EGNOS performance in UAS

Executive summary

The European Geostationary Navigation Overlay Service (EGNOS), Europe's regional satellite-based augmentation system (SBAS), enhances the performance of global navigation satellite systems like GPS and, in the future, Galileo. Initially deployed for safety of life navigation services in aviation, EGNOS has expanded its applications to emerging domains such as Unmanned Aircraft Systems (UAS) operations.

This document reviews the EGNOS services and their current and future applications in unmanned aviation, including not only present EGNOS services and its immediate application in non-safety critical applications, but also the main considerations for the development of a possible future safety critical EGNSS service based on EGNOS and tailored to UAS operations akin to the current EGNOS SoL Service for manned aviation.

Following this comprehensive overview, it offers an in-depth analysis of the current performance of the EGNOS Open Service (OS) and the EGNOS Data Access Service (EDAS) in UAS operations. By showcasing the performance in real operating conditions, the document aims to provide readers with a clear insight into how EGNOS OS and EDAS can currently support and enhance this type of non-safety-critical operations.

The document also contains the analysis of the flight data obtained from the tests which show that EGNOS OS and EDAS provide improved accuracy to UAS operations by reducing the Navigation System Error (NSE) and Total System Error (TSE) for non-safety-critical operations.

Version 01-00 released: September 2024

Contents

List of Figures

List of Tables

1 Introduction

UAS operations have evolved exponentially in the recent years. This transformation has been driven by technology improvements, regulatory developments, and increasing demand for various UAS applications. European Union Aviation Safety Agency (EASA) is still developing a comprehensive regulatory framework to ensure safe and efficient UAS integration into airspace. Innovations in UAS technology have enhanced capabilities, enabling diverse applications in sectors like agriculture, infrastructure inspection, and emergency services. As a result, UAS operations in Europe have expanded, becoming more sophisticated and widely adopted.

In this type of operations, GNSS has become essential for a safer and more reliable navigation of UAS, and GNSS receivers are integrated on most new commercial UAS as a standard feature. European GNSS (EGNSS) -EGNOS (European Geostationary Navigation Overlay Service) and Galileo-, provide significant added value to UAS navigation, positioning and related applications, with respect to other systems.

The European Geostationary Navigation Overlay Service (EGNOS) is Europe's regional satellite-based augmentation system (SBAS) that currently augments and improves one GNSS constellation, GPS, and will augment Galileo in the future. While EGNOS was deployed to provide safety of life navigation services to aviation, its use has been expanded to other emerging domains such as UAS operations.

EGNOS corrections provide higher safety of navigation and improved accuracy of the GNSS PVT solution over Europe. Moreover, EGNOS corrections could be tailored in such a way as to support navigation of UAS and adapt the integrity concept to the needs of UAS' operations, as it is done in manned aviation.

This document presents a comprehensive and user-oriented overview of the performance of some GNSS receivers using the EGNOS Open Service and the EGNOS Data Access Service (EDAS) in non-safety-critical UAS operations. By demonstrating their performance under real operating conditions, this document aims to provide the reader with a clear understanding of how EGNOS can currently support and enhance low-risk UAS operations, as well as to understand the evolution of EGNOS towards operations with higher risk.

The present document is organized in the following sections:

- Section 1 provides an introduction to the purpose of the document and offers a brief context to the reader.
- Section 2 outlines a comprehensive overview of European regulations for UAS, guiding the reader through the various categories of operations and associated risk levels. This prepares the reader to understand the different applications of EGNOS to UAS operations.
- Section 3 contains a brief description of the different EGNOS services currently available.

- Section 4 explains the role of EGNOS for both low-risk and medium and high-risk operations, detailing how UAS operators can currently enable EGNOS OS and outlining the future for advanced UAS applications.
- Section 5 provides quantitative results on the performance of EGNOS OS and EDAS in real UAS operations.
- Section 6 concludes by presenting the primary conclusions of the document.

