maintenance, operations, training and aerodromes organisations by a National Aviation Authority. - Design and approval of foreign organisations by EASA

Table 4 - EASA category classification for drone operations

Once defined the three categories, a more detailed description of each one is made giving specific data of limitations and requirements that must ensure safety above all.

- *Open category – Low risk*

An open category operation is defined as any operation with a small drone, whose maximum take off mass cannot exceed 25 kg, always maintaining direct visual line of sight and a safe distance from people on the ground or other airspace users.

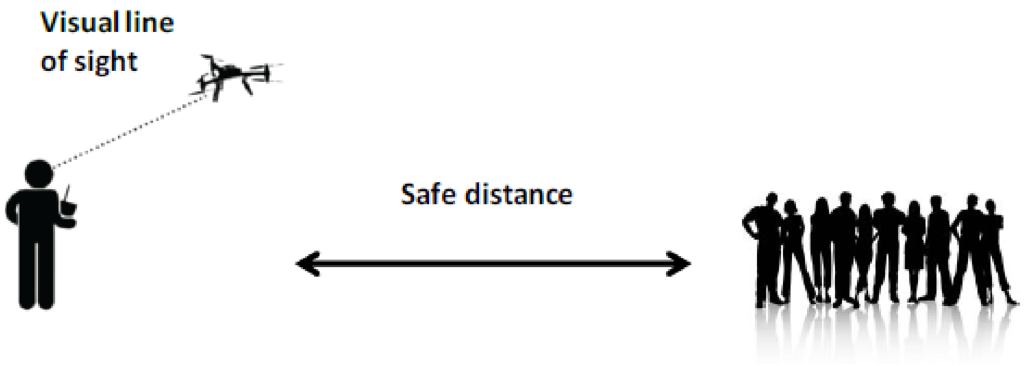

Figure 7 - Open category scheme

The Agency also delegates to competent authorities the possibility to define two types of areas in order to ensure safety, environmental protection, security and privacy:

- No-drone zones: no drone operations are allowed unless an authority approval is conceded.
- Limited-drone zones: limited mass and must provide a way to enable easy identification and automatic limitation of the airspace drones can enter with geofencing and other leading technologies.

Irrespective of the type of area a drone overflies, the pilot is always responsible for the safe separation from any other airspace user and shall give right of way to any other one. In addition, a drone in this category must not operate at an altitude greater than 150 meters above the ground and never fly above crowds, considering a crowd a group of people around 12 or more.

As it can be seen, the pilot in this category is a key element. In fact, it has been considered that for any drone operation over 50 meters above ground or water, the pilot must be required of basic aviation awareness.

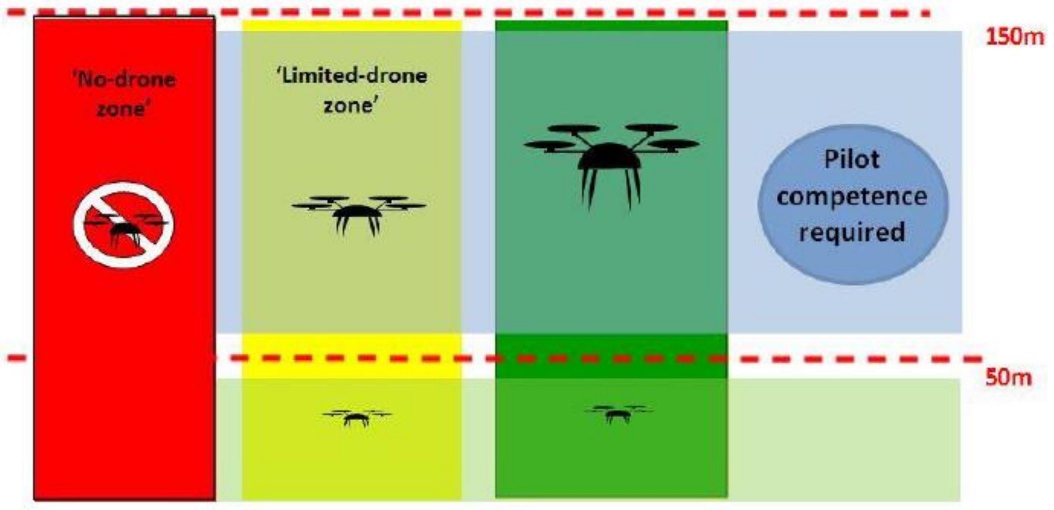

Figure 8 - Pilot competence above 50m and drone operational areas

Mass is the parameter that EASA has chosen to do a subcategorization in the open category as it is directly proportional to the damage a drone can cause. Normally, the larger the maximum take off mass is, the more damage can be caused, so the open category is split up into three subcategories.

- CAT A0 – MTOM < 1 kg

  This subcategory, particularly represented by very low mass drones, encompasses the majority of consumer products including tethered balloons, kites, toys and more sophisticated devices like "mini drones" that are operated in all kind of environments. The major part of aircraft in this category are just used for recreational purposes.

- CAT A1 – 1 kg ≤ MTOM < 4 kg

  Better performing consumer products equipped with navigation and automation systems conform this subcategory. The fact that they become drones able to carry payload increases significantly risk to other people or airspace users.

- CAT A2 – 4 kg ≤ MTOM ≤ 25 kg

  Characterised to be the subcategory with heavier drones, it is mainly formed by products operated commercially that can carry for example high quality camera systems.

Once these three categories are defined, additional requirements are applied for each subcategory in order to ensure safety of operations. In Figure 9 - Three subcategories' operational areas, the areas where each category is allowed to operate are shown, as well as the altitude where pilot competence is required. It should be remarked that heavier drones, those that correspond to subcategory CAT A2, are not allowed to overfly limited-drone zones because they represent a higher risk as their mass is noteworthy enough. In the requirements, it is also stated that any operation corresponding to CAT A0 must not operate higher than 50 meters above ground.

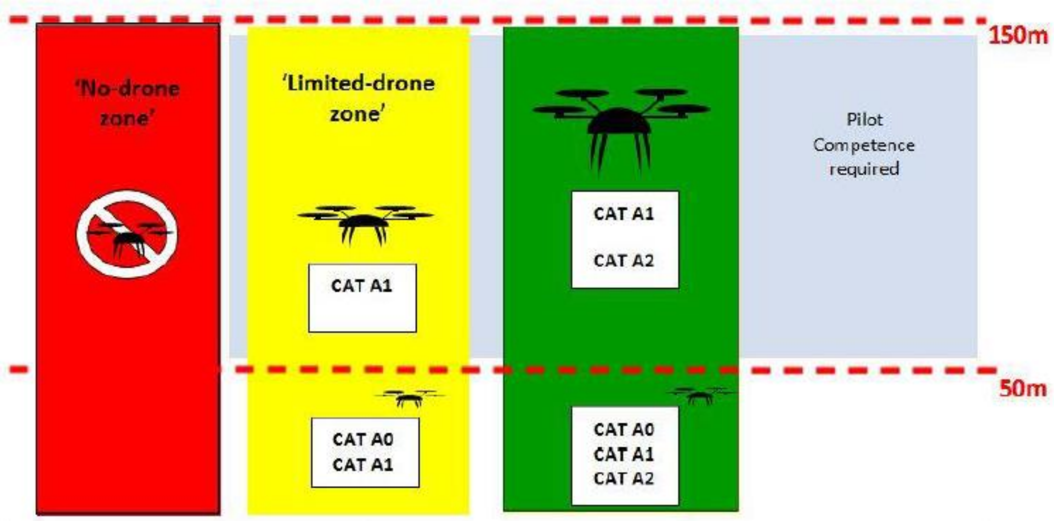

Figure 9 - Three subcategories' operational areas

- *Specific category – Medium risk*

An operation of the specific category is considered as any operation with drones that poses more significant aviation risks to people overflown or involves sharing the airspace with manned aviation. A safety risk assessment is made to analyse and mitigate each specific aviation risk in any operation that exceeds the safety barriers of the open category. Some operations that could fit this category are those including large and small drones above densely populated areas like city centres or other crowded places due to some social event.

This category is characterised because the need of an Operation Authorisation (OA) by a national authority with specific limitations adapted to the risk that the operation poses in order to reduce it to an acceptable level so that the operation could be performed. This Operation Authorisation would be valid in all EASA member states giving detail of how the drone has to be operated, where and under what limitations.

Identification of all hazards of the drone operation and the consequences of their effects should be present in the risk assessment. In fact, two types of hazards are differenced, those related to technical aspects that can produce a failure of aircraft functions and those related to operational issues that concern the use of airspace and pilot competences.

The risk assessment done by the corresponding authority should take into account all the following factors in order to ensure the safety of the operation:

- Area of operation
- Airspace
- Drone design and specifications
- Type of drone operation
- Pilot competence
- Operator's organisational factors

It is obvious that many risks posed by the operation need to be mitigated through technical specifications of the drone, therefore systems and equipment used in the operation must be certified to ensure safe flight.

- *Certified category – Higher risk*

In this last category, operations are associated to a higher risk and the operations that are placed in this certified category are those that risk rises to a level similar to normal manned aviation. As these operations are treated like manned operations, they will require the same certificates for manned aviation and some extra specific for drones.

Operations in certified category are thought to be for drone operations with a high risk and with a wider scope of operation than the specific category. Actually, what differences also these two categories is that in the specific category only a concrete operation is authorised, whereas in the certified category a variety of operations are considered appropriate for a same design of drone.

