EUROPEAN GLOBAL NAVIGATION SATELLITE SYSTEMS (EGNSS) FOR

DRONES OPERATIONS

WHITE PAPER

GALILEO EGNOS
NAVIGATION MADE IN EUROPE

European Global Navigation Satellite Systems Agency

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01 INTRODUCTION

Drones are a novel and very quickly emerging technology with a vast array of applications. As such, drones will grow to outstrip any other user base in the aviation market[1]. GNSS is essential for the safe and reliable navigation of drones, and GNSS receivers are implemented on almost all new commercial drones as a standard feature. With increasing demand for BVLOS (Beyond Visual Line of Sight) operations, GNSS (possibly with various augmentations) is the most obvious choice of technology for navigation, although it is not the only one.

European GNSS (EGNSS)- EGNOS (European Geostationary Navigation Overlay Service) and Galileo, provide significant added value to drone navigation, positioning and related applications, with respect to other systems. EGNOS corrections provide over Europe improved robustness and higher safety of navigation as well as improved accuracy, specially relevant in thevertical axis for drones operations. With Galileo satellites in addition to GPS, drones may use signals from more satellites for position determination which improves the accuracy and also will increase the availability of received signals (e.g. key in urban canyons). Galileo also offers distinct and unique features benefitting drones operations, e.g. Galileo's authentication will provide additional trust on the veracity of the position, being more protected from intentional or unintentional interferences (e.g. spoofing). Several drone navigation receiver manufacturers already offer EGNSS capabilities in a multiconstellation suite, and the number of models is increasing continuously.

> GNSS IS ESSENTIAL FOR THE SAFE AND RELIABLE NAVIGATION OF DRONES, AND GNSS RECEIVERS ARE IMPLEMENTED ON ALMOST ALL NEW COMMERCIAL DRONES AS A STANDARD FEATURE.

The regulatory framework for drones operations is under development and significant progress has been made in 2019 by the publication by the EC of regulations 2019/945 (CE marking process; technical requirements fron UAS) and of Regulation 2019/947 (Operations of drones in open and Specific categories and registration of operators and certified drones). Drones operations in the open category will have to comply with strict limitations (e.g. flight in visual line of sight), requirement on remote pilot training , requirements on the operator and depending of the class of drones technical requirement for the drone such as e-identification, geo-awareness, height limitations capabilities. As a general principle, drone operations in the specific category will be subject to an approval by the competent authority based on a risk assessment performed by the operator. EGNSS can contribute to more accurate and robust drones operations.

The main objective of this paper is to introduce the added value of EGNOS and Galileo for current drones operations and future U-Space services.

1 Source: GNSS Market Report, GSA, issue 5, 2017

02 BACKGROUND

2.1 DRONE MARKET

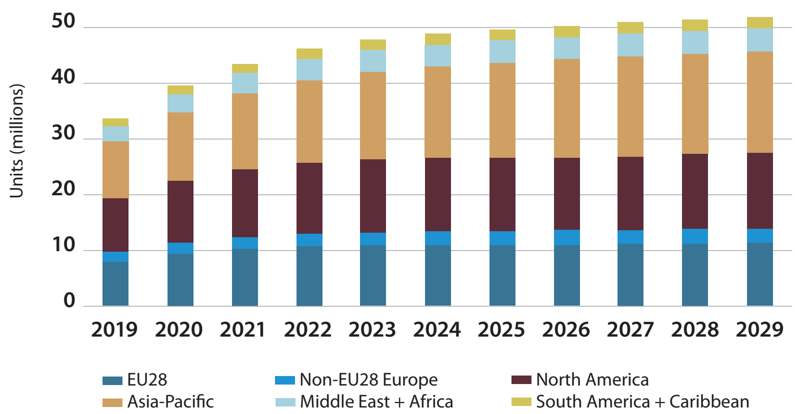
The drone market is growing rapidly, with European demand estimated at in excess of EUR 10 billion annually, in nominal terms, to 2035 and over EUR 15 billion annually to 2050[2]. The service component of the drone market is growing. Today dedicated drone services are being offered by a number of specialised companies. European drone service revenues are expected to nearly double from €32 mln in 2018 to approximately €60 mln by 2020 and are eventually forecast to reach €150 mln by 2023. It is forecasted that from 2021 onwards, services will increasingly be offered in the urban environment. Services such as drone package delivery will see initial services kicking off, paving the way towards more mass-market adoption of drone services[3].

DRONES WILL BE A GLOBAL PHENOMENON AND THE NUMBER OF DRONES EQUIPPED WITH GNSS RECEIVERS WILL GROW SIGNIFICANTLY IN THE COMING YEARS.

Drones will be a global phenomenon and the number of drones equipped with GNSS receivers will grow significantly in the coming years. As can be seen from the figure below (Figure 1) when it comes to drones, the installed base of GNSS devices in the EU, North America and Asia-Pacific region is comparable. In 2017, 88% of receivers for drones are provided by North American and Asian suppliers with European companies providing the remaining 12%. Within the drone segment most system integrators (i.e. drone manufacturers) are based in Asia (86%), although European companies such as Parrot remain important players (14% of the market). European companies lead the provision of drone related services (Flock, Sensefly) and drone trafc management (Altitude Angel, Airmap and Unifly).

Depending on their specific payload and other characteristics, drones can enable a vast array of different applications. Whilst the list of drone use cases is almost endless, many of them can be categorised along the following classes of application[4]:

Figure 1: Installed base of GNSS devices by region

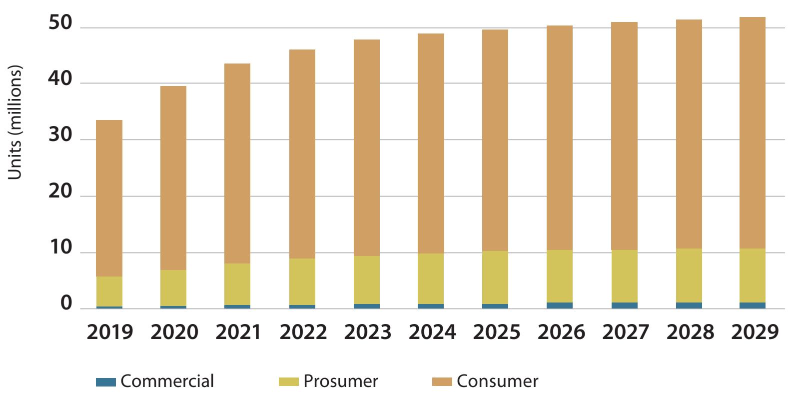


2 Source: European Drones Outlook Study: Unlocking the value for Europe; SESAR JU
3 Source: GSA Market Report 6
4 GNSS Market Report Issue 5; GSA

- **Agriculture & environmental:** precision agriculture, crop/field/soil monitoring, variable rate applications, livestock tracking, insurance, forest monitoring & management, etc
- **Inspection & maintenance:** bridges, gas & oil infrastructure, energy distribution infrastructure, solar panels, windmills, etc.
- **Surveying and mapping:** environmental monitoring, cadastral surveying, mine surveying, marine surveying, GIS, photogrammetry, etc.
- **Government:** police applications, crowd observation, border control (including maritime), security, etc.
- **Public safety:** SAR operations, firefighting, urgent medicine/medical equipment delivery, other natural disaster monitoring (e.g. floods, earthquakes), etc.
- **Scientific:** meteorological monitoring, atmospheric measurements, swarm techniques, general R&D, etc.
- **Education:** teaching tool in schools and faculties (e.g. aeronautics, geomatics, navigation).
- **Observation:** film, photography, TV/other media-broadcasting (e.g. sport events), etc.
- **Communications:** local coverage broadcasting using high altitude drones or HAPS (high-altitude platform stations).
- **Leisure:** toys, models flying, self-tracking/filming drones (first person view), sports (e.g. drone racing), etc.
- **Goods delivery:** transport of various types of goods or cargo.
- **Other applications:** calibration of aviation nav-aids, asset management, advertisement, marketing, entertainment, etc.
- Military

The expected growth in the drone market is huge. Figure 2 presents this growth from 2019 to 2029 by illustrating the increasing number of drones equipped with GNSS receivers. The installed base of GNSS devices for drones is increasing significantly since 2015 when prices had decreased sufciently for consumer drones to become more widely available.

Figure 2: Installed base of GNSS devices for drones, by application



The following definitions are used:

- **Commercial** – drones used solely for commercial applications and which are invariably better equipped. These are always assumed to be GNSS-equipped.
- **Prosumer** – drones which may be used for commercial applications but are also affordable for some recreational use.
- **Consumer** – drones used primarily for recreational use. Due to their cost and nature, the type of sensors and cameras that may be carried on this category is limited. The integration of GNSS on these devices is limited due to the intended market and planned use of the platform. These platforms do not have the expandability or levels of automation demonstrated in the commercial and prosumer categories.

2.2 REGULATORY STATUS

The uptake of drone technologies in Europe is strongly dependent on regulations governing the use of drones in different Member States (MS) with regards to policies on authorisation, certification and spatial limitations.

THE UPTAKE OF DRONE TECHNOLOGIES IN EUROPE IS STRONGLY DEPENDENT ON REGULATIONS GOVERNING THE USE OF DRONES.

2.2.1 EASA

Significant progress on developing a common European regulatory framework for drones has been made in the past 4 years. EASA published an advance notice of proposed amendment (A-NPA) in 2015, proposing a proportional and operation centric approach. It introduces 3 categories of operations, based on the risk the operation is posing to third parties, and is divided into: Open (low risk), Specific (medium risk) and Certified (high risk). This proposal was followed by a technical opinion in December 2015, by prototype regulations in August 2016 and building on this preparatory work, by a Notice to Proposed Amendment (NPA) in May 2017 (NPA 2017-05) for the introduction of a regulatory framework for the operation of drones in the open and specific category. The NPA received many comments during the 4 month consultation from all the different stakeholders in the drone industry. After consideration of these comments EASA published Opinion 01/2018 in February 2018, which included a draft delegated regulation "on making unmanned aircraft intended for use in the 'open' category available on the market, and on third-country UAS operators" and a draft implementing regulation "on rules and procedures for the operation of unmanned aircraft".

On the 22nd of August 2018 the new EASA Basic Regulation 2018/1139 was published. It establishes common rules in the field of civil aviation and is in force since 11th of September 2018. This adoption enabled te formal process of adoption of the opinion.

Following consultations involving Member States, the Council, the Parliament and the manned and unmanned aircraft Communities, the Commission published the two regulations mentioned in paragraph 1 Introduction.

This publication is a major milestone but the work does not stop there. 3 major streams of work can be identified:

- Implementing the regulations:
    - Development of Acceptable means of Compliance and Guidance Material for Regulation 2019/ 947 including the methodology for the risk assessment in the Specific Category.
    - Development of the common unique standard for the drone zones.
    - Adoption of an Opinion for the first two standard scenarios for the specific category. Standard scenarios define the necessary risk mitigation measures for a given type of operation and allow operators to start operations based on a declaration that they comply with those measures.
    - Development of the necessary standards to support the technical requirements for drones included in Regulation 2019/945.
    - Development in cooperation with Member States and the drone community of safety promotion material.
    - Development of the necessary procedures for monitoring the implementation by Member States of Regulation 2019/947.
- Developing a high level regulatory framework[5] for U-Space covering in particular:
    - The definition of the U-space services
    - The requirements for the service providers and
    - The requirements for Member States
- Development of an NPA[6] for the certified category :
    - The scope of this NPA will cover:
        - Operations type #1: IFR operations of certified drones cargo flying in airspace classes A-C and taking-off and landing at aerodromes under EASA's scope.

        - Operations type #2: Operations of drones in urban environment using scheduled routes in volume of airspace where U-space services are provided. This includes operations of drones VTOL (vertical Take-Off and Landing) type carrying passengers (i.e. air taxis) and small drones cargo providing delivery services.
        - Operations type #3: Piloted VTOL in urban and non urban environment.

