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Final degree project

U-space minimum separation distance analysis in high-density scenarios

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FULL DE RESUM – TREBALL FI DE GRAU DE L'ESCOLA D'ENGINYERIA

Títol del Treball Fi de Grau: U-space mínimum separation distance in high-density scenarios	
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Paraules clau (mínim 3)

- Català: drons, u-space, estudi distància separació mínima, avions tripulats
- Castellà: drones, u-space, estudio distancia separación mínima, aviones tripulados
- Anglès: UAV's, U-space, minimum separation distance analisys, manned aircraft

Resum del Treball Fi de Grau (extensió màxima 100 paraules)

Català: Visió general de la situació d'avui en dia en relació amb els drones i U-space. Consta de: part teòrica on es responen preguntes com què és el U-space i com es gestionarà, entre d'altres, i part pràctica, on es realitza un estudi per veure com afecta la separació que hi ha d'haver entre drons i avions comercials, a la seguretat, capacitat i flexibilitat del sistema, per tal d'evitar conflictes en un escenari d'alta densitat. Les aeronaus estudiades són avions comercials i drons, que tenen la missió de transportar paquets des d'Amazon fins la terminal de cargo de l'aeroport del Prat.

Castellà: Visión general de la situación de hoy en día en relación con los drones y U-space. Consta de: parte teórica donde se responden preguntas como qué es el U-space y cómo se gestionará, entre otras, y parte práctica, donde se realiza un estudio para ver cómo afecta la separación que debe haber entre drones y aviones comerciales, a la seguridad, capacidad y flexibilidad del sistema, para evitar conflictos en un escenario de alta densidad. Las aeronaves estudiadas son aviones comerciales y drones, que tienen la misión de transportar paquetes desde Amazon hasta la terminal de cargo del aeropuerto del Prat.

Anglès: Overview of today's situation regarding drones and U-space. It consists of: a theorical part where questions such as what is U-space and how will it be managed are answered, among others, and a practical part, where a study is made to see how the separation that should exist between drones and commercial aircrafts affects the security, capacity and flexibility of the system, to avoid conflicts in a high density scenario. The aircraft studied are commercial planes and drones, which have the mission of transporting packages from Amazon to the cargo terminal at El Prat airport.

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1. INTRODUCTION

What are drones or UAVs? As simple as unmanned aerial vehicles, which will have very important and fundamental functions in the near future. Some examples of when we can use them could be: for delivery methods, in emergency situations (accessing areas that are difficult to access and taking advantage of the fact that in a short time it can cover huge areas), for blood bank transfers, search for people, fiscal controls, forest fire controls, biological and archaeological purposes, film support, and so on. Nevertheless, there is not a good integration for them in the European civil aviation area, and as they constitute a rapidly developing aviation sector with a great potential for creating new jobs and economic growth in the European Union, is for this reason that there's an urgent need to establish legal limits on the use of these aircraft; to improve safety and to create a common regulatory framework.

It is recently created a European regulation to standardise the different regulations of the Member States and to regulate the civilian use of drones regardless of their size or weight. In this way, it will be possible to offer a common regulatory framework, which identifies the main principles regarding the roles and responsibilities of organizations involved in U-space, the necessary services to be provided, and the requirements for unmanned aircraft operating in U-space airspace. As well as encompasses all possible operational scenarios, and which is in line with current technological reality. We are talking about the following two documents:

1. Commission delegated regulation (EU) 2019/945 → 12th March 2019, aimed at regulating the requirements and specifications of UAS.[1]
2. Commission implementing regulation (EU) 2019/947→ 24th May 2019, regulating the use of UAS by operators and pilots of drones, whether recreational or professional.[1]
3. Opinion No. 01/2020 → 13th March 2020, to create and harmonise the necessary conditions for manned and unmanned aircraft to operate safely in the U-space airspace, to prevent collisions between aircraft and to mitigate the air and ground risks.[2]

Although they have been in force since their publication in 2019, it is not until 2020 that their progressive implementation begins.

The main objective of the present project is to give a general vision of the situation that is presented nowadays and in a future in relation to drones. Existing problems will be shown, in addition of possible solutions to solve it, and other questions like what u-space is, how it will be managed and the impact that it will have in a future airspace will be responded too. In the practical part, a study of separation between manned and unmanned aerial vehicles into an aerodrome will be executed, while unmanned will carry out a mission: to transport parcels from Amazon Logistic Center to the specific cargo handlings of the airlines located into the cargo terminal of El Prat Airport. Different values of separation between both unmanned and manned aircraft will be fixed using a simulator, and how it would affect the capacity, security and flexibility of the system will be shown. Finally, an analysis of the density of the conflicts that will appear will be realized, and we'll also observe and comment the results obtained with the simulator.

It should be noted that it is assumed that the competent authority, in this case Enaire, gives us prior authorisation to fly in space belonging to the airport. Since in a Controlled Airspace (CTR) or Flight Information Zone (FIZ) (airports, unless it is in an authorized model airfield), it is not possible to fly without authorisation, nor within 8 km of any airport or airfield that is outside of controlled airspace, plus 120 metres above the ground or the highest obstacle within a radius of 150 metres.

The CTR of the airport of El Prat-Barcelona starts from the centre of the airport and goes north to Mataró and south to Calafell, affecting the inland area to the west and east (from the centre of the airport 44 km in the north, 44 km in the south, 22 km in the east and 22 km in the west).

To do so, this project is going to be divided in the following way:

1. A state-of-the-art study about U-space in general.
2. A created scenario in which the drones' entry and exit points for their missions will be reflected on, in addition of some other relevant information about them to realize the study.

3. Using a simulator, different safety distances will be set and a study of their impact on different parameters is going to be performed.
4. Analysis of results and conclusions

2. U-SPACE

2.1 WHAT IS U-SPACE?

U-space was created in 2016 and is the term used in the European Union to refer to the management of traffic for unmanned aircraft. It is meant as a set of new services relying on a high level of digitalisation and automation of functions and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. As such, U-space is an enabling framework designed to facilitate any kind of routine mission, in all classes of airspace and for all types of environment - even the most congested - while addressing an appropriate interface with manned aviation and air traffic control.

In support of this initiative, in 2017 the SESAR Joint Undertaking drafted the U-space blueprint[3], a vision of how to make U-space operationally possible. The blueprint proposes the implementation of 4 sets of services to support the EU aviation strategy and regulatory framework on drones. So, how is the implementation of u-space planned?

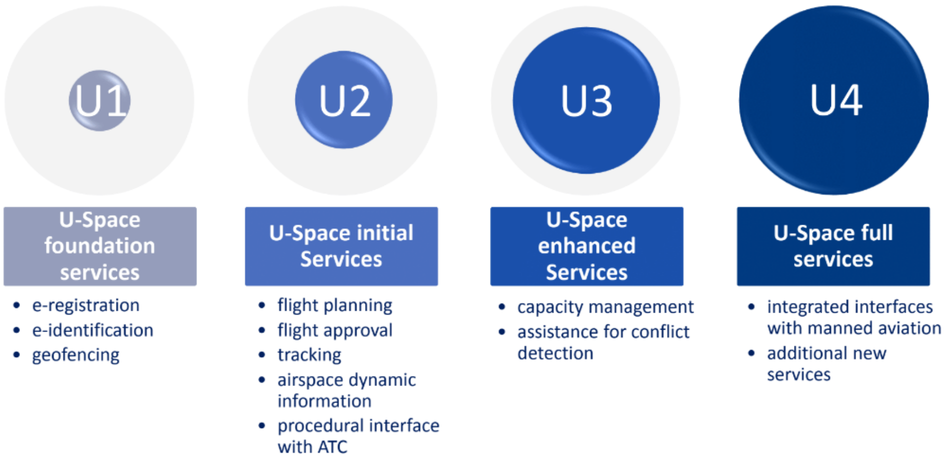


Figure 1 - Breakdown of roles in each phase[4]

It is explained clearly below:

- U1: U-space foundation services provide e-registration, e-identification and geofencing.

- U2: U-space initial services support the management of drone operations and may include flight planning, flight approval, tracking, airspace dynamic information, and procedural interfaces with air traffic control.
- U3: U-space advanced services support more complex operations in dense areas and may include capacity management and assistance for conflict detection. Indeed, the availability of automated DAA functionalities, in addition to more reliable means of communication, will lead to a significant increase of operations in all environments.
- U4: U-space full services, offering very high levels of automation, connectivity and digitalisation for both the drone and the U-space system.

2.2 WHAT IS SESAR JU?

Single European Sky Atm Research - Joint Undertaking is a public-private partnership that gathers both the administrations with relevance to airspace management, and big manufacturers in the sector like Airbus. It has channelled the most relevant proposals considered in different working groups, to define a safe, solid and sustainable European ecosystem that will ensure that we can carry out safe missions with our drones which are currently restricted or banned. In other words, they are looking for a solution for drones' integration.[5]

2.3 WHY IS U-SPACE IMPORTANT?

Because drones are a growing business in Europe: delivering services in all environments, (including urban areas), mapping, infrastructure inspections, in agriculture, delivery of goods and e-commerce are just some of the possible services using drones, as explained in the introduction. A clear framework at EU level would allow the creation of a truly European market for drone services and aircraft, thereby harnessing potential for jobs and growth creation in this new sector of the economy.

2.3.1 BENEFITS

The main benefits are[6]:

For drone users/operators:

- Offer fair, flexible and open access to the airspace

- Open up drone services market

For citizens:

- Offer new and innovative services

- Ensure safe and secure drone operations

- Safeguard privacy and ensure environmental protection (noise and visual pollution)

For regulatory authorities:

- Maintain control over airspace

- Ensure privacy, safety, security and environmental protection

- Enforce registration and identification of drones

- Protect safety and security critical areas

For businesses:

- Enabling the development of new business models

- Spurring jobs and market growth

- Support move towards automation and digitalisation

2.4 WHEN?

The roll out of each new phase should be seen as a high-level sequence for EU wide harmonisation and it is scheduled to be implemented over the following years:

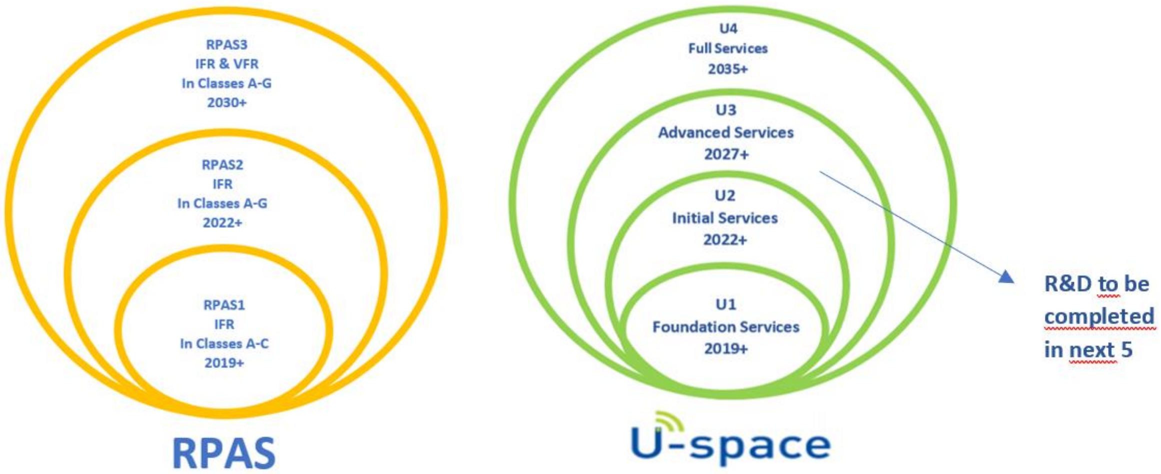


Figure 2 - Initial operating capability (IOC) dates for the integration of RPAS with manned aviation and development of U-space services at scale[7]

2.5 NEXT MAIN STEPS

The next main steps are expected to be the following[8]:

- June 2020. Registration of UAS operator & certified drones becomes mandatory:
  - All drone operators shall register themselves before using a drone
  - In the 'Open' category, with a weight more than 250g or less then 250g when it is not a toy and it is equipped with a sensor able to capture personal data
  - All certified drones (operated in high risk operations) shall be registered as well.
- June 2020. Operations in 'specific' category may be conducted after the authorisation given by the National aviation authority:
  - Based on the risk assessment and procedures defined by the EU Regulation
  - Based on pre-defined risk assessment published by EASA as an AMC

- June 2020. Drone user can start operating in limited 'open' category. Between June 2020 till June 2022:

  - Drones with a weight less than 500 g may be operated in an area where reasonably it is expected that no uninvolved person is overflown

  - Drones with weight up to 2 kg may be operated up to 50 m horizontal distance from people

  - Drones with weight up to 25 kg may be operated at 150 m horizontal distance of residential, recreational and industrial areas, in a range where reasonably it is expected that no uninvolved person is overflown during the entire time of the operation
- June 2021. National authorisations, certificates, declarations are fully converted to the new EU system
- June 2022. All model clubs and associations should receive an authorisation by the National Aviation Authority

2.6 OBJECTIVES OF U-SPACE

It is a project that pursues to provide different solutions to big present and future challenges, giving us[5]:

- Security for our operations
- A system that adapts to the peculiarities of the sector and responds flexibly to technological and business changes
- Facility to perform high-density operations in environments where automated drones are monitored
- Equal access for all users to this space
- Underselling of the operation costs by taking advantage of aeronautical services and infrastructures, including satellite navigation and communications systems in other sectors
- Solutions based on security, environmental respect, protection of people's privacy and data, etc.

2.7 WHAT SERVICES WILL U-SPACE INCLUDE?

Mandatory U-space services should be provided to cover all designated U-space airspace and be provided as a package of services. The establishment of institutions that provide U-space services should avoid the possibility of conflicts of interest and abuse of monopolistic market power. The goals of U-space services should be to prevent collisions between UAS and UAS and manned aviation, accelerate and maintain the orderly flow of UAS, provide advice and information that is conducive to the safe and efficient operation of UAS, and notify appropriate organizations of UAS-related emergencies or anomalies may endanger people and cargo on the ground or manned aircraft, and ensure that environmental, safety and privacy requirements are met.

