EGNOS-based navigation and surveillance system to support approval of RPAS operations

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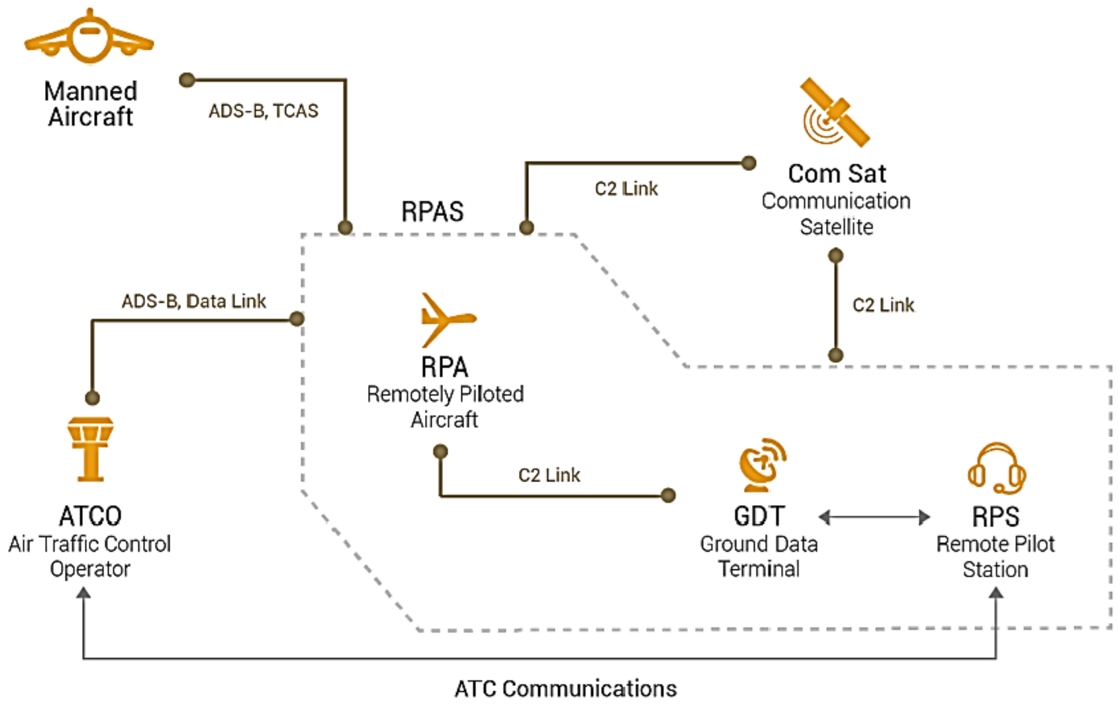
Introduction

RPAS are a set of configurable elements consisting on a remotely piloted aircraft, its associated ground station, command and control links and other systems that may be required at any point of the operation.

Nowadays, **RPAS operator's regulations are progressively being introduced**. However, **there is still some inconsistency on the applicable requirements** for the Airworthiness Approval and Operational Criteria for RPAS to operate, in particular within VLL operations.



Introduction

- REAL project promotes the use of EGNOS in the RPAS sector by integrating an EGNOS based navigation and surveillance sensor in two different RPAS platforms, and as such enabling to perform innovative operations by contributing to its approval.
- The solution consisted not only in developing the navigation and surveillance system, but to validate it and demonstrate its benefits throughout two concrete commercial-based scenarios:
  - Scenario 1 - Urgent medicines transport
  - Scenario 2 - Fire extinction operations

Scenario 1: Urgent Medicine Transport

RPAS is load with requested urgent medicines

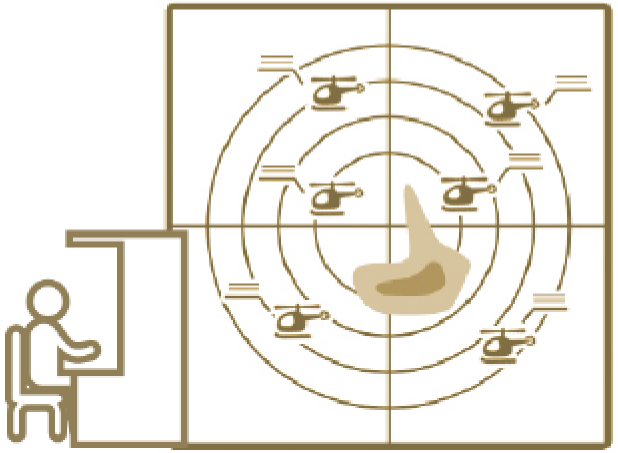
RPAS fly along a low level route below 500ft