5.3.2 American proposals

Because of the lack of regulations regarding the use of small unmanned aircraft systems, the Department of Transportation's Federal Aviation Administration has proposed a regulatory framework that would allow routine use of certain small unmanned aircraft systems (UAS) in today's aviation system and integrate them in the National Airspace System, which also involves populated areas [15]. At the same time, it is conceived in a way that it is flexible to accommodate future technological innovations.

The FAA proposal offers safety rules for small unmanned aircraft always for non-recreational operations. The rule would limit flights to daylight and visual line of sight operations and addresses altitude restrictions, operator certification and operational limits as well. As it has been said in special rule for model aircraft, already exposed in section *5.2 Study of present* regulations, the new rules would not apply to model aircraft. However, model aircraft operators must continue to satisfy all of the criteria specified in Sec. 336 Special Rule of Model Aircraft being always operated only for hobby or recreational purposes.

The proposed rule would also find that airworthiness certification is not required for small unmanned aircraft system operations that would be subject to this proposed rule. Finally, this proposed rule also has the aim to prohibit model aircraft from endangering the safety of the National Airspace System.

The summary of major provisions of proposed rule for the integration of small unmanned aircraft systems into the National Airspace System is detailed below:

- Operational limitations
    - Unmanned aircraft must weigh less than 55 lb (25 kg)
    - Visual line of sight of the pilot only, remaining close enough to be seen with vision unaided by any device
    - Small unmanned aircraft may not operate over any person not directly involved in the operation
    - Daylight only operations
    - Must yield right-of-way to other aircraft, manned and unmanned as well
    - Maximum airspeed of 100 mph (87 knots)
    - Maximum altitude of 500 ft (150 meters) above ground level
    - Minimum weather visibility of 3 miles from control station
    - No operations allowed in Class A airspace above 18.000 ft
    - Class B, C, D and E airspace operations allowed with required ATC permission, while operations in Class G airspace are allowed without this permission
    - No careless or reckless operation.

- Operator certification and responsibilities

Pilots of small UAS, who would be considered operators, would be required to:

- Pass an initial aeronautical knowledge test by FAA
- Obtain an unmanned aircraft operator certificate with a small UAS rating
- Pass a recurrent aeronautical knowledge test every 24 months
- Be older than 17 years old
- Conduct a pre-flight inspection to ensure small UAS is safe for operation
- Make available the small UAS to FAA upon request for any test or inspection

6 Benchmark of best practices

Once analysed the regulatory framework concerning UAVs from different countries and some current European and American proposals related, it is possible now to designate which are the best practices regarding the possibility to operate with UAVs and RPAs in congested and hostile areas and their integration to the shared airspace with the rest of aviation.

From all country regulations, France is probably the leading European country and must be stood out among others, just because presently it is already permitted to operate over populated areas complying with some restrictions and requirements. In fact, dividing the regulatory framework into four different possible scenarios is a practical way to develop regulations, so that operators just need to focus on fulfilling the requirements to fit one of the scenarios, concretely the one more appropriated to the characteristics of the pertinent mission. Another good point in favour of French regulatory framework is that a maximum of total energy is established, not allowing to be overpassed since severity of accident consequences is in most cases directly proportional to the impact energy.

Although in present UK regulatory framework the operation of UAVs in congested areas is not taken into account, it is considered instead in CAP 722 of Air Navigation Order [10] which is a guidance material for developing a future regulatory framework. The aim of this document is also to make UAVs operating in the UK to meet at least the same safety and operational standards as manned aircraft, what means that they must not create a greater hazard to people, property and vehicles neither in the air nor in the ground, than that posed by equivalent category operations of manned aircraft.

Some of the issues treated in this document that stand out for not being considered in present regulations are security issues, human factors in UAS operations, remote pilot competencies, safety assessments, and operational procedures, operational limitations and incident procedures in congested areas.

Another best practice that can be considered is the A-NPA 2015-10 [13] published by EASA, because despite of being just a proposal and not a current regulation, it regards in one of the categories defines, the specific category, the possibility of approving some operations over densely populated zones and sharing the airspace with manned aviation. To obtain these approvals, the proposal stablishes previously doing a risk assessment to reduce all possible risks to obtain an Operation Authorisation, which will be valid in all EASA member states, what will also be useful to unify all European regulations.

Finally, it should be remarked that practically all regulations and proposals analysed, take into account that pilots of UAVs and RPAs must be controlled in some way avoiding novel operators to fly UAVs by themselves endangering the airspace, which must be considered as good practice, because human errors and unawareness are a frequent source of accidents nowadays. The most common way to have a control over the pilots is to enforce them acquiring some specific license or to demonstrate knowledge related to the use of UAVs by passing some exams, and finally a medical report certifying that the pilot has all physical and mental capabilities to operate.

7 Analysis of operational conditions

In this section, the operational conditions for unmanned aerial systems are analysed, what means that all facts that take action during any drone operation in a congested or hostile area are taken into account, with the aim of posteriorly identifying risks and maintaining a high safety level in these unmanned aircraft operations. The concept of safety of an operation must be understood as some guarantees given by the operator certifying that no damages, hazard or hurt will be produced under any circumstance to any third party, specially to any person, neither in the ground nor in the air.

7.1 UAV physical components

Before identifying any risk, all elements involving a drone operation that can suppose or can introduce a risk must be clearly defined. Therefore, this is why an approach to components that conform unmanned aerial systems is made at first.

Firstly, it may be observed that there are some differences between multirotor and fixed wing unmanned aircraft, with their respective advantages and disadvantages, but a remarkable one is that multirotor drones are able to overfly any place following a static and relatively stable performance while fixed wing drones need to be in constant movement. Another key point in favour of multirotor drones is their vertical take off and landing, that makes them ideal to be used in congested and hostile areas where normally there are not large zones where a fixed wing drone can land safely. These are the main reasons why multirotor drones are currently more used than fixed wing drones. In fact, to study the operational conditions in congested and hostile areas, multirotor are the type of drone in which the study is going to be centred but some fixed wing characteristics may be also considered if it is needed.

Basically, the components that are present in a multirotor drone are the following: frame, engines, propellers, flight controller board, radio transmitter and receiver, batteries, GPS, and other additional devices like cameras and gimbal.

- Frame: the skeleton of the multirotor, the structure that gives its shape and where all other parts are fixed. Variety of designs, very light and resistant, made of different materials but of carbon fibre for professional purposes. Different designs of multirotor frames are showed in Figure 10.

Figure 10 - Different designs of frames

- Engines, propellers and electronic speed controllers: essential components to keep the aircraft up in the air. Engines are responsible of converting the electrical current into circular movement that will be transmitted to the propellers, which will produce thrust. Electronic speed controllers are really important for its correct propulsion because they adjust electrical power to make engines rotate with dynamism and efficiency. They are like control surfaces on fixed-wing aircraft since they are the responsible of yaw, pitch and roll of a multirotor by changing rotating speeds. These components are shown in Figure 11.

Figure 11 - Motors, propeller and electronic speed controller

- Flight controller board: it is the drone's brain where practically all other components are connected. It acquires data from sensors of all the system, like GPS location, engine speed, gyroscopes and accelerometers, processes it and gives orders to actuators in order to maintain aircraft's stability and to transmit properly to each engine the commands sent of the pilot.

- Radio ground station and receiver: elements responsible of making the pilot possible to control the aircraft. The receiver receives the radio signal transmitted from the ground station, which is transformed into data and is sent to the flight controller board in order to execute its instruction. Frequencies usually used are 433 MHz, 2,4GHz and 5,8 GHz. Communication losses between ground station and the aircraft is one of the most common causes of accidents with UAS.

- GPS, magnetometer, accelerometers and other sensors: Positioning and navigation systems are essential for stability and safety. GPS together with other sensors connected to the flight controller board like magnetometer, accelerometers and gyroscope, make it able to know its exact location, flight altitude and speed of the multirotor. They also provide the flight controller with measurements to know what flight corrections must be performed to stabilize the aircraft movements.

- Batteries or fuel: are the power source for the aircraft. Normally they compound one of the heaviest parts of the aircraft, so it is important to have a good weight/capacity ratio to maximise flight autonomy. Due to its density of energy as well as its high discharge rate and low weight, lithium polymer batteries are the most used for multirotor unmanned aircrafts.

7.2 Operation description

An operation with an UAV could seem simpler than it actually is, because many other facts apart from flying the aircraft are involved in the operation that must be taken into account. Down below, a simple description of the stages of a typical UAV operation are explained.

First of all, the location where the operation will take place must be determined. In this location, a safe place to take off and land must be specifically defined, which characteristics will be different for multirotor and fixed-wing aircraft because of the obvious differences when landing and taking off, vertically and horizontally respectively.

Then, after checking that all communication systems work properly, batteries are fully charged or fuel tanks are filled with the appropriate combustible and meteorology is adequate to operate safely, the operation can start. For autonomous UAVs, the route to follow must be pre-programed at this point, whereas in the case of RPAS the pilot can proceed to take off.

Once the UAV has taken off, it should be remarked that communication link with the ground station uses radiofrequency signal and navigation system is provided with GPS signal. During an operation in congested areas, many other signals are in the environment, so interferences will be a serious thing to try to avoid in order to keep the drone under control. This type of environment described in previous sections, is also characterised by the presence of obstacles and other aircraft sharing the airspace that should be dodged.