The following table shows the services defined for the U-space implementation organised by the stage of development blocks (U1-U2-U3-U4) for which they are planned. Services for the U4 block have not been defined yet.

U1	U2	U3	U4
E-registration	Tactical geofencing	Dynamic geofencing	*[Pending definition]*
E-identification	Tracking	Collaborative interface with ATC	
Pre-tactical geofencing	Flight planning management	Tactical deconfliction	
	Strategic deconfliction	Dynamic capacity management	
	Weather information		
	Drone aeronautical information management		
	Procedural interface with ATC		
	Emergency management		
	Monitoring		
	Traffic information		

Figure 3 – Services defined for the U-space implementation organised by the stage of development blocks[9]

U1:

- **E-registration (electronic registration):** mandatory for drone operators, except operators of drones weighing below 250 grams, as well as some classes of drones used in the open category, and all drones used in the specific category. Confirming the validity of the operator, any pilot training, the type of drone mentioned in any plan.

- **E-identification (electronic identification):** will allow authorities to identify flying drones and link them to information stored in the registry; identification supports safety and security requirements and law enforcement procedures
- **Pre-tactical geofencing:** Synthesise all data into a single image and supply the service (to an adequate level of performance)

U2:

- **Tactical geofencing**: the GNSS system should prevent drones from entering unauthorized or isolated areas. It requests authorization from the U-space controller. The request can be processed by an automated system without manual intervention.
- **Tracking:** The tracking service shall comprise UAS telemetry messages with actual information about the UAS flight sent from the unmanned aircraft, flight plans, and identification information from UAS operators and other U-space service providers. This service shall associate consecutive surveillance observations of the same UAS flight with tracks, including the current position, heading and speed, and if necessary, shall generate alerts of outages or of degradation of service
- **Flight planning management**: it checks all existing active flight plans by querying the pre-tactical geo-fencing service with internal business logic, uses the information provided by the user in the approval request to check any possible restricted areas in the operating area and other available aeronautical information (such as valid NOTAM) and the Interface to acquire and process aviation information. It also calculates a new flight plan to avoid the restricted area and transmits the new plan to the U space controller.
- **Strategic deconfliction:** Explained in the following point (3.7.1)
- **Weather information**: it is connected to aviation weather-related services and other local weather information sources to notify relevant weather warnings for the drone operation.

- **Drone aeronautical information management:** service information about the drones flying in the vicinity. This information is updated by tactical geofencing service. It is concerned with collecting together temporary and permanent changes to the drone "flying map" which are not of interest to other aviation and supplies drone specific restrictions like: where Open is not allowed, where are types X Y Z, where Geo-fences exist…
- **Procedural interface with ATC:** explained in the following point (3.7.1)
- **Emergency management**: it provides the nearest emergency pad on the roof of a nearby building, assistance to a drone pilot experiencing an emergency with his/her drone, communication of emergent information to those who may be interested. It consumes information from the Tracking, Monitoring and Operation plan processing services.
- **Monitoring:** integrates the code sent by tracking service, with other data sources related to non-cooperative obstacles and vehicles to provide an air situation status report for authorities, service providers, and operators, including pilots
- **Traffic information:** shall provide the UAS operator with information on other known or observed air traffic which may be in proximity to the position or intended route of the UAS flight to alert and to help the UAS operator to avoid a collision. It also includes real-time 3D position of the known air traffic which may include manned and unmanned aircraft.

U3

- **Dynamic geofencing:** gets updated by the geofencing system and allows airspace managers to dynamically create and distribute geofences to connected operators for real-time flight path adjustments. It will keep the drone up-to-date even during flight. The capability is recommended for all but not mandated. It may be that local implementations lead to this capability being mandated in some volumes.

- **Collaborative interface with ATC**: explained in the following point (3.7.1)
- **Tactical deconfliction:** during the flight, the flying drone may be notified about conflicts that may require changes to its flight parameters. The difference

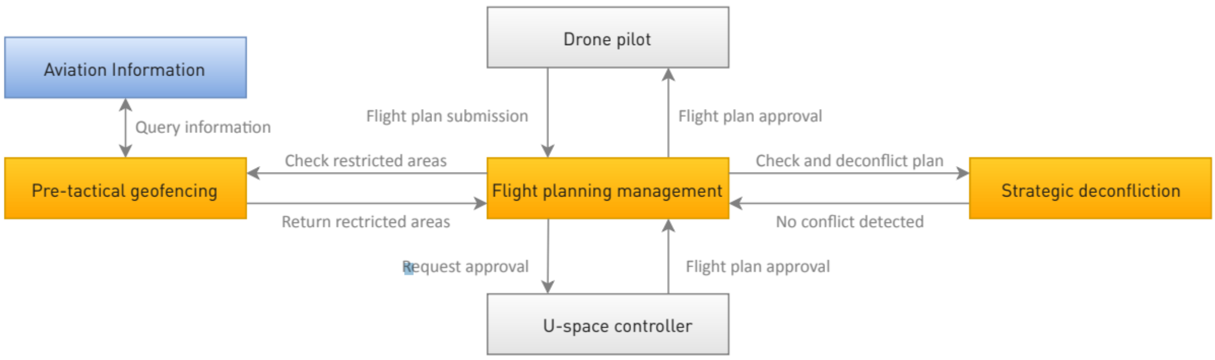
between strategic conflicts is twofold: drones can receive information, and this conflict is set during the flight phase. The Tactical conflict resolution service requires that the positions of all aircraft are known and frequently updated in the airspace volume being served, and further that the precision with which these positions are known can be reliably determined.

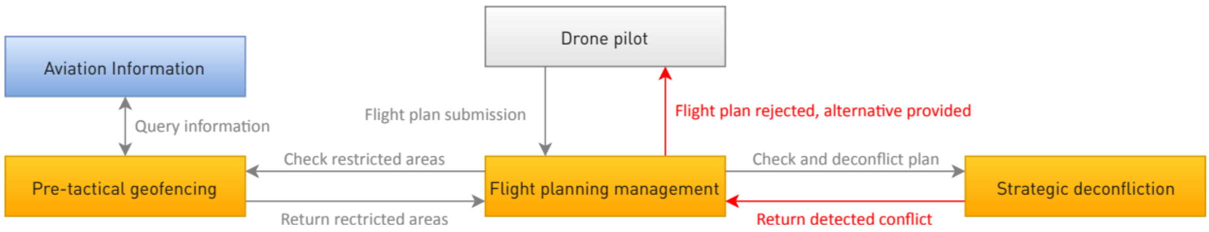
- **Dynamic capacity management:** the service monitors demand for airspace and manages access to that airspace as new flight notifications are received. It aims to match demand with capacity and has two threads. Demand may be regulated to match capacity, or capacity may be changed to match demand.

2.7.1 MAIN SERVICES FOR THIS PROJECT

It is important to highlight and explain these services apart, together with their representative schemes of how they work, since they are fundamental because they are directly involved in this project.

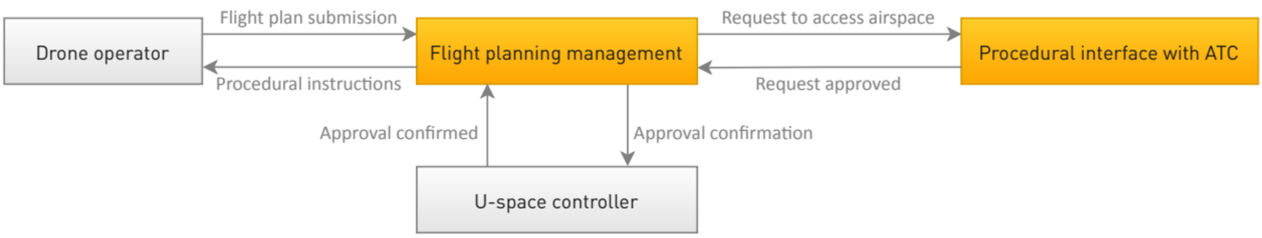
- **Strategic deconfliction:** the service provides conflict resolution assistance for drone operators at a strategic level (when submitting a flight plan, it will be compared with other known flight plans and it is recommended to avoid conflicts on time or route). It has a database that contains all approved and current flight plans in the area. The service can compare the planned flight plan with the approved plan to determine any potential conflicts by relying on an internal engine. Upon successful completion of all checks, the U-Space Controller will be requested for final authorization, the U–space controller can be a human or a software system. If the final clearance is given, the notification is forwarded to the drone pilot. Based on the detected conflict, try to make possible modifications to the submitted flight plan for the Return to Home or landing procedures of the drones involved to eliminate the conflict. The Strategic conflict resolution service is invoked by the Drone operation plan processing service. It can be invoked because a new operation plan has been submitted or because an already submitted operation plan has changed. Strategic conflict resolution is before flight. The service has two phases. First it detects conflicts, then it proposes solutions. Detection broadly involves examining the probabilistic 4D trajectories predicted by the Drone operation plan processing service and looking for pairs which have a reasonable probability of coming closer than is allowed in any given airspace. Resolution is by changing either of the pair. See the representation in the following schemes:



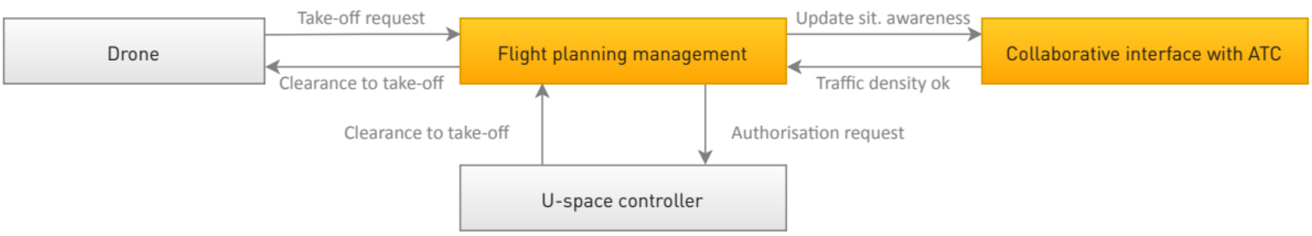


- **Procedural interface with ATC:** this involves digital and non-digital programs (such as voice communications with ATC officials). This service provides an interface with the ATM. Is a mechanism to coordinate an entry of a flight into controlled airspace. The interface works before flight. The Operation plan processing service will invoke the service and through it:
    - ATC can accept or refuse the flight
    - ATC can describe the requirements and process to be followed for the flight

  It's the first U-space service to connect both ATM and the new U-space worlds. This service should support commercial drone operators by providing a single interface to access controlled airspace through U–space services. See the following schemes:



- **Collaborative interface with ATC**: is a service offering communication between the Remote Pilot (or the drone itself in case of automatic flight) with ATC while a drone is in a controlled area. The communication may be verbal or textual. This service allows flights to receive instructions and clearances in a standard and efficient manner, replacing ad-hoc solutions used prior to this service being used. The Procedural Interface with ATC is the normal method to get approval to enter a controlled area. ATC may refuse to accept flights as they choose. The collaborative interface is not a means to avoid such approval. It also provides a means of communication between ATC and Remote Pilots. In addition to communications, safe operation is enabled by ATC having access to U-space surveillance data. See the following schemes:



2.8 HOW WILL U-SPACE OPERATE?

U-space helps to fulfil any kind of mission, whether it is delivery of goods, air work, search and rescue or many others that have already been discussed in the introduction. Its framework comprises a large and progressive range of services that are based on the standards agreed by the European Union and are provided by service providers. These services don't replicate the role of the ATC but provide key services to organise the safe and efficient operation of drones, as well as ensuring a proper interface with manned aviation, the ATC and the relevant authorities. They may include the provision of data, supporting services for drone operators such as flight planning assistance and more structured services such as tracking or capacity management.

If a conflict is detected, a mitigation module study and suggest a departure shift, within a pre-defined interval of time (launch window), assuring the approval of a conflict free mission. The mission is denied when a deadlock is detected (no departure time shift can solve the conflict with other missions already approved)[10].

2.8.1 DESCRIPTION OF POSSIBLE MISSION ILLUSTRATING SOME ASPECTS OF HOW THE U-SPACE CONCEPT COULD WORK IN REALITY

1. Mission planning

   A drone operator plans to fly a drone to carry a small package from a village to the city centre 30 kilometres away. It's selected a suitable drone from a fleet and also a drone supervisor who will not actually be piloting the drone but will be supported by automated functions and tools allowing to monitor several drones flying at the same time. To prepare the flight, the drone operator uses information-sharing services connected to ATM via SWIM (NOTAMs, meteorological conditions and forecasts at the nearest aerodrome…), combined with other U-space services, such as navigation and communication coverage services, flight planning assistance services and services providing the expected density of traffic in the mission area. Since the drone is registered, the system automatically links the elements described in the registry with elements of the flight request, in which full details of the airworthiness of the drone and its behaviour in emergency situations are described. For example, this information could include designated safe landing areas, or details of the equipage and capabilities of the drone. By that way, if the drone fails at any point in its flight, it will behave in a predictable manner, minimising risk to people and property on the ground.

2. <u>Submission of a flight request and reception of an acknowledgement</u>

   The planned route adheres to applicable regulation, airspace requirements (including airspace availability, temporary and permanent restricted areas) and requirements on specific drone equipment. If the flight requires an additional approval, then the request is submitted to the relevant entity and an answer is sent to the drone operator. The planned flight does in fact conflict with several other planned drone operations so, the operator is offered the possibility of a longer route or a delay to the drone's arrival by X minutes, for example. Is it chosen the latter option and receives an acknowledgement, which includes the drone's 4D trajectory describing the entire flight. When the drone is airborne, it receives information and alerts and might alter its original route to avoid traffic, meteorological conditions or any changes to airspace accessibility. Throughout the flight, the drone broadcasts its unique identifier. The tracking service allows the drone flight path to be followed and supports other services like the situation awareness, which is provided, with some limitations, to a wide range of customers (for example: drone operators, ATC, police).