All information regarding the EASA activities on drones can be found here: https://www.easa.europa.eu/easa-and-you/civil-drones-rpas.

2.2.2 JARUS

The Joint Authorities for Rulemaking on Unmanned Systems (JARUS) is a group of experts from 60 worldwide national aviation authorities (NAAs) and 2 regional aviation safety organisations (EASA and EUROCONTROL), whose aim is to develop harmonised rules for UAS.. The concept of operation centric regulation with the three categories (open, specific and certified) has been developed within JARUS ategories. JARUS is in charge of developing the methodology for Specific Operations Risk Assessment (SORA). SORA v2.0 has been published by JARUS in March 2019.

More information on JARUS may be found at: http://jarus-rpas.org/

5 The opinion is scheduled for the end 2019
6 The NPA is scheduled for Q3 2019

2.2.3 EUROCONTROL

As part of their activities aimed at the safe integration of UAS, EUROCONTROL has run several webinars based on certain hot topics in the UAS domain, with the participation of the most relevant stakeholders in the different sessions. The objective of these webinars was to develop guidelines that are not directly related to a particular regulation.

EUROCONTROL has developed and published three discussion documents so far based on the outputs of the different webinars:

- UAS ATM Airspace Assessment: in order to ensure the safe integration of drones into the European airspace, assessments are essential to enable common and harmonised rules and scenarios. This involves taking a look at the airspace volume in which operations are taking place, in order to examine the associated air and ground risks, and covering all related elements and requirements that must be taken into account (e.g. re-design, CNS coverage, geo-fencing).
- **UAS ATM CARS Common Altitude Reference System:** UAS will certainly share airspace with manned aviation, and this will lead to separation requirements. For this it is essential that the altitudes of all of these aircraft are well known, with no place for ambiguity. Manned aviation uses pressure altitude obtained from barometric readings but UAS use inputs from other systems such as satellite based calculations. Each system works well in its domain (manned or unmanned separately), but to ensure safe separation when working together a common altitude reference system needs to be defined.
- **UAS ATM Flight Rules:** UAS operations can be performed by pilots who are not necessarily aware of the rules of the air. UAS themselves usually have very different dynamics to manned aircraft – some of them are not comparable to conventional aircraft in terms of speed and size, implying a certain safety threat to manned aviation when sharing airspace (e.g. under VFR). New flight rules applicable to UAS and to other aircraft operating near them are therefore needed.

UAS OPERATIONS CAN BE PERFORMED BY PILOTS WHO ARE NOT NECESSARILY AWARE OF THE RULES OF THE AIR.

2.2.4 EUROCAE

EUROCAE is the European leader in the development of worldwide recognised industry standards for aviation. EUROCAE develops standards by industry/members for the industry that:

- Build upon the state of the art expertise of its members and address global aviation challenges;
- Are fit for purpose to be adopted internationally;
- Support operational, development and regulatory processes.

EUROCAE is running several Working Groups. The one related to drones is WG 105. EUROCAE WG-105, in coordination with RTCA SC-228, is developing standards and guidance material to allow the safe operation of UAS in all types of airspace, at all times and for all types of operations. The work of WG-105 is organised in six groups working in specific areas. Some of the identified areas have GNSS relevance, such as geofencing and the emerging UAS Traffic Management.

In February 2019, a new sub-group was created: WG-105 SG-62 "GNSS for UAS". The group will publish "Guidelines on the use of multi-GNSS for UAS", in order to support operators to design their operations within the SORA framework by benefitting from EGNSS receivers. This deliverable is prepared under the H2020 GAUSS project in close cooperation with EC and GSA.

2.3 EUROPEAN INITIATIVES – SESAR

SESAR JU is considering initially grouping RPAS into small drones flying in VLL and larger RPAS in controlled airspace. Regarding the second, three phases are foreseen, starting with IFR RPAS operating in airspace A to C, followed by IFR drone in classes A to G, and finally all RPAS in all airspace. For the VLL side, the U-space itself will also have several service evolutions, beginning with foundation services, going to full integration by 2035. Its roll-out is presented in Figure 3 below, with four service phases:

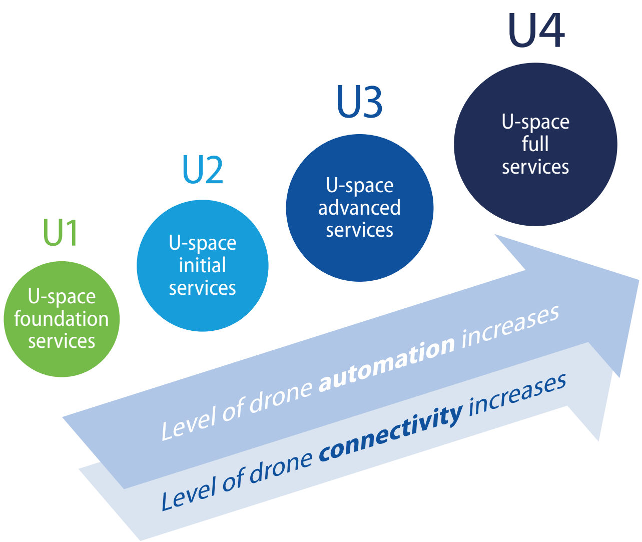


Figure 3: U-space rollout

U1: U-space foundation services provide e-registration, e-identification and basic geo-awareness services.

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 (Detect and Avoid) DAA functionalities, in addition to more reliable means of communication, will lead to a significant increase of operations in all environments and may require a more robust framework.

U4: U-space full services, particularly services offering integrated interfaces with manned aviation, support the full operational capability of U-space and will rely on a very high level of automation, connectivity and digitalisation for both the drone and the U-space system.

By 2019, U-space is expected to be established with U1 services enabling new drone operations. In addition, 2019 will deliver pre-operational demonstrations of the initial U-space services (U2), as well as first results from SESAR research and development projects, which will pave the way for the roll-out of U-Space (U2-U4).

U-space services, like e.g. geo-fencing, e-identification, and detect and avoid, could benefit from the introduction of EGNOS and Galileo, as this will improve the accuracy and robustness of positioning and navigation.

It is important to consider the reference to European GNSS in the drones' regulatory framework, as it can have a positive impact. The Space Strategy for Europe adopted by the Commission in October 2016 stated that the space sector needs to be better connected to other policies and economic areas and the potential of EGNOS and Galileo must be better exploited[7]. Some Member States are already referring to the use of EGNSS for drones, e.g. the Spanish authorities (AESA) are already including EGNSS for drones operations in their AMC[8].

IT IS IMPORTANT TO CONSIDER THE REFERENCE TO EUROPEAN GNSS IN THE DRONES' REGULATORY FRAMEWORK, AS IT CAN HAVE A POSITIVE IMPACT.

More information on U-space roll-out can be found at SESAR JU website.

7 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Space Strategy for Europe, Brussels, 26.10.2016, COM(2016) 705 final

8 Requisitos de los Equipos para la Operación con RPAS según el Real Decreto 1036/2017 (Artículo 23 Quáter. Requisitos de los Equipos.)

03 LOCALISATION OF DRONES

A key element of the U-space[9] concept defined above will be geo data, because reliable information on drone position is a must for its operations.

There are several functionalities widely used by drones, where accurate, reliable and continuous real-time positioning is needed:

> GEO-FENCING IS A CONCEPT WHEREBY A VIRTUAL BARRIER IS PLACED ON A SPECIFIC REAL-WORLD GEOGRAPHIC AREA OR VOLUME.

- **Geo-fencing**[10] is a concept whereby a virtual barrier is placed on a specific real-world geographic area or volume. In the context of drones this translates into programme airspaces/classes that are forbidden to drones (or only accessible with specific flight permissions). The geo-fencing capability can send an alert to the pilot/operator when the drone is approaching the restricted area, or the drone can be programmed to handle restricted areas (e.g. automatically turn back or fail to proceed further into the fenced area). Geo-awareness is a 'softer' capability that informs the pilot/drone operator about different access rights and restrictions. There are the following types of geo-awareness for drones:
  - Pre-tactical (U1 – U-space foundation services) - the service provides the operator with geo-information about predefined restricted areas (prisons, etc.) and the available aeronautical information (NOTAM, AIRAC cycle) used during flight preparation. This service requires the identification of accredited sources and the availability of qualified geo-information related to restricted areas. This service provides information that allows the drone operator to make use of the geo-awareness capability of the drone.
  - Tactical (U-space initial services) – compared to U1 pre-tactical geo-awareness, tactical geo-awareness offers the possibility to update the operator with geo-awareness information even during the flight.
  - Dynamic (U3 – U-space advanced services) – compared to tactical geo-awareness in U2, the dynamic geo-awareness targets the drone itself and then this service requires data-link connectivity to a geo-aware system that allows the data to be updated during the flight[11].

- **Waypoint navigation**, as part of the guidance, navigation and control (GNC) function. Waypoints define the desired trajectory to be followed by the drone. Waypoints are specified geographical locations (3D coordinates) with the possibility to also indicate a desired change in direction, speed or altitude along the flight path. Waypoints allow the drone's autopilot to follow the path (e.g. automatic flight with the possibility of interruption by remote pilot).
- **Geotagging** during drone missions is the process of adding timing and geographical information to on-board measurements from cameras or other sensors, and is a form of geospatial metadata. This data may consist of latitude and longitude coordinates, altitude, distance, place names, camera pointing angles and the time stamp (e.g. UTC time provided by GNSS).

9 Sesar JU
10 For the time being Regulations 2019/945 and 947 only require geo-awareness
11 European ATM Master Plan: Roadmap for the safe integration of drones into all classes of the airspace, SESAR JU

- **Drone telemetry** is used to provide drone position, velocity and timing (PVT) information to the operator along with other information such as heading, battery status, distance to home, flight time, attitude, etc.
- **Detect and avoid** capability is key to avoiding collisions; this feature gives drones autonomous capabilities to avoid unreported ground obstacles, providing cooperative surveillance information on other drone traffic.
- **E-identification** is a function that enables the identification of a drone without direct physical access to the drone.
- **Tracking/surveillance** – the position of the drone is also displayed to the drone operator, enhancing their situational awareness.
- **Go-home/Return to Launch (RTL)** is a function that enables the drone to fly back to its take-off position in case of loss of the Command & Control (C&C) link. In general, the function overrides the pilot's command but may also be activated by the pilot. The drone stores in its memory the place from where it took off, and when the RTL is triggered it will automatically return to this spot.
- **Altitude hold** allows the drone to maintain a fixed altitude.
- **Loiter**, also known as Position Holding, makes it possible to maintain the position of the drone at a fixed altitude and location (i.e. auto hover). This allows a fixed-wing drone to loiter within a given radius and at a fixed altitude around a fixed point.

3.1 CURRENT TECHNOLOGIES USED FOR DRONE POSITIONING AND NAVIGATION

The following main technologies are used/tested today for positioning and navigating of drones:

- stand-alone GNSS,
- augmented GNSS,
- visual,
- inertial,
- signals of opportunity.

Some of the listed solutions are more in that experimental phase rather than the commercially useable phase (e.g. signals of opportunity). What is important to highlight is the fact that the best solution for drone positioning and navigation will always be a combination of technologies, with a hybridisation of sensors. This will allow the best performance and, moreover, will provide a certain redundancy, which is very much appreciated in the aviation domain.

Below you can find a short overview of the most promising positioning/navigation technologies for drones that use GNSS.