Finally, after doing its corresponding mission, the UAV will be disposed to land, in the majority of the cases in the same location of take off, but the possibility of landing in other sites known to be safe for that purpose might be regarded, especially in long distance operations where the aircraft has not enough autonomy to return back to the starting point.

8 Risk analysis and safety study

Currently, unmanned aircraft systems have accident rates of up to two orders of magnitude greater than those presented for manned and conventional aviation, this fact is principally caused because of the low reliability of the systems employed like communication links and other ground control elements [16]. This accident rates are no longer acceptable and still less for operations in congested and hostile areas where consequences of hazard might be much more catastrophic, since the operations are held in inhabited areas with people, buildings and other goods being overflown.

The methodology employed to finally obtaining an accurate safety study consists in doing a risk identification process where all situations that may cause some problem during an operation must be considered. It might be noted that in order to identify the risks successfully, the environment and the framework of the operation have been defined in previous sections.

Once a list of risks is obtained, the next step is to make an evaluation of them, where many variables like likelihood of happening and consequences are regarded. After making an evaluation of the risks, it is then possible to identify a safety level for every different operation depending on the risks associated to it. Finally, after evaluating the safety level it is decided how rigorous and imminent must be the mitigation of the hazard in order to guarantee an acceptable level of risk so that the operation could be performed.

8.1 Identification of risks

In order to make clear and reliable the identification of risks and not to leave any risk out, risks are classified into groups based on the nature of the risk. In fact, three differentiated groups are clearly defined, internal and external to the operation and risks introduced by human errors or decisions, defining as internal all risks encompassing the drone itself with its components and communications with the pilot. External risks are considered those that have nothing to do with the drone but can interfere with it and cannot be controlled by the pilot, in other words these risks are those posed by the environment of the operation.

8.1.1 Internal risks

These risks are those related to all physical components integrated to the aircraft that can fail, in other words the hardware. Although the communication system is not completely attached to the aircraft and some hardware is present in the ground station, it is also considered an internal risk and all hazard related to failures in communications belong to this category.

Hazard identification	**Description**
Flight controller board failure	The flight controller board can be considered as the brain of any unmanned aircraft where all other functionalities are connected and give orders from. Thus, if it fails or does not work properly, the aircraft does not execute any action and the propulsion system consequently stops functioning, so it all ends with an uncontrolled fall of the aircraft.
Lack of power from batteries or fuel	Power source is the most essential thing up in the air, if the batteries or fuel tank are empty, for electrical or combustion engines respectively, the operation is at its end. If it occurs in the air, the aircraft has no more thrust and will fall to the ground.
Motor failure in a quadcopter	During the operation, a motor failure is produced, giving as a result an unstable quadcopter multirotor, which is impossible to have any control of it. Electronic speed controllers are also a cause to have a motor failure since they are susceptible to have overheating problems due to a long period dealing with high currents.
Propeller shooting off	Due to high rotation speeds, a propeller can be shot off if it is not firmly tightened, leaving the multirotor uncontrollable and impossible to recover.

Partial failure or loss of navigation systems	The navigation system usually employed in drone operations is the GPS. In fact, it is really important for the operator and for the autonomous UAVs to know the exact position of the aircraft at any moment. For example, in a return to home manoeuvre, the system must know the position of the aircraft relative to the base. If the navigation system is not working, the conflict is served. A minimum of satellites is needed to keep flying, for less than six satellites is usual to start having problems with the GPS signal.
Lost link	Maintaining the communication with the drone from ground station is the way of maintaining it controlled, however this link can be lost without being re-established and the drone can drift far from its intended target. Communications with radio frequency only work properly if there is visual contact with the aircraft. Then, in congested areas, characterised to be full of obstacles, it would be common to loss communications.
Camera failure	During an operation the on board camera fails, which results in a loss of image displaying for the pilot who only has the direct view with the drone as reference in a visual line of sight flight or no reference in the case of an operation beyond visual line of sight to the pilot.
Electrical or electronic failure	Electrical circuits are present in many parts of a multirotor, interconnect all components between them and are responsible to give energy from the batteries to other components. Therefore, an electrical failure can leave many components inoperative. Electro-static discharge, electrical overstress from a power surge and vibration causing connector and solder joint issues are the most common ones.
Structural failure	In many occasions, UAVs are used to do some missions that would be dangerous for human, because UAVs can support large load factors that a human cannot. As these large accelerations are applied to the aircraft as well, it is possible that it does not resist the resultant forces resulting in a structural disaster breaking the aircraft.

Altitude sensors giving incorrect information	Sometimes, barometers attached to the aircraft give wrong information and many of the times due to changes in speed. This fact, can display a higher altitude than the real one or vice versa with the implied associated risks. Other times, sudden drop in pressure due to a breaking manoeuver is understood as if the vehicle was rising and altitude controllers react to counter the effect and the vehicle drops aggressively.
Wing control surfaces failure	Fixed wing unmanned aircraft need control surfaces to manoeuver the aircraft and they are vital for the proper control of it. Thus, a failure of these mechanisms may lead to an uncontrolled aircraft with potential risk of crash.
Payload loss	Nowadays, many aircraft already carry small payload like cameras but in a near future many applications will be intended to carry heavier payload like for example in delivery company applications. This payload is susceptible to fall from the aircraft in a congested area for any circumstance with the damages it can produce.
Inaccuracies in the display of visual imagery in BVLOS flight	The operator usually relies on imagery from on board sensors to control the aircraft and target detection. However, the quality of this visual information may be degraded due to datalink bandwidth limits and transmission delays. This includes poor spatial resolution, limited field-of-view, low update rates and delayed image updating. These inaccuracies bring difficulties on both visual air traffic detection and vehicle control.

Table 5 - Internal risks identification

8.1.2 External risks

These are the risks that cannot be controlled by the pilot but have nothing to do with the drone itself. All external objects to the operation, climatic conditions that can change suddenly and any other interference with the proper performance of the aircraft fit this category.

Hazard identification	Brief description
Bird impact	Birds are a permanent risk and it is impossible to have any control of them. Since they share the airspace with UAVs, it is possible to have an impact with one of them, as it occurs with manned aviation. Moreover, in some cases birds have been felt attracted by UAVs which have been attacked by them causing a fall in some cases.
Collision with unmanned aircraft	Unmanned aircraft operations are increasing every day and future expectations say that will increase much more. Therefore, the probability of mid-air collision with other UAVs is real and will also be increasing.
Collision with manned aircraft	Mid-air collision with manned aircraft is also a hazard that must be taken into account following the same reasoning employed with collision with other unmanned aircraft but with manned aviation, which will have different consequences.
Collision with buildings	Presence of buildings is a characteristic of congested areas and drones that operate in this environment are susceptible to crash with them and other civil constructions.
Collision with power lines or antennas	Power lines and electrical towers are problematic to drone operations as they go more unnoticed than larger buildings but represent a high risk as well, as it is for other manned aircraft like helicopters.

Exposed propellers causing or suffering damage	On one hand, propellers are vulnerable and fragile components and they can be damaged for small impacts of tree branches or other objects, which are found in congested and hostile environments, leaving the drone unstable. On the other hand, propellers can cause damage since they rotate at high speed and a slight contact with them can produce a severe cut in a human.
Severe wind conditions	Wind can be a serious hazard for those small drones that have low mass and affects severely their stability. Gusts of wind or zones with abrupt changes in wind direction represent also risk for unmanned aircraft.
Icing	Icing conditions can produce ice formation on aircraft's control surfaces of fixed wing UAVs, blocking them and leaving the aircraft uncontrolled. Ice formed on any drone structure or surface increases its total mass and drag and reduces lift.
Bad visibility conditions	For all drone operation, bad visibility conditions are hazard added to a normal operation and increase likelihood of other risk happening like collisions. Since the majority of operations are held in visual line of sight with the pilot, good visibility is a key point in the operation
Lightning strike	As it happens with manned aircraft, as a semi metallic object moving into the sky, UAVs are potential targets for lightning strike. Unlike large commercial aviation aircrafts that normally do not suffer damages, small drones are more vulnerable due to its lower mass and simpler electrical circuits.
Radio and electromagnetic interferences	UAVs are equipped with electrical circuits and electromagnetic interferences can interfere its proper working, giving as a result unwanted actions by the pilot. Communications with ground station can be disrupted by radio interferences. This hazard is aggravated in congested and urban areas where more electronical devices are present and consequently, more interferences are produced.

Cyber-attack, hacking or hijacking	Design flaws make UAVs vulnerable to cyber-attacks. The aircraft can be forced to change its pre-programmed route or the connection with the ground station can be invalidated. Autonomous UAVs are most susceptible to this kind of attacks by spoofing fake GPS coordinates so they can crash or redirect the UAV.

Table 6 - External risks identification

8.1.3 Risks posed by the pilot

The pilot, as the maximum responsible of the operation, can introduce many risks by doing incorrect actions, which are under his control. The most common risks posed by the pilot during an operation are showed in this section.