3. <u>Flight performance</u>

   Our drone is equipped with a 'detect and avoid' system (DAA) which allows it to avoid hazards. The DAA system navigates it around a flock of birds and an unreported obstacle (e.g. a crane). As it arrives in the city, it receives an alert on a modification of airspace availability on its route: a car accident has just taken place and the local police have set up a temporary highly restricted zone to automatically geofence the site. The geofenced zone is not actually empty as the police are using a drone to give them an aerial view of the accident, and this mission is approved. The incoming helicopter ambulance is a priority flight, and this information is shared to ensure drones crossing its path will route round it.

4. Mission completed

   The drone arrives with a total security at its destination and delivers the parcel. Then, it is ready for its next mission.[3]

2.8.2 DRONE OPERATION STEPS AT AIRPORT

The main are[11]:

1. Aerodrome operator initiates drone inspection
2. The drone pilot is briefed about operational constraints/procedures
3. Drone pilot request permission
4. ATC provides permission
5. Drone pilot launches the drone at a pre-designated take-off location for the operational Volume
6. Drone pilot verifies that data to be monitored/inspected is being captured properly
7. Drone pilot flies the drone in the relevant operational volume in VLOS or BVLOS
8. Drone pilot finishes the flight and drone returns to the pre-designated landing location
9. The drone is secured
10. Drone pilot reports operational volume vacated to ATC
11. ATC acknowledges the relevant operational volume is vacated

2.8.3 CONNECTION U-SPACE/ATM

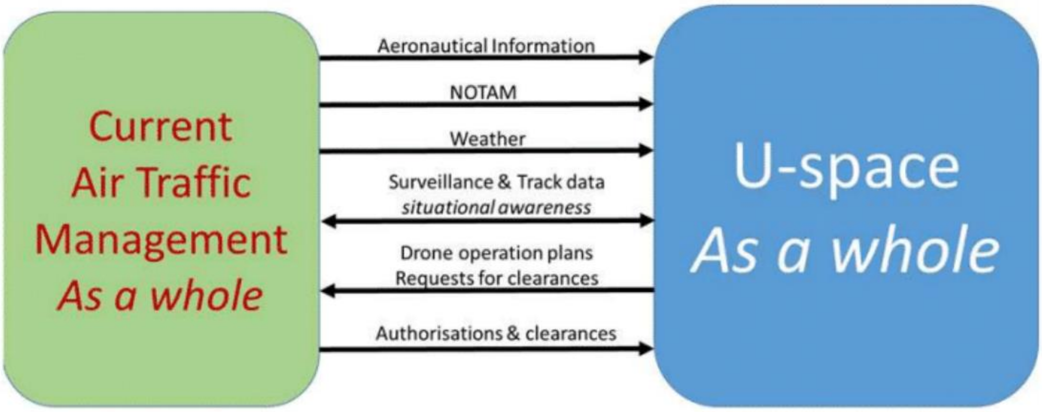


Figure 4 - Representative diagram of the connection between U-space and ATM [11]*M*

2.9 U-SPACE DIVISION

Figure 5 - How U-space is generally divided [12]

X, Y, Z types will be explained in detail below: X zones are destined for those who want to fly their drone, in a place without danger or low risk. There is no conflict resolution, it enables VLOS and the pilots remain responsible to remain well clear:

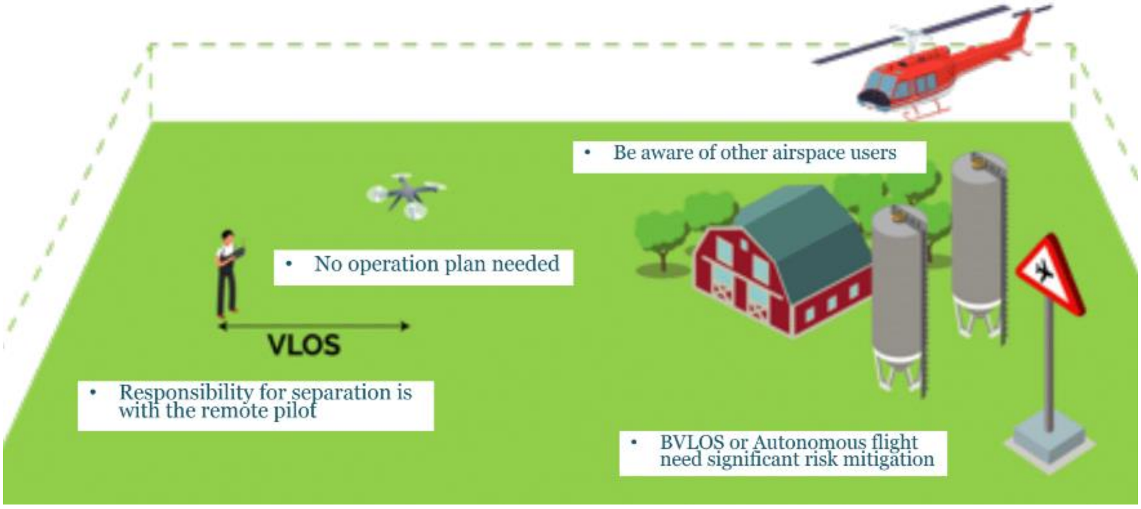


Figure 6 - Representation of the X zone of the U-space [12]

The Y type is for those who fly their drone in a restricted area like could be near a nuclear central; the access is only approved by an operation plan and specific technical requirements per volume. It is needed a conflict resolution before the take off and usually the position reporting is required and some information is given to the pilot during the flight (conformance & geo-awareness, warnings & traffic information, for example):

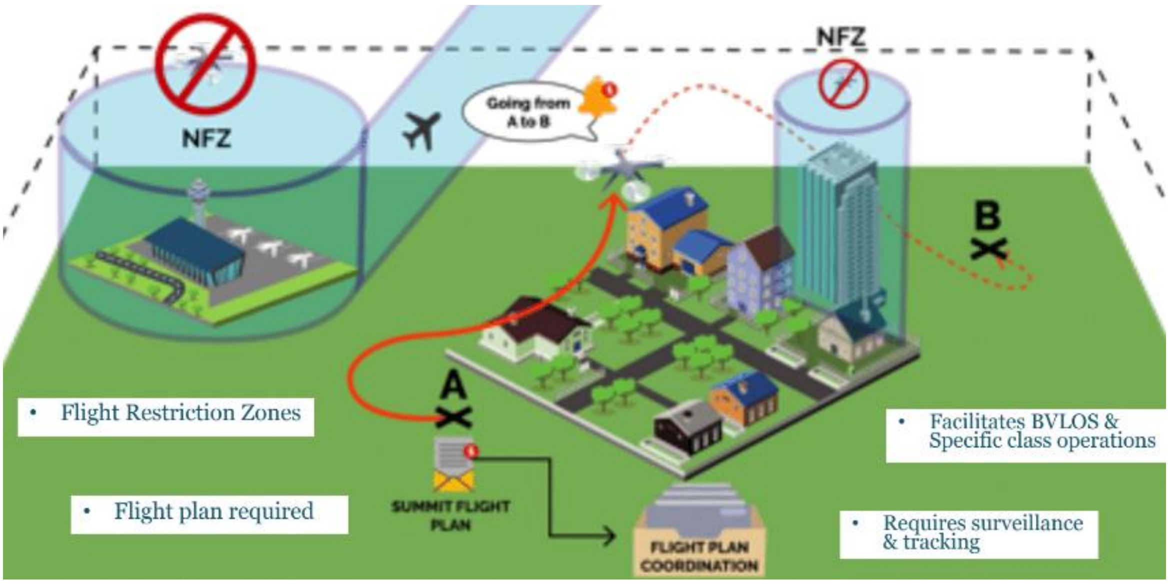


Figure 7 - Representation of the Y zone of the U-space [12]

And the Z type (where this project is going to focus on) allows higher density operations than Y, and hence are expected in areas where traffic demand exceeds the capacity of Y, or there is a particular risk. Access to Z requires an approved operation plan, and additionally, the pilot has to be connected to U-space continuously and it is required a position report submission for the aircraft with enough performance to enable tracking. This area is divided into the types Zu and Za: Zu refers to the outside of aerodromes (uncontrolled airspace) and U-space software provides conflict resolution from the ground during flight, and Za volume is a controlled airspace, ATS are in control and provide services in this volume, making use of U-space services if necessary, for example, to enable communication, surveillance and so on. Here the u-space provides situational awareness to ATC, communication tools and standard ways of working.

The present project will be focused on studying the minimum separation distance in high-density scenarios on Za area:

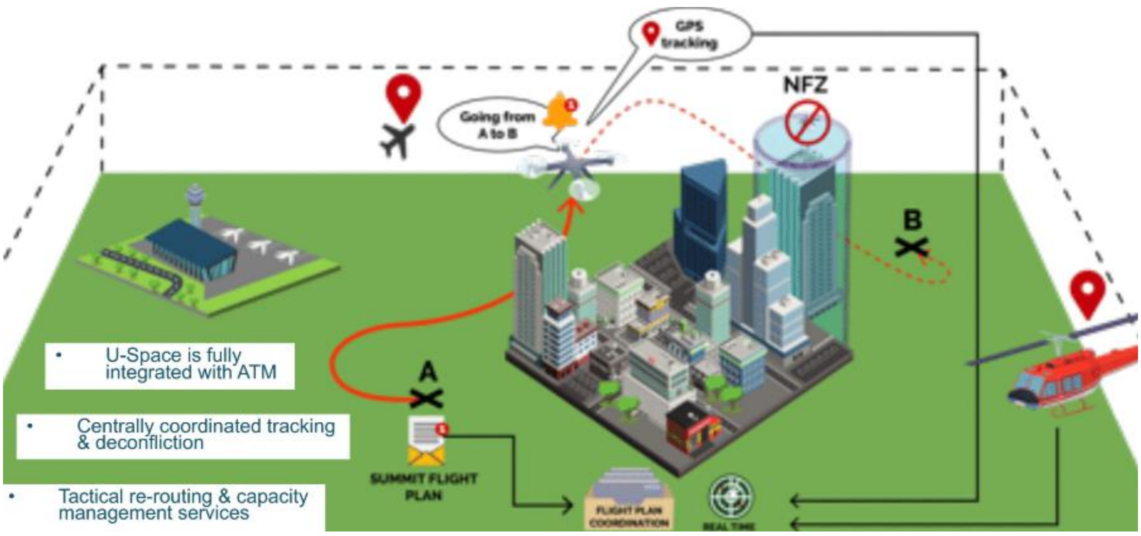


Figure 8 - Representation of the Z zone of the U-space [12]

3. STATE OF THE ART

3.1 U-SPACE EXPLORATORY RESEARCH COVERAGE

3.1.1 CORUS: CONCEPT OF OPERATION FOR EUROPEAN UTM SYSTEMS

A set of easy-to-use-rules for low-level airspace operations

CORUS consortium developed a Concept of Operations (CONOPS) for U-space to integrate drones into an uncontrolled very low-level airspace and in/around controlled and/or protected airspace such as airfields. It proposes an initial architecture for this airspace which describes an initial architecture that identifies the airspace types, services and technical development necessary for implementation of the CONOPS, quantifying the levels of safety and performance required, so that operations are safe and efficient. It also includes use-cases for nominal scenarios such as contingencies and emergencies; and proposes a method to assess the safety of service provision (MEDUSA). Finally, it proposes solutions for easing social acceptance of drones by examining aspects including safety, privacy, noise and other societal issues.[13]

3.1.2 SECOPS: AN INTEGRATED SECURITY CONCEPT FOR DRONE OPERATIONS

Security is key to safe operations in very low-level airspace

SECOPS defined an integrated security concept for drone operations, including addressing resistance of drones against unlawful interference, protection of third parties and integration of geo-fencing technology. The research reviewed technological options for both airborne and ground elements. Firstly, a preliminary cyber security risk assessment was performed to determine the risks concerning confidentiality, integrity and availability of the U-space information flows. Then an experimental proof of concept integrating common-off-the-shelf technologies of the consortium partners was executed in order to prove the feasibility of parts of the integrated security concept and co-operability of the more mature technical solution. Finally, SECOPS found the trustworthiness of drone track and position information to be important and concluded drone countermeasures are likely to be a combination of different technologies.[13]

3.1.3 IMPETUS: INFORMATION MANAGEMENT PORTAL TO ENABLE THE INTEGRATION OF UNMANNED SYSTEMS

New technologies to support U-space information needs

The framework of the IMPETUS solution is based on a federated architecture based around microservices due to this architecture supports flexible and rapid information updates. This architecture is made up of a central actor that provides a single point of truth of the airspace situation, an intermediate interface composed of multiple U-space service providers, and an external layer for the end users (drone operators). IMPETUS replicated aspects of this architecture and concluded it can meet relevant U-space challenges. For example, one experiment explored how a drone deconfliction service can interact with other services in the system to maximise the airspace capacity for drones based on dynamic volumes. Impetus looked at whether this is not only technically possible, but also a viable option when realised in coordination and conjunction between services.[13]

3.1.4 DREAMS: DRONE EUROPEAN AERONAUTICAL INFORMATION MANAGEMENT STUDY

Drones need essential aeronautical information to fly safely

This project set out to identify gaps between existing information used by manned aviation and new needs coming from U-space. DREAMS assessed the present and future needs of aeronautical information to support the growth of unmanned aviation and ensure the safety of operations. Operational and technical aspects, environmental scenarios, technologies and safety and security impact were analysed, and they examined how information might be sourced, managed and disseminated.

The project concluded aeronautical information available today is insufficient to support U-space operational needs without some extension or tailoring and additional research. It confirmed, for instance, that U-space will need new aeronautical features such as geofencing and geo-caging, geo-vectoring and speed vectors. [13]

3.1.5 CLASS: CLEAR AIR SITUATION FOR UAS

Safe drone operations require reliable tracking and monitoring

This project examined the potential of ground-based technologies to detect and monitor cooperative and non-cooperative drone traffic in real-time. CLASS tested tracking and display of these drones in six operational scenarios. They were able to define and detail the functional and technical requirements for tracking, monitoring and tactical deconfliction. Also found variations in the performance of tracking technology and recommended the drawing up of standards for different U-space services.[13]

3.1.6 TERRA: TECHNOLOGICAL EUROPEAN RESEARCH FOR RPAS IN ATM

U-space relies on existing and new ground infrastructure technologies

TERRA project set out to identify relevant ground technologies and to propose a technical ground architecture to support drone operations. A qualitative evaluation was performed for all selected technologies using a set of performance characteristics, together with an assessment of the pros and cons for drone operations. A study to assess whether machine learning can help monitor very-low-level operation was also carried out and the analysis showed that machine learned application of traffic rules performed relatively well under higher traffic densities.