RPAS delivers medicines to inaccessible areas

Scenario 2: Fire Extinction Operations

RPAS is transported to the emergency location by ground

RPAS takes off and stay above fire extinction traffic

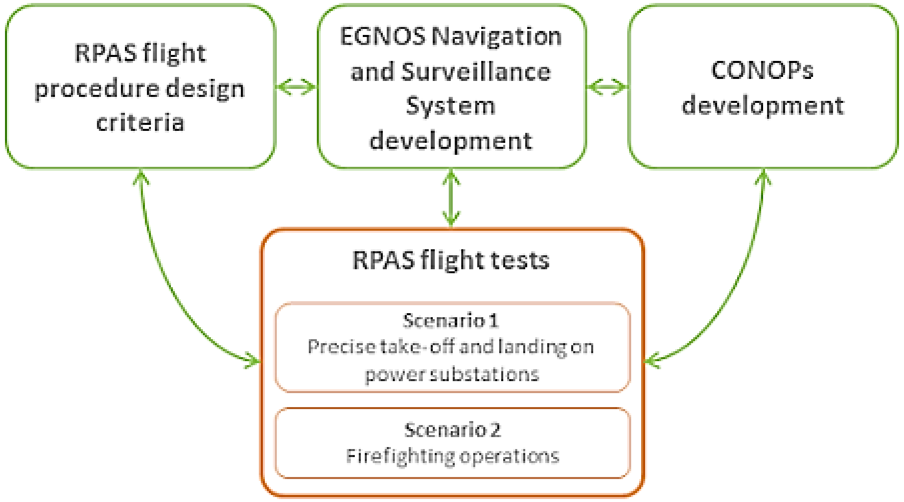


On ground, RPA is controlled and extinction traffic is coordinated

Objectives

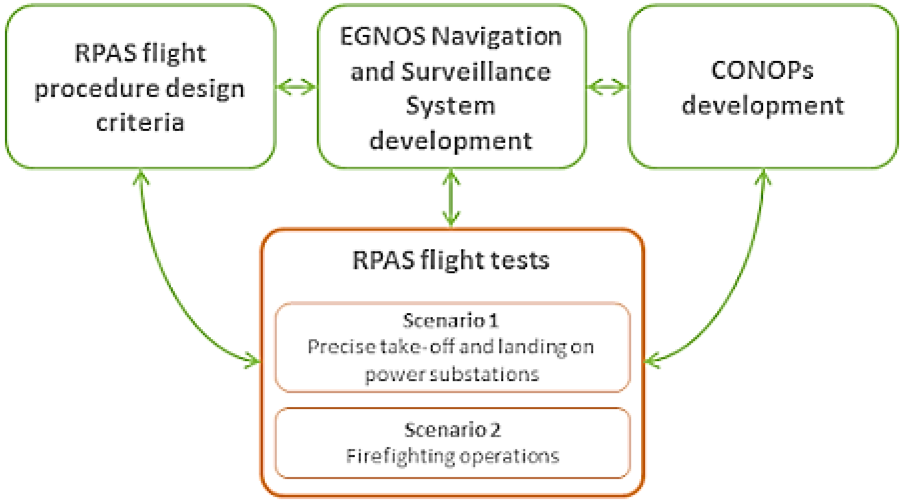
On one hand, the objective of this research is to propose an instrument flight procedure design criteria for RPAS based on current procedure design provisions for manned aircraft.

- This new criteria should take into account the physical and operational unmanned aircraft differences with manned aircraft, as well as considering the project scenarios as the initial application areas.



Objectives

On the other hand, this research aims at demonstrating the benefits that EGNOS can offer for the safe future integration of UAS in the airspace.



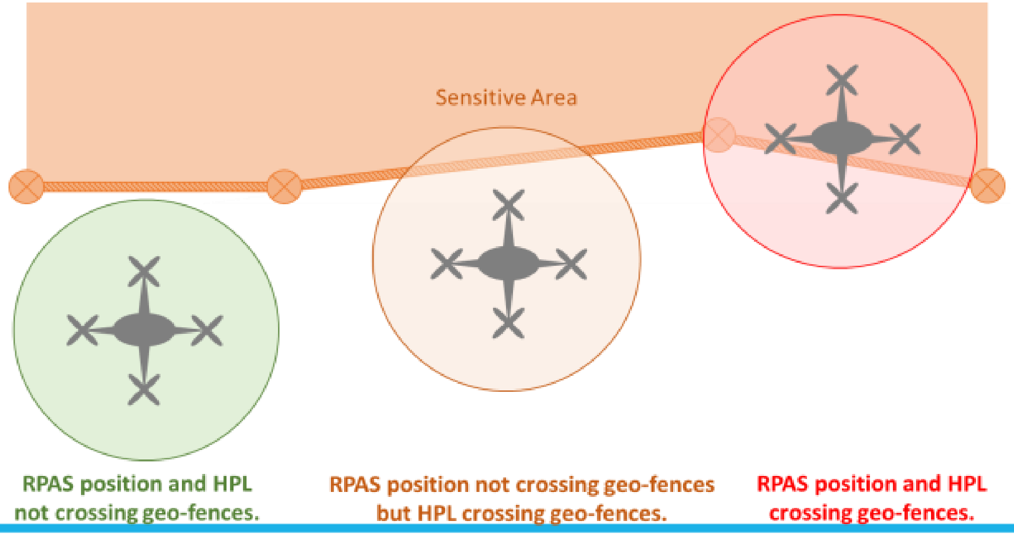
EGNOS and its application to RPAS Navigation Systems

- GPS have been the main positioning source in most applications over the last three decades. However, **applications are progressively requiring higher accuracy requirements** and, at the same time, lower price levels.
- In the User Guide for EGNOS application developers, it is presented that the expected performance of the GPS signals uses to be between 7 and 13 meters