Finally, at the end of the document the list of references, acronyms and abbreviations is included for the reader to consult.

2 Regulatory overview

In 2018, a new Basic Regulation (Regulation (EU) 2018/1139) [RD 5] was adopted including among other elements: "unmanned aircraft". Following these requirements new **European Commission Implementing Regulation (EU) 2019/947 [RD 6] and Delegated Regulation (EU) 2019/945 [RD 7] were adopted**, establishing a first set of detailed provisions for the harmonised operation of UAS and minimum technical requirements for UAS, respectively.

Additionally, **within RuleMaking Task RMT.0230 [RD 10], EASA is also developing a regulatory framework to address new operational and mobility concepts that are based on innovative technologies, like UAS and aircraft with vertical take-off and landing (VTOL) capability and** foster and promote their acceptance and adoption by European citizens. New Regulations have been already published in 2024 but new ones are expected in the coming years.

On the other hand, it has been also found necessary to define a minimum set of requirements for the UAS operations in certain UAS geographical zones at U-space airspace as per **Commission Implementing Regulation (EU) 2021/664 [RD 8], which provides the regulatory framework for the U-space**.

According to previous details, a summary of the applicable European UAS regulatory framework is shown in the next figure:

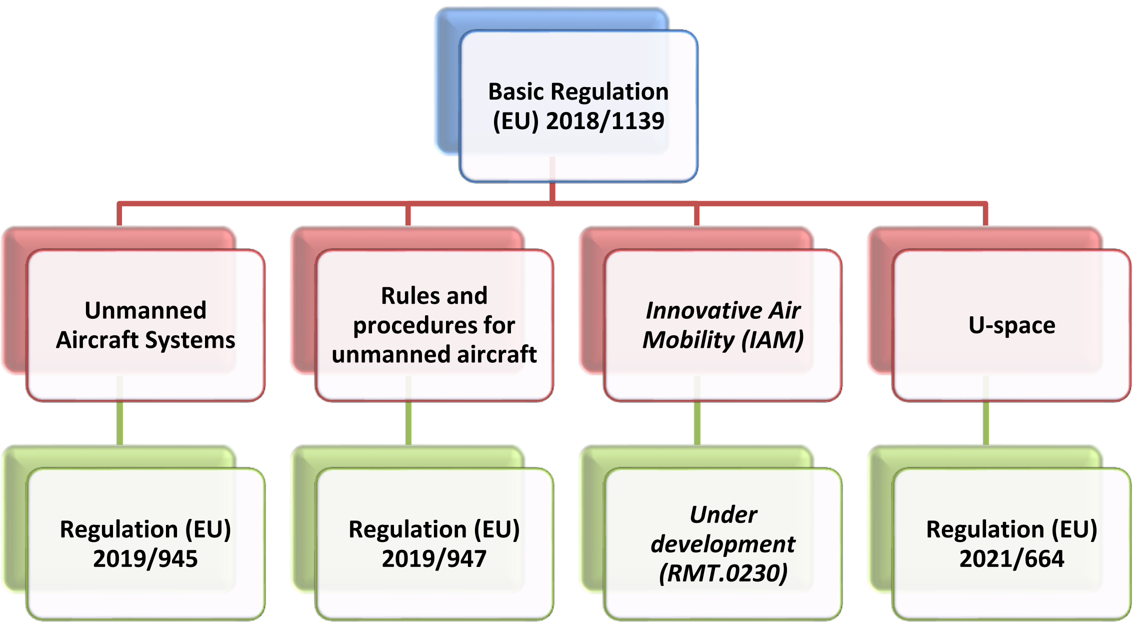


Figure 1. Summary of UAS Regulatory Framework.

In relation to the scope and purpose of this document it is essential to clarify the applicable regulatory framework which establishes a proportional risk-based approach based with the identification of three categories of UAS operation: **open, specific and certified**.