3.1.1 STAND-ALONE GNSS

This is the most basic (and probably cheapest) navigation solution available today. GNSS infrastructure allows users with a compatible device to determine their position, velocity and time by processing signals from navigation satellites providing global coverage. There are four constellations available today (two of them in the final phase of full deployment), and all offer free global access to their signals. Other advantages are the availability of different frequencies and a relatively low power consumption on the receiver side. Disadvantages are the need for a minimum number of satellites in line of sight, signals that are unable to penetrate obstacles such as mountains or buildings, and the fact that the overall solution is prone to multipath, jamming and spoofing. Accuracies better than five metres can be achieved. This GNSS stand-alone solution is mainly used for leisure drones and other applications without stringent navigation requirements.

3.1.2 AUGMENTED GNSS

SBAS: Satellite-based augmentation systems use geostationary or geosynchronous satellites and a ground reference network to augment and improve the performance of GNSS systems. SBAS systems provide crucial integrity information needed for civil (manned) aviation applications. There are five operational SBAS systems available today, each covering a different region (EGNOS over Europe, WAAS over North America, MSAS over Japan, GAGAN over India, and SDCM over Russia). SBAS allows increased accuracy performances compared to stand-alone GNSS at a relatively low cost. Its signals can be received and applied over, typically, continental areas. The integrity information can be used in more safety critical applications, and a final advantage is that SBAS is already a widely adopted technology for navigation in manned aviation. Disadvantages are a need for direct line of sight, which can be an issue for low flying drones in obstacle rich environments and high latitude areas. Sub-meter accuracy levels are achieved with SBAS and it can therefore be used for linear infrastructure surveillance, agriculture and surveying (GIS applications).

EGNOS is the European SBAS system and is already certified for aviation usage. It offers increased performance over the entire ECAC area. EGNOS improves the accuracy and reliability of GNSS positioning information, while also providing a crucial integrity message regarding the continuity and availability of a signal. In addition, EGNOS also transmits an extremely accurate universal time signal. Certified receivers are already on the market today and are operationally used in civil aviation to enable RNP Approaches to LPV minima and support other Performance Based Navigation applications.

EGNOS IMPROVES THE ACCURACY AND RELIABILITY OF GNSS POSITIONING INFORMATION, WHILE ALSO PROVIDING A CRUCIAL INTEGRITY MESSAGE REGARDING THE CONTINUITY AND AVAILABILITY OF A SIGNAL.

PPP: Precise Point Positioning is a method to achieve high-accuracy positioning solutions. It replaces broadcast navigation messages with precise values, and either by modelling or estimating all residual errors at the receiver level. Real time PPP involves delivery of these data to the users in a timely manner, usually through L-band geostationary satellites. The service is expected to have global coverage. The main advantages are absolute positioning solutions and no need for local or regional reference stations. For Precise Point Positioning drone kinematic positioning, horizontal accuracy between 10 cm and 1 m are achievable. Although PPP provides very high accuracy it does not provide integrity information as SBAS systems do. As a result it may not be used for navigation purposes in civil aviation. Its main disadvantages are the cost of the receivers and the convergence time required to achieve centimetre accuracies: although this strongly depends on the type of the receiver, it still may reach 5 minutes (e.g. a typical receiver for agriculture purposes)[12].

RTK: Real time kinematic is a differential GNSS method providing high positioning performance in the vicinity of a base/reference station. The service is offered at local/country level and is offered by public authorities (e.g. IGN, CUZK), private providers (e.g. Trimble, Topcon) and expensive in-situ own base stations (e.g. connected to the Ground Control Station of the drone). RTK is a highly accurate technology, reaching accuracies between 1 and 5 cm. The European landmass is well covered with network RTK. In this method, reference stations are used and performances are depend-

12 GNSS User Technology Report, Issue 2, 2018

ent on distance to the reference station. Moreover, there is a need for a real time communication link between the base (for stand-alone solutions) or the RTK provider and the receiver (drone), which can cause problems in, for example, areas without GSM coverage. Most of the time this is a paid service. Due to its high accuracy, this technology is widely adopted in the drone community, with precision mapping and precision agriculture being the biggest user groups. However, some solutions also adopt a private reference station with VHF radio link connection to the drone for RTK augmentation. It is important to mention, as in the case of PPP, the pricing and convergence time of this solution: the RTK initialisation time is normally a disadvantage when it comes to drones operations.

INTRODUCING THE INTEGRITY CONCEPT TO DRONE NAVIGATION IS MORE AND MORE ATTRACTIVE AS A RESULT OF EMERGING APPLICATIONS.

ABAS (Airborne Based Augmentation Systems) is an avionics solution that processes the GNSS signal and other onboard sensors information in order to check integrity. The most widely used system is RAIM which uses redundant GNSS signals to ensure integrity and fault detection (FD), giving the ability to warn the user about a potential error in the estimated position. More advanced strategies such as FDE (fault detection and exclusion) are able to exclude faulting satellites from the solution. In addition, work is ongoing towards Advanced RAIM (ARAIM), aiming at providing a global integrity service based on multiple constellations and frequencies, and in particular with GPS and Galileo. Compared to classic RAIM, ARAIM provides the required integrity parameters so that the aircraft receiver can detect and exclude multiple satellite failures occurrences. Those integrity parameters, generated at the ground level, are encapsulated into the Integrity Support Message (ISM) and then provided to the aircraft. Introducing the integrity concept to drone navigation is more and more attractive as a result of emerging applications in stringent environments such as controlled airspace, urban areas or restricted areas However, the integrity monitoring algorithms developed in the aviation domain are tailored to manned aviation operations, and have not been yet applied to the majority of drone GNSS receivers available today. Further work may be needed in order to tailor the concept to specific drones operations and needs.

04 EGNSS BENEFITS FOR DRONES

Global Navigation Satellite Systems (GNSS) are a key enabling technology for drones, as we know them today, and it is expected that this role will continue to grow. European GNSS, namely EGNOS and Galileo offer several differentiators that can be leveraged in order to safely integrate drones into non-segregated airspace and into the U-space.

GNSS is the Key Enabling Technology for the unmanned air traffic management system to unlock BVLOS operations and to enhance U-Space final capacity. GNSS increases accuracy and contribute to integrity or a measure of trust on the positioning, which could be further improved by combining GNSS with other sensors/technologies.

GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS) ARE A KEY ENABLING TECHNOLOGY FOR DRONES AND IT IS EXPECTED THAT THIS ROLE WILL CONTINUE TO GROW.

EGNSS receivers for drones are already in the market. They are produced by the main players like: Novatel, u-Blox, Javad, Septentrio. The useGALILEO website (https://www.usegalileo.eu/) is listing all the GNSS receivers that are EGNOS and/or Galileo capable. Moreover, drones in VLL airspace also benefit from EGNSS signals for increased availability and accuracy, thanks to more satellites in view and multifrequency capabilitites that improves the impact of multipath in urban environments. Special attention is given to the need to maintain vertical separation between drones and with conventional aircraft sharing the airspace. In order to achieve this goal, it is essential to know the altitude of each of these platforms and discussions are ongoing to define the approach to vertical separation for manned and unmanned traffic. The Eurocontrol 'UAS ATM Common altitude reference system' report recommends UAS to select the technical solution best suited to its operation.

Drones often use GNSS reference for altitude determination and increasing number of commercial flights use GNSS-based altitude information, however, barometric pressure is still used to ensure separation between commercial aircraft. GNSS offers improved height accuracy for drones and is not prone to errors due to temperature gradients in the cities that can affect barometric measures. In VLL, GNSS height accuracy is expected to be around 5ft/1.5m and pressure altitude will probably not be able to provide such accuracy in all situations. In fact, EGNOS already provides a vertical accuracy within 2 metres and Galileo multifrequenacy capable receivers are already in the market improving accuracy globally. Galileo will also soon provide accuracy to decimetre level with its upcoming High Accuracy Service[13]. Therefore, for drones' vertical separation, a geodetic approach based on a common reference datum (e.g. WGS84 ellipsoid or EGM96 geoid) may represent a good mechanism to define a common zero altitude when flying in VLL airspace.

Separation with manned aviation in VLL using barometer may be assured at the level of UTM/U-Space with the implementation of a service which guarantees the separation independently of the sensor used for altitude determination. This approach has at the same time a positive impact on improving the safety of manned aviation.

13 Eurocontrol UAS ATM Common altitude reference system (CARS). https://www.eurocontrol.int/publication/uas-atm-common-altitude-reference-system-cars

4.1 EGNOS ACCURACY AND INTEGRITY

EGNOS improves the accuracy of the position, ensuring more accurate navigation capabilities. As described above, due to the expected high number of drones, their relatively small size, and most operations in VLL, having an accurate navigation solution is a key requirement for safe navigation.

Moreover, EGNOS corrections could be tailored in such a way as to support robust navigation of drones and adapt the integrity concept and protection levels to the needs of drones, as is done in manned aviation. The Safety of Life service provides the most stringent level of signal-in-space performance to all Safety of Life user communities. The main objective of the EGNOS SoL service is to support civil aviation operations down to Localizer Performance with Vertical Guidance (LPV) minima. To date, a detailed performance characterisation has been conducted only against the requirements expressed by civil aviation in ICAO documentation. However, the concept of the EGNOS SoL service might also be used in a wide range of other application domains, including drones.

EGNOS broadcasts corrections to GPS satellite clock and ephemeris data, as well as corrections for the ionospheric delay experienced by a single frequency user. It also broadcasts parameters that describe the residual range errors after application of both the clock and ephemeris corrections (the User Differential Range Error - UDRE) and the ionospheric corrections (Grid Ionospheric Vertical Error – GIVE). The receiver combines satellite/user geometry information with EGNOS-corrected pseudo-ranges and internal estimates of the tropospheric delay and other local errors to compute the precise user position. As a result, the accuracy of an EGNOS-based position is more precise than with GPS only, as illustrated in the graphs below. The first figure shows the performances registered by the Zurich RIMS station on 11 December 2018. As can be observed, the deviation from the reference when using EGNOS is 0.66 metres, while with GPS only the error grows to 1.55 metres.

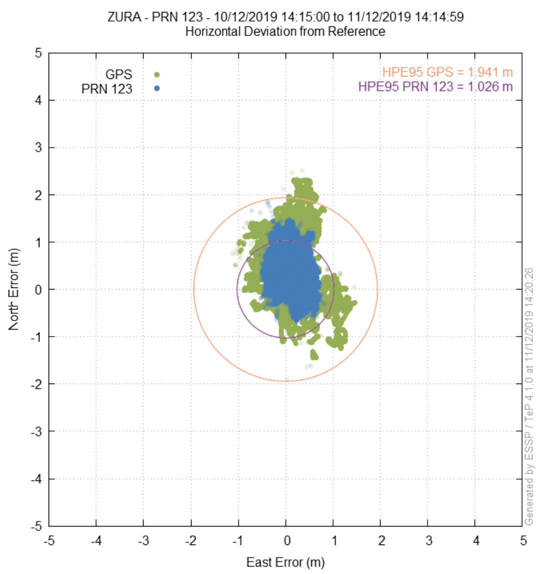


Figure 4: Horizontal deviation from reference station (RIMS in Zurich), 11 Dec 2019 with use of GPS only and GPS+EGNOS[14]

14 Source: https://egnos-user-support.essp-sas.eu/new_egnos_ops/os_gps_egnos

The second figure depicts the measured vertical error, in the same RIMS and time, both with and without EGNOS. With GPS only the error is above 5 metres, while with EGNOS it stays below 2 meters and most of the time is less than 1 metre.