Hazard identification	**Brief description**
Loss of visual contact with the aircraft flying behind an obstacle	When an unmanned aerial vehicle flies behind an obstacle and the visual contact with the pilot is lost, a risk is posed since the only way of having some reference of the performance is through images from on board camera if it has. Moreover, it is also more probable to lose link with the aircraft.
Take off and landing incidents as under-shooting or over running	Take off and landing are two critical moments in all kind of aerial operations because they are the moments when the aircraft is closer to the ground and other obstacles or people and there is a small margin of manoeuver. For fixed wing aircraft main risks are over running and under-shooting while multirotor aircrafts do not have this problem since they take off and land vertically.
Drones entering no-drone zones or airspace close to an airport	The airspace where drone operations are held, it is known that it is shared, but the risk is highly increased if the operator enters an airspace close to an airport or aerodrome and zones specifically denoted as no-drone areas.

Returning to home at low altitude	Some unmanned aircraft have the functionality *Returning to home (RTH)* that consists in returning to the base point previously programmed when the link is lost. The problem is that many times, the link is lost when the pilot drives the aircraft behind an obstacle, then the RTH functionality is activated with the consequent crash because of lower altitude of the obstacle at that moment.
Pilot not familiar with the environment of the operation	If the operator is not familiar with the environment, it is more probable to introduce more risks to the operation, for example due to unknown obstacles that are difficult to notice at first sight, zones prone to sudden changes in weather conditions or zones with notable air traffic.
Operator piloting the aircraft in reverse	In operations beyond visual line of sight to the pilot, where all visual reference of the environment around the aircraft is acquired through on board camera images, piloting the aircraft in reverse not having any reference of the obstacles behind can be so dangerous. In fact, many pilots have done this instinctive manoeuver at least once to change and expand the visual field.
Speeding and braking distance	As well as it happens with other types of aircraft and ground vehicles, speeding and not having a safe braking distance or margin of manoeuver is a common cause of accidents. Thus, pilots speeding in congested areas are increasing notoriously the risk of the operation.
Aircraft exceeding distance limitations from the pilot	There are several distances declared, that can slightly vary from one to another regulation, which define a volume, normally a cylinder centred in the operator, from which the aircraft must not exceed. Exceeding them may put in danger third parties on the ground or other aircraft in the air if the altitude restriction is overpassed.
Operator feeling sick or having any medical problem	During a RPA operation, the pilot is the maximum responsible of the well performance of the aircraft and the safety of the operation is in his hands. However, the operator can feel sick or have any other medical problem in the middle of the operation that can endanger the activity severely.

Table 7 - Identification of risks introduced by the operator

8.2 Evaluation of risks

Once multiple risks of an operation are identified, it is time to evaluate them taking into account the likelihood of happening as well as the consequences of them in a congested and hostile environment. In fact, making the evaluation in this environment, described with detail in previous sections, provides a differentiating factor to the risk analysis because the severity of a produced hazard can be much higher than it could be in an isolated area, since it is an environment completely exposed to people, buildings and other material goods.

Furthermore, likelihood of hazard happening is also greater in a congested or hostile zone than in an isolated area, for the reason that there are more obstacles like building or power lines with which the aircraft can run into or be in the line of sight to the pilot. Another fact are Interferences, which in urban areas are more frequent because of the large amount of electronical devices and communication links that are present.

Despite these notable difficulties added when operating in this kind of environment, an operation in a congested area must be performed with an acceptable level of safety, even higher than other type of operations because in many cases people lives are one of the most worrying consequences and cannot be put in danger under any circumstance.

The procedure used in the evaluation of risk requires defining a likelihood of happening and a level of severity of the potential damage. Five categories are defined for both analysed items.

In terms of likelihood of happening, all risks are divided into the following five categories from less to more probable:

- Extremely unlikely: Unlikely to occur but possible. It is considered that the event can happen less than once every 10.000 operations (less than 0,01%).
- Remote possibility: Unlikely, but can reasonably be expected to occur. It is considered that the event can happen between 1 and 10 times every 10.000 operations (between 0,01% and 0,1%).

- Possible occur: Will occur several times. It is considered that the event can happen between 1 and 10 times every 1.000 operations (between 0,1% and 1%).
- Will probably occur: Will occur frequently. It is considered that the event can happen between 1 and 10 times every 100 operations (between 1% and 10%).
- Almost certain: Continuously experienced. It is considered that the event can happen more than once every 10 operations (more than 10%).

In terms of severity of potential damage or injury, the five categories defined from less to more severe are the following:

- Insignificant: Negligible damage to property, equipment or minor injury without requiring attention. It could result in monetary loss less than 1.500 euros.
- Minor: It could result in an injury or illness that would not require any lost workday. Monetary loss between 1.500 and 7.000 euros or minimum damage to environment that would not require restoration.
- Moderate: It could cause injuries or occupational illnesses that would cause one or more lost workdays. Moderate damage to environment, reversible without applying correction measures. Monetary loss between 7.000 and 150.000 euros.
- Major: It could result in permanent partial disability, injuries or professional illness that may result in hospitalization of at least three people or prolonged medical treatment. Serious damage to environment, reversible with correction measures. Monetary loss between 150.000 and 700.000 euros.
- Catastrophic: It could cause death or permanent total disability of human being, irreversible significant damage to environment and monetary loss greater than 700.000 euros.

With the given categories defined for likelihood and severity, each risk must be associated to a probability level and a severity level. Once assigned the levels, with values from one to five, it is time to enter these values into the risk evaluation matrix, shown in Table 8. This matrix gives as a result a safety level for the operation that is classified into four categories depending on the associated risk. It may be noted that each position of the matrix has a number together with a risk rate, which has been obtained by multiplying the severity per the likelihood index.

		Severity of the potential injury or damage				
		Insignificant **1**	Minor **2**	Moderate **3**	Major **4**	Catastrophic **5**
Likelihood of happening	Almost certain **5**	Acceptable 5	Tolerable 10	Unacceptable 15	Unacceptable 20	Unacceptable 25
	Will probably occur **4**	Acceptable 4	Tolerable 8	High 12	Unacceptable 16	Unacceptable 20
	Possible occur **3**	Acceptable 3	Tolerable 6	Tolerable 9	High 12	Unacceptable 15
	Remote possibility **2**	Acceptable 2	Acceptable 4	Tolerable 6	Tolerable 8	Tolerable 10
	Extremely unlikely **1**	Acceptable 1	Acceptable 2	Acceptable 3	Acceptable 4	Acceptable 5

Table 8 – Evaluation of risk matrix

As it can be seen in the risk evaluation matrix, the four risk rates obtained are acceptable, tolerable, high and unacceptable. In Table 9, safety levels are defined as well as the intervals of each risk rate.

Risk rates definition		
Acceptable	1 – 5	The operation can be performed. Anyway, the operation should be in continuous observation to even reduce more the risk in a future by reducing the likelihood or the consequences.
Tolerable	6 – 10	The operation can only be performed if the competent authority gives an explicit authorization. It should be redefined as far as possible concerning the implied risks or mitigating them before the operation starts.
High	11 – 14	The operation cannot be performed. However, adopting some measures that reduce the risk, the operation could be performed with a previous authorisation. The operation must be redefined to reach an acceptable level of safety.
Unacceptable	15 – 25	The operation cannot be performed under any circumstance. Redesigning the operation and increasing strictly safety measures is essential if the operation has to be performed in a future.

Table 9 - Risk rates definition

Now, after describing the method employed to classify the risks, it is time to take the list of risks previously identified and associate them with a likelihood and severity level in order to acquire the resulting risk rate. This procedure of assigning a likelihood and severity rate to each hazard is very relative and has been made with the maximum strictness possible, consulting historic data and previous accidents as far as possible.

8.2.1 Internal risks

Hazard identification	Likelihood	Severity	Risk rate
Flight controller board failure	3	5	15 Unacceptable
Lack of power from batteries or fuel	3	5	15 Unacceptable
Motor failure in a quadcopter	4	5	20 Unacceptable
Propeller shooting off	3	4	12 High
Partial failure or loss of navigation systems	2	4	8 Tolerable
Lost link	4	3	12 High
Camera failure	2	2	4 Acceptable
Electrical failure	3	4	12 High
Structural failure	2	5	10 Tolerable
Altitude sensors giving incorrect information	4	4	16 Unacceptable
Wing control surfaces failure	2	5	10 Tolerable
Payload loss	2	4	8 Tolerable
Inaccuracies in the display of visual imagery in BVLOS flight	5	2	10 Tolerable

Table 10 - Internal risks evaluation

8.2.2 External risks

Hazard identification	**Likelihood**	**Severity**	**Risk rate**
Bird impact	2	4	8 Tolerable
Collision with unmanned aircraft	2	5	10 Tolerable
Collision with manned aircraft	2	5	10 Tolerable
Collision with buildings	4	3	12 High
Collision with power lines	3	3	9 Tolerable
Exposed propellers causing or suffering damage	3	3	9 Tolerable
Severe wind conditions	4	4	16 Unacceptable
Icing	3	4	12 High
Bad visibility conditions	4	4	16 Unacceptable
Lightning strike	2	4	8 Tolerable
Radio and electromagnetic interferences	5	4	20 Unacceptable
Cyber-attack, hacking or hijacking	1	5	5 Acceptable

Table 11 - External risks evaluation

8.2.3 Risks posed by the pilot

Hazard identification	Likelihood	Severity	Risk rate
Loss of visual contact with the aircraft flying behind an obstacle	4	3	12 High
Take off and landing incidents as under-shooting or over running	4	5	20 Unacceptable
Drones entering no-drone zones or airspace close to an airport	3	5	15 Unacceptable
Returning to home at low altitude	3	3	9 Tolerable
Pilot not familiar with the environment of the operation	4	4	16 Unacceptable
Operator piloting the aircraft in reverse	4	3	12 High
Speeding and braking distance	4	4	16 Unacceptable
Aircraft exceeding distance limitations from the pilot	4	3	12 High
Operator feeling sick or having any medical problem	3	4	12 High

Table 12 - Risks posed by the pilot evaluation

As it can be seen in Figure 12, many of the hazard identified have resulted in an unacceptable or high risk rate, so the operation cannot be performed like it is conceived since safety is not ensured. This large proportion of unacceptable risk above tolerable and acceptable risk is mainly due to the fact that the operation is evaluated considering a congested and hostile environment.