	GPS Specifications	Real expected performance
Horizontal Accuracy	< 17 meters (95 %)	7.1 meters
Vertical Accuracy	< 37 meters (95 %)	13.2 meters
Time Accuracy	< 40 ns (95 %)	12 ns

EGNOS and its application to RPAS Navigation Systems

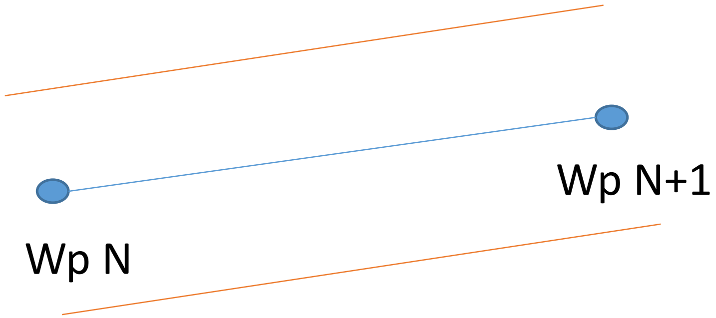
- The use of the EGNOS system jointly with GPS can provide a **horizontal accuracy better than 3 meters and a vertical accuracy better than 4 meters at 95 % of the time**..
- This allows **safer operations in flights Beyond Visual Line Of Sight** (BVLOS) where the pilot is not able to see the aircraft during the different phases of the operation (critical in landing).
- By last, EGNOS also can help to improve the geo-fencing capabilities of the guidance module. Geo-fencing concept aims to use geographical information to establish boundaries or fences, to prevent hazardous RPAS flights in sensitive areas.



RPAS Normal Flight Plans Creations

RPAS Flight Plans Creations

- Currently, the approach that is being followed by U-space developers is based on:
  - Reservation of a zone for performing the operations. This zone will be used only for the operator that has reserved it.
  - List of waypoints. The line that joins the different WP has a boundary that limits the zones reserved to the RPAS.



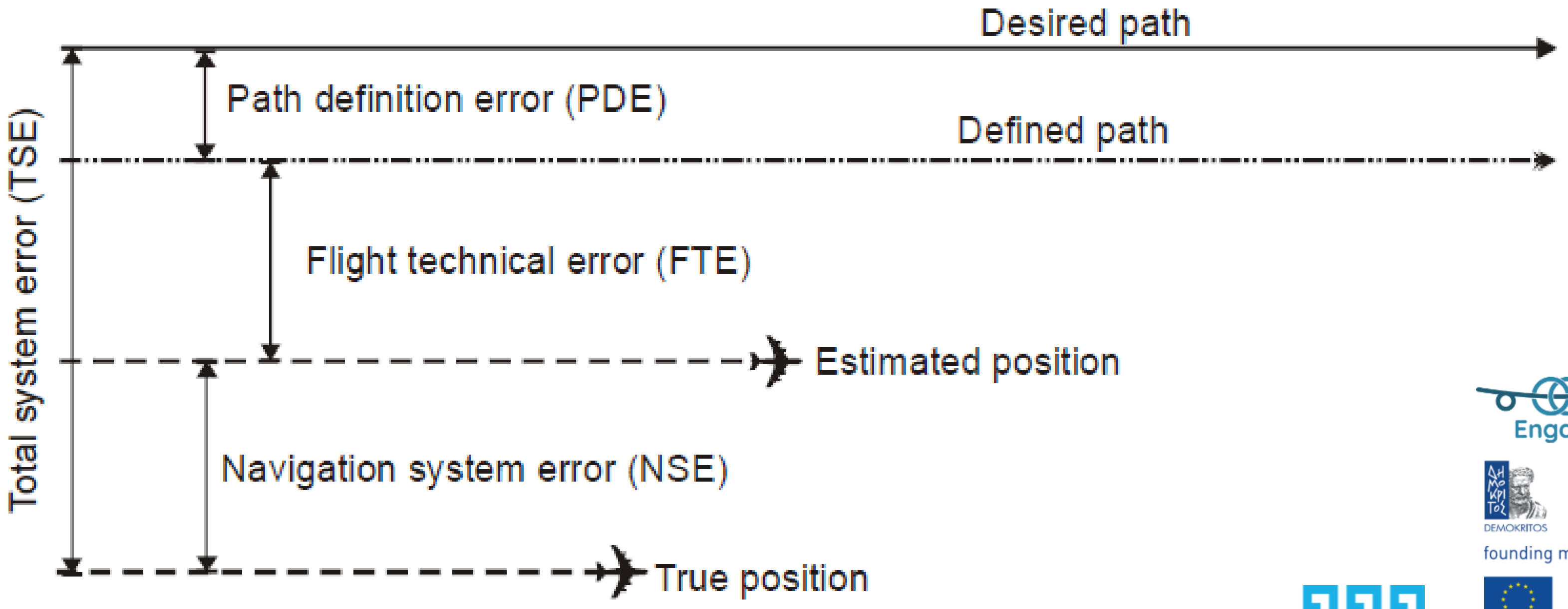
RPAS Navigation Specification Assesment

- This research aims to define a first proposal of a navigation specification (NAVSPEC) tailored to the performance of a drone equipped with the Navigation Surveillance System (NSS) developed during the project
- Current EASA rules prescribe indeed a navigation performance, but not a list of receivers. Therefore, the PBN concept was chosen for RPAS navigation, considering that GNSS is the most widely used navigation technology in the RPAS sector.