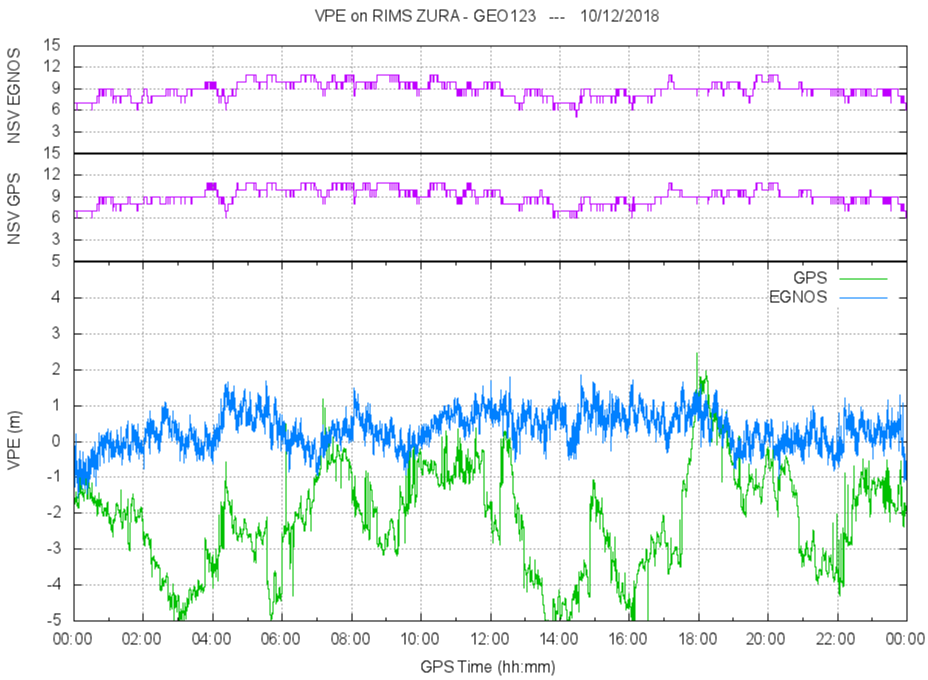


Figure 5: Temporal comparison of position's vertical error determined with GPS only and GPS+EGNOS (RIMS ZUR, 10 December)[15]

The GSA is coordinating several testing campaigns with drones, comparing the positioning performance of GPS alone and GPS augmented by EGNOS.

4.1.1 FLIGHT DEMONSTRATIONS WITH EGNOS-ENABLED RECEIVERS

4.1.1.1 DUTCH AEROSPACE CENTRE (NLR)

The table below shows the results of a first flight test campaign, using a Quadcopter drone from the Dutch Aerospace Centre (NLR), equipped with a Septentrio AsteRx3, a u-blox EVK-M8T and using a Trimble NetR9 receiver as a base station for carrier differential reference position determination. It should be noted, however, that as the time duration of the RPAS trials is limited to about five minutes per flight these performance figures do not accurately represent the mean GNSS accuracy performance figures: to determine these with sufficient levels of confidence at least one day of observables collection is considered the bare minimum.

As can be seen from the data and graphs above, GPS/EGNOS delivers a significant accuracy advantage compared to GPS alone. The increased accuracy is particularly true for height errors, where errors are reduced by 50% or even more.

15 Source: https://egnos-user-support.essp-sas.eu/new_egnos_ops/os_deviation

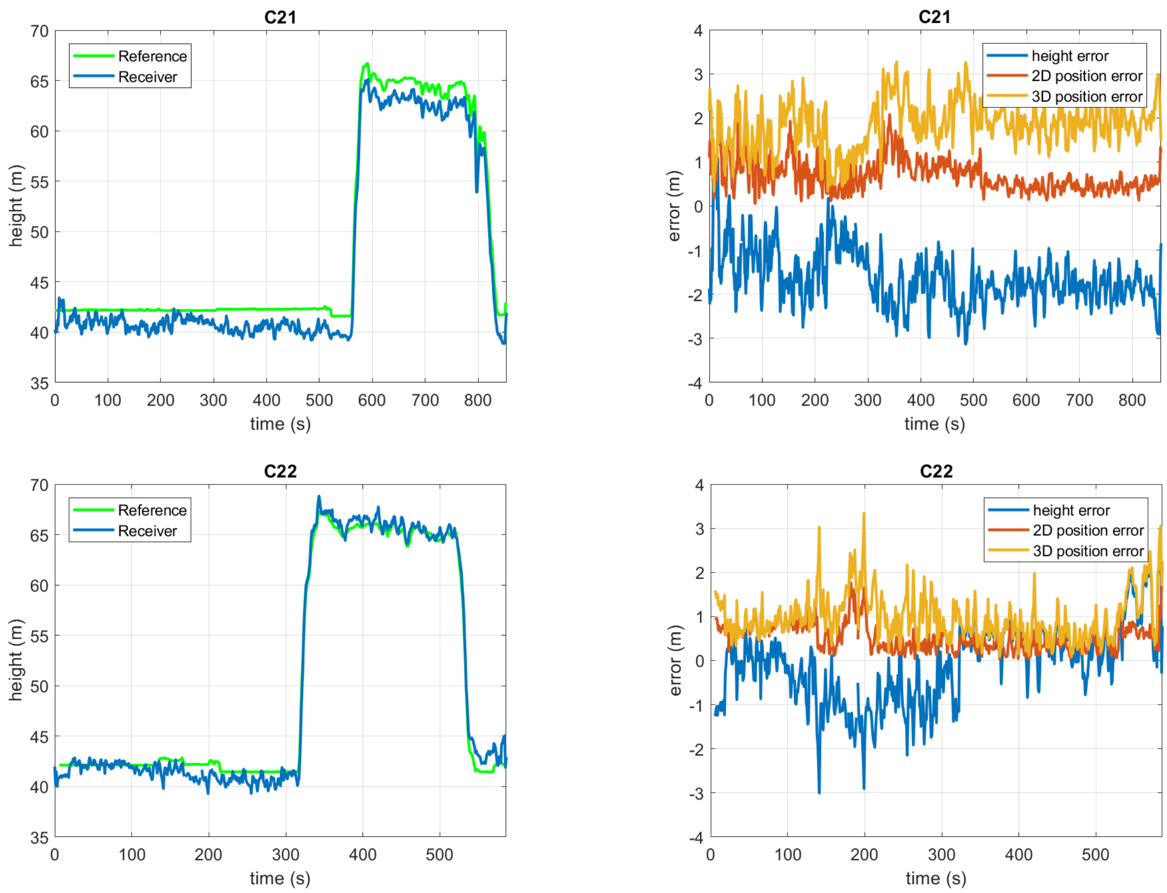


Figure 6: Height and error profiles of runs with Septentrio AsteRx3 receiver: C21 using GPS guidance and C22 based on using GPS + EGNOS

Flight path: 25 m radius circle flight at 2 m/s		
Errors during flight	95% height error	95% 3D error
C21 (GPS only)	2.4 m	2.5 m
C22 (GPS+EGNOS)	1.4 m	1.5 m

4.1.1.2 REAL PROJECT

Another series of demonstrations was performed within the REAL project with Septentrio AsteRx4 and u-blox NEO-M8N receivers (described further in chapter 5.2). During these trials, drones were successfully conducted through different IFPs (Instrument Flight Procedures) under two flight modes: automatic and manual.

An assessment was carried out of the accuracy benefits provided by EGNOS during the drone operations, comparing GPS-only and GPS+EGNOS against a reference path. The precise trajectory followed by the RPA was obtained through a post-processed kinematic (PPK) assessment, performed with Novatel Inertial Explorer version 8.70 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. As can be observed in the figure below, lateral deviations from both solutions are similar on the average values; however, in the 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 the GPS stand-alone solution increases the error between 2 m and 3 m relative to the EGNOS solution.

Figure 7: REAL project Flight 2 - Difference between PP trajectory and EGNOS/GPS positioning solutions

Table 1: Difference between PPK trajectory and EGNOS/GPS positioning solutions

	Flight 2	
	EGNOS	GPS
95% Lateral Positioning Error (m)	1,178	1,505
95% Vertical Positioning Error (m)	1,226	4,241

It is important to note that COTS autopilots are not currently able to perform IFPs, so it was a valuable experience for operators to see the added functionality that the navigation system provided. Only by engaging the REAL box system, consisting of a large number of hardware and software parts working together to create an integrated platform providing drone navigation and traffic surveillance functions, and connecting it to the autopilot, does the navigating experience becomes compatible with conventional EGNOS Safety-of-life aviation procedures (for approach and landing for example). This is something that is currently frequently overlooked.

The incorporation of EGNOS into drones will not only respond to issues related to accuracy of positioning but also ensure integrity of the data in line with PBN requirements.

4.1.1.3 EUROPEAN SATELLITE SERVICES PROVIDER (ESSP SAS)

The tables and graphs presented in this section reflect the data gathered and analysed for two sets of flights executed with ESSP's EH-1 hexacopter in January 2019.

The hexacopter navigation function makes use of a u-blox M8N receiver, which is integrated into its Here2 GNSS module.

Figure 8: ESSP's EH-1 hexacopter

All flights were executed by configuring the u-blox M8N in one of the two following modes:

- GPS/EGNOS: sensor providing PVT (Position, Velocity and Time) based on GPS augmented by EGNOS;
- GPS-only: sensor providing PVT based on GPS only.

The drone was also equipped with a multi-constellation/multi-frequency receiver, a Septentrio AsterRx3, in order to record the GNSS observation measurements and compute the "true" path (i.e. the Actual Flight Path, AFP) in post-processing using a PPP (Precise Point Positioning) technique. The AFP is considered the reference against which the Navigation System Error (NSE) of the u-blox measurements is computed.

The Total System Error (TSE), on the other hand, is computed as the difference between the AFP and the Desired Flight Path (e.g. the hover waypoint in the first set of flights, as explained below). The TSE is a combination of the NSE and the Flight Technical Error (FTE), understood as the ability of the autopilot to maintain the desired position based on the estimated navigation solution, combining measurements from the GNSS source and other sensors such as accelerometers, gyroscopes, magnetometers, barometers and so on.

As mentioned above, two different sets of flights were executed, a static or "hover flight" and a dynamic flight:

- **Hover flight:** the drone is commanded to fly to a 3D fixed position (e.g. a waypoint defined by latitude, longitude and height) and to remain in that position for several minutes. Two flights were performed, one in GPS/EGNOS mode and another in GPS-only mode, in order to compare the FTE and NSE;
- **Dynamic flight:** the drone was commanded to follow a pre-defined flight path (Desired Flight Path) using its autopilot functionality. Two flights were performed, one in GPS/EGNOS mode and another in GPS-only mode, in order to compare the FTE and NSE.

4.1.1.3.1 Hover flight

Hover (or static) flight: As mentioned above, two flights were performed, one lasting around 11 minutes in GPS/EGNOS mode, and a second flight lasting around 8 minutes in GPS-only mode. Both flights were configured to stay fixed at the following waypoint:

Lat. 40.574300 N

Long. 3.194700 W

Height Above Ground Level: 30 m

The following figures present the Total System Error and Navigation System Errors computed during both hover flights as defined in 4.1.1.3 above.