The ‘open’ category is characterised by a set of operational restrictions and technical requirements depending on the UAS Class. The compliance with the technical requirements is determined by market regulation mechanisms linked to the placing of CE Marking on products made available on the European Union market. One of the most important operational restrictions is that all the subcategories of operation must be operated in Visual Line Of Sight (VLOS). To enable economic operators to demonstrate and the competent authorities to ensure that UAS intended to be operated in the ‘open’ category made available on the market comply with the essential requirements, it is necessary to provide for conformity assessment procedures.

On the other hand, **the detailed provisions for the ‘certified’ category of operations are currently under development at European Level within Rule Making Task RMT.0230 [RD 10].** In any case, the requirements for UAS in the certified category are expected to be very similar to the ones for manned aviation.

In the middle, for operations in the ‘specific’ category, an operational authorisation issued by the competent authority of registration is required[1]. A drone can be operated in the ‘specific’ category when it is operated outside of the operational limitations laid out under the ‘open’ drone category. If the risk of the operation is even higher, the drone must be operated in the ‘certified’ category. This operational authorisation will be based on the outcome of the risk assessment conducted in accordance with Article 11 of Regulation (EU) 2019/947 [RD 6]. As an acceptable methodology for such risk assessments, EASA published the specific operations risk assessment (SORA) as Acceptable Means of Compliance (AMC) to Article 11, RD 6].

The SORA consolidates the ground and air risk analyses (GRC & ARC) within the specific assurance and integrity level (SAIL), which drives the required activities. The SAIL is a figure from I to VI, leading to the identification of operational safety objectives (OSOs) to be met with a certain level of robustness (i.e., integrity and assurance), which tend to increase with an increasing SAIL: **Low risk (SAIL I & II), Medium risk (SAIL III & IV) and High risk (SAIL V & VI).**

In order to support UAS operations, EGNOS is considered as an external service, where OSO#13 “External services supporting UAS operations are adequate for the operation” is especially relevant. In particular, the OSO#13 requires that the UAS operator demonstrates that external services supporting UAS operations, which encompasses any service providers necessary for the safety of the flight, are adequate for the operation, in terms of the level of performances provided by the external service and the effective communication and the roles and responsibilities between the service provider and the UAS operator.

Following sections of this document will further investigate the current, potential and future use of EGNOS in the three categories of UAS operation: open, specific and certified.

[1] Unless the operation is covered by a standard scenario (STS)

3 EGNOS Services

3.1 Open Service (OS)

The main objective of the EGNOS OS is to improve the achievable positioning accuracy by correcting various error sources affecting the GPS L1 signal. The corrections transmitted by EGNOS help to mitigate the ranging error sources related to GPS satellite clocks, GPS satellite position and ionospheric effects. EGNOS can also detect distortions affecting the L1 signal transmitted by GPS and prevent users from tracking unhealthy or misleading information. The EGNOS OS is accessible free-of-charge in Europe to any user equipped with an appropriate GPS/SBAS compatible receiver for which no specific receiver certification is required, and it provides the minimum availability performance that is depicted in Figure 2. The EGNOS OS has been available since 1st October 2009.

Table 6-1 **OS Horizontal and Vertical Accuracy**

Accuracy	Definition	Value
Horizontal	Corresponds to a 95% confidence bound of the 2-dimensional position error[8] in the horizontal local plane for the Worst User Location	3m
Vertical	Corresponds to a 95% confidence bound of the 1-dimensional unsigned position error in the local vertical axis for the Worst User Location	4m

Figure 2. EGNOS Open Service minimum accuracy [RD 1].

The EGNOS Open Service SDD – Service Definition Document- can be found here [RD 1].