RPAS Navigation Specification Assesement

- A GNSS RNAV NAVSPEC (RNAV and RNP) defines the size of the areas that protect the instrument flight procedure designed trajectory.
- The RNP NAVSPECs define the total system error (TSE) value limits where aircraft must be contained for at least 95% of the total flight time
- The TSE is dependent upon position estimation error (also known as navigation system error (NSE)), path definition error (PDE) and flight technical error (FTE)

$$TSE = \sqrt{FTE^2 + NSE^2 + PDE^2}$$



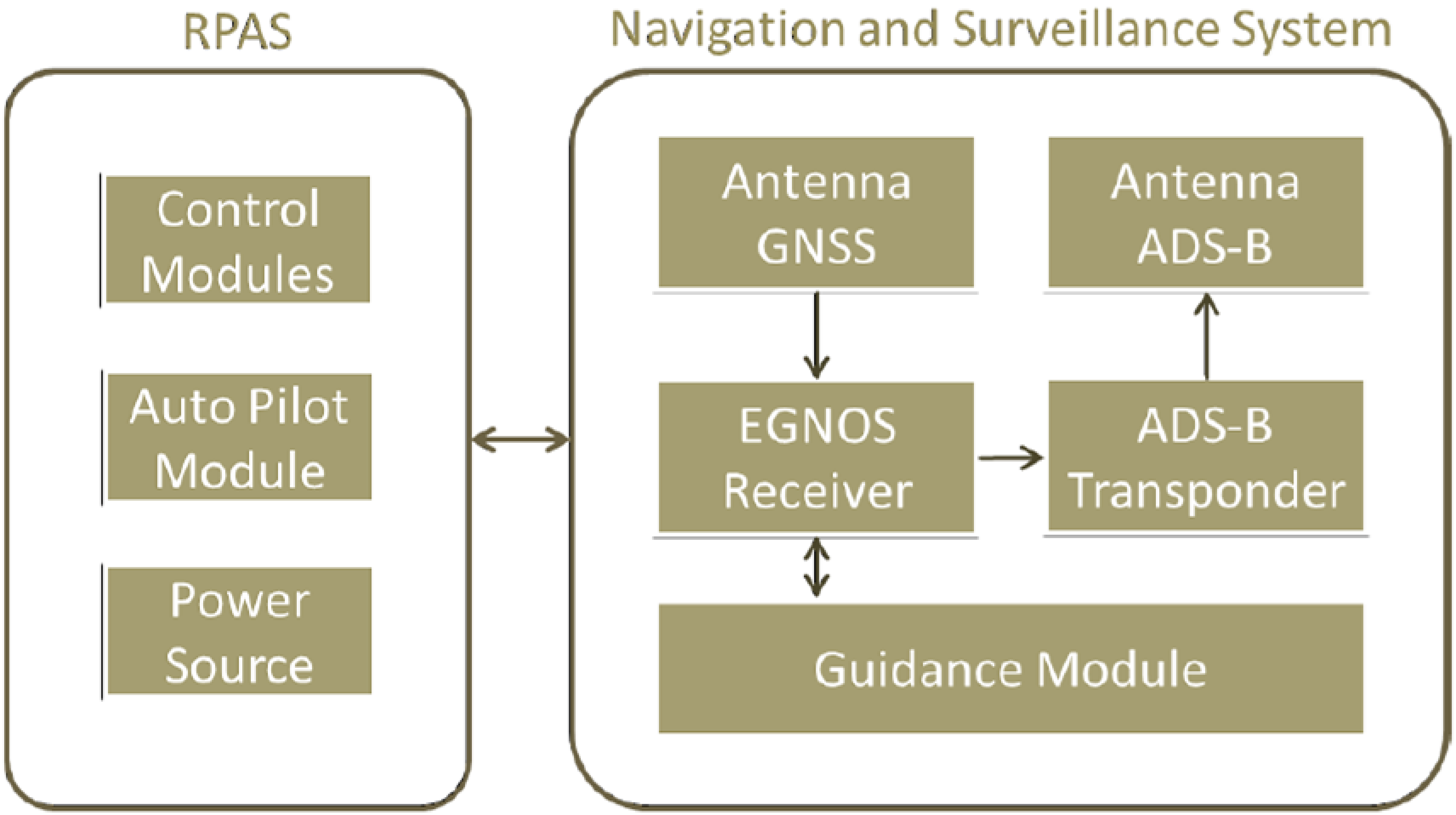
RPAS Navigation Specification Assesment: Results

The criteria followed to demonstrate that the new horizontal and vertical protection parameters values are adequate for small RPA performance and characteristics was validated **from the data gathered through the campaigns of flight validations**.