TERRA concluded that in environments with a low density of drones and a low level of complexity the current CNS technologies are sufficient to support U-space service. Additionally, artificial neural networks modelling shown the potential benefits of machine learning for use in predicting and classifying drone trajectories in the urban scenarios.[13]

3.1.7 PERCEVITE: PERCEVOIR ET EVITER – DETECT AND AVOID

Developing an autonomous sense and avoid package for small drones

The main requirement was that the chosen solution could detect and avoid ground-based obstacles and flying air vehicles without necessitating human intervention. The work centred around developing a low-cost, lightweight, energy-efficient sensor for small drones and processing package to maximise payload capacity. They started designing the hardware and software and activity then transitioned to live demonstrations using innovative concepts to test the different functionalities (for example, cameras were used to identify objects such as cars, people and obstacles…). PercEvite partners developed 2 systems: one designed for extremely small drones (20 grams); and a more comprehensive solution weighing 200 grams suited to drones commonly used in commercial activities. Development work continues in 2020.[13]

3.1.8 DROC2OM: DRONE CRITICAL COMMUNICATIONS

Reliable communications are central to safe drone operations

Command and control (C2) information needs to be reliably transferred in support of functions and specific procedures, enabling drones and manned vehicles to operate safely in the same airspace. TheDroC2om project reviewed the capability of the existing cellular and satellite infrastructure that supports C2 data link communications, using live flight trial sand simulations to test availability and performance. The project provided solid empirical evidence on the drone to cellular networks channel in urban areas and validated dual LTE C2 performance using live trials. It also tested multi-link connectivity and beam switching to ensure drone C2 link quality is maintained in highly loaded cellular networks. It concluded a hybrid cellular-satellite architecture, combining low latency and coverage of cellular with reliability of satellite communications, contributes to robust C2 performance.[13]

3.1.9 AIRPASS: ADVANCED INTEGRATED RPAS AVIONICS SAFETY SUITE

Identifying on-board technology necessary for drones to share the airspace

To interact safely with all other airspace users and services, AIRPASS partners defined a high-level architecture for the on-board equipment they need to carry. AIRPASS carried out an analysis of available on-board technologies and identified gaps between these systems and technologies necessary to operate drones. This research enabled the partners to develop different subsystems and defined a general functional architecture which has no implications for hardware. Also supports the development of U2 services and paves the way for drone's integration. The project identified some gaps in currently available on-board technologies.[13]

3.2 U-SPACE DEMONSTRATIONS COVERAGE

3.2.1 DIODE: D-FLIGHT INTERNET OF DRONES ENVIRONMENT

Safe and secure drone operations in each and every environment

The DIODE project focused on demonstrating capabilities to safely manage multiple drones flying in very low-level air space at the same time, while accomplishing multiple tasks and missions. The project worked on the assumption that each aircraft will report its positions. A consortium of Italian companies conducted 11 missions in Rieti, with different geographical situations. The demonstrations covered a wide range of operations (road traffic patrol, professional photography…). Flights were carried out in combination with manned flights and took account of third parties on the ground. Drones were monitored using D-flight. New competences and technology to support the growth of drone services were looked. DIODE demonstrated emerging and mature capabilities on-board drones, which support the deployment of a risk-based and an operation-centric concept of U-space. The project considered a huge range of drones and highlighted opportunities where the drone market can also contribute to development of more advanced U-space services.[13]

3.2.2 DOMUS: DEMONSTRATION OF MULTIPLE U-SPACE SUPPLIERS

Putting multi-service provision to the test

By integrating already developed technologies and concepts around a federated architecture, members of the DOMUS consortium showed that initial and some advanced U-space services are possible. DOMUS demonstrations involved three service providers interacting with one ecosystem manager and simultaneously provided services to five different drone operators in proximity. The eco system manager is the principal U-space service provider and provided data integrity to the system as a single point of truth. It also provided the single interface with air traffic management. The service providers operate in parallel to deliver U-space and added value services to the various drone operators, who need to exchange data to carry out their operations. Thanks to the ecosystem manager, DOMUS demonstrated some of the initial services detailed in U1 and U2 definitions of U-space and some U3 services were also tested. The project also demonstrated the feasibility of connecting U-space operations to the smart city platform. Drones can respond to emergency situation, including recreational flights without flight plans and they can also conduct strategic and tactical conflict resolution in real-time.[13]

3.2.3 EURODRONE: A EUROPEAN UTM TESTBED FOR U-SPACE

Identifying key criteria necessary for fully autonomous operations

EuroDRONE tested different concepts, technologies and architectures to promote the cooperation of the relevant stakeholders in a U-space environment. By using cloud software and hardware, the research experimented with U-space functionalities. They conducted highly automated unmanned flights using a cloud-based UTM system connected to a miniature, intelligent transponder processing board on drones fully capable of flight mission planning. The tests used an innovative vehicle to infrastructure link, integrated to a self-learning UTM platform, with a capability to share flight information in real time. The flights demonstrated end-to-end UTM applications focusing on both visual and BVLOS logistics and emergency services. The project also identified key user needs and regulatory challenges and compared the results with the CONOPS. The findings were used to define a practical and automated cloud-based UTM system architecture, and to validate this architecture using simulation and live demonstrations too. In conclusion, the project demonstrated robust end-to-end UTM cloud operations, including beyond visual line of sight medical deliveries over 10km in coordination with ATC and commercial operation. It also demonstrated innovative vehicle to infrastructure and vehicle to vehicle communications, equipped with operational detect and avoid algorithms. The flights were able to demonstrate high levels of autonomy using cloud-based infrastructure envisaged for an advanced UTM environment. The demonstrations ranged from sea areas to countryside and urban environments, and tested LTE communications links.[13]

3.2.4 GEOSAFE: GEOFENCING FOR SAFE AND AUTONOMOUS FLIGHT IN EUROPE

<u>Avoiding no-fly zones in busy low-level airspace</u>

The GEOSAFE research set out to establish state-of-the-art geofencing U-space solutions and to propose technological improvements and recommendations for future geofencing system definition. They did a flight-test campaign which assessed a number of commercially-available geofencing solutions. Project partners considered some issues. Nevertheless, the results were used to identify ways in which the technology can be used to support safe interaction with all airspace users. The project concluded most drones meet the requirements for pre-tactical geofencing and demonstrated that existing technology is ready for initial U-space service. However, technology capable of supporting dynamic geofencing is not sufficiently mature to meet full U-space service levels. Geofencing prevents drones straying into protected areas, for example around critical infrastructure such as power plants or airports.[13]

3.2.5 GOF-USPACE: SAFE DRONE INTEGRATION IN THE GULF OF FINLAND

Mixing manned and unmanned aircraft relies on reliable data exchange

The GOF-USPACE partners established a pre-operational authority FIMS by creating an interoperability architecture for integrating existing solutions from three U-space service providers to show case U-space in all phases of drone operations. The GOF U-SPACE architecture integrated U-space service provider microservices that enabled a collective and cooperative management of all drone traffic in the same geographical region. A microservice-oriented data exchange layer provided standard protocols to connect various U-space services from different service providers and the capabilities of service provision was demonstrated during the trials. Integration between FIMS and U-space service providers, FIMS and FIMS, and U-space service providers to ground control services was established with a link to receive data from the ATM systems, demonstrating interoperability between systems. The demonstrations showed commercial off-the-shelf UTM components to be fit for purpose to demonstrate all phases of drone operations with a focus on pre-flight and flight execution. The project demonstrated the need for single truth and common standards for communications between systems.[13]

3.2.6 PODIUM: PROVING OPERATIONS OF DRONES WITH INITIAL UTM

Putting U-space services to the test in operational scenarios

PODIUM carried out demonstrations at five operational sites and the project testes the performance of pre-flight and in-flight services using different scenarios ranging from airport locations to beyond visual line of sight. The results were used to draw up recommendations on future deployment, regulations and standards. The project collected and analysed validation some data and partners considered the maturity of services and technology and analysed the impact on flight efficiency, safety, security and human performance metrics. PODIUM looked to reduce the risks inherent to the operational and industrial deployment of U-space.

They have a web-based platform that enables drone operators and authorities to follow drone operations in real time and connect with pilots if necessary. PODIUM concluded that there is a very strong demand from all stakeholders for U-space solutions that can ease the burden of obtaining flight authorisations for drone flights and that significant action is needed to ensure that U-space services can really take off in the flight execution phase.[13]

3.2.7 SAFEDRONE: UNMANNED AND MANNED INTEGRATION IN VERY LOW-LEVEL AIRSPACE

Addressing the safe integration of general aviation aircraft and drones in very low-level airspace

The SAFEDRONE project sought to define and detail pre-flight services to detect and avoid obstacles in order to demonstrate how to integrate manned aviation and drones into non-segregated airspace. SAFEDRONE partners carried out demonstrations involving eight different aircraft types. The flights were carried out recreating some determined situations. The project also considered increased levels of autonomy necessary to operate in non-segregated airspace to carryout dynamic in-flight activities, within the U-space approved flight plan, and autonomous generation of coordinated trajectories within an approved U-space area of operation. It assessed the viability of using 4G networks for communication during BVLOS flights and GNSS technologies enabled by Galileo to estimate the drone's height. Finally, the research included a pre-risk assessment scenario of the concept of operation based on the technical, safety and operational requirements as detailed in the SORA. Lessons learned and results from the technologies tested have been passed to EASA and standardisation bodies EUROCAE and GUTMA to help develop the standards that will enable safe integration of different drone categories under U-space.[13]

3.2.8 SAFIR: SAFE AND FLEXIBLE INTEGRATION OF INITIAL U-SPACE SERVICES IN A REAL ENVIRONMENT

Automation brings efficiency to drone operations

To safely integrate drones into the airspace, the U-space SAFIR consortium conducted a series of demonstrations to show how technology can support the safe deployment of a multitude of drones in a challenging airspace environment. They tackled the issue of unregistered drones and their impact on legal drone operations and manned aviation. A specialised radar developed by the CLASS project was deployed to detect rogue drones in critical areas and provide a live feed for the U-space service providers. SAFIR's federated model enabled information sharing between multiple interoperable services, categorised according to their function. SAFIR proved the ability of drones to safeguard critical areas and it was demonstrated how the Port of Antwerp could request a drone to inspect a certain area should there be reason for concern, as well as create no-drone zones to manage safety in the port. The project also showed how multiple U-space service providers can operate in the same geographical area at the same time thanks to UTM systems can be interoperable. SAFIR demonstrated full availability of some services and they also concluded that tracking data sourced from different places needs to be fused.[13]

3.2.9 USIS: EASY AND SAFE ACCESS TO THE AIRSPACE

Ensuring U-space services are safe and secure

USIS research sought to validate the services that will be provided by U-space service providers to drone operators and third parties, to demonstrate their readiness at a European level. In this project initial U-space services and scheduling and dynamic airspace management were considered. USIS partners carried out live demonstrating using a dedicated application allowed drone operators to submit flight requests which were then analysed and approved or declined by the appropriate authority. An embedded hardware connected to the mobile phone network was used to securely identify and track the equipped drones. The project showed that initial U-space services can support multiple numbers of drone operations without creating additional workload for an operator or impacting the safety of the airspace. It highlighted the need for flexibility when carrying out flight planning and approval management processes to cope with different national and local regulations.[13]

3.2.10 VUTURA: VALIDATION OF U-SPACE BY TESTS IN URBAN AND RURAL AREAS

Defining rules for manned and unmanned systems to share the same airspace

Demonstrations carried out by members of the VUTURA consortium looked at the new digital smart cities, and how unmanned vehicles can become a part of this interconnected world. VUTURA focused on four major goals. These are: validating the use of shared airspace between existing airspace users and drones, validating more than one U-space service provider can provide U-space services in a specific airspace and the procedures needed to support drone flights, ensuring developments within SESAR and services of commercial USP's are aligned and contribute to proposals for aligning these and for regulation & standardisation, and finally increasing the pace by which European cities and companies exploit emerging technologies related to drones.

The consortium conducted beyond visual line of sight demonstration flights involving multiple U-space services. In the tests, drones gave way to high priority drones autonomously (medical deliveries, for example) and the U-space service providers facilitated the drone traffic de-confliction using interoperable systems. They finally demonstrated that commercial drone traffic can safely co-exist with traditional air traffic in different kinds of environments and the technology to safely manage drone traffic is feasible, scalable and interoperable. It also flagged up areas in need of further research and they also concluded that airspace users need to be registered in order to share airspace, be identifiable and meet geofencing requirements before the industry can move closer to supporting urban air mobility.[13]

4. SCENARIO

This project is going to be focused on the study of separation between unmanned aerial vehicles and different types of manned aircraft (in our case, commercial aviation), while unmanned carry out a mission: to transport parcels from Amazon Logistic Center to the specific cargo handlings of the airlines. In that way, cargo may be stored in the warehouse and will be ready for palletization before entering into the aircraft holds, located at the cargo terminal of El Prat airport (IATA code: BCN & OACI code: LEBL), and we'll see how the problem with intended trajectories in conflict in the air (air-risk) of both drone and manned aircraft can be solved.