3.2 EGNOS Data Access Service (EDAS)

EGNOS Data Access Service (EDAS) offers ground-based access to EGNOS data through the Internet on a controlled access basis. EDAS is the single point of access for the data collected and generated by the EGNOS ground infrastructure - mainly RIMS (Ranging and Integrity Monitoring Stations) and NLES (Navigation Land Earth Stations)- distributed over Europe and North Africa. EDAS allows registered users to receive the EGNOS internal data collected, generated and delivered by EGNOS assets. EDAS also provides EGNOS data corrections to users who cannot always have in view the EGNOS GEO satellites (such as in urban canyons), or to support a variety of other services, applications and research programmes, with the minimum availability and latency performances depicted in Figure 3 and Figure 4. The EGNOS EDAS service has been available since the 26th of July 2012.

Table 6.1 EDAS services availability

	SL0	SL2	SISNeT	FTP	Data Filtering	Ntrip
EDAS Services Availability	98.5%	98.5%	98%	98%	98%	98%

Figure 3. EDAS minimum monthly availability [RD 2].

Table 6.2 EDAS services latency

	SL0	SL2	SISNeT	FTP[11]	Data Filtering		Ntrip
					SL0	SL2	
EDAS Services Latency	1.3 seconds	1.450 seconds	1.150 seconds	N/A	1.6 seconds	1.75 seconds	1.75 seconds

Figure 4. EDAS maximum monthly latency (95th percentile) [RD 2].

The EGNOS Data Access Service SDD can be found here [RD 2].

3.3 Safety of Life (SoL) service

This service is also provided openly without any direct charge, and is tailored to safety-critical transport applications in various domains, in particular for aviation applications, and it is based on integrity data provided through the EGNOS satellite signals. 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, providing the performances included in Figure 5. However, similar services to EGNOS SoL have been developed (maritime[2]) and might be developed in the future for a wide range of other application domains (e.g. rail, road, UAS, …). To guarantee the provision of EGNOS SoL Service, the EGNOS system has been designed so that the EGNOS Signal-In-Space (SIS) is compliant with the ICAO SARPs for SBAS [RD 4]. The EGNOS SoL Service has been available since 2nd March 2011.

[2] EGNOS Safety of Life (SoL) assisted service for MAritime userS (ESMAS) is provided openly and is freely accessible without any direct charge since 13 March 2024.

Table 6-2 EGNOS SoL Service performance values

		Accuracy		Integrity		Continuity	Availability
		Horizontal Accuracy 95%	Vertical Accuracy 95%	Integrity	Time-To-Alert (TTA)		
Performance	NPA	220 m	N/A	$1 - 1x10^{-7}$/h	Less than 6 seconds	$<1 - 1x10^{-3}$ per hour in most of ECAC $<1 - 2.5x10^{-3}$ per hour in other areas of ECAC	0.999 in all ECAC
	APV-I & LPV200[21]	3 m[21]	4 m[20]	$1 - 2x10^{-7}$ / approach		$<1 - 1x10^{-4}$ per 15 seconds in the core of ECAC $1 - 5x10^{-4}$ per 15 seconds in most of ECAC landmasses	0.99 in most of ECAC landmasses
Comment		Accuracy values at given locations are available at: https://egnos-user-support.essp-sas.eu/ For LPV-200 new accuracy requirements imposed by ICAO Annex 10 ([RD-1]) see section 6.3.3.2		N/A		See sections 6.3.1.3, 6.3.2.4 and 6.3.3.4 for detailed availability maps See sections 6.3.1.4, 6.3.2.5 and 6.3.3.5 for detailed continuity maps	

Figure 5. EGNOS SoL Service performance values.

The EGNOS Safety of Life Service SDD can be found here [RD 3].

4 EGNOS in UAS operations

4.1 EGNOS for non-safety-critical operations

As explained in section 2, the applicable regulatory framework establishes a proportional risk-based approach based with the identification of three categories of UAS operation: open, specific and certified. Within the specific category, operations are further classified by risk levels: Low risk (SAIL I & II), Medium risk (SAIL III & IV) and High risk (SAIL V & VI).