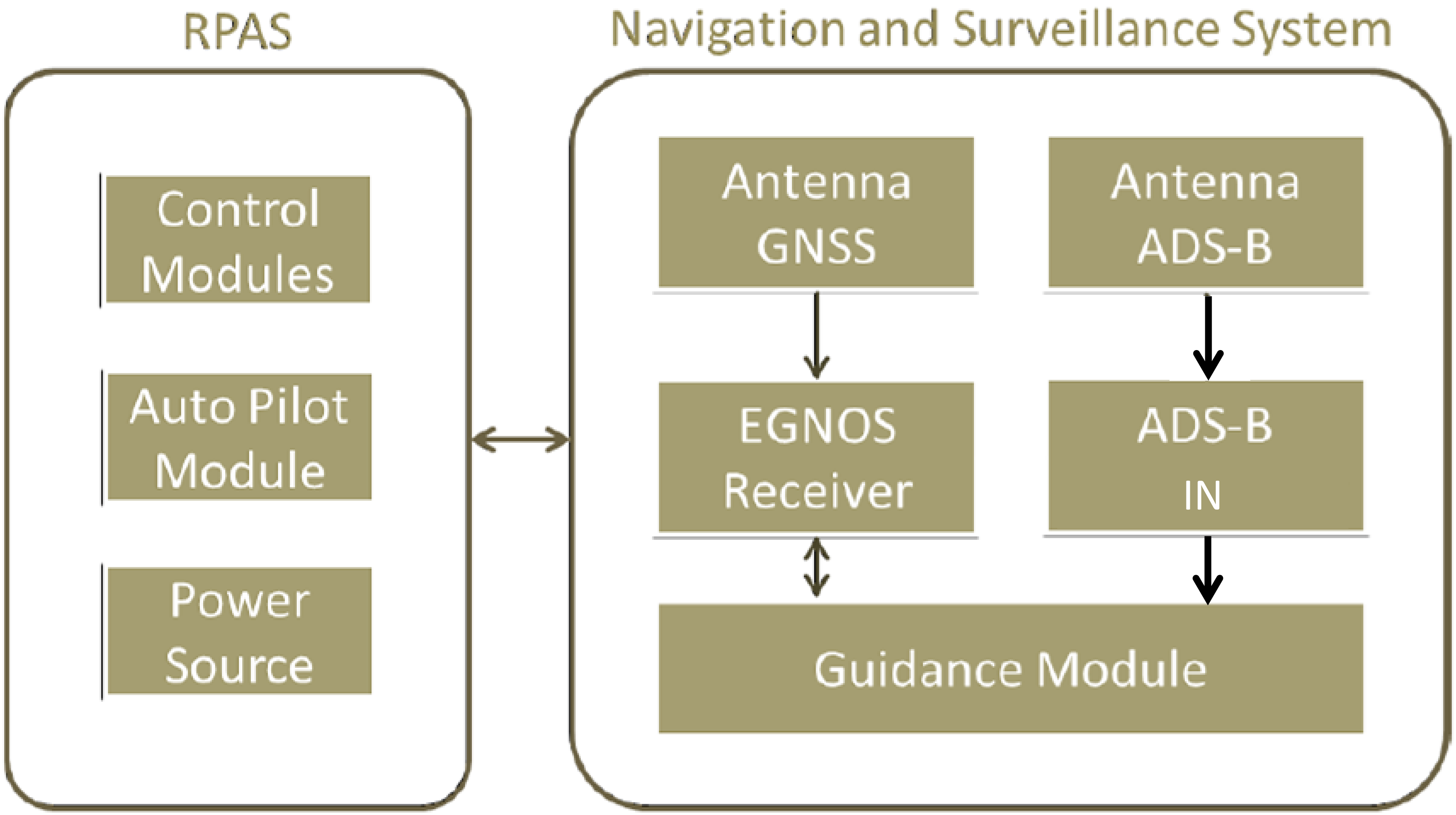
- **NSE assumed value is 3 meters**, which corresponds to the EGNOS Safety-of-Life horizontal accuracy 95-percentile value described in EGNOS Service Definition Document.
- **PDE is neglected**.
- **FTE considered is the highest value of the 95-percentile HFTE values obtained** in all the flights performed during the project. Thus, the **FTE is 11.45 meters**. A safety parameter multiplying this value is considered due to the small number of flights performed to obtain it, which is not representative at all to model the FTE correctly. The **safety margin parameter selected is n = 3** (FTE= 11.45*3= 34.35).

Finally, and using all the parameters described above, the computed TSE is 34.48 meters (0.02 NM), which is translated into **RNP 0.02 NAVSPEC**

Initial Navigation and Surveillance System Architecture



Final Navigation and Surveillance System Architecture



Testing Scenario

ATLAS (Air Trafic Laboratory for Advanced unmanned Systems) is a Test Flight Centre located in Jaen (Spain) exclusively dedicated to testing UAS

ATLAS facilities count with a segregated airspace that has an extension of 1,000 km2, which turns it into an ideal center for R&D and flying tests with this kind of platforms and aircrafts

RPAS Platforms used during the tests

Electrical 4-rotor multicopter. This drone has a maximum takeoff weight of 24kg and a payload of up to 16 Kg. It was specifically designed for being able to fly up to 48 minutes.