4.1 LEBL'S RUNWAYS

It's necessary to introduce the runways of the airport: how they are positioned, their names, what function has each one… to know what take-off and landing procedures commercial aircraft make, and take into account the movement and density of planes that is necessary to carry out and understand the project:

Except when any of the following conditions are present or expected:

- Dry, or wet runway with breaking action below good
- Cloud ceiling below 500 ft over aerodrome elevation
- Visibility lower than 1.9 km
- Notified or forecasted wind gradient or storms on departure or approach

Traffic conditions, operational needs, safety situations and all other weather conditions that preclude it, air traffic controllers shall maintain the preferential configurations described below up to wind components of 10 kt tailwind, gusts included, and/or 20 kt crosswind:

<u>between 07.00 and 23.00</u>

1. Preferential: West configuration parallel runways
    a. Arrivals: 25R

    b. Departures: 25L and 25R (*1)
2. No preferential: East configuration parallel runways
    a. Arrivals: 07L
    b. Departures: 07R and 07L (*2)

<u>Between 23.00 and 7.00</u>

1. Preferential: North configuration intersecting runways
    a. Arrivals: 02 (*4)
    b. Departures: 07R (*3)
2. No preferential: West configuration single runway
    a. Arrivals: 25L (*3)
    b. Departures: 25L (*3)

(*1) The use of runway 25R is restricted to those aircraft which can justify they need a longer runway than the available on runway 25L, except for ambulance, rescue and state flights or flights servicing Autonomous Communities and other Local Authorities whenever they provide non-commercial public services and request this from ATC, it being mandatory to carry out conventional departure procedure

(*2) The use of runway 07L is restricted to those aircraft which can justify they need a longer runway than the available on runway 07R, except for ambulance, rescue and state flights or flights servicing Autonomous Communities and other Local Authorities whenever they provide non-commercial public services and request this from ATC, it being mandatory to carry out conventional departure procedure

(*3) The use of runway 25R for landing or take-off and runway 07L for night-time take-off, for aircraft requiring it

(*4) If runway 02 cannot be used for arrivals, West configuration shall be used. Only, ultimately, the East configuration shall be used with arrivals on runway 07L, the ATIS messages will provide the information of the runway configuration in use.[14]

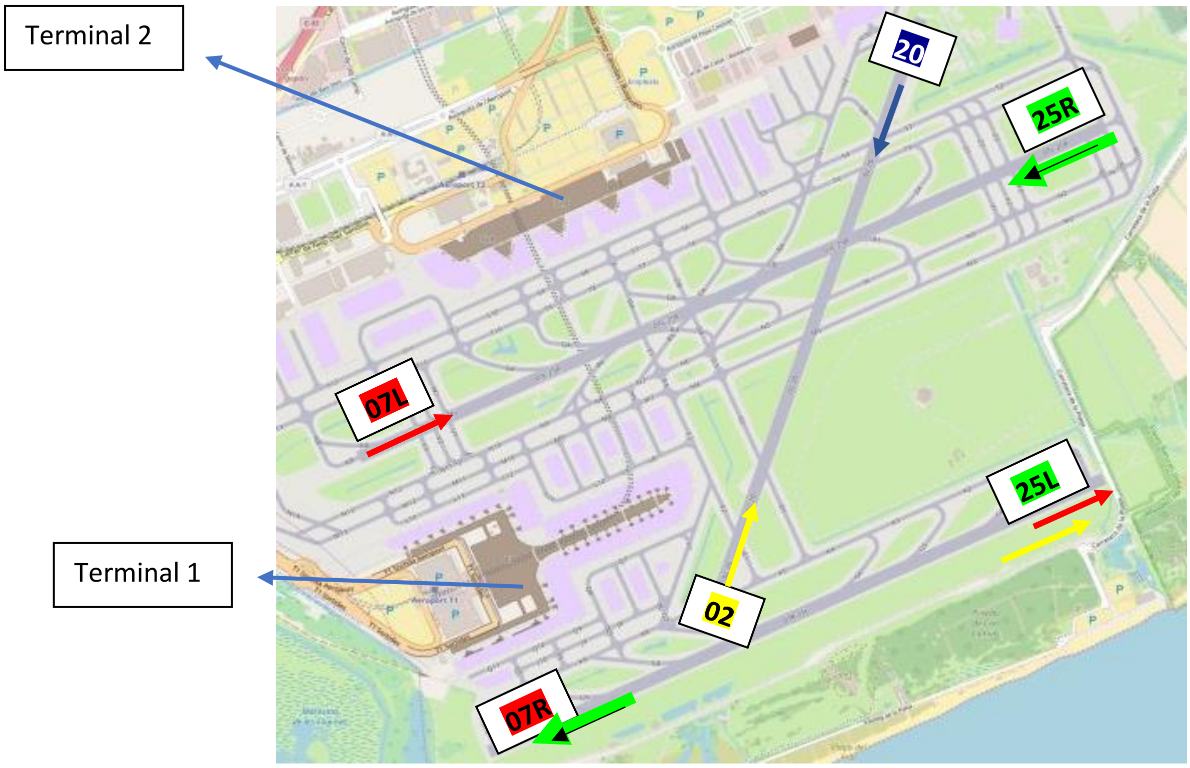


Figure 9 - Runway's identification and possible directions of both take off and departure procedues

4.2 AIRSPACE STRUCTURES NEAR AIRPORTS

Airspace is divided in different structures and they are the following: ATZ, CTR, TMA, CTA, UTA, FIR, UIR, AWY, ADA, ADR. And each one can have 1 or more airspace classes: A, B, C, D, E, F, G. Project will be concentrated only on ATZ, because this is the airspace where the study will be performed on and therefore, where the aircraft will operate in.

ATZ: Aerodrome Traffic Zone. It is established around an airfield for the protection of VFR traffic entering or leaving the airfields. May be uncontrolled or controlled, under the dependence of TWR. There are no regulations indicating the exact volume of an ATZ, since it depends on the characteristics of the airfields, its operations and the state it is in. It is located into the CTR structure.

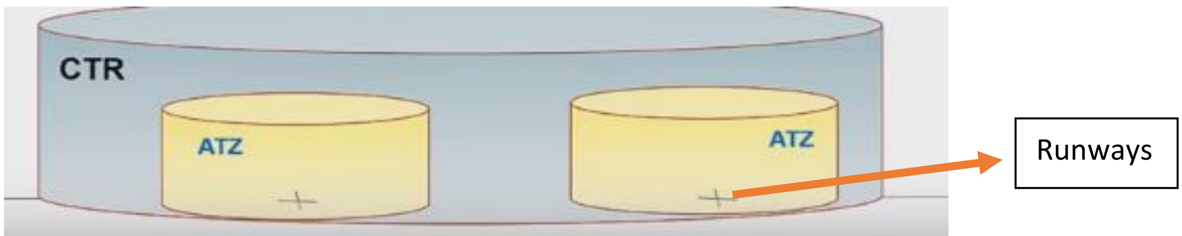
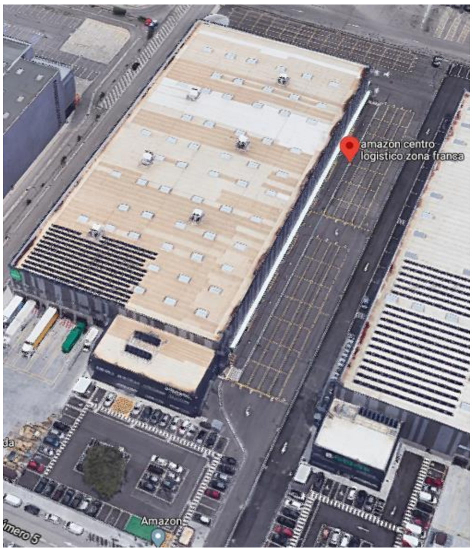


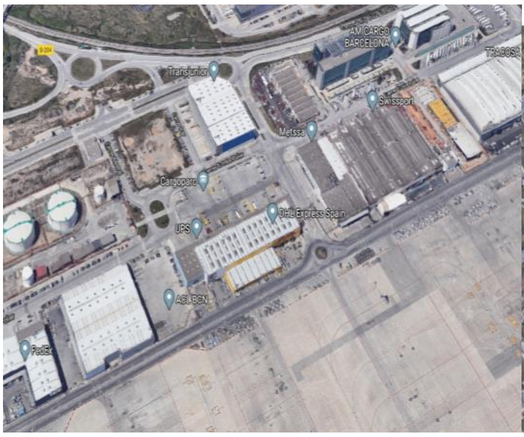
Figure 10 - Representation of airspace structures[33]

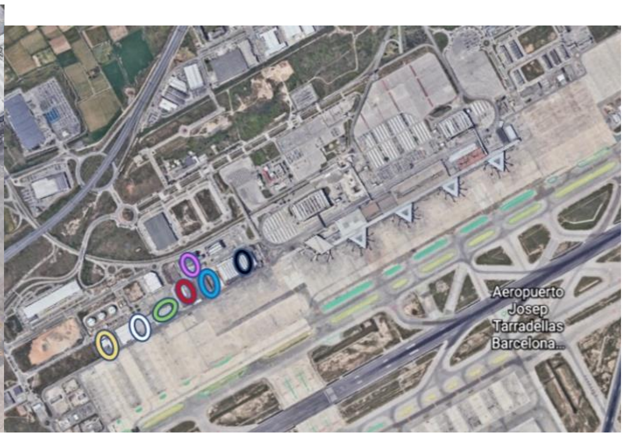
As mentioned above, the main objective is to deliver parcels from the bases of Amazon's logistic, located 7km far from the airport to cargo centers in the cargo terminal of El Prat airport. This idea has been choosen due its importance nowadays, since transporting parcels by means of air is faster and safer than land routes. We could add other important factors, for exmaple: the traffic jams that are going to be spared and an increase in reliability.

Figure 11 - Representation of the route that the drones will take on their missions from their departure (yellow cross) to their destination (yellow circle)[15]



Figures 12 and 13 – Amazon logistics centre & bases. (start line) [16]





Figures 14 and 15 – Arrival points in scenario 1.[17]

SWISSPORT [41.300356, 2.065327]

DHL [41.299084, 2.063980]

FEDEX [41.297931, 2.060300]

METSSA [41.299961, 2.064744]

WFS [41.301024, 2.068170]

ACL BCN [41.298282, 2.062136]

AM CARGO BCN [41.301182, 2.066199]

4.3 DEPARTURE POINT

At first the departure point was going to be the Amazon logistics centre, but at a later stage we noticed that there was a problem: it was going to be a bottleneck, because all our drones want to go and come back and there would be a lot of conflicts there, so to avoid that, some bases were established near the logistics centre, to start and finish the missions from there. These are separated by at least 150 metres between each one.

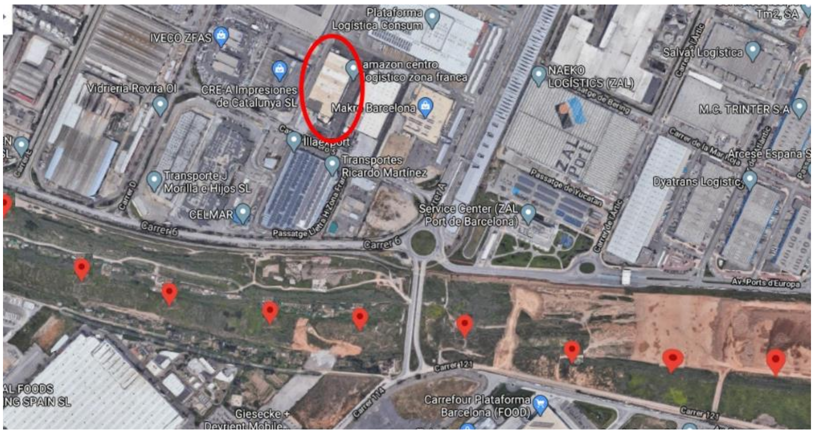


Figure 16 – Bases of departures and arrivals and Amazon circled in red.[18]

The GPS coordinates of the departure points are:

41.320048, 2.141498 // 41.320145, 2.138806 // 41.320430, 2.136301 // 41.320926, 2.133517 // 41.320966, 2.130914 // 41.321031, 2.128561 // 41.321298, 2.126178 // 41.322082, 2.123794 // 41.323012, 2.121460 //

4.4 WHAT TO DO BEFORE FLYING INTO A CONTROLLED AIRSPACE

To fly drones in a controlled airspace by ENAIRE, it is required the following:

1. Carry out an aeronautical safety study (EAS)[19] based on the SORA[20] methodology of risk analysis (evaluates the operation, classifies it in one of the 6 different SAIL "*Specific Assurance and Integrity*" levels and according to the assigned one, establishes a series of recommendations. SORA is a methodology established to serve as a guide) for the type of operation you wish to carry out in controlled airspace.
2. Submit the EAS through the Security Coordination Form[21]. ENAIRE's Security Division will contact us through the email we have specified in that form and we will start the EAS coordination. Once this process is finished, they will provide you the evidence of the coordination with ENAIRE so that we can request from AESA the authorization to operate in controlled airspace under the conditions reflected in our EAS.
3. When we have the AESA authorization and all the required permissions to realize our operation, then it is required to see in EnaireDrones[22] and check who to address our operating request to.
4. The day we are going to fly our dron:
    a. Check the NOTAM and obtain your pre-flight information (PFI)[23]
    b. Formulate the flight plan[24]
    c. Attend to the instructions the ATC give you by radio and follow their instructions
    d. Close the flight plan with the ARO office[25]

4.5 DRONES USED FOR MISSIONS

The website *Foxtech*[26] has been used to choose these drones and it has been selected because it has them organized by categories: hybrid, agriculture, professional camera, VTOL... and for each of these categories shows every different types of drones that there are, along with all their characteristics, which are of great importance as it's fundamental to find the model whose features fits better to the mission necessities.

It is necessary to concentrate on the VTOL type: it means vertical take-off landing, and it is important to select these feature because if all the drones we would use were fixed-wing, it would mean that both take-off and landing would require a runway.