The application of the current EGNOS services to UAS operations is currently considered for EGNOS Open Service and EGNOS EDAS service. Both of them improve the performance of the PVT solution onboard the UAS' GNSS receiver as demonstrated in section 5, and can be openly used by UAS operators in non-safety critical scenarios, such as operations in the open category and in the lower risk levels of the specific category, where integrity information is not considered a must. It is yet to be defined at which risk level inside the specific category the integrity concept is necessary (medium risk operations - TBC)

The following subsections 4.1.1 and 4.1.2 are intended to provide general guidance to UAS operators on enabling EGNOS OS and EDAS for their current low-risk operations. Further details on the application of EGNOS in higher risk operations are detailed in section 4.2.

4.1.1 Enabling EGNOS OS in UAS

The EGNOS Open Service is the one currently used in low-risk UAS operations (open category and specific low risk operations), as most of the GNSS receivers present in the market have the capability to apply EGNOS corrections to the GPS solution. In order to get benefit from the improved accuracy that EGNOS provides, the user needs to ensure that the following requirements are met:

- **The onboard GNSS receiver must be SBAS-capable**: The user needs to make sure that the GNSS receiver used for the UAS navigation is able to apply EGNOS corrections. That can be achieved by looking at the receiver datasheet and verifying its SBAS capability.
- **EGNOS should be properly configured in the equipment**: The receiver should be configured to compute SBAS position. In order to use EGNOS corrections, it is recommended to confirm that the proper EGNOS geostationary satellites are configured through their PRN codes. For further details and free support, refer to the EGNOS User Support Guidance Material section or place a request at the EGNOS Helpdesk.
- The UAS must **operate in the EGNOS OS service area** (See Figure 6).
- The UAS operator consider maintaining **line of sight between the GNSS antenna and at least one of the EGNOS geostationary satellites** in critical situations such as low-level flights in urban environment, high manoeuvrability or high latitude

(For further information please refer to EGNOS visibility map and EGNOS visibility city map).

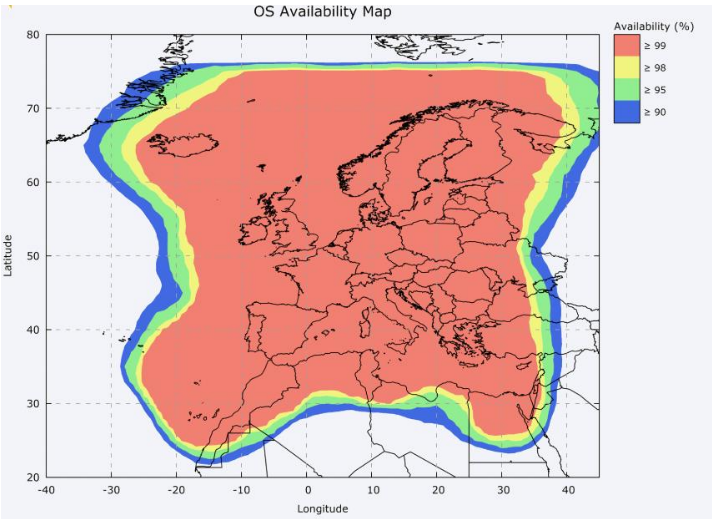


Figure 6. EGNOS OS compliance area [RD 1].

Following these three steps, the user can be sure that they are correctly applying EGNOS OS corrections for get improved accuracy against GPS standalone position solution.

4.1.2 Enabling EGNOS EDAS service in UAS

The use of EDAS (Ntrip) in drones highly improves the positioning and navigation for UAS in the open category and specific low risk operations. The EGNOS corrections are broadcast via Internet avoiding any GEO satellite shadow, having more availability and stability. The EDAS Ntrip Service (RTCM 3.1 format, Figure 7) can be used to provide EGNOS data from the EGNOS network through the Ntrip protocol [RD 1].