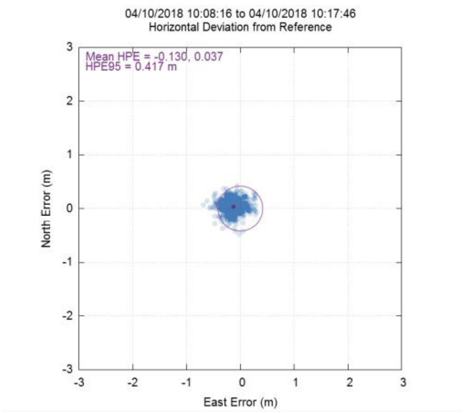
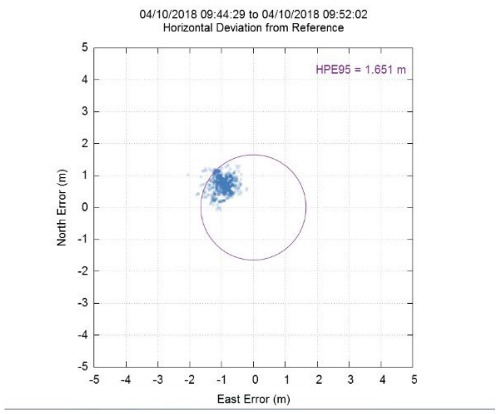
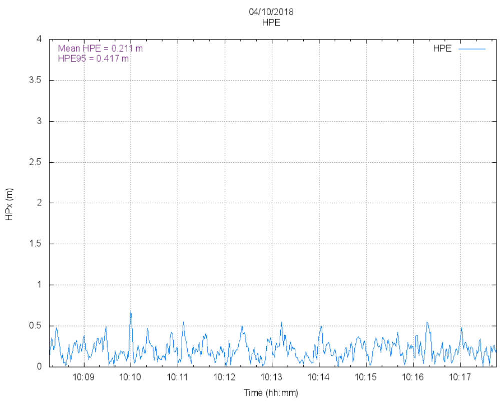
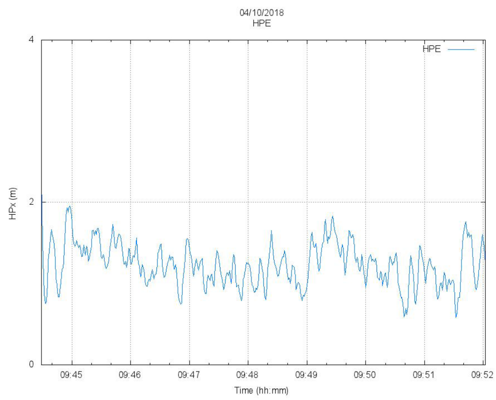
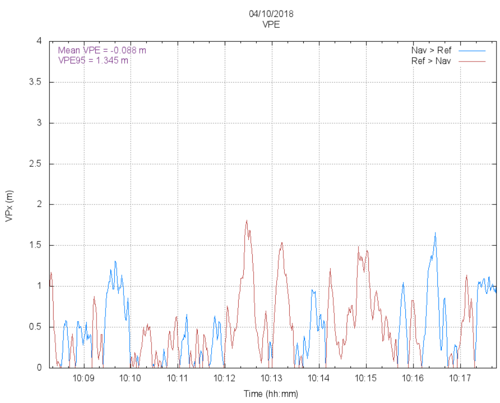
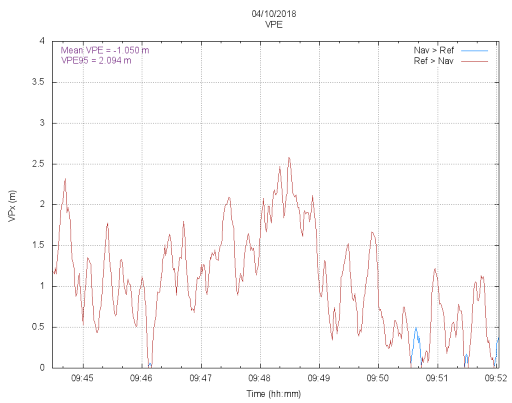
GPS/EGNOS	GPS-only
 Horizontal TSE	 Horizontal TSE
 Horizontal NSE	 Horizontal NSE
 Vertical NSE	 Vertical NSE

Figure 9: GPS/EGNOS and GPS-only FTEs and NSEs during hover flight

It can be concluded, based on the above results, that during the hover test GPS/EGNOS performance was better than GPS-only:

- GPS/EGNOS was more accurate and stable
- Percentiles 95 (horizontal):
    - GPS/EGNOS TSE= 0.79 m
    - GPS TSE = 1.65 m
- The average EGNOS Navigation System Error was lower than 1 m both in the horizontal and vertical domains whereas GPS NSE was always greater than 1 m.

4.1.1.3.2 Dynamic flights

Again, two flights were conducted: the first one in GPS/EGNOS mode and the second one in GPS-only mode, both lasting 6 minutes approximately. The flights took place in good weather conditions and, in particular, with almost no wind.

The figure below shows the paths followed by the drone during the flights, where the yellow line is the trajectory followed by the drone in GPS/EGNOS mode and the dark blue is the trajectory followed when in GPS-only mode. The Desired Flight Path, loaded in the drone's controller (i.e. in the drone's Flight Guidance System), is represented in cyan.

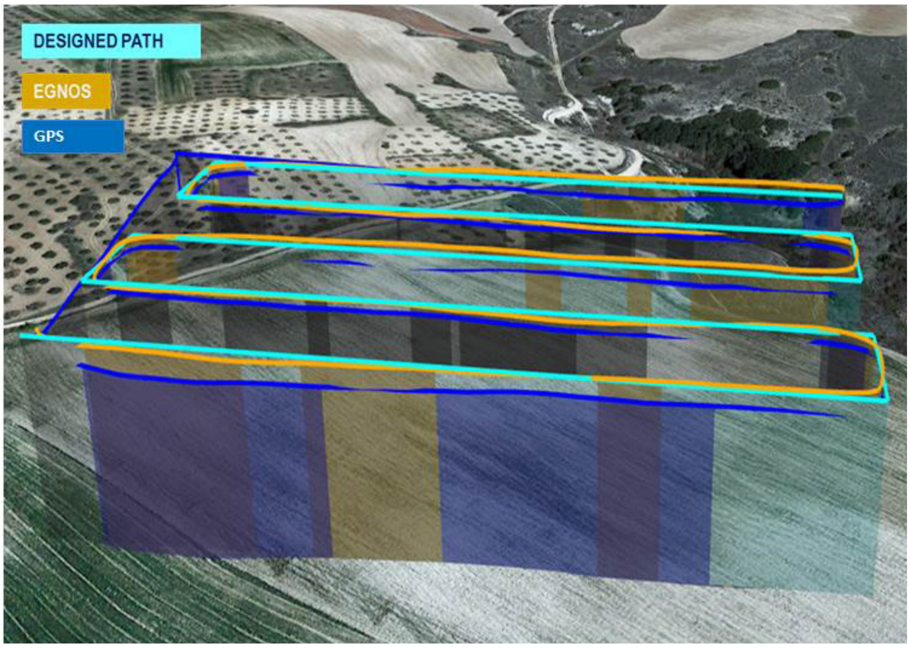
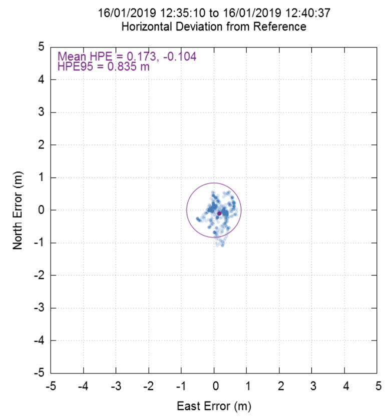


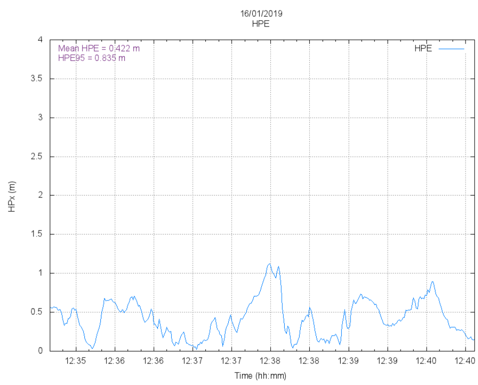
Figure 10: Desired Flight Path (cyan) versus GPS/EGNOS and GPS-only trajectories

The following figures present the Total System Error and Navigation System Errors computed during both dynamic flights.

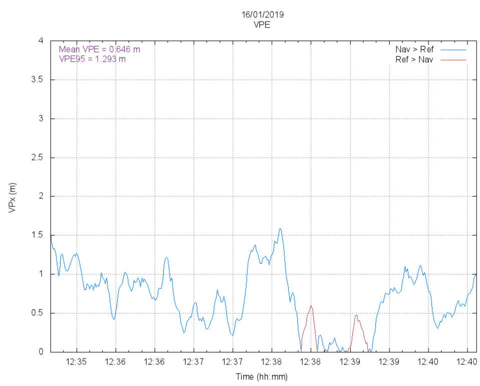
GPS/EGNOS



Horizontal TSE

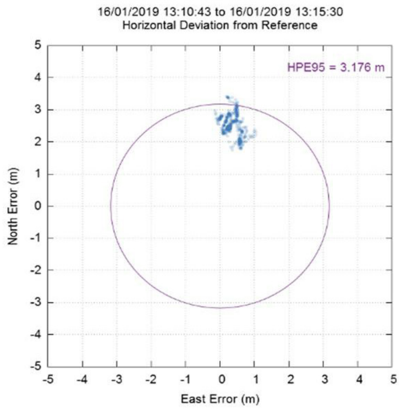


Horizontal NSE

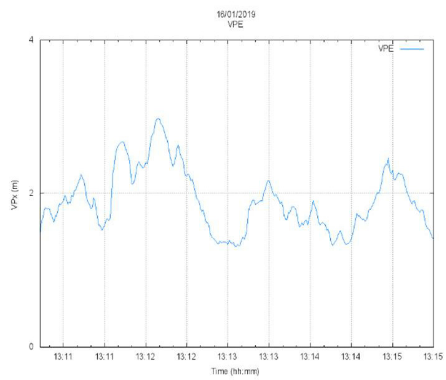


Vertical NSE

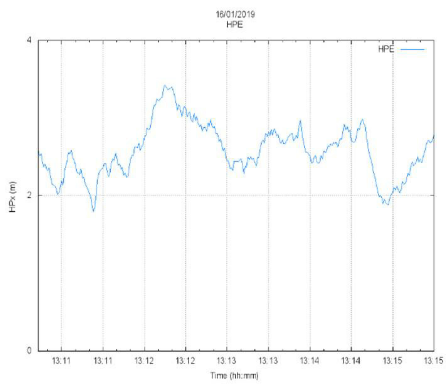
GPS-only



Horizontal TSE



Horizontal NSE



Vertical NSE

Figure 11: GPS/EGNOS and GPS-only TSEs and NSEs during dynamic flight

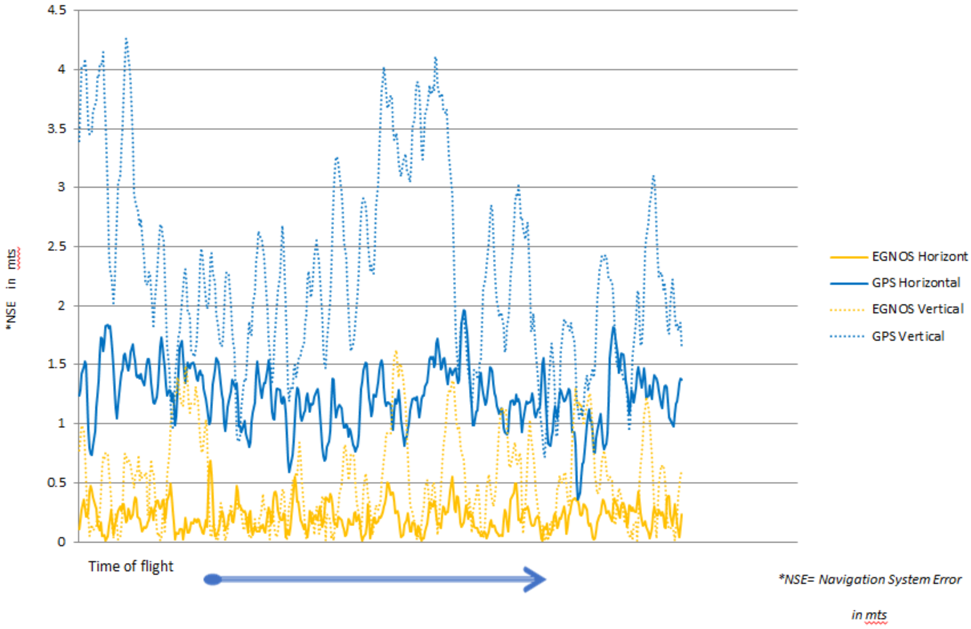


Figure 12: GPS/EGNOS and GPS-only NSEs

The obtained results indicate that the GPS/EGNOS performance was better than GPS-only in terms of NSE and, consequently, TSE:

- Total System Error with EGNOS was lower than 1 meter in the horizontal plane, whereas it was greater than 1 meter for GPS. For the vertical plane, EGNOS was lower than 2 meters, whereas it was greater than 2 meters for GPS.
- When EGNOS augmentation is used, there is a potential reduction in the number of operator interventions thanks to the increased accuracy achieved (see specific case in 4.1.1.3.2.1).