Next the list of UAVs selected to perform the scenario mission will be presented, those that are best suited to the type of mission and package to be carried out. Several factors have been taken into account when choosing the most optimal and efficient ones, which are shown below:

4.5.1 DRONE NUMBER 1

Figure 17 - VOLODRONE[27]

- **Cruise speed:** 80 km/h	- **Diameter:** 9.2 m
- **Max speed:** 110 km/h	- **Height:** 2.3 m
- **Range:** 40 km	- **Flight time**: 30 min
- **Payload:** 200 kg	- **Propellers:** 18
- **Max take-off mass:** 800 kg	- **Electric motors:** 18

4.5.2 DRONE NUMBER 2

Figure 18 – EAGLE HERO VTOL[28]

- **Max speed:** 110 km/h	- **Max payload:** 7.8 kg
- **Cruising speed:** 86 km/h	- **Endurance:** 2 h
- **Stall speed:** 64.8 km/h	- **Unfolded dimensions:** 1.61m*0.25m*3.5
- **Wingspan:** 3.5 m	- **Max take-off weight:** 16 kg

4.5.3 DRONE NUMBER 3

Figure 19 - FOXTECH BABY SHARK 260 VTOL[29]

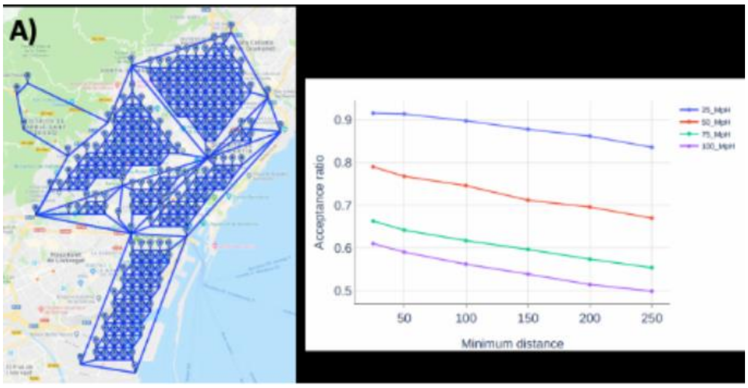
- **Max speed:** 100km/h	- **Unfolded dimensions:** 2.5m*0.55m*1.44m
- **Max take-off weight:** 12kg	- **Flight time**: 2.5h
- **Max payload:** 3kg	- **Working Voltage:** 48V
- **Flight Altitude**: ≤3000m	- **Fuel Consumption:** 1.5kg/h (750g/kw.h)
- **Wingspan:** 2.5m	- **Stall Speed:** 54km/h – 57,6 km/h

5. SIMULATOR

For the realisation of the present project the simulator U-space, DronAs, has been used, developed by Aslogic (spin-off from UAB). This simulator was developed within the framework of the CEF-SESAR project (https://www.sesarju.eu/U-space) EuroDRONE, in which some demonstrations activities of the U-space services were developed across the bay of Greece. Subsequently, the solution was equipped with new functionalities, such as the creation of scenarios, and is currently operational at The Rozas Airport Research Centre (CIAR) is located in Castro de Rei (Lugo).

The simulator allows the creation of traffic of different densities, setting the configuration of the airspace through a customizable HJSON, with the ability to generate free routing zones or corridor-based scenarios. Once the probability of a mission starting or ending in a given region is defined, the solution generates random scenarios (start/end time and location within the defined region) according to the airspace restrictions set.

On the other hand, the solution has integrated a U-space service of strategic deconflicting (based on another SESAR project, PARTAKE https://www.sesarju.eu/projects/partake), which allows the detection of potential conflicts during the planning phase, and their mitigation, thanks to a modification of the mission start time (see section 2.7.1). In addition, the spatial parameters (minimum vertical and horizontal separation) and temporal parameters (minimum time of submission and confirmation, among others) of this strategic service can be parameterised, allowing the impact on safety and airspace capacity of different values to be analysed. The software exposed will be the basis of the simulations presented below:



Where we can see that in figure A there’s a example of an scenario created in DronAs, representing a future configuration of the airspace U-space on the city of Barcelona. The figure next to the A, is an example of the study of the impact of the horizontal separation on the number of missions accepted by the strategic service. The simulations were performed through a DronAs API in which through a call the configuration to be simulated is defined (through a HJSON) together with the spatial and temporal parameters of the strategic deconflicting service. As a result of the simulation it is returned the following:

- Acceptance ratios of the created scenarios
- Mean shift applied at the beginning of the missions
- Scenario display file with the missions (waypoints and timestamps) of the generated and accepted missions

5.1 AIRPORT TRAFFIC

There are 24-hour operation scenarios, but it was necessary to focus just on a high time-slot activity. The landing and take-off operations of aircraft in El Prat Airport for a full day was studied, and a busy time slot was chosen to analyse it and work on it for further the study. It was done in this way because if we started simulating the entire 24-hour operation scenario, it would start a simulation that would take about 8 hours or so to run, and it was too long. That was the basis of our study.

A script was performed to create a flight counter for the 24 hours of operations of a selected day in El Prat to choose a high-density slot to work on it, and the results were the following:

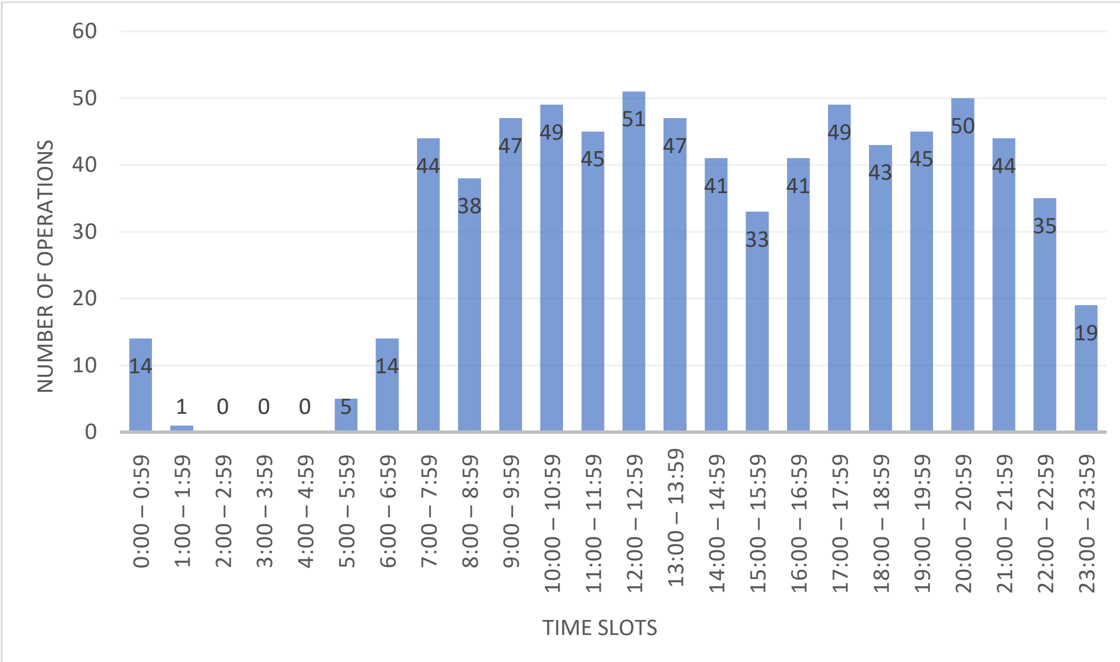


Figure 20 – Results of the flight counter of El Prat

Even though it's not the highest one, we choose the time slot of *7:00 – 7:*59 because it's a high density hour of operations, as we can see, with 44 operations.

5.2 SIMULATION PARAMETERS

When using the simulator, the following input parameters could be varied:

- The duration of the simulation as "duration" in the code: 1800'', 3600''…
- The operating density per hour as "density": 25, 50, 100, 150…
- The minimum given time before the execution of the mission as "submission_window": 300'', 600''…
- The mission start time that is assigned to the operator, such as a take-off time as "confirmation_window": 300'', 600''…
- A described period of time in which a particular mission must be launched as a "launch_window": 3000''…
- The minimum horizontal and vertical separation between drones to see when we find more conflict as "minimum_horizontal_separation": 500m, 200m, 350m…

- The number of seconds that the mission can start before or after the confirmation time as "tolerance".

Figure 21 – Input values in Postman[32]

When changing the parameters, subsequently we sent a request and the program returned a token that had to be put in Receive Analysis (see figure 22).

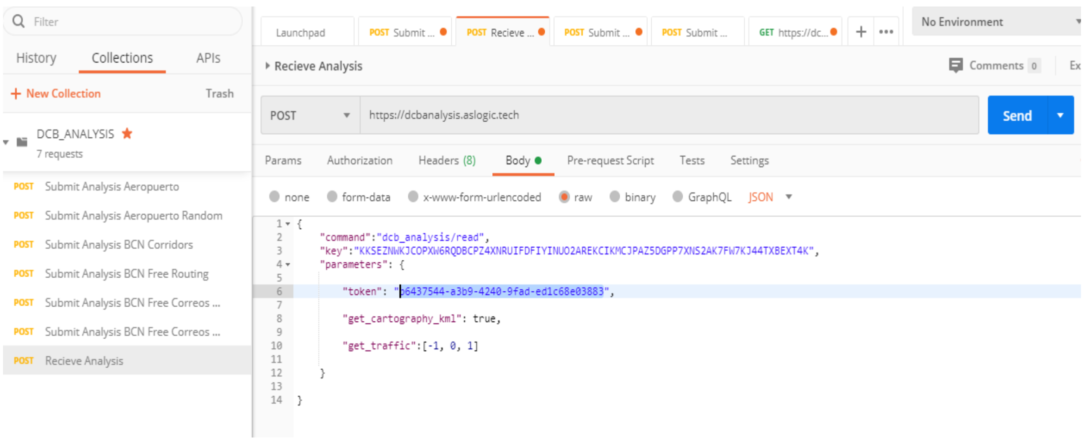


Figure 22 – Receive analysis token[32]

Then a request had to be sent again, and the program returned the final results, see the following output parameters:

```
"result": {
    "acceptance_ratios": [
        0.25,
        0.03333333333333333
    ],
    "means_shifted": [
        972,
        1152
    ],
    "statistics": [
        {
            "nSubmittedMissions": 20,
            "nAcceptedMissions": 5,
            "nRegectedMissions": 15,
            "nRegectedMissionsOnlyVsOtherMissions": 15,
            "nRegectedMissionsOnlyVsRegulatedTraffic": 0,
            "nConflictsWithMissions": 25,
            "nConflictsWithRegulatedTraffic": 0
        },
        {
            "nSubmittedMissions": 150,
            "nAcceptedMissions": 5,
            "nRegectedMissions": 145,
            "nRegectedMissionsOnlyVsOtherMissions": 145,
            "nRegectedMissionsOnlyVsRegulatedTraffic": 0,
            "nConflictsWithMissions": 253,
            "nConflictsWithRegulatedTraffic": 0
```


In the example above: for a density of 20 missions per hour, only the 25% of missions had been accepted, and for a density of 150, almost anyone; not even 1% of the missions had been accepted. If there were a 1 instead of 0.25/0.03, for example, it would indicate that all the missions would have been allowed. And in the shifted means we can see that 972 have been shifted for the first case and 1152 for the second one. These two values are the average (in seconds) of what the mission start time moves.

If acceptance ratios values are low, parameters like separations distance, launch window, etc, can be changed to see if the new results ascended. In the same example above is possible to observe how many submitted missions we had, how many had been accepted, and so on.

6. RESULTS

6.1 SCENARIO A

The first idea was that for one scenario (Amazon with multiple entry/exit points based on the zone where Amazon is located while retaining only one point per package delivery store), made several times the simulations varying the different parameters each time trying to obtain an acceptance ratio that was good enough for the project.

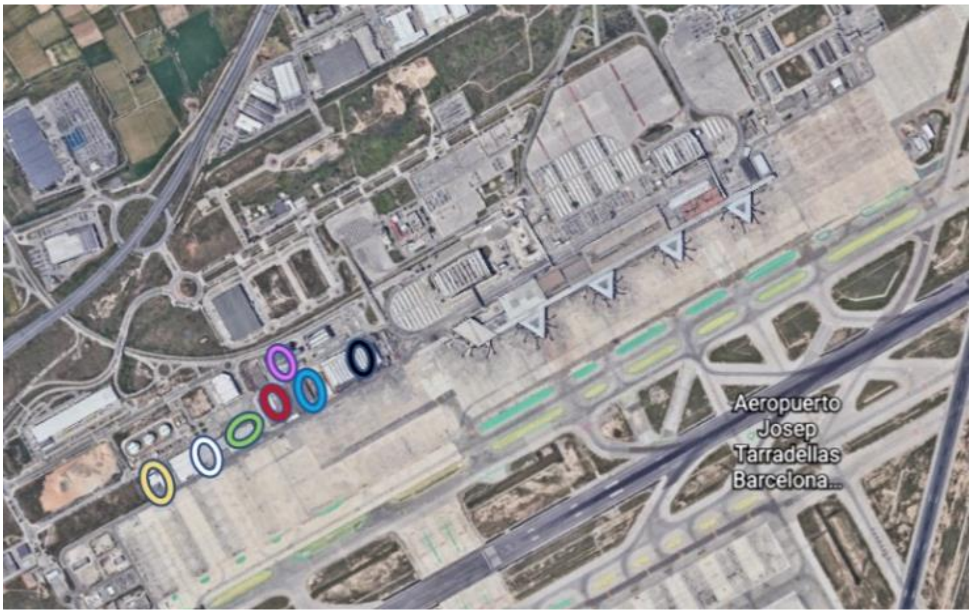


Figure 23 – Arrival points of the scenario A.[30]

6.2 SCENARIO B

When that was done, we figured out that we had some troubles because the acceptance ratios were too low. So the second idea was to create another configuration to see if in this way their values would increase. So, there was going to be a second scenario which unlike the first one, would have several arrival points per warehouse.