6-rotor vehicle powered by electric motors driving fixed-pitch propellers with a takeoff weight of 18kg. It is capable of fully automated consolidated inspection missions having a flight time for inspection up to 30 minutes with full sensor payload

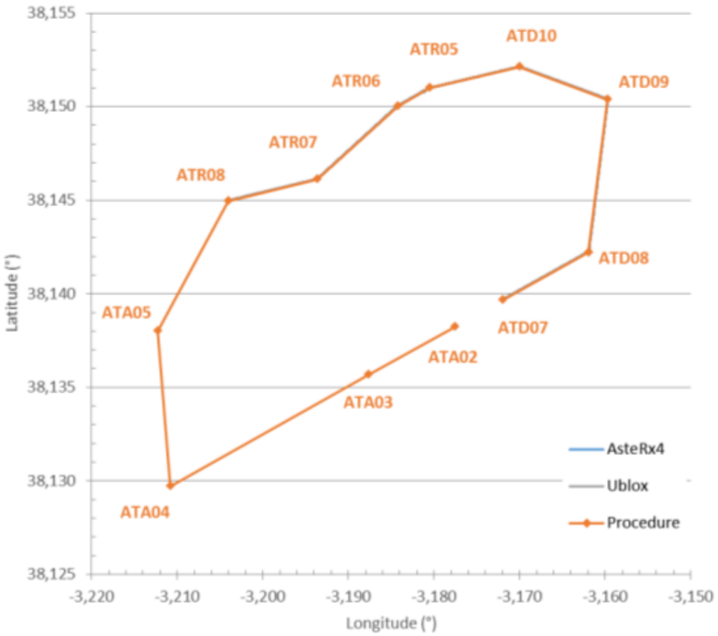
EGNOS-based Navigation and Surveillance System

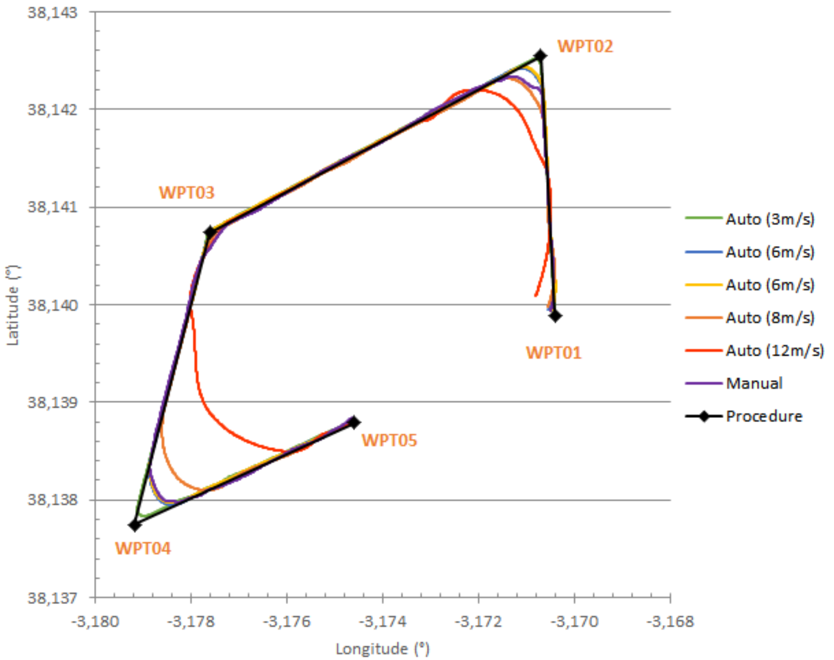
This system has been developed as an independent module capable of being installed easily into any type of RPAS as payload :

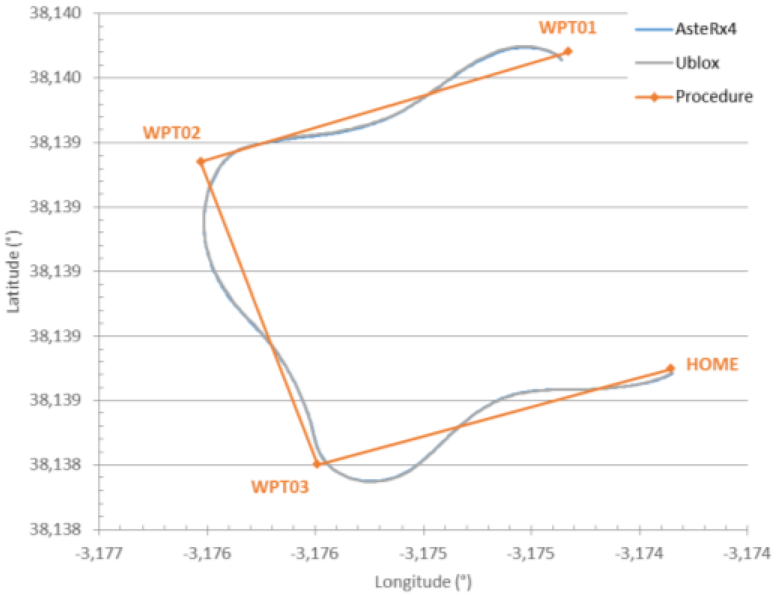
- **GNSS multi-constellation, multi frequency, professional receiver:** This is the GNSS receiver used by the platform to receive GNSS data and compute the aircraft position during its operation.
- **Mass market GNSS receiver:** This is the GNSS low cost receiver which performances have been compared with professional multi-frequency and multi-constellation GNSS receiver results.
- **High-end Inertial Aided GPS Sensor:** a high-performance, miniature, Inertial Aided GPS Navigation System (GPS/INS) that combines micro inertial sensors and a high-sensitivity embedded Global Positioning System (GPS) receiver.
- **On-board processor:** This is the processor unit that is used by the platform to run the software packages and to interface with the GNSS receivers.