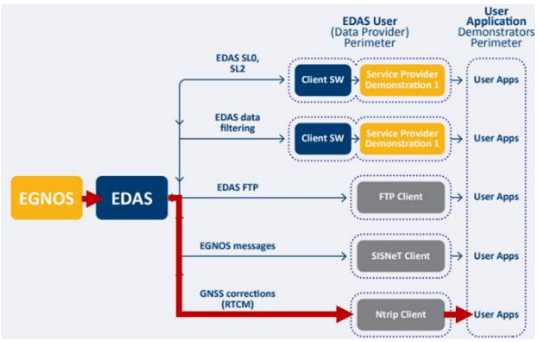


Figure 7. EDAS High level architecture.

In order to get benefit from the improved accuracy that EGNOS provides, the user needs to ensure that the following requirements are met:

- **The onboard GNSS receiver must be Ntrip-capable:** a GNSS on-board drone receiver that is compatible to Ntrip (v2.0) protocol in RTCM 3.1, RTCM 2.1 and RTCM 2.3 formats. Differential GNSS corrections and phase measurements, as well as additional messages for RTK (real-time kinematic) implementation, are provided within the Ntrip data for the EDAS reference stations.

- **User is registered into EDAS Service**: Users shall follow the following steps:
  1. Register in the EDAS and Maritime User Support Website.
  2. Fill and submit the EDAS registration form (only accessible upon registration on the website), requesting the Ntrip Service level.
  3. After successful registration, users receive the account details, comprised by username and password.

- **EDAS Ntrip should be properly configured in the equipment**: An Internet connection is required to retrieve EDAS Ntrip data. Some receivers include the connection of a SIM card, otherwise the Internet access should be provided through an external device. The receiver should be configured to use the EDAS Ntrip Service.
  In order to use EDAS Service, user should be registered to the service, with a valid account credentials. The information on how to connect to and use the EDAS Ntrip service can be found in the EDAS Ntrip-User Information Package, which is available to registered users for download in the EDAS user support website.

  For the connection to the EDAS Ntrip service, the following information is necessary:

  - **DNS name** of the EDAS Data Server.
  - **Ntrip Port**: 2101
  - **Username** and **Password:** obtained during registration to the EDAS Ntrip Service

- The UAS must **operate close to an EDAS reference station**, retrieving the correction information from the closest possible station. EDAS stations can be shown in the EDAS DGNSS Coverage map (https://edas-maritime.gsc-europa.eu/resources-tools/edas-dgnss-coverage-map), showing the available positioning solutions based on EDAS (SBAS, DGNSS or RKT) in the area depending on the distance of the user from the EDAS reference station:

  a) When located near- the base station (< 50 km), Real Time Kinematics (RTK) algorithm is used by the receiver, providing high accuracy solution, where expected performance levels are:
     - RTK fixed - HPE < 0.1 m and VPE < 0.1 m

  b) When located further the base station (> 400 km), the receiver is able to provide enhanced position solution with respect to GPS standalone in “float mode” or DGNSS position, where the expected performance levels are:
     - RTK float - HPE < 1.5 m and VPE < 2 m

As an example, the map[3] in Figure 8 shows the coverage of EDAS corrections available for Spain. Further details in section 5.