4.1.1.3.3 EGNOS benefits shown in specific dynamic flight

This section shows a GPS flight that required manual intervention, whereas when using EGNOS it flew as specified over the designed path.

Figure 13 depicts the u-blox computed GPS/EGNOS trajectory in yellow. This flight was carried out to evaluate the performance of EGNOS-based navigation. As can be seen in the figure, it flew very close to the PPP/AFP.

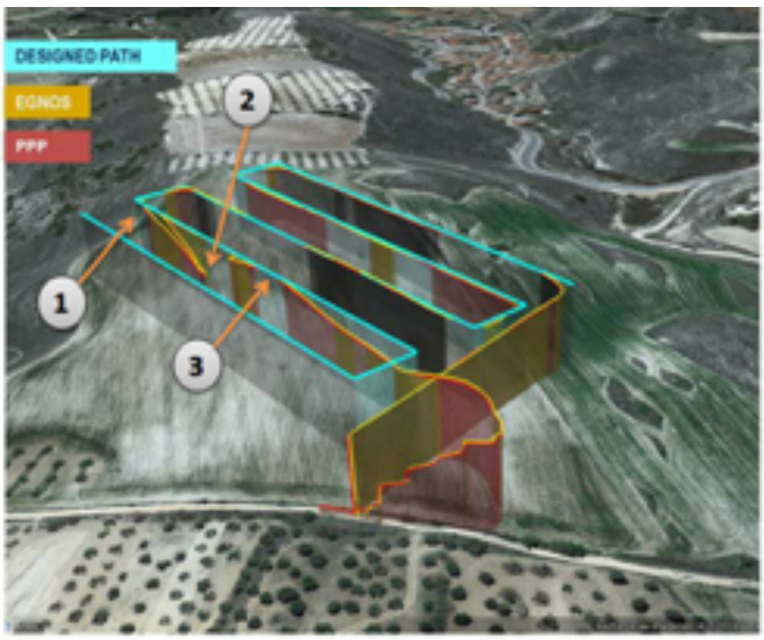


Figure 13: Desired Flight Path, GPS/EGNOS and PPP (AFP) trajectories

It is worth mentioning that, at one point in the GPS flight, the operator undertook some actions which interrupted the execution of the designed flight pattern to its full extent in order to test contingency actions. The drone was instructed to "Return to Launch" (identified in the figure as (1)) and then ordered to go back to the Designed Flight Path (at point (2)). Some seconds after (3), the pilot took command and flew the drone manually all the way back to the landing zone.

One particular issue detected during the flight performed in GPS-only mode was the big horizontal and vertical errors computed by the end of flight, which required the operator to change the drone's navigation mode from automatic to manual in order to land at the designated area. In fact, when still in automatic mode, the drone was more than 2 m away from the landing zone.

Figure 14 shows this situation graphically. This shows a clear operational benefit when using EGNOS augmentation: there is potential for reducing the number of operator interventions and hence the workload, thanks to the increased accuracy achieved.

With this example, we can conclude that when EGNOS augmentation is used, there is a potential reduction in the number of operator interventions thanks to the increased accuracy achieved.

4.2 GALILEO ACCURACY AND AVAILABILITY IN THE MULTI-CONSTELLATION AND MULTIFREQUENCY CONCEPT

Integration of observations from multiple GNSS systems is currently crucial when developing applications that need precise positioning algorithms. Combined multi-GNSS positioning has an undeniable advantage over standard single GNSS system utilisation in terms of accuracy, reliability, availability and convergence of the position solution. Multisystem positioning is especially beneficial in obstructed environments with limited access to open sky (i.e. urban canyons).

4.2.1 FLIGHT DEMONSTRATIONS WITH GPS/GPS + GALILEO

On 17 July 2017, the GSA performed several flight tests in collaboration with NLR. For the purpose of the tests the Mikrokopter MKGPS V3 carrying the AsteRx3 GNSS receiver was used. The trials were executed within the designated test airspace available to NLR in Marknesse, using single frequency measurements. The flight took place in an open field (e.g. limited buildings and trees around the testing zone). The drone was guided along a rectangular (approximately 43 x 54 meters) pre-defined trajectory. The

Figure 14: Landing zone and location where the drone would have landed with GPS only (in blue), if no operator intervention was triggered

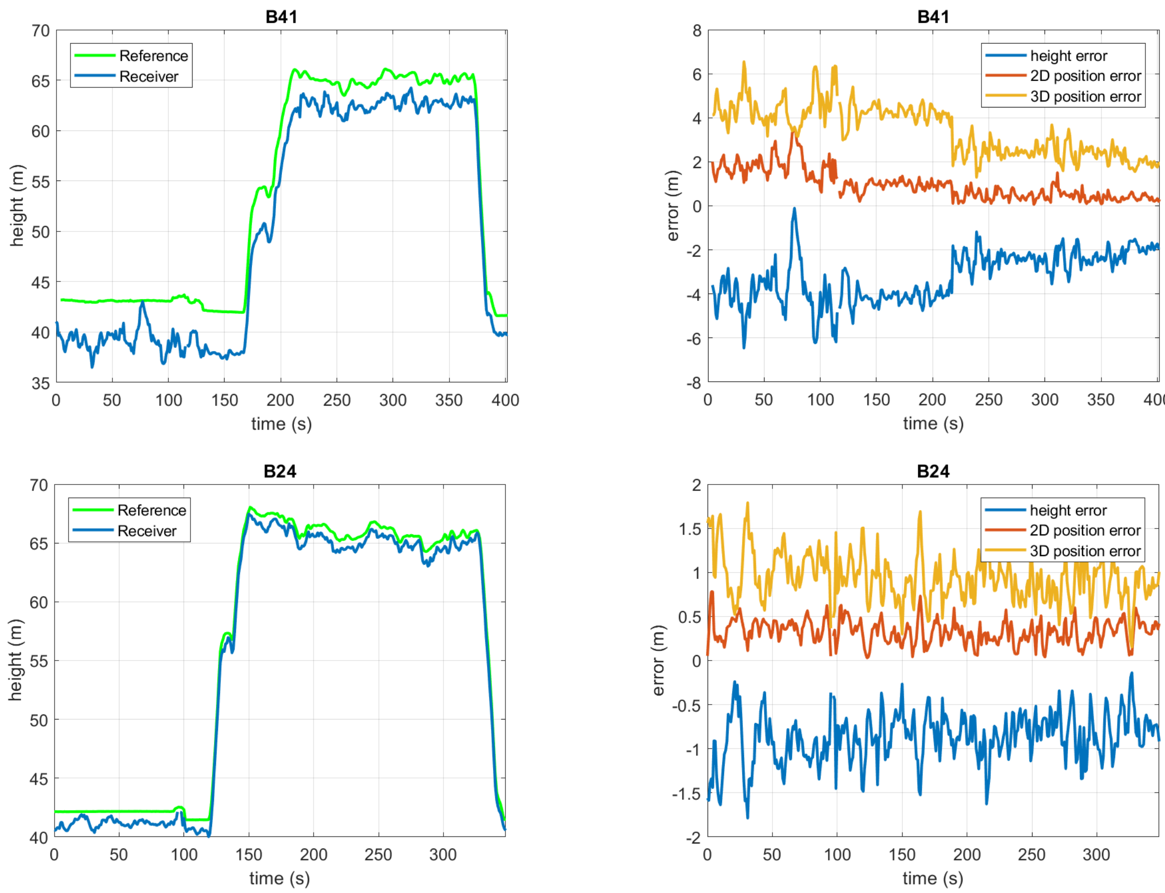


Figure 15: Height and error profiles of runs: B41 based on AsteRx3 receiver using GPS guidance and B24 based on AsteRx3 receiver using GPS + Galileo

Errors during flight	95% height error	95% 3D error
B41 (GPS)	4.4 m	4.5 m
B24 (GPS+Galileo)	1.3 m	1.4 m

navigation performance was determined and is presented below for the following constellation(s) in use: GPS stand alone and GPS+Galileo. It is important to mention that the Galileo system is not (yet) a fully operational constellation and that we can expect even better results when the system reaches FOC (Full Operational Capability, expected 2020).

As can be seen from the graphs above, Galileo in a multi-constellation concept increases the 3D accuracy and significantly reduces the height error. The relative performances above were taken from two different flights. As the visible GNSS constellations are highly in-stationary it would be more accurate to determine relative performances from one single flight under identical conditions.

4.2.2 SIMULATIONS OF RTK GPS/GPS + GALILEO POSITIONING

The emergence of a high-volume drones market calls for RTK technologies previously limited to niche markets due to their complexity and cost. The technology is now commonly used in professional UAV-based applications, like surveying and precision agriculture. Taking into account that dual frequency chips are now also available for the mass market, we may soon expect to have dual frequency receivers for drones as a standard.

J. Paziewski and P. Wielgosz from the University of Warmia and Mazury in Poland (Investigation of some selected strategies for multi-GNSS instantaneous RTK positioning) made a comparative performance assessment of strategies combining GPS + Galileo dual-frequency observations in relative kinematic satellite positioning. The work takes into account simulated data from the full constellations of Galileo and modernised GPS with L5 signals[16]. The results obtained by J. Paziewski and P. Wielgosz prove an important benefit in the coordinate domain from combining multi-GNSS observations.

More tests and simulations are ongoing with the inclusion of Galileo in determining drones position.

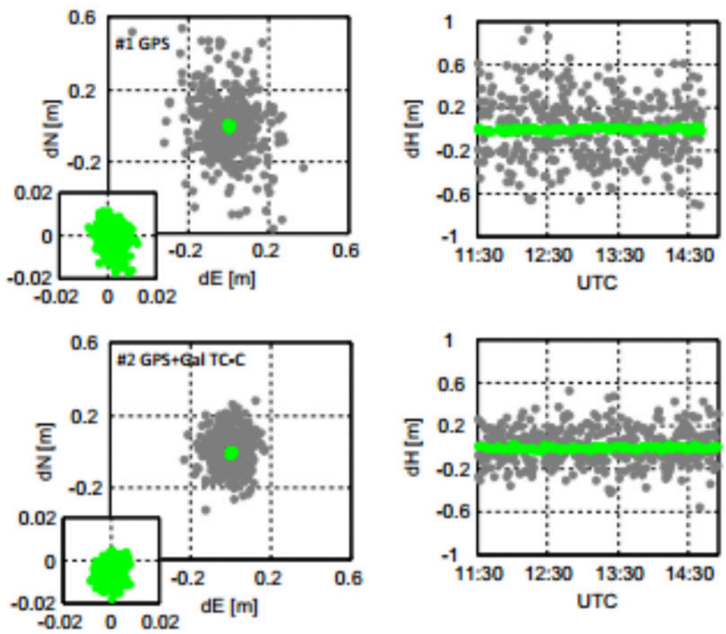


Figure 16: Rover coordinate residuals for floating (grey) and fixed (green) solutions (#1- single GPS, #2 GPS+Galileo)

16 In the analysis made by J. Paziewski and P. Wielgosz, the coordinate residuals were obtained by comparing the rover's positions obtained in both floating as well as fixed solutions to the benchmark coordinates. Overall, the RTK algorithms estimates the number of double-differenced ambiguities - and yield either a fixed or floating solution. In a fixed solution, the number of wavelengths is a whole number, or integer. A low number of visible satellites, poor satellite constellation geometry and a poor radio link between the base station and the rover may prevent a fixed solution. In a floating solution, the algorithm does not yield an acceptable fixed solution, so the ambiguity is allowed to be a decimal or floating point number.