Flight Data Analysis

During the flight campaign, several flight plans were created in order to study the results obtained from different routes, velocities, locations, etc.







The purpose of conducting this procedure is to execute a flight plan similar to the one that could be used in a firefighting activity. This FP has approximately 6 km and was designed by using the navigation specification RNP 0.02

This procedure corresponds to a medium-size route, formed by 4 segments legs around the departing point. It is a reduced version (1700m) of the LR, allowing performing multiple flights without RPAS operation time limitations

Short procedure (419m), formed by three segment legs of 150m length, deployed around the departing point

Results: Flight Deviations

HFTE per each flight with the aim to facilitate the comparison and procurement of general results

Flight	LR	SR	MR 3m/s	MR 6m/s	MR 6m/s	MR 8m/s	MR 12m/s	Manual
Maximum	8,68	4,82	4,00	3,52	4,40	5,09	8,29	11,20
Minimum	0,00	3,30	0,01	0,00	0,02	0,00	0,00	0,01
Average	2,32	4,14	1,89	1,18	1,74	1,41	2,70	2,25
Percentile 95%	4,25	4,75	3,10	2,32	3,32	3,97	7,76	5,95

By analyzing the flight trajectories and the calculated FTE parameters the following statements can be highlighted:

In the lateral plane, the HFTE are quite low, and the error variations when transitioning from a straight segment into a turn are relatively small. This is thanks to the improvement of the NSS Box guidance algorithm during the turns.

Results: Flight Deviations

VFTE per each flight with the aim to facilitate the comparison and procurement of general results

Flight	LR	SR	MR 3m/s	MR 6m/s	MR 6m/s	MR 8m/s	MR 12m/s	Manual
Maximum	4,04	11,3	12,63	8,38	4,53	11,05	14,12	-
Minimum	0,00	0,03	6,33	3,80	0,00	7,90	10,87	-
Average	2,13	4,60	8,09	5,73	1,17	9,40	12,08	-
Percentile 95%	3,62	10,6	11,76	8,02	4,44	10,86	12,89	-

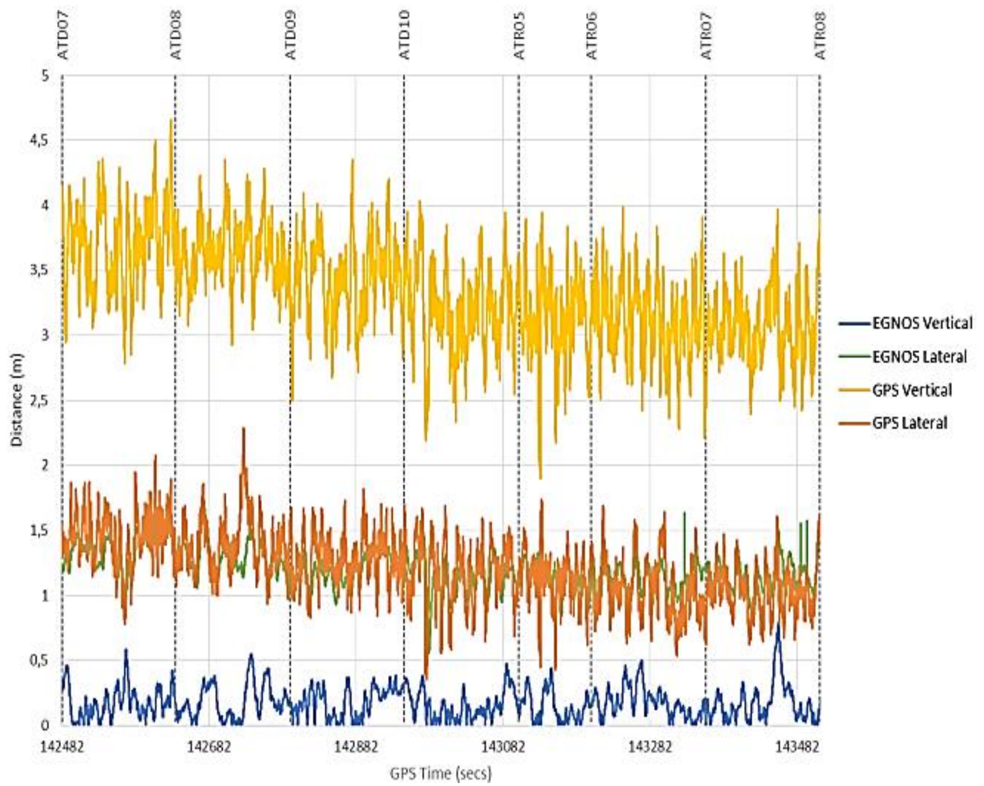
In the vertical plane, it is observed a relevant deviation in most of the flights, indicating that the GNSS altitude is always a few meters below the desired altitude (negative VFTE). One of the factors that was causing this effect was the altitude difference between both local reference positioning solutions (NSS Box and RPAs autopilot). As this issue was solved, the remaining factor related to vertical deviations is the difference between the altitude computed by NSS Box and the one computed by RPA autopilot.