Figure 24 – New arrival points per each warehouse in Scenario 2.[30]

SWISSPORT: [41.300356, 2.065327] [41.301545, 2.065942] [41.301998, 2.067572]

WFS: [41.301024, 2.068170] [41.302278, 2.068988] [41.303558, 2.067888]

DHL [41.299084, 2.063980] [41.300669, 2.061959] [41.299948, 2.060238]

ACL BCN [41.298282, 2.062136] [41.299455, 2.061443] [41.300049, 2.063612]

FEDEX [41.297931, 2.060300] [41.297140, 2.058146] [41.296533, 2.056481]

AM CARGO BCN [41.301182, 2.066199] [41.302145, 2.064627] [41.303308, 2.063790]

METSSA [41.299961, 2.064744] [41.299343, 2.066321] [41.298803, 2.064753]

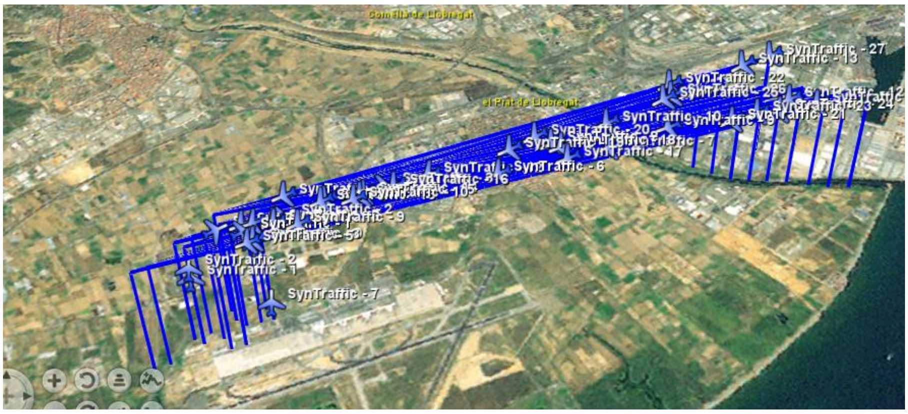


Figure 25 – generated traffic from Amazon to Cargo terminal.[31]

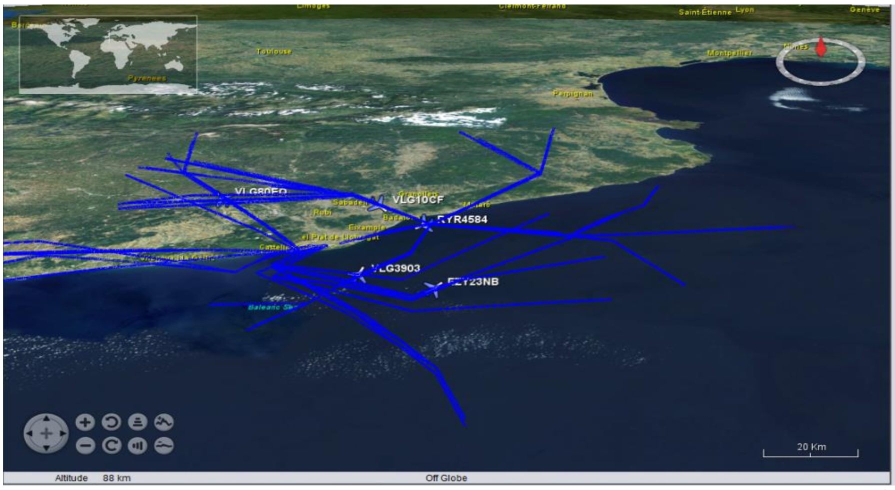


Figure 26 – Regulated one-day comercial traffic[31]

The following simulation tables are the ones for the first configuration (A). Each time one specific parameter was variable (marked in yellow), whereas the others were fixed to see which one had the highest acceptance ratios. Every column is an average of 5 simulations with those same parameters. *Note that number of duration, submission, configuration and launch windows, and tolerance are in seconds.*

	1	2	3	4
duration	1800	1800	1800	1800
density	10 80	10 80	10 80	10 80
sub_window	360	360	360	360
conf_window	600	600	600	600
launch_window	*300*	*600*	*900*	*1200*
horiz_sep	150	150	150	150
vert_sep	10	10	10	10
tolerance	120	120	120	120
acc_ratios	0,28 - 0,61	0,4 - 0,074	0,48 - 0,08	0,44 - 0,085
means shifted	36 - 100	216 - 253	236 - 347	542 - 509

Figure 27 – First four simulations, changing the launch window value in every column. Results obtained with DronAs.

	1	2	3	4	5
duration	1800	1800	1800	1800	1800
density	*20 - 80*	*80 - 120*	*120 - 210*	*30 - 60*	*50 - 250*
sub_window	360	360	360	360	360
conf_window	600	600	600	600	600
launch_window	1200	1200	1200	1200	1200
horiz_sep	150	150	150	150	150
vert_sep	10	10	10	10	10
tolerance	120	120	120	120	120
acc_ratios	0,28 - 0,085	0,08 - 0,052	0,058 - 0,026	0,236 - 0,112	0,128 - 0,0256
means shifted	536 - 497	537 - 534	515 - 538	453 - 500	513 - 579

Figure 28 – Second five simulations, changing the density values in every column. Results obtained with DronAs.

	1	2	3	4
duration	1800	1800	1800	1800
density	30 60	30 60	30 60	30 60
sub_window	360	360	360	360
conf_window	600	600	600	600
launch_window	1200	1200	1200	1200
horiz_sep	*150*	*290*	*480*	*530*
vert_sep	12	12	12	12
tolerance	120	120	120	120
acc_ratios	0,12 - 0,024	0,088 - 0,024	0,112 - 0,024	0,096 - 0,024
means shifted	520 - 540	588 - 600	579 - 596	576 - 600

Figure 29 – Third four simulations changing the horizontal separation in every column. Results obtained with DronAs.

	1	2	3	4
duration	1800	1800	1800	1800
density	30 60	30 60	30 60	30 60
sub_window	360	360	360	360
conf_window	600	600	600	600
launch_window	1200	1200	1200	1200
horiz_sep	530	530	530	530
vert_sep	*5*	*130*	*250*	*520*
tolerance	120	120	120	120
acc_ratios	0,10 - 0,024	0,10 - 0,024	0,12 - 0,024	0,12 - 0,02
means shifted	586 - 600	580 - 600	566- 600	580 - 600

Figure 30 – fourth four simulations changing the vertical separation in every column. Results obtained with DronAs.

As we can see, the acceptance ratios were very low because we had a bottleneck for incoming and outgoing packages; we had only one point of arrival/exit. For this reason, another second configuration, (B), as mentioned previously, was chosen to see if the acceptance ratios grew or not and if there were conflicts with manned aircraft. This configuration was the same as the A configuration, but with the difference that *had several arrival points per warehouse instead of one.*

For the following simulations, the first table of the simulations of the A configuration was choosen as a reference, but 2 parameters changed mainly (submission window → 360 to 900 and launch window → 1200 to 3000 in order to get higher acceptance ratios). And in every table a parameter was changed every time, whereas the others are fixed, as we did in the simulations of the A configuration.

duration	3600	3600	3600
density	*10 80*	*20 170*	*30 250*
sub_window	900	900	900
conf_window	600	600	600
launch_wind	3000	3000	3000
horiz_sep	150	150	150
vert_sep	10	10	10
tolerance	120	120	120
acc_ratios	1 - 0,2125	0,7 - 0,10	0,56 - 0,08
means shifte	804 - 1090,58	1152 - 1110	995 - 1128

Figure 31 – First three simulations changing density values. Results obtained with DronAs.

To create the following tables of simulations, the value that was variable and which had the highest acceptance ratio from each previous tables, was chosen to fix it in the next table and vary another one, assuming that in this way the values that before were variable and now fixed, would be the ones that made the acceptance ratio higher from there on.

duration	1800	1800	1800	1800
density	10 80	10 80	10 80	10 80
sub_window	900	900	900	900
conf_window	600	600	600	600
launch_wind	3000	3000	3000	3000
horiz_sep	*400*	*500*	*5000*	*7000*
vert_sep	*400*	*5000*	*6000*	*500*
tolerance	120	120	120	120
acc_ratios	1 - 0,15	0,8 - 0,1	0,6 - 0,1	0,6 - 0,1
means shifte	996 - 1040	1035 - 1116	1040 - 1110	945 - 1095

Figure 32 – Second four simulations changing separation distances. Results obtained with DronAs.

duration	1800	1800	1800	1800
density	10 80	10 80	10 80	10 80
sub_window	900	900	900	900
conf_windov	600	600	600	600
launch_wind	3000	3000	3000	3000
horiz_sep	400	400	400	400
vert_sep	400	400	400	400
tolerance	300	240	120	60
acc_ratios	0,6 - 0,1	0,8 - 0,1	0,8 - 0,125	1 - 0,15
means shifte	960 - 1110	1050 - 984	1350 - 1164	996 - 1050

Figure 33 – third four simulations changing tolerance. Results obtained with DronAs.

duration	1800	1800	1800	1800
density	10 80	10 80	10 80	10 80
sub_window	900	900	900	900
conf_windov	300	600	900	1200
launch_wind	3000	3000	3000	3000
horiz_sep	400	400	400	400
vert_sep	400	400	400	400
tolerance	120	120	120	120
acc_ratios	0,8 - 0,125	0,8 - 0,125	0,8 - 0,15	0,8 - 0,15
means shifte	1080 - 1128	900 - 1164	1185 - 1060	1125 - 990

Figure 34 – Last four simulations changing confirmation window. Results obtained with DronAs.

As we can see, then, in the second configuration, the acceptance ratios were higher than in the A configuration.

7. ANALYSIS OF RESULTS

In this section are represented and explained the results of the previous section. Note that only the essays of the first part of the new configuration are studied in detail, because they're the ones who are worth for this project, rejecting the results of the first configuration.

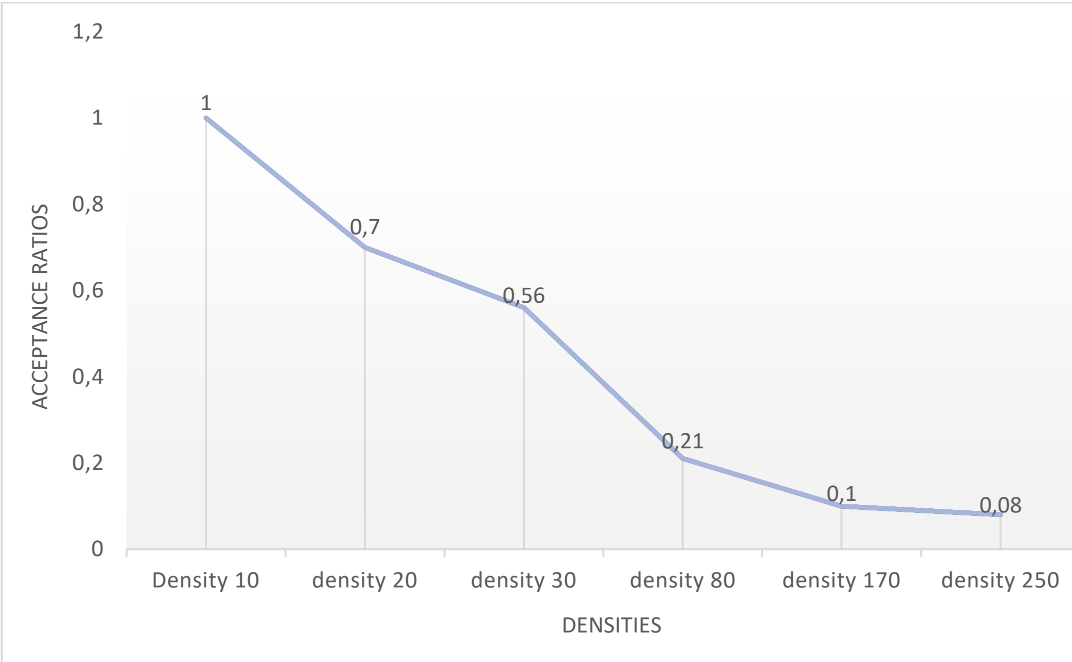


Figure 35 – Acceptance ratios Vs. Densities (duration 3600, Sub. Window 900, conf. Window 600, launch window 3000, Horiz. Sep 150, Vert. Sep 10, tolerance 120)

This graphic shows the relation between the densities of the missions and the acceptance ratios. It's possible to observe that the more we enlarge the density, the less acceptance ratios we have. With 10 missions/hour it's assumed that the 100% of the missions are accepted, and with 250 missions/hour not a single percent is accepted.

Assuming a minimum submission time of 15 minutes, a confirmation time of 15 minutes too and a launch window of 5 minutes we have:

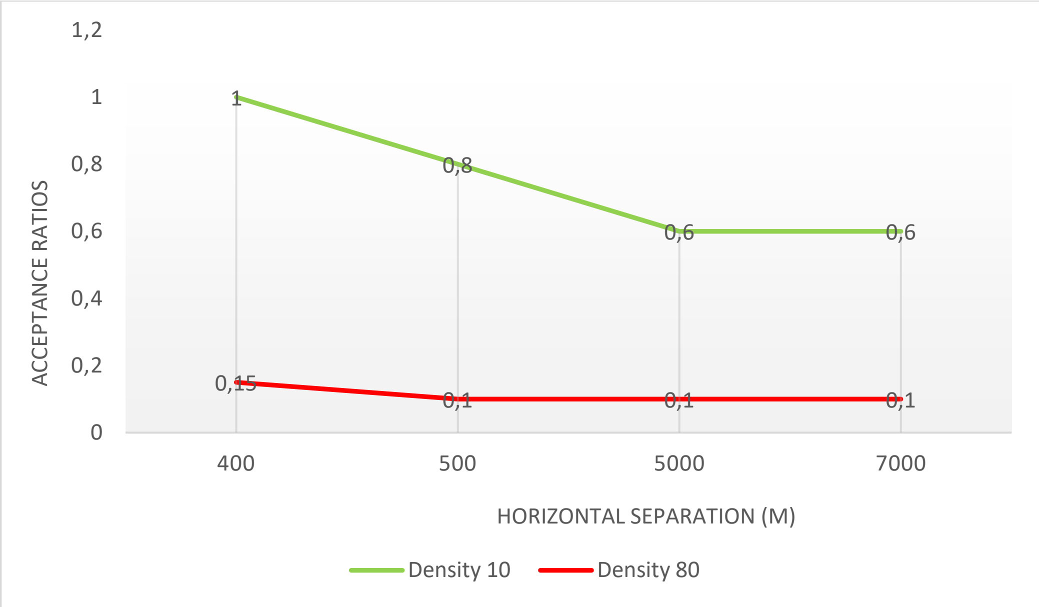


Figure 36 – Acceptance ratios Vs. Horizontal separation. Representation of figure 32.