4.3 GALILEO HIGH ACCURACY SERVICE (HAS)

The ranging signals of Galileo, i.e. the modulation, are far more **precise** than the GPS ones, but in order to turn the **precision** of the ranging signals into the **accuracy** of positioning, the EU is developing the Galileo High Accuracy Service.

This service could be very useful for professional drone operations, where high precision for position determination is key.

In short, the characteristics of the Galileo High Accuracy Service[17] are described below:

- Free access;
- **No need for additional** ground communication **channel** *(448 bps allocated on Galileo E6B)*;
- **No need for proximity to base stations** to access corrections *(unlike RTK)*;
- **Triple frequency** to further **increase accuracy** and reduce PPP **convergence time**;
- Improved line-of-sight and **better coverage** at high latitudes;
- "User error of less than two decimetres"- this depends on the user's receiver, algorithm and environment.

> INTRODUCING THE INTEGRITY CONCEPT TO DRONE NAVIGATION IS MORE AND MORE ATTRACTIVE AS A RESULT OF EMERGING APPLICATIONS.

With the aim of studying the feasibility of HAS through Galileo E6B, the Galileo programme carried out some HAS tests with the real signal-in-space as early as 2014 and these testing activities have continued. The latest HAS tests were performed with a GPS/Galileo receiver receiving the E6B HAS message in 3 different environments: open-sky, suburban and urban. As the Galileo satellites cannot transmit HAS yet operationally, the testing platform re-computed the HA solution in post-processing, as if the E6B HAS messages were actually transmitted by the satellites and received by the test receiver according to the exact reception conditions. The tests took place in Tres Cantos, their duration was one hour and they were performed using a Septentrio AsteRx-U mounted on a car with *magicPPP* user algorithm. The results of the performances in the different conditions are illustrated in the figure below.

17 COMMISSION IMPLEMENTING DECISION (EU) 2018/321 of 2 March 2018 amending Implementing Decision (EU) 2017/224 setting out the technical and operational specifications allowing the commercial service offered by the system established under the Galileo programme to fulfil the function referred to in Article 2(4)(c) of Regulation (EU) No 1285/2013 of the European Parliament and of the Council

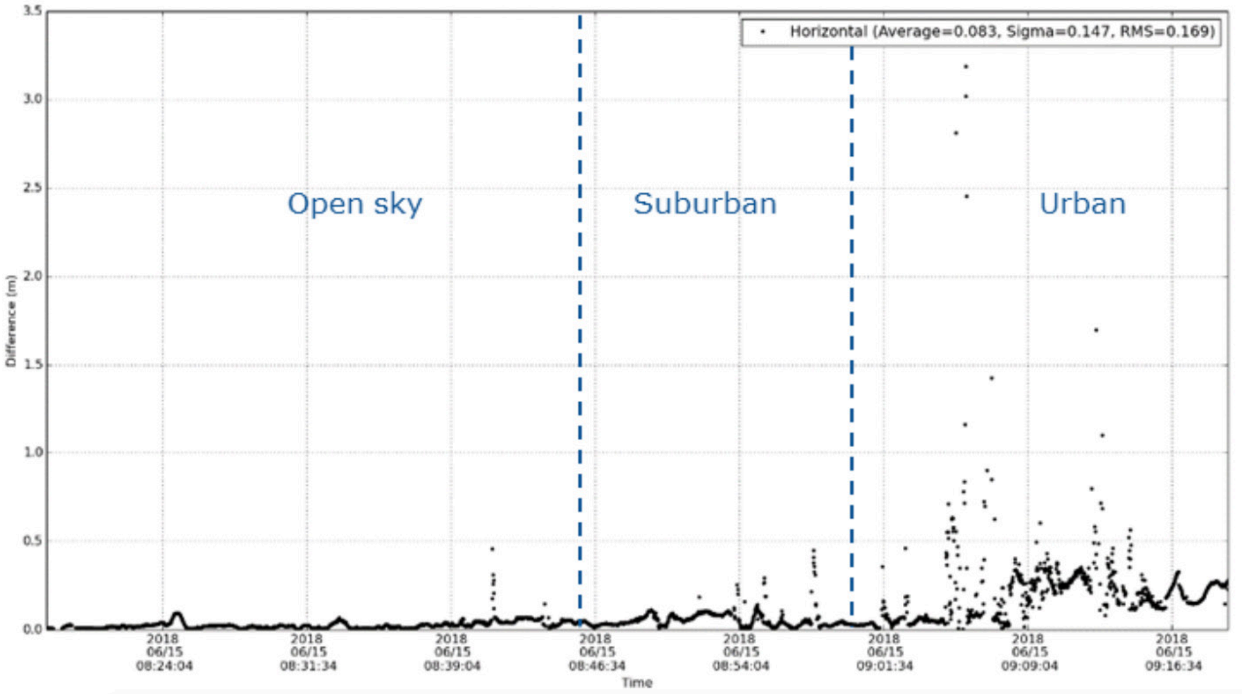


Figure 17: Horizontal accuracy – kinematic GPS/Galileo receiver with E6B HA message

As can be seen in Figure 19, the accuracy in the urban scenario is degraded, especially toward the end, including some outliers above 1-m error, when the receiver was in a traffic jam surrounded by trucks. Even so, horizontal accuracy was below 30 cm RMS in urban environments, and below 20 cm overall. The performance is considered very good, particularly taking into account the constraints. In any case, the test shows that satellite-based PPP can provide at least a few decimetres of accuracy for kinematic users even in degraded environments, which is very promising for drone operations[18].

SATELLITE-BASED PPP CAN PROVIDE AT LEAST A FEW DECIMETRES OF ACCURACY FOR KINEMATIC USERS EVEN IN DEGRADED ENVIRONMENTS, WHICH IS VERY PROMISING FOR DRONE OPERATIONS.

18 *Satellite-Based High Accuracy Messages for Road Applications*, I. Fernández-Hernández, T. Senni, S. Cancela, D. Calle, G. Vecchione, G. Seco-Granados

05 GALILEO AUTHENTICATION FEATURES

GNSS interference threats are significant in drone usage, because of the dependency of the drone upon the satellite signal. In particular, spoofing attacks aim at transmitting fake GNSS signals which could impact the drone operation. As part of its service portfolio, Galileo plans to provide authentication features that could mitigate the vulnerability of RPAS to spoofing threats.

The Galileo authentication capability will increase the degree of safety and prevent risks of forgery and fraud. In the case of drones, authentication features will be a key technology for professional applications in urban and semi-urban areas and for the practical implementation of U-space, because it increases resilience to spoofing.

Two kinds of authentication mechanisms are planned for Galileo:

- **Open Service Navigation Message Authentication** (OS-NMA) is the ability of the system to guarantee to users that they are using navigation data that has not been modified and comes from the Galileo satellites and not from any other source. The open service authentication will be provided in the Galileo E1 navigation message.

- **Commercial Authentication Service** will be based on the E6 signal code encryption, allowing for increased robustness of professional applications. For instance, the authentication capacity of the commercial service will integrate the Open Service Navigation Message Authentication, with unique identification of the signals. This identification will be possible thanks to the reading of encrypted codes also contained in the signals, access to which will be subject to a fee.

AUTHENTICATION FEATURES WILL BE A KEY TECHNOLOGY FOR PROFESSIONAL APPLICATIONS IN URBAN AND SEMI-URBAN AREAS AND FOR THE PRACTICAL IMPLEMENTATION OF U-SPACE, BECAUSE IT INCREASES RESILIENCE TO SPOOFING.

The Galileo authentication feature will be useful for RPAS in order to minimise the risk of GNSS spoofing threats, which can lead to dangerous consequences and will contribute to the safe integration of RPAS in non-segregated airspace.

06 GSA-SUPPORTED PROJECTS: DEMONSTRATORS AND APPLICATION DEVELOPMENT FOR E-GNSS IN DRONES

As described above, navigation of drones is a key element for their operation, and the inclusion of Galileo and EGNOS can improve the accuracy, availability and reliability of positioning data, and support the integration of drones into non-segregated airspace. Through R&D funding, the GSA is supporting initiatives related to the implementation of drones: from equipment development, through definition of operations to commercial applications development.

6.1 EQUIPMENT DEVELOPMENT AND INTEGRATION

The GSA is also contributing to the development of equipment for drones through R&D initiatives, e.g. the H2020 Skyopener project. Skyopener is developing a surveillance system dedicated to drone operations in VLL airspace. The ANSP (Air Navigation Service Provider) will receive data from the drones to show the aircraft's position in real time, and will combine it with other data (Mode S Transponder) coming from other aircraft and will share with the RPAS the situational awareness close to the RPAS.

NAVIGATION OF DRONES IS A KEY ELEMENT FOR THEIR OPERATION, AND THE INCLUSION OF GALILEO AND EGNOS CAN IMPROVE THE ACCURACY, AVAILABILITY AND RELIABILITY OF POSITIONING DATA

As part of the project a data encryption device is also being developed. This provides a more secure C2 (Command & Control) link against cyber-attacks such as anti-jamming and anti-spoofing to mitigate against security risk and potential piracy. Finally the mission payload will be integrated within the project. This will consist of: LiDAR, high definition cameras, direct geo-referencing with GNSS, in order to provide accurate information about obstacles to e-TOD (electronic-Terrain Obstacle Database) services, geographical boundaries including vegetation, and failures of linear critical infrastructure.

6.2 OPERATIONS

Another initiative, the REAL project, funded under the GSA Aviation Grants, developed and integrated an EGNOS navigation and surveillance sensor in two different RPAS. The project also validated and demonstrated the benefits of the solution in two concrete commercial-based scenarios: power line inspection and fire extinction operations.

REAL also provided a test-bed aiming at supporting the development of equipment, simulation and validation on how RPAS could perform different PBN procedures defined today for manned aviation, and explore potential adaptation of such concept to future drone operations. The proposed solution consists of adapting the manned aviation concept of operations (through the use of pre-designed safe routes using instrument flight procedure design criteria) and coupled it with a generic safety case as an enabler for the unmanned operations. This is backed up by the development of a navigation and surveillance system coupled with widely used COTS (commercial-off-the-shelf) drone autopilots and ground control station systems. This, together with the design of specific routes, allows the validation and demonstration of the concept in two concrete commercial scenarios (power lines inspection and firefighting operations).