This particular environment worsens the consequences of possible damage since third parties are permanently present and increases the probability of happening as well. If the study had been done considering a desert environment, it is highly probable that many of the hazard rated with a high risk would have been rated with a tolerable or an acceptable risk.

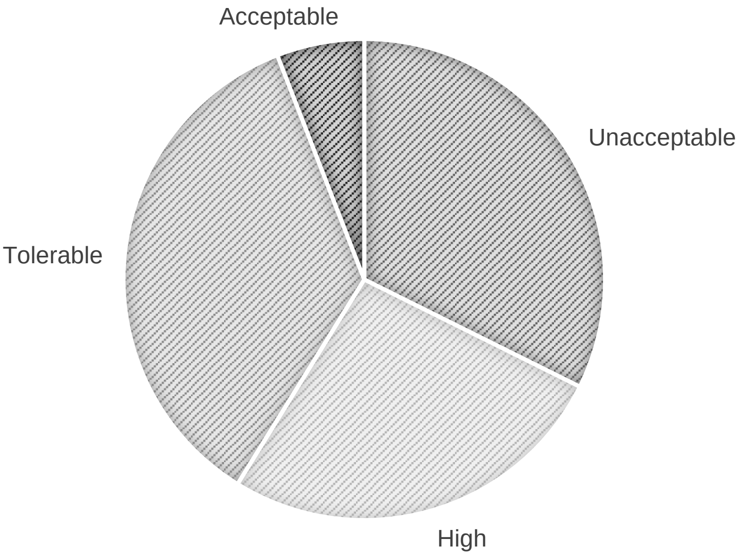

Figure 12 - Risk rate distribution after evaluation

9 Proposal of operational procedures and technology

After rating each identified risk and classifying the operations with a safety level, the result obtained is that many of them represent a real threat if they are operated in a congested or hostile area where many people and material goods are totally exposed. As seen, many risks are posed by problems of reliability of the systems employed in the aircraft, which is at present the most worrying problem in the unmanned aerial vehicles' field, whilst others are just posed by external events like climatic conditions or by human errors.

However, nobody doubts that the future of UAVs and RPAs is in the performance of many operations in populated areas, being integrated in the airspace just like if they were manned aviation. Therefore, elevated risk rates are no longer acceptable and safety must be guaranteed. In order to make the operation safe, some mitigation measures must be applied through both operational procedures and contribution of technology, which would reduce principally the likelihood of risk happening and the severity of the consequences as far as possible, so that the resulting risk rate becomes acceptable or at least tolerable.

In this section, operational procedures and technological solutions are proposed in order to mitigate to an acceptable level each hazard that resulted in a high and unacceptable rate of risk, or even tolerant. These mitigation measures will be enforced in a near future if the operation is intended to be performed in a congested and hostile area.

9.1 Mitigation measures

Despite all mitigation measures that will be presented in this section with the aim of reducing the probability of accidents happening, there will always remain a possibility of a fatal crash. This is the reason why before proposing mitigation measures for each specific risk, a general one is proposed for all aircraft operating in congested and hostile areas. This mitigation measure consist in incorporating parachutes and optional airbags to reduce the severity of a possible fatal crash.

Parachute and airbags should be deployed by the operator if possible but an automatic system must also be designed, that could identify some system failure or that the aircraft starts to fall uncontrollably, so that if communication link with ground station is lost, the protection devices are activated. Some examples of this technology are showed in Figure 13 for both multirotor and fixed-wing aircraft.

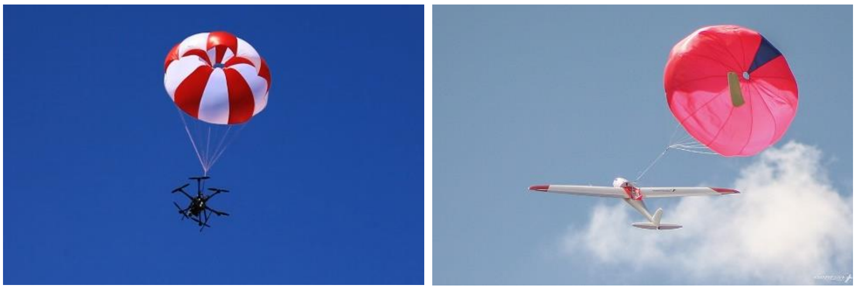

Figure 13 - Parachutes deployed in multirotor (left) and fixed-wing (right) UAVs [17]

Another general mitigation measure that must be applied for all operations, no matter what the mission consists on, to reduce the consequences in case of crash. This measure consists in adding limitations in the maximum energy of the aircraft, since it is directly proportional to the severity of consequences if an accident occurs. The only regulation regarding this limitation of energy is the French one.

Once presented these general mitigation measures, it is time to analyse each risk independently and propose some solutions through technology or operational procedures.

- Flight controller board failure

As the most important component of the UAS, a failure in the flight controller is intolerable. The mitigation measure employed to reduce this risk is to turn to redundancy systems. It is proposed to use two flight controllers working in parallel instead of a single one, so that if one fails the other can keep processing, receiving and transmitting information in order to maintain the aircraft up in the air. The basic redundant scheme with two controllers working in parallel is shown in Figure 14.

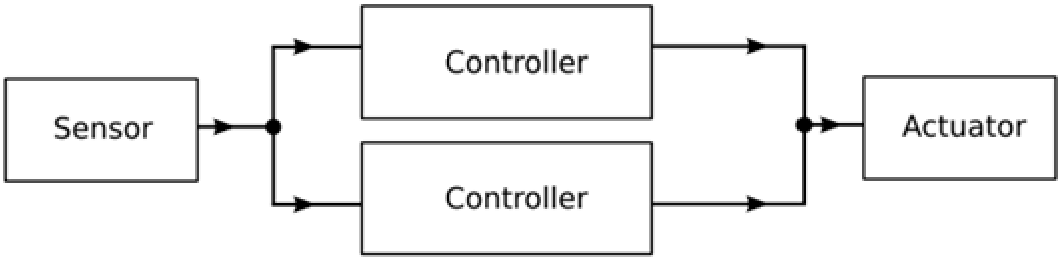

Figure 14 - Redundancy scheme with two flight controllers [18]

The redundant controller can be run in two modes: cold and hot redundancy. Using hot redundancy, any state information stored by the primary unit is shared with the backup unit, whilst using cold redundancy the backup unit starts with no information of the system's state. In this way, when a controller fails hot redundancy works faster than cold redundancy and in the context of a quadcopter speed in failover time is essential, therefore hot redundancy must be used.

- Lack of power from batteries or fuel

In order to reduce the likelihood of exhausting the power source of the aircraft still in the air, which would result in a fatal accident, several mitigation measures are taken into account. First of all, UAVs using batteries must initiate the operation completely full of energy, at maximum capacity, since the weight is not increased for this reason and the aircraft is provided with more autonomy, which is always better. Operators of UAVs using fuel as its power source must make a study of the duration of the operation and carry the fuel needed for it with the corresponding reserves because carrying more fuel than needed could represent a significant loss of efficiency.

Another action to be taken is to monitor continuously the levels of energy and fuel respectively and be conscientious to land the aircraft before it is too late, normally when levels are around 85% of its total capacity, the pilot must start to take the aircraft back to ground.

In fact, to not to leave this relevant action in hands of a human that is another source of risk, a function must be implemented based on its location and that of where it has previously took off or other near zones destined to land which must be added before into the system. This functionality must calculate the energy needed to reach one of these landing locations from its current position, which must be lower than the energy remaining in cells or tank so that it is ensured that the landing can be done. Thus, if the energy remaining is equal to the estimated considering a safety factor, the aircraft should automatically be redirected.

- Motor failure in a quadcopter

A solution to a motor failure in a conventional quadcopter, which leaves the aircraft unstable and uncontrollable, is to employ a coaxial motor configuration so that the one in the same position than the failed one could meet the other's functionality as well. Other multirotor configurations like hexacopters or octocopters instead of quadcopters are also a good measure that could keep the aircraft under control in the air.

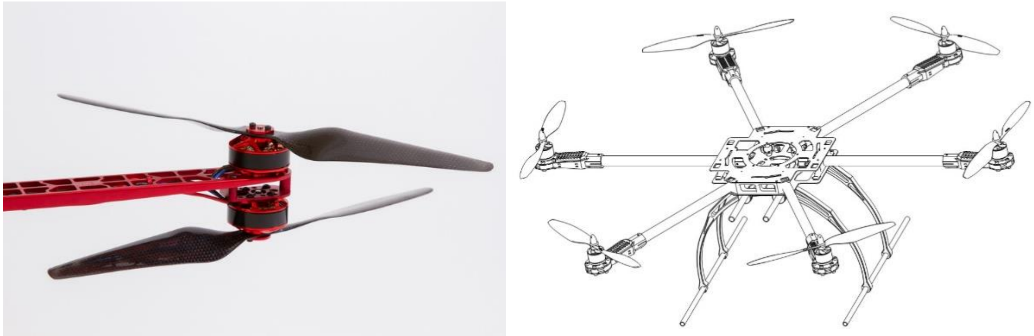

Figure 15 – Coaxial quadcopter configuration (left) and hexacopter configuration (right) [19]

However, all these measures are based on redundancy and they contribute to increase the total mass of the aircraft, what makes it less efficient and more dangerous since it would have more energy in a hypothetical impact. This is the reason why an innovative software has been developed, concretely a control algorithm designed by the Swiss Federal Institute of Technology in Zurich to keep the quadcopter in the air safe after a propeller of motor failure [20].