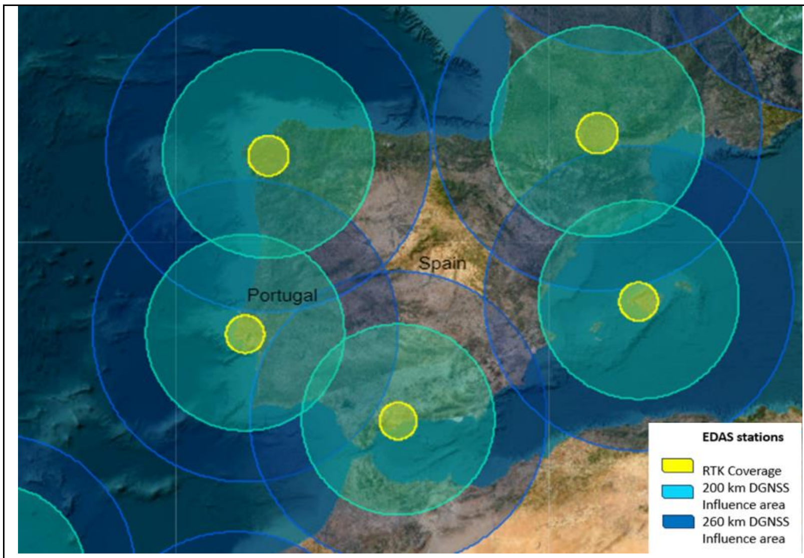


Figure 8. EDAS DGNSS Coverage Map.

4.2 EGNOS for safety-critical UAS operations

Previous section 4.1 provided guidance to UAS operators on enabling EGNOS OS and EDAS for their current low-risk operations. This section fosters the UAS applications at which the integrity concept is necessary: medium (TBC) and high-risk operations of the specific category but also UAS in the certified category.

While the present landscape of UAS operations lacks a safety critical service akin to the aviation Safety of Life (SoL), as this service is not directly applicable to UAS operations but to manned aircraft (as described in its SDD [RD 3]), the distinctive feature of UAS operations is that the navigation services should be able to provide specific performance for UAS positioning (accuracy, availability, continuity, integrity and resilience depending on the missions) to allow the safe execution of a wide range of operations **not only in open sky conditions** but also in other complex or obstacle-rich scenarios, congested, or degraded local environments, such as IAM environments (e.g. urban corridors), where the navigation performance degradation could potentially endanger human lives.

Information on the integrity navigation performance particularly plays a crucial role for the safe and reliable positioning of UAS in these complex environments, especially for safety critical applications where integrity information is considered a necessity or even a must, as it measures the trust in the positioning information. In this regard, EGNOS provides integrity information through its satellite signal (refer to EGNOS SoL SDD to obtain details on EGNOS integrity concept [RD 3]), which would have to be tailored to

[3] https://egnos-user-support.essp-sas.eu/new_egnos_ops/resources-tools/edas-dgnss-coverage-map

such safety critical UAS operations, especially in little hampered enabling environments. Current UAS operations using EGNOS OS (UAS in open category and low-risk operations in the specific category) are not considered safety critical.

Positioning requirements for UAS operations are however still to be formally defined. Likewise, UAS operations requiring integrity in the position determination are still under discussion in different standardisation forums. Nevertheless, considering the expected evolution of UAS market and the great variety of UAS operations and environments, it seems plausible that medium-to-high-risk-UAS operations in the specific category and/or those in the certified category (e.g. those performed over-populated areas, or for the transportation of passengers and parcel delivery) will be required to meet stringent navigation positioning requirements, including integrity information. Under these premises, the provision of an appropriate EGNSS service for UAS based on EGNOS akin to the SoL Service would be of added value.

By addressing these safety critical positioning needs and aligned with the evolving European regulatory framework, such supporting service for UAS is key to ease compliance with expected positioning requirements if defined, while optimizing the operational costs. Based on European pioneer initiatives, such us EUGENE and SUGUS projects, the service would be tailored:

- to comply UAS user community needs,
- with functionalities such as performance forecasting, monitoring, and alerting of navigation system performance degradation,
- to be provided with the appropriate service liabilities according to the regulatory requirements in or out of the U-space airspace.

Starting in 2022 within RMT.0230 [RD 10], EASA is working on the establishment of a comprehensive regulatory framework to address new operational and mobility concepts that are based on innovative technologies, like UAS in the specific and certified category, and aircraft with VTOL capability. While Performance-based navigation (PBN) requirements are still to be addressed, stringent specifications like RNP 0.3, as for helicopters' operations, with both accuracy and integrity in the position determination, are expected for VTOL-capable aircraft (VCA) and even UAS in the certified category. UAS and VCA positioning requirements and needs for integrity information are to be considered in future European rulemaking.