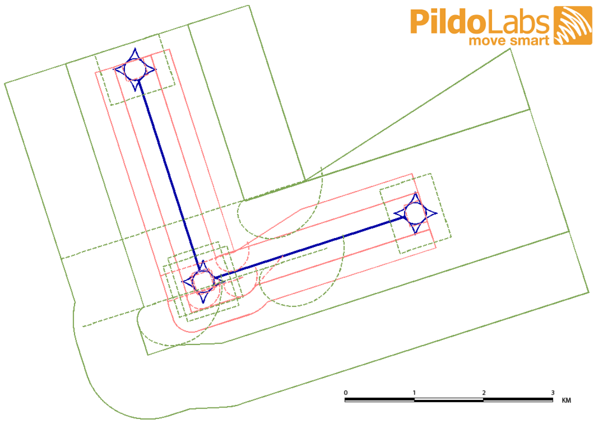


Figure 18: RNP 0.3 (green) vs RNP 0.1 (red) turn areas comparison

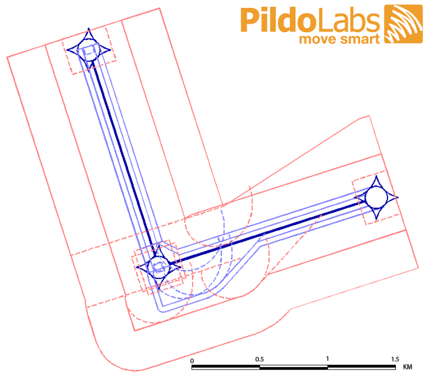
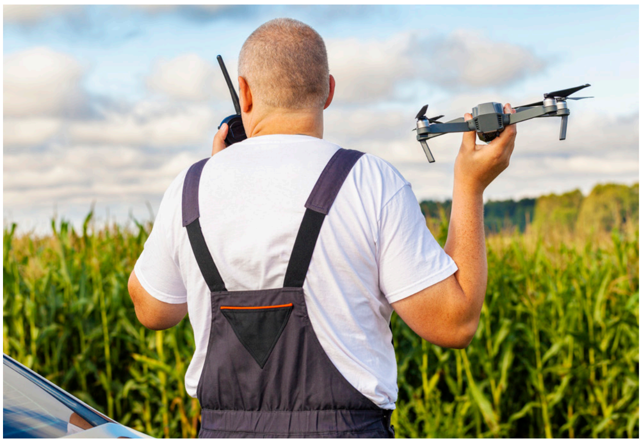


Figure 19: RNP 0.1 (red) vs RNP 0.02 (blue) turn areas comparison

After successfully validating the drones compliance with RNP 0.3 and RNP 0.1 (Required Navigation Performance specifications) , the project explored the possibility to reduce the accuracy value to 0.02. This is of utter relevance, as there are significant differences between protection areas required for Required Navigation Performance (RNP) 0.3, RNP 0.1 and a potential; 'RNP 0.02' specification (see figures below). The larger the areas, the harder it is to design a procedure with a low flight profile, a paramount aspect for drones operations to be efficient and to comply with potential future regulations inside the U-space (maximum 500ft above surface). The validation was performed via flight tests complemented by simulated data, testing the flight dynamics in different conditions.



6.3 APPLICATIONS DEVELOPMENT

The number and variety of applications using drones is growing. Within the GSA projects portfolio there are a number of initiatives that support the drone implementation roadmap in different market segments. Examples of some of the most influential missions, in terms of the potential number of drones and economic impact, include the following:

6.3.1 AGRICULTURE

Drones could help enable precision agriculture that will be critical to meet productivity needs for Europe and support the greener agricultural practices that are a focus of the EU Common Agricultural Policy (CAP) of 2020.

Examples include efficient use of water resources. Irrigated land is by far the most productive agricultural land there is. The MISTRALE solution, funded by the GSA within H2020, delivers relevant information to farmers regarding the soil moisture content, which is an important variable to optimise crop growth. The project aims at providing a soil moisture mapping service based on GNSS signal reflectometry (GNSS-R) in order to improve water management, both for saving fresh water for irrigation and for monitoring flooded areas. The project developed a GNSS-R sensor embedded on a dedicated RPAS platform. Use of GALILEO and EGNOS in the solution makes it possible to increase the number of satellite signals, and hence the resolution of the reflectometry mapping. On the other hand, EGNSS improves the UAV positioning performance, which is also key for the accuracy of the soil moisture maps.

6.3.2 ENERGY

In the energy sector, drones are expected to improve maintenance and can be used for inspections. The detailed imagery collected by a drone can be used to better assess and forecast the asset's maintenance needs. This will reduce the risk of breakdowns and minimise production downtime, therefore improving the industry's competiveness.

The EASY PV (EGNSS high Accuracy System improving PhotoVoltaic plants maintenance) project, funded within H2020, is an example of an application using a drone equipped with an EGNSS receiver for inspections. The solution provides an automatic system for acquiring, geo-referencing and processing both visible and thermal images captured by an RPAS equipped with a Galileo/EGNOS high accuracy receiver, flying over a photovoltaic field. In this way it is possible to easily detect a defective module that needs to be replaced. EASY PV uses thermal cameras installed on board an RPAS to detect thermic anomalies only on the defective modules (not the entire array series). The enabling technology is high accuracy GNSS positioning.

IN THE ENERGY SECTOR, DRONES ARE EXPECTED TO IMPROVE MAINTENANCE AND CAN BE USED FOR INSPECTIONS. THE DETAILED IMAGERY COLLECTED BY A DRONE CAN BE USED TO BETTER ASSESS AND FORECAST THE ASSET'S MAINTENANCE NEEDS.

6.3.3 MAPPING/SURVEYING

The use of drones for local surveying that is mostly within visual line of sight (VLOS) has the potential to increase rapidly thanks to applications in areas such as infrastructure inspections, mining and construction, insurance (property inspections) and media (new coverage), amongst others. The mapKITE project, funded by the GSA within H2020, is an innovative solution for the creation of new generation maps using a tandem system composed of an Unmanned Aerial Vehicle (UAV) and a Terrestrial Vehicle (TV) equipped with remote sensing technology (cameras and LiDAR) and operating as a virtual kite (the UAV follows the TV by receiving its navigation information). The goal is the simultaneous acquisition of aerial-terrestrial geo-data for mapping missions. The use of EGNSS is key in mapKITE. Firstly, EGNOS brings the desired levels of accuracy and safety for UAV navigation, which is fundamental to prove the commercial feasibility of the mapKITE concept. Secondly, the new Galileo signals, such as the E5 AltBOC, are a valuable asset due to its unprecedented high performance against multipath errors in harsh GNSS environments.

6.3.4 PUBLIC SAFETY

Drones could be used by a variety of authorities to better assess and monitor hazardous situations, complete search and rescue missions, gather evidence for investigations and detect and prevent other crises.

The GSA supports the implementation of SARA project, which aims to set up a semi-automatic system for detecting people lost at sea. The system uses Earth Observation data to initially detect the trajectories of suspect vessels and supports Search and Rescue operations based on a dedicated deployable RPAS which is tightly coupled with a ship's architecture through a cable (tethered flight). When required, the aircraft flies from a dedicated hangar on the ship and becomes a "virtual pylon" which elevates a VIS-TIR sensor (Visual Spectrum and Thermal Infrared) up to 100 metres from the vessel, enhancing its horizon by several nautical miles. The captured images are available in real time to the vessel's crew. Both the RPAS and hangar are equipped with 2 high-accuracy EGNSS receivers in order to provide the relative positioning (baseline) between the vessel's hangar and the RPAS. EGNSS represents an essential technology ensuring reliable autonomous operations and guaranteeing protection of the cable's integrity and idle torque for cable deployment with the knowledge of the baseline between two EGNSS receivers. EGNSS is also a key technology enabling the drone to safely follow the ship during navigation and for estimating the distance and bearing from the ship, when survivors are detected.

Another example is the GEO-VISION solution, which captures images and video streaming from the UAV, which are then sent to the pilot and routed in real-time to a control room. Core application areas for GEO VISION are mission-critical visual communications, where, in addition to true location and time, trust, reliability and robustness are also needed in all elements, ranging from the information capture via the communications to analysis and decision-making. EGNSS is a key enabler of the technology, it provides information on position and time, but also signal authentication. The Galileo authentication feature makes it possible to prove/verify location as part of a process of creating reliable and trustworthy observations that are key for the GEO VISION solution.

EGNSS IS A KEY ENABLER OF THE TECHNOLOGY, IT PROVIDES INFORMATION ON POSITION AND TIME, BUT ALSO SIGNAL AUTHENTICATION.

07

CONCLUSIONS

There are already a number of civil user applications for drones and many others could emerge in the future. The use of drones is growing rapidly worldwide. The on-going work on regulatory aspects for drones suggests the rapid development of drones operations. Future regulation will strongly support the drone market uptake.

Drone-based applications will face more demanding requirements in terms of availability, accuracy and integrity. Here Galileo and EGNOS can contribute answering to those requirements:

- Integration of Galileo multicontellation and multifrequency receivers and integration with other sensors (e.g. inertial, vision) will significantly improve the accuracy, availability, continuity and reliability of positioning/navigation solution for drones;
- Galileo authentication can contribute minimizing the risk of cybersecurity threats;
- SBAS improves accuracy and provides integrity to the navigation solution, supporting a more robust ATM and UTM system in the case of RPAS integration in controlled airspace;
- SBAS, RAIM and in the future ARAIM (Advanced Receiver Autonomous Integrity Monitoring) will cover the more demanding requirements especially in terms of integrity and facilitate integration of drones in the Certified category with manned aviation.

The use of EGNSS for drones' altitude determination deliver higher accuracy than other alternative technologies and is not affected by temperature gradients, therefore EGNSS is one of the most suitable options to ensure vertical separation in VLL operations.

E-GNSS, plays a crucial role in all applications, and is expected to become the backbone of drone navigation applications, particularly for BVLOS operations. Depending on the specific operational needs, a combination of technologies, with a hybridisation of sensors, as well as operational procedures, may be required to achieve the required performance and meet safety requirements.

THE ON-GOING WORK ON REGULATORY ASPECTS FOR DRONES SUGGESTS THE RAPID DEVELOPMENT OF DRONES OPERATIONS. FUTURE REGULATION WILL STRONGLY SUPPORT THE DRONE MARKET UPTAKE.

08 LIST OF ACRONYMS

AIRAC	Aeronautical Information Regulation and Control
AMC	Applicable Means of Compliance
ANSP	Air Navigation Service Provider
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
BVLOS	Beyond Visual Line of Sight
C&C	Command and Control
C2	Command and Control
CAP	EU Common Agricultural Policy
COTS	Commercial off-the-shelf
DAA	Detect and Avoid
DF	Dual Frequency
EASA	European Aviation Safety Agency
ECAC	European Civil Aviation Conference
EGNOS	European Geostationary Navigation Overlay Service
e-TOD	electronic-Terrain Obstacle Database
FL	Flight Level
FOC	Full Operational Capacity
FPV	First Person View
GAGAN	GPS-aided GEO Augmented Navigation
GIS	Geographic Information System
GIVE	Grid Ionospheric Vertical Error
GM	Guidance Material
GNC	Guidance, Navigation and Control
GNSS	Global Navigation Satellite Systems
GNSS-R	Global Navigation Satellite System-Reflectometry
GPS	Global Positioning System
HAPS	High-altitude Platform Station
ICAO	International Civil Aviation Organization
IFP	Instrument Flight Procedures
IFR	Instrument Flight Rules
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
KPI	Key Performance Indicator
MC	Multi Constellation
MSAS	Multi-functional Satellite Augmentation System
NAVSOP	Navigation Signals of Opportunity

NLR	Netherlands Aerospace Centre
NMA	Navigation Message Authentication
NOTAM	Notice to Airmen
NPA	Non-Precision Approach
PBN	performance-based navigation
PPP	Precise Point Positioning
PVT	Position Velocity Timing
QFE	Q code used by pilots and air traffic controllers that refers to atmospheric pressure and altimeter settings
QNH	Q code indicating the atmospheric pressure adjusted to mean sea level
R&D	Research & Development
RNP	Required navigation performance
RTK	Real Time Kinematic
SAR	Search and Rescue
SBAS	Satellite-based Augmentation Systems
SDCM	System for Differential Corrections and Monitoring
SF	Single Frequency
SJU	SESAR Joint Undertaking
TV	Terrestrial Vehicle
UDRE	User Differential Range Error
UTC	Universal Time Coordinated
UTM	UAS Traffic Management
VHF	Very High Frequency
VLL	Very Low Level
VLOS	Visual Line of Sight
WAAS	Wide Area Augmentation System

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