- Propeller shooting off

The effect of a propeller shooting off can be approximated to that of a motor failure because the multirotor loses a part of its propulsion. Thus, for quadcopters the same mitigation measures taken for a motor failure are taken to reduce this risk, so that if a propeller is shot off the aircraft is able to continue with the operation.

Nevertheless, propellers must be prevented from shooting off so frequently when rotating at high rates. The mitigation measure in this case is a procedure that always must be done during previous moments before the start of the flight, consisting in the operator checking and ensuring that all propellers are firmly tightened. Although there are commercial UAVs with self-tightening propellers, the operator must not rely on this and must check the propellers as well.

- Partial failure or loss of navigation systems

For autonomous UAVs or remotely piloted operations flying in an automatic mode where a flight path is pre-programmed, everything is relied on the navigation system, in practically all operations a GPS. Thus, this system must be very reliable and the quality of the GPS antenna must be high. Moreover, in order to avoid any degradation of the signal due to interference or by loss of number of satellites, the antenna must be isolated from other electronics like on board cameras or electronic speed controllers as far as possible. Flying near places where GPS signal is usually bad, like near tall buildings or in valleys, should be avoided if possible.

In addition, if the GPS signal was lost, the navigation system would be inoperative at all. Then, the *returning to home* function should be activated, but since the navigation system would not be working, it would be impossible to take the UAV back to the launch site. Thus, redundancy systems must be employed by always incorporating inertial navigation systems, formed by three gyroscopes and three accelerometers that determine the angular rotation and the acceleration respectively, which are packed together into an inertial measurement unit. This inertial navigation system is then able to determine the position, orientation and angular velocity, but with less precision than GPS. However, incorporating an inertial navigation system would permit to take a UAV back to home, with a margin error from two to three meters approximately.

- Lost link

In order to avoid losing the data link with the aircraft form ground station, it is advisable not to interpose obstacles between transmitter and receiver, what means not to fly behind obstacles, but since congested and hostile areas are characterised to have many obstacles, this is assumed that can frequently occur.

Therefore, the *returning to home* function as a failsafe mode, that nowadays some UAVs already have, must be employed. Its working principle is based on storing the take off location so that if the aircraft loses communication with ground station it automatically returns to this position using the navigation systems. Apart from the launching site, other safe landing locations should be pre-programmed in a map previously loaded in the aircraft with the intention of landing the sooner possible in the closest site. In the case of big cities, some rooftops of high buildings could be destined to this mission.

Redundancy should also be used to reduce likelihood of this risk happening, using satellite communication systems to control the UAV as some military drones are controlled at present when the aircraft leaves the line of sight with the operator, which would be a frequently repeated situation for operations in the middle of narrow streets of crowded cities. Furthermore, satellite communications permit more quantity of data transferring and at higher speed in civil environments. A scheme of these communication systems is presented in Figure 16.

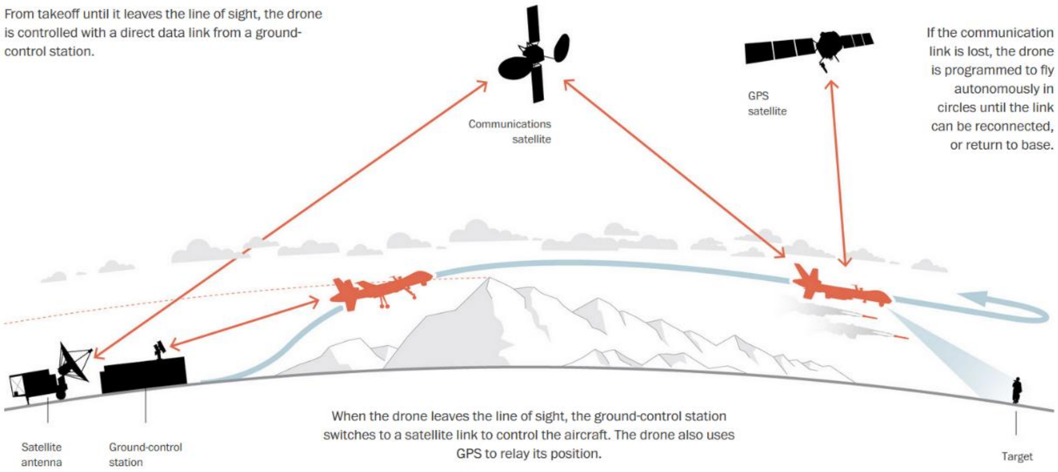

Figure 16 - Scheme of UAV communication system [21]

It is obvious that satellite communication system is more complex, less practical and not affordable by many operations because they would not be economically profitable at all. Thus, mobile networks would be a better solution using 3G or 4G networks, which do not need to have visual contact with the aircraft, for example if an obstacle is between ground station and the aircraft, and is cheaper than communications via satellite.

Another possible mitigation measure if returning to home function wants to be avoided at first, is to pre-program the aircraft to fly in circles or even hovering for multirotor aircrafts, waiting to recover the signal from ground station if the communication link is lost.

- Camera failure

If operating in BVLOS and the on-board camera fails leaving the operator without any visual reference near the aircraft, the *returning to home* function previously explained must be activated immediately.

- Electrical failure

Electrical circuits are essential to communicate the flight controller with actuators and antennas, so they are not allowed to fail. Therefore, some mitigation measures are taken to reduce the probability of an electrical failure happening like current protection, surge protection, properly implemented ground circuit, periodically inspects before flight, reinforcing wires, connections, and adding redundant lines if necessary.

- Structural failure

In order to avoid structural failures or damages, the maximum load factor that the aircraft can resist must be represented in function of the speed, similar to a flight envelope in the case of manned aircraft. Then, it will be possible to identify a never exceed speed which is very useful for the pilots and during the design phase of the UAV, engineers will be able to design an aircraft complying with structural regulations that might determine a maximum load factor for all operations.

- Altitude sensors giving incorrect information

Barometric altitude sensors in some cases give incorrect information due to the aerodynamics of the aircraft, so in the design phase of the aircraft the barometric altimeter should be placed in some part of the aircraft where aerodynamics cannot alter the measures. When the flight stabilizer tries to compensate a sudden change in altitude probably fictitious because a high-pressure zone created in some part of the aircraft, it first must be compared the change of barometric altimeter and GPS altitude information, although it is not precise it would identify properly the altitude changes.

Apart from the barometric altimeter, the UAV must incorporate other types of altimeter like sonar to get information more precise during the landing operation, which is critical.

- Wing control surfaces failure

Before any operation using fixed-wing UAVs, the operator must check that all control surfaces, ailerons, flaps, vertical and horizontal stabilizer, work properly and the actuator systems as well. In icing conditions that can block someway the complete movement of the surfaces, they should be sprayed with anti-icing fluids.

Apart from doing a pre-flight check that reduces the probability of happening, some measures have to be taken to reduce the consequences if finally the wing control surfaces failure occur leading the aircraft to an unavoidable crash. Thus, a parachute must be incorporated to reduce the falling speed, which must be activated by the pilot when the aircraft does not react as expected to the commands given.

- Inaccuracies in the display of visual imagery in BVLOS flight

A well-designed system for display of visual imagery will be required to contrast the benefits and costs of temporal resolution, spatial resolution and field of view determining what information is task-critical, that will change in every operation depending on its mission. Then, it must be established the optimal compromise between spatial resolution, temporal resolution and field of view since the bandwidth is not large enough to transmit all variables at their maximum resolutions respectively. For different types of missions, it would be helpful to create sensitivity curves to show performance quality or degradation as a function of spatial and temporal resolution, so that it will be easy for the pilot to determine the configuration parameters depending on the type of mission before its take off.

- Bird impact

Preventing bird impacts should be done employing an innovative guidance anti-collision system, which still has to be improved, provided with several sensors that are able to detect and avoid any type of obstacles even at relatively high speeds.

Apart from incorporating this technology into the aircraft, flying above zones that are known to be frequented by birds or natural parks should be avoided if possible to protect the environment.

Nevertheless, some birds are insistent to interact with the drones even attacking those that are smaller, so some measure has to be taken to keep birds away from UAVs. The solution is to incorporate a sonic bird repellent to act like those in the airports, so that if a bird is permanently near the UAV the operator can activate this option to send the it away.

- Collision with manned, unmanned aircraft, buildings and power lines

The UAVs in a future will be enforced to incorporate a detect and avoid system, currently still in development, maintaining the adequate separation with other aircraft, manned or unmanned, and other obstacles like buildings and powerlines, obtaining as a result a safe integration of UAV into all airspace.

Apart from incorporating this useful technology, the operator must be aware of the presence of obstacles, power lines and if the zone is frequented by low altitude manned aircraft or not to adopt some preventive measures. The operator should avoid flying in an area with other UAVs operating simultaneously as well to avoid potential collisions and radio interferences.