It was demonstrated in figure 31 that the couple of densities that would have more missions accepted were 10 – 80. So, from now on, in all the graphics are studied the relations between acceptance ratios and the parameter, which was varied every time, for both densities. In the graphic above (Figure. 36), is studied the relation with the horizontal distance, and is shown that for a density of 10 m/h and with a minimum distance of 400m, all the missions are accepted, and we can also see how the acceptance ratios decrease as there is more separation distance. If we increase 100 meters the horizontal distance (from 400 to 500), it is observed that the acceptance ratios decrease till a 80%. If we increase the distance from 500 meters to 5000, the acceptance ratios decrease again, from 80% to 60%. With a separation of 7000 meters, the acceptance ratios are kept in 60%, but if we still increase more the distance, we would see that every time the separation is increased, the acceptance ratios would decrease, because the more we increase the distance, the more conflicts there will be.

And on the other hand, with a density of 80m/h with 400m of horizontal separation there are very few accepted missions, and the more we increase the distance, even if it makes little difference and is almost everything regular, the less acceptance ratios are.

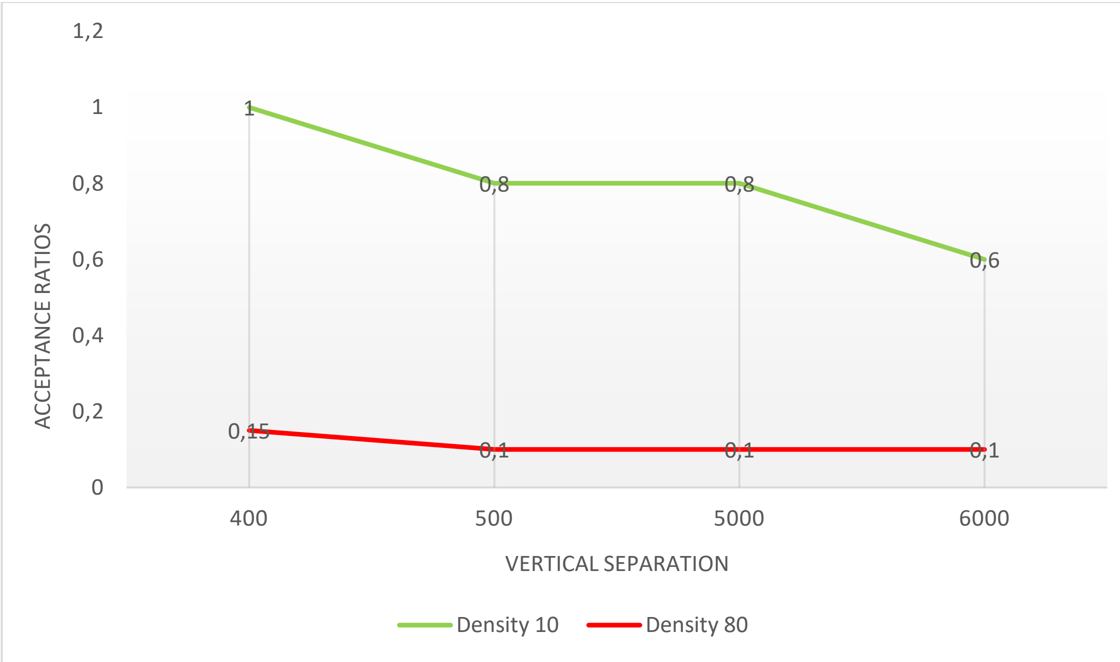


Figure 37 – Acceptance ratios Vs. Vertical separation

With vertical separation in a density of 10m/h happens the same that with horizontal separation: the more we increase the distance, the less acceptance ratios there will be. There's a drop of acceptance ratios between 400 and 500 meters of a 20%, between 500 and 5000 meters the acceptace ratios are kept and finally from 5000 to 6000 there is a drop of a 20% again.

With a density of 80%, there is a drop between 400 and 500 meters, but from there on, the acceptance ratios are kept in a 10%.

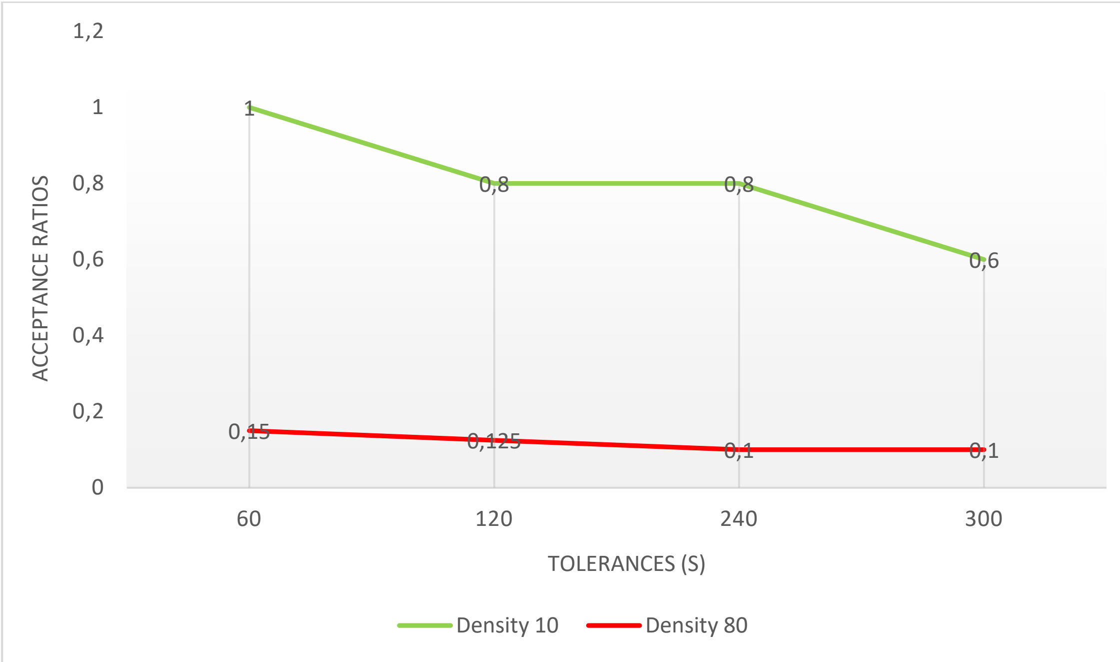


Figure 38 – Acceptance ratios Vs. Tolerances (in seconds)

Regarding tolerances with a density of 10m/h, if we focus on the first and the last point: note that with a tolerance of 60 seconds, (the lowest) there are 100% of the acceptance ratios, but in the other hand, if we compare it with the highest tolerance (300), it can be observed that this is reduced by almost 50%. And this is because the more tolerance there is, the less acceptance ratios there are. All the results are quite high.

Furthermore, if we pay attention to the 80m/h of density, is perceived that every tolerance is pretty bad because the maximum acceptance ratios are 15% with 60 seconds, then it decreases to 12,5%, and from there on, it is kept in 10%.

Figure 39 – Acceptance ratios Vs. Confirmation window (in seconds)

Regarding the time of the confirmation windows, if we see the corresponding table of simulations, we can see that the means shifted vary but the acceptance ratios not. They remain the same for both densities: 80% for the 10m/h and 12,5% for the 80m/h.

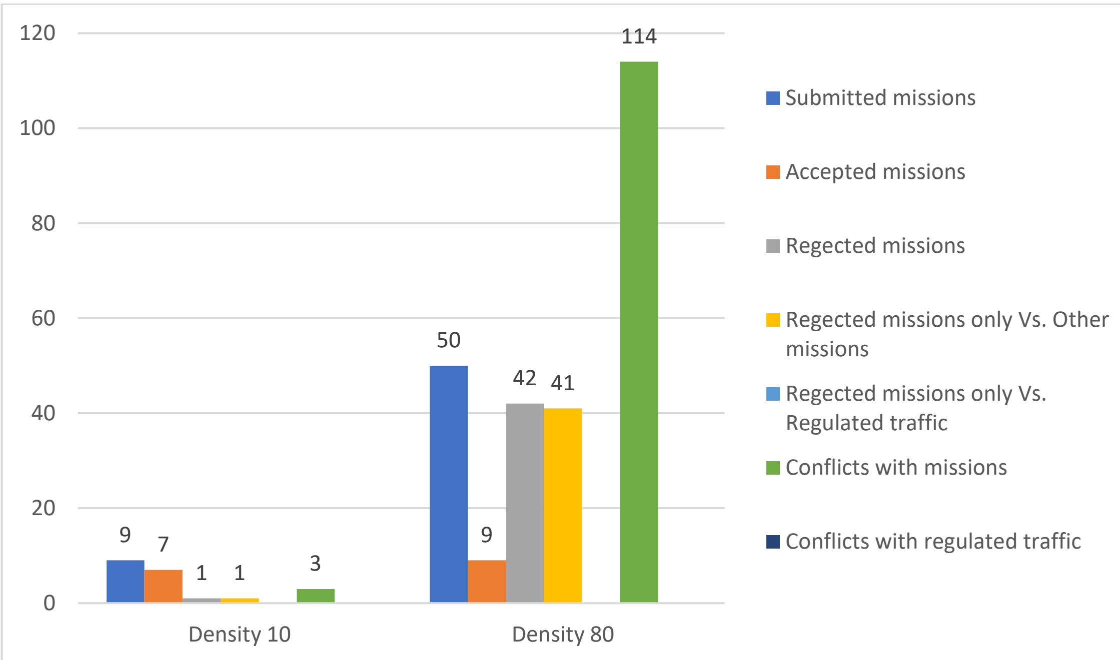
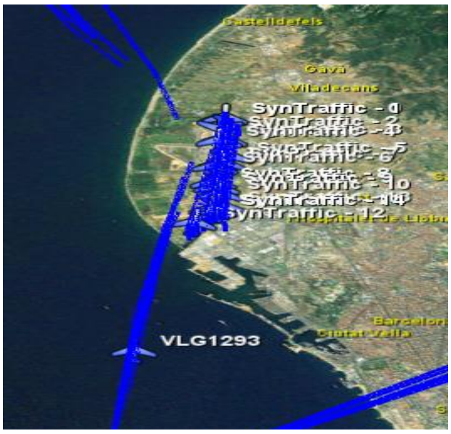


Figure 40 - Representation of the average of the results of each simulation returned by DronAs.

In this last bar chart, there is the representation of the average statistics of the results returned by DronAs, of all the simulations that have been used.

With a density of 10m/h, broadly speaking, if there were 9 submitted missions, 7 are accepted, 1 rejected, 1 rejected only vs other missions, 0 rejected only vs regulated traffic, and there would be 3 conflicts just between missions, anyone with regulated traffic.

And with a 80m/h, if there were 50 submitted missions, just 9 would be accepted, 43 would be rejected, 41 only with other missions, and 114 conflicts between them because there are 0 rejected missions only vs regulated traffic and also 0 conflicts with regulated.



Figures 41 and 42 - trajectories of UAVs away from airport entrances and exits


Figure 43 - We can see from another perspective that the drones are quite away from the runways of the airport, where the entrances and exits of the manned aircraft are.

8. CONCLUSIONS

As it was mentioned in the introduction section, it can now be confirmed that not only the minimum separation distance impacts flexibility (the number of missions accepted), capacity and security of the system, but depends on many others such as durations, densities, submission, confirmation and launch windows and tolerances, for instance. As well as important services like strategic deconfliction, procedural interfaces with ATC and collaborative interfaces with ATC too.

This scenario was chosen instead of another one because it was thought that it would be more likely to find interactions between manned and unmanned aircraft, and having done so many simulations, changing the altitude and other parameters so many times, and doing all the tests possible to see if there were conflicts between drones and commercial planes, it has been proven that there is no conflict whatsoever with the planes entering and leaving El Prat airport, in this particular configuration, and therefore it is concluded that the scenario is feasible and the project could be realized without problems.

It was tried to put a minimum separation distance that wasn't too low, because if we put for example 150m of separation, it would mean that a drone would have to get 150m closer to a commercial aircraft and that would never happen, that's why we had such a low number of conflicts in the first scenario. On the other hand, if the separation was too high, we might have conflicts with the aircraft, but also the number of conflicts between drones would grow a lot, which is what happened in the second scenario, but without having conflicts with commercial aircraft.

Nevertheless, we have been able to create a logistic scenario in which the viability of a mixed scenario is demonstrated (with the acceptance ratios that we obtain, more or less, we have about 40 missions per hour, so we would have to complement the air logistics by land), and in which it has been demonstrated to be able to link the different warehouses with Amazon without compromising the security of the commercial operations of the airport.

Conceptions I've personally learnt up are that u-space services promise to provide lots of drone-based business in a future, changing the appearance of what sky is nowadays, and that a comprehensive set of strategic conflict resolution services are needed to ensure the safety of operations, even at low-density operational levels, among others.

I think that this project would be a good idea to implement it in the future since many benefits would be obtained progressively, and also, taking into account that drones are increasingly used for commercial use. Also note that the main objectives of the present project have been achieved, like for example: *to give a general vision of the situation presented nowadays and in a future in relation to drones, what u-space is, how it will be managed and the impact that it will have in a future airspace,* without forgetting that I've learned how to understand what the simulator did and to interpret the outputs, how to use it and to solve doubts and curiosities that I had about UAV's.

8.1 ASSUMPTIONS

All the simulations performed in this report make the next set of assumptions:

A. UAVs used in the simulations: The simulations were based on a fleet of rotor UAVs assuming vertical take - off and landing and whose maximum horizontal speeds during the mission execution goes up to 110km/h .

At the same time, it is supposed that the autonomy of each UAV goes from 30 minutes to 2.5 hours. The missions generated by the synthetic traffic simulator have a length of 7km approximately.

B. Minimum separation distance: A minimum separation distance among UAVs of 400m vertically and 400m horizontally have been assumed.

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@41.3016885,2.0690751,928m/data=!3m1!1e3!4m5!3m4!1s0x12a49c2aa511a489:0x1f0484f2b19d04!8m2!3d41.3032562!4d2.0660141.

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