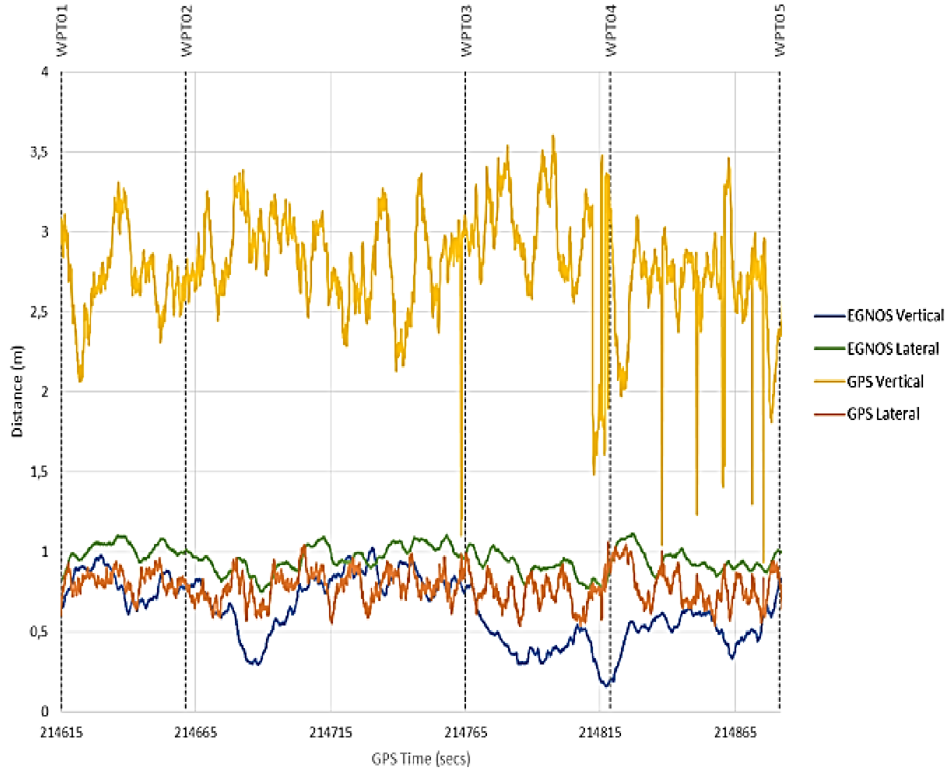
Results: GPS vs EGNOS-based navigator

- Aiming to assess which are the benefits provided by EGNOS during the RPAs operation, it was computed the trajectory solution (with and without using EGNOS). This solution was processed based on the GNSS raw data recorded during the flights.
- The precise trajectory followed by the RPA was obtained through a post-processed kinematic (PPK) assessment in differential processing mode using both GPS and GLONASS constellations when available. Two base stations and precise GNSS files were used for each trajectory processing. Solutions in forward & reverse directions were calculated and combined

Results: GPS vs EGNOS-based navigator

Next Figure aims to present the differences between the precise trajectory and the positioning solution computed by using EGNOS and the GPS solution in two flights of the first campaign.





Results: GPS vs EGNOS-based navigator

As can be observed, **lateral deviations from both solutions are similar on the average values**; however, in GPS solution, the value dispersion is slightly higher, obtaining a small increment in the 95th percentile.

On the other side, noticeable differences are obtained in **the vertical axis**, where **EGNOS solution improves the accuracy between 2m and 3m from GPS solution.**

Numerical difference between the PPK trajectory and the EGNOS/GPS positioning solutions

	C1 Flight 2				C1 Flight 4			
	EGNOS		GPS		EGNOS		GPS	
	H	V	H	V	H	V	H	V
Maximum	1,68	0,79	2,29	4,66	1,83	2,16	1,82	5,47
Minimum	0,55	0,00	0,36	1,90	0,67	0,00	0,43	0,00
Average	1,20	0,17	1,22	3,34	1,04	0,75	1,00	2,72
Percentile 95%	1,47	0,39	1,65	3,97	1,18	1,23	1,51	4,24
	C2 Flight 4				C2 Flight 13			
Maximum	1,13	0,75	1,21	1,88	1,43	1,46	1,46	4,62
Minimum	0,64	0,25	0,19	0,00	0,81	0,73	0,33	0,39
Average	0,69	0,46	0.87	0,47	0,81	1,05	1.11	1,94
Percentile 95%	1,07	0,65	1,07	1,04	1,32	1,34	1,07	2,48

Conclusions

From the results obtained, it has been possible to define an RPAS RNP 0.02 navigation specification, a value below the challenging RNP 0.1 which was defined at the beginning of the project.

Conclusions

By comparing EGNOS versus GPS positioning solution, it is identified that EGNOS provides noticeable benefits, especially on the vertical axis by reducing the error around 2m. In that way, it is possible to conclude that EGNOS improves the navigation and surveillance functions of a RPA by introducing the following benefits

- Satellite Navigation (PinS) is an opportunity for RPAS operators
- Better navigation performance through higher accuracy, specially vertical
- Robust geofencing thanks to positioning integrity and reliability
- Low-level routes, lower protection volumes, more opportunities under challenging environments

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Thanks for your attention!

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