- Exposed propellers causing or suffering damage

In order to avoid propellers causing damage to people and other goods or just avoid being damaged resulting in a useless propeller, all propellers must have fairings or protections affecting as little as possible to aerodynamics and efficiency of flight. Some examples are shown in Figure 17.

Figure 17 - Examples of fairings in UAVs

- Severe wind conditions

In general, for strong wind conditions the operation should be cancelled as far as possible. However, meteorological training courses will be given to the operators in order to learn how to control the UAV in different wind conditions and analyse the wind forecasts before the beginning of the flight. Equipment dedicated to measure the intensity and direction of wind will be incorporated in the zone of operation and some limitations in these magnitudes will be stablished at which the operation is considered safe and consequently can be performed.

- Icing

In zones where the weather is usually cold and at high altitudes of flight where the temperature is still lower, icing can appear and cause severe problems, so the surface of UAVs must be sprayed with anti-icing and de-icing fluids, especially on key surfaces.

Moreover, research has been done in this field since other conventional ice protection technologies for manned aircraft are not suitable for UAVs just because they are too complex, too heavy or require too much power to effective. Thus, an innovative carbon nanotube coating has been designed that can be sprayed onto an aircraft surface much like paint or as a laminated sheet creating a heated area when power is applied [22]. This innovative system is lighter and does not require much power, what makes it ideal for UAVs operating in cold weather zones.

- Bad visibility conditions and lightning strike

Under unfavourable weather conditions like electrical storms and foggy days when it is almost impossible to maintain direct visual contact with the UAV and the cameras do not offer a clear image, the operation must be cancelled as soon as possible. If a sudden change in the visibility occurs and the operator loses the visual contact with the aircraft, the pilot must activate the *returning to home option* immediately before the visual conditions get worse. Apart from this, meteorological training courses will be given to the operators, so that they will be able to assess if it is safe or not to start an operation, once analysed the weather forecast and the current meteorological conditions.

- Radio and electromagnetic interferences

It may be noted that there are no specific frequencies allocated for UAV's use but the most common frequency used for connecting the ground transmitter to the UAV is 2.4 GHz, which is the same employed for wireless computer networks that are highly present in congested areas. This is the reason why before starting the operation and turning on the transmitter, it must be ensured that there are no frequency conflicts by using a frequency scanner or spectrum analyser and that there no identical NetID in the area of the operation. In operations with on board cameras that allow doing operations beyond visual line of sight to the pilot, another frequency must be used to transmit the video images, usually 5.8 GHz.

Concerning electromagnetic interference, it can be caused by other components of the aircraft or by external sources. Therefore, transmitter and receiver antennas on board must be isolated from other electrical components as far as possible, and all phone repeaters, radio transmitters and power lines seen during the operation should be avoided.

- Cyber-attack, hacking or hijacking

Hijacking resulted in an acceptable risk because its probability of happening is low in congested areas where commercial applications are the most common ones and the interest of cyber-attacks is more focused on military applications in war-deserted zones. Mitigation measures concerning this risk to this day are not so proved and hacking procedures are in constant development, so evolution of better UAVs in time is the solution to this problem. However, some considerations can be made to reduce this risk like keeping computers and devices in ground station free of malware that might cause cyber-attacks.

- Loss of visual contact with the aircraft flying behind an obstacle

It should be avoided flying behind the obstacles if the aircraft is not provided with on board cameras that allow the operator know the UAV's attitude being able to redress any wrong manoeuver. If this is the case, the operation environment must be parcelled up so that the flight is only performed in a zone where the obstacle in question is not present and does interfere the visual contact.

- Take off and landing incidents

Take off and landing are definitely the two most critical stages of an operation since they are the moments where the aircraft is closer to the ground and consequently closer to people. Thus, to reduce the severity of the consequences if an accident occurs, during take off and landing manoeuvers a safe distance must be kept from other people or goods simultaneously alerting of the situation aloud, landing or launch, by the operator.

In the case of fixed-wing UAVs that do not land vertically, safety margins must be taken in the runways and high obstacles must not be present in the surroundings of the runway, especially in approaching and ascending zones.

- Drones entering no-drone zones or airspace close to an airport

First of all, the operator should be aware of no-drone zones or airport airspaces before starting any operation. Nevertheless, the airspace a drone can enter must be limited automatically by geofencing. Nowadays, there are already relatively simple two-dimensional solutions using geofencing and in the future, the principle might be applicable in a dynamic way to support operators and pilots in complying with temporarily limitations or even local needs.

Moreover, another measure to prevent UAVs entering prohibited controlled airspaces or at least having them identified is to enable some drone identification functionality able to react to interrogations from enforcement entities and provide information about the drone, the operation and the operator. This system might use technologies like cell-phone networks or radio frequency.

- Returning to home at low altitude

When the *returning to home* function is activated by a loss of communication link with ground station, the aircraft automatically returns to the launch site following the straight line with its position at current altitude, giving as a result a crash if there is a higher obstacle in the middle. In order to solve this problem, before the beginning of the operation the operator must be informed about the highest obstacle of the zone it is going to be operate. This value must be introduced to the system, so that if the communication link is lost, the aircraft firstly will reach this maximum altitude, with a safety factor as margin, and then it will start returning home ensuring that no crash will be produced if the communication is lost at low altitude.

- Pilot not familiar with the environment of the operation

Many accidents occur due to the lack of familiarity of the operator with the environment of the operation. Then, before any operation the pilot must do a reconnaissance tour around the environment it is to be performed, in order to notice any obstacle, possible sources of interference and prohibited zones that can introduce a risk and must be avoided if possible.

What is more, the pilot must be also informed of usually weather conditions of the zone, if it is a zone prone to some kind of wind for example or sudden changes in meteorology for example. Apart from this specific knowledge, operators will need to demonstrate some knowledge in the aeronautical field, obtaining some kind of license that allow them to operate safely. In the process of acquiring this license, some courses will be imparted about operational procedures to follow before and during an operation, consisting in pre-flight, in-flight and post-flight checklists to be followed.

- Operator piloting the aircraft in reverse

Operators must be raised awareness through formative courses for obtaining the license that piloting in reverse in operations beyond visual line of sight where the only reference is given by an on-board camera is dangerous. Furthermore, when the pilot is operating BVLOS, some functionality must be implemented to allow only flying towards directions where the field of view of the camera can offer images, whilst if the operator tries to pilot in reverse, the UAV first will turn around itself to see if it is safe or not to do that manoeuver.

- Speeding and braking distance

As it is for other types of transport like cars or just manned aircraft, speeding is an undeniable source of accidents and the probability of happening must be mitigated. Then, some strict limitations in speed must be established for operating UAVs in congested areas for commercial applications, where safety and reliability comes first than speed, as it would be a priority for other applications like military. Keeping a safe speed also would make detect and avoid system more reliable, which at very high velocity is not too precise and consequently does not work properly.

- Aircraft exceeding distance limitations from the pilot

In order to keep the operation safe, the pilot must not exceed from the current distance limitations laterally or vertically that define a fictitious cylinder. Then, apart from having it controlled manually by the operator, it must be automatized to prevent human errors. Some similar functionality like geofencing should be introduced, this way the pilot must introduce the distance limitations before the flight, 400 ft or 150 m normally as maximum altitude and horizontally depending of the country regulation, so that if the maximum distance is reached and the pilot continues giving power the aircraft will not obey and will stay there until the operator realises.

- Operator feeling sick or having any medical problem

All operators will be required of a medical certificate to guarantee that they do not suffer any major illness or permanent disability and that they have all physical and psychological requirements to practise as a UAV's pilot. Nevertheless, since some pathologies like dizziness, drops in blood pressure and heart attacks are not predictable at all, the presence of two operators at least will be enforced in operations in congested and hostile areas.

Furthermore, even for operations with autonomous UAVs the human presence must be also compulsory. Operators in this case, will not be piloting the aircraft manually, reducing the probability of human errors, but will be present in ground station monitoring all flight data and controlling everything is as expected, being aware of a possible failure of autonomous systems as well.

10 Environmental impact

Nowadays, every technological advance in whichever the field is, it is questioned for the impact it will have to the environment. Then, guaranteeing that a product will not affect severely the environment is a fact that must be taken into account and is as important as any other design issue, because without an approval saying that the product does not pose any risk to the environment and that it helps to the proper maintenance of it, this product will seldom be brought to the market.

This study about operations with unmanned aerial vehicles in congested and hostile areas also contributes in some way to maintain the environment. Many of the large variety of innovative applications using UAVs are conceived to be performed in densely populated areas like city centres. In fact, these areas are usually highly polluted but the use of UAVs will not increase this level of pollution since the vast majority of them have electrical propulsion systems, basically because of their light weight that allows it, with null polluting emissions.

Furthermore, UAVs will replace some operations currently done by helicopters and light aircraft in congested areas, like surveillance, traffic control or advertising for example. Then, it is possible to affirm that introducing UAVs in urban operations would even reduce pollution levels, since they will be replacing operations that once belonged to helicopters and other aircraft equipped with internal combustion engines that have undeniably more elevated polluting emissions by large. Moreover, these internal combustion engines also have higher levels of acoustic pollution than electrical propelled unmanned aircraft, which is another key point in favour of UAVs regarding the environmental impact.

An evidence of this larger contamination of light helicopters in cities is the example of the Eurocopter Ecureuil AS355 F2R Biturbine. This helicopter is frequently used to fly over cities since complies with the regulation requirements for this kind of areas having two operative engines simultaneously. To get an idea off the great pollution they produce to the environment, it is possible to observe in its technical sheet [23] the great fuel consumption, which is about a litre for each 0,98 km. This can be contrasted with the null fuel consumption of electric UAVs.

11 Economic impact analysis

Similarly to the case in which have been analysed the environmental impact of the use of UAVs in congested and hostile areas, any product must have some beneficial economic impact to the society, if not, it will have more difficulties to be successful in the market.

Following the same case explained in the environmental section, where the UAVs replace helicopters and light aircraft to do their operations, it is possible to extract several conclusions in favour of UAVs.

Firstly, operation costs of an helicopter are by large more expensive than those corresponding to an operation with a small UAV, because its heavy mass requires more power from the combustion system, which at the same time is less efficient than electrical propulsion systems employed in UAVs. Apart from the operating costs, the acquisition costs are also much more expensive for the manned aircraft and by buying one of them, it would be possible to buy many UAVs and consequently, more operations could be performed simultaneously.

Moreover, there are already many studies concerning the economic impact of UAVs being integrated in the airspace, one of them has been done by the Association for Unmanned Vehicle Systems International and shows the economic benefits of UAS integration in the United States of America until 2025 [24].

It is expected that UAS integration into the American National airspace system will have enormous economic and job creation impacts in the USA, being these impacts due to direct, indirect and induced effects of total spending in unmanned aircraft systems development.

It is calculated that between 2015 and 2025, UAS integration will contribute $82,1 billion to the economy by agriculture ($75,6 billion), public safety ($3,2 billion) and other activities ($3,2 billion). As it can be seen in Figure 18, the fact that relates the importance of agriculture sector among others is the large difference in the expectations of annual sales between them, which has even a better growing rate from 2017 to 2025.

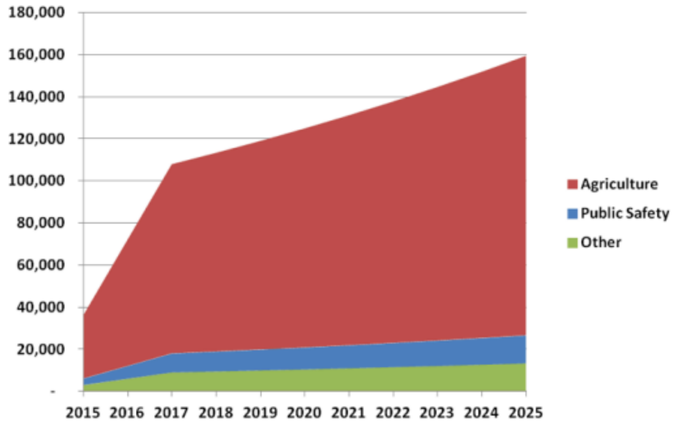

Figure 18 - UAV annual sales by sector [24]

These economic benefits will also result in the creation of around 103.776 new jobs in the United States, with a fraction of approximately the half that are direct employment as it can be observed in Figure 19.

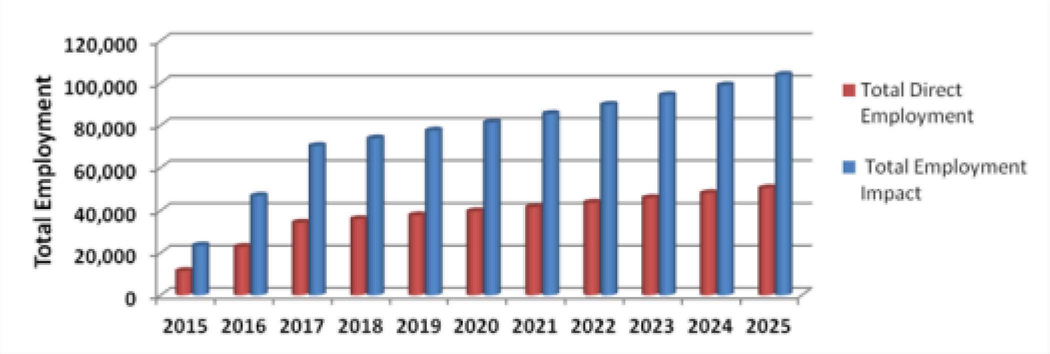

Figure 19 - Total employment impact in the USA [24]

All these economic impacts can be extrapolated in some way to other markets like European or Asiatic, at least the growing tendency, giving an optimistic future to the use of UAVs and giving more reasons to start developing regulations to allow operations in congested areas.

12 Conclusions and Future Works

After finalizing this study and fulfilling successfully all the tasks proposed at the beginning, it is possible now to draw some conclusions concerning the use of UAVs and RPAs in congested and hostile areas.

Firstly, it should be noted that thanks to the rapid evolution of technology in the last years, UAVs have been able to be improved by employing better materials and better systems that consequently have given a more important role to them in the field of aviation, with a large range of applications replacing those manned operations that could represent a high risk for integrity of the on-board crew or those that could be too exhausting missions for the pilots.

As some of these applications are conceived to take place in urban areas, regulations should contemplate that operations in this environment pose higher risks to people and other material goods, so they might be treated separately from other operations that take place out of congested areas. Nevertheless, after analysing the regulatory framework from several countries, it has been found that practically none of them allows operating over inhabited areas, with the exception of France that establishes some requirements to comply with, in order to be able to operate in this kind of environment.

Furthermore, it has been analysed that international regulating authorities, like the European Aviation Safety Agency and the Federal Aviation Administration, have published proposals, amendments and guidance material for the proper development of future regulations, trying as well to unify the operational requirements and limitations stablished to operate safely, without endangering third parties, in congested and hostile zones.

After this approach to regulatory framework, the operational conditions of UAVs to this day have been studied taking into account all physical components, systems and operational procedures as well, obtaining the final conclusion that nowadays UAVs are not reliable at all and that if they want to be operated in congested environments where there are even more difficulties and hazards than in an isolated area, reliability must be strongly improved. This low reliability, has also been contrasted with information found that have corroborated that nowadays, unmanned aircraft vehicles have accident rates of up to two orders of magnitude greater than those presented for manned and conventional aviation.

This current low reliability of unmanned aircraft systems has led the study to a risk analysis and a safety study. The risk analysis has started with the identification of all possible risks that can appear during an operation in a populated area, caused either by internal, external or human factors. It may be remarked that due to the fact that risk identification process has been done considering operations over congested and hostile areas, number and variety of hazard have resulted larger since there are more obstacles like buildings, antennas and power lines and the heavy use of communication equipment, like mobile phone and Wi-Fi, increases the likelihood of suffering interferences.

Once risks have been identified, they have been evaluated by associating each risk to a likelihood of happening and a level of severity of the consequences, obtaining as a result a safety rate, which could be acceptable, tolerable, high and unacceptable. In addition, it has been concluded that those operations with associated risks resulting in a not acceptable safety rate, which are the vast majority of them, could not be performed because they would be endangering people's lives on ground and in the air.

Therefore, it has been decided to make a proposal with mitigation measures that will reduce the risks of the operations to an acceptable safety rate by introducing some improved technology and establishing operational procedures, which would reduce the probability of hazard happening or the severity of a potential damage. In fact, some of the measures intended to reduce harm are incorporating airbags and parachutes, adding fairings to the propellers or limiting the energy of the aircraft, while others conceived to reduce the probability of happening are based on employing redundancy systems, like using two flight controllers or octocopters instead of quadcopters, and avoiding operations in adverse weather conditions.

Another conclusion that can be extracted from the mitigation measures is the high level of responsibility the pilots have in this kind of operations, where a human error can lead to a severe accident. Thus, it is concluded that pilots of UAVs will require a license accrediting their knowledge in the UAV's field, in meteorology and a health certificate as well. This license will be acquired once demonstrated that they have enough aeronautical knowledge to operate safely without endangering nobody on ground.

In order to finally obtaining this license, apart from being taught how to pilot properly the aircraft, they will also be required to attend some courses about operational procedures to follow before and during an operation, consisting in pre-flight, in-flight and post-flight checklists to be followed, which will reduce some risks identified, improving the reliability of the systems, which is essential to operate in urban areas. All these operational procedures will help, for example, avoiding radio interferences by previously scanning the zone, propellers shooting off by tightening them before take off or encountering undesirable obstacles in mid-flight by previously analysing the environment of the operation in search of potential hazards.

To sum up, this study evinces a current real conflict concerning the use of unmanned aircraft, which is the lack of regulations regarding operations in congested and hostile areas, leaving the operators unable to operate in this environment. As this situation is no longer suitable, an approach considering possible solutions that might be acquired in future regulatory frameworks have been made, trying to integrate unmanned aircraft in the airspace together with the rest of aviation without endangering third parties at all and taking advantage of the wide range of applications they are able to carry out.

Regarding future works, many technological improvements can be made and then considered in unmanned aircraft systems in order to increase the safety of the operations, which is essential for operations over populated areas. One special case that can pose several high risks to the operation is UAVs being intercepted maliciously and cyber-attacks, for which nowadays there are not many effective solutions since these situations are relatively difficult to detect by the user. Thus, this risk must not be ignored and research regarding this current problem should be done in a near future to establish procedures or some technological development that could avoid this situations.

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