Such considerations appear to show how integrity in the position will play a crucial role in some operations and a suitable EGNSS service would positively support this need. As mentioned within Section 2, UAS Regulation identifies GNSS services as external service to be considered in the OSO OSO#13 within the SORA methodology, which was published by EASA as AMC of Regulation (EU) 2019/947 [RD 6] on the performance of risk assessments in Article 11 to obtain the operational authorisation to perform certain operations in the 'specific' category.

OSO#13 concentrates in "External services supporting UAS operations are adequate for the operation" delivered by service providers other than UAS operators. In this regard, the following solutions to be provided by an EGNSS Service for UAS, of which EGNOS may be a part, would ease compliance of the requirements that are stemmed from OSO#13 in the 'specific' category, and possibly from the expected evolution of the UAS rulemaking in the certified category (similar to current requirements in the manned aviation domain) considering the increasing demand for more challenging UAS operations, especially those requiring positioning integrity:

- **Service Definition Document (SDD)**: OSO#13 particularly identifies the SDDs as evidence of compliance for roles and responsibilities. Current EGNOS SoL SDD is reviewed by EASA within the EGNOS Service Provider certification process. EGNOS SoL SDD outlines service areas of availability for manned aviation operations, UAS operations should comply adherence to areas similarly tailored for such purpose.

- **Service-Level Agreement (SLA)** or official commitment with the service provider (including quality, availability, roles and responsibilities) as evidence that service performances can be achieved for the full mission of the flight. In the case of an EGNSS Service, this SLA might be established among the EGNSS Service Providers (e.g., EGNOS Service Provider) and the appropriate organization (Common Information Service – CIS - provider or U-Space Service Provider – USSP or UAS operator) to support UAS operations within and outside U-space airspace.

- **Approved receiver equipment** as complementary method:
    - To compute the actual positioning performance along a mission.
    - Ensure consistency with the provided Service.
    - With an eventual performance monitoring service to give UAS operators the capacity to take appropriate contingency actions in case of service degradation, as required to medium-to-high-risk operations by OSO#13.

  Approved EGNSS receivers refer to on-board equipment that guarantee the implementation of a set of requirements to ensure alignment with the service provided, and that are able to provide positioning information (e.g. achieved positioning performances). While the standardization process for EGNSS receiver equipment is still under development, according to the applicable regulatory framework, for the different UAS categories (open, specific, and certified) different approval processes are expected in order not to make the process unnecessarily costly. Some receivers' manufacturers are already implementing SBAS functionality in their devices, including the provision of integrity information, though not yet intended for Safety of Life applications, according to the equipment specifications.

- **Service tools and documentation** to ease the compliance with the OSO#13's level of integrity and assurance and to ensure that the level of performance of the service is adequate for the flight. EGNOS already offers tools to manned aviation that are expected in the provision of an EGNSS Service for UAS as well: Service Documentation, EGNOS Service Performance and Monitoring Tool and EGNOS Service Information Tool. Likewise, EGNOS already delivers communication tools through its website and EGNOS Helpdesk, to ensure the effective communication means required in OSO#13.

- **Validation of the claimed level of integrity provided by the external service** by a competent authority as required to medium to high-risk UAS operations, according to OSO#13. EGNOS Service Provider is already certified by EASA, as per Regulation 2017/373 [RD 9]. Even if such certification is not yet required in the UAS regulatory framework, it would be advisable to take profit of it, since it eases the validation by the competent authority.
- **Contracting services with service provider compliant to ICAO SARPs** related to UAS as stated in OSO#13. If required to EGNSS Services for UAS, current EGNOS performances are compliant with ICAO Annex 10 requirements [RD 4].

The existence of an EGNSS Service for UAS akin to EGNOS SoL would then represent a significant stride towards enhancing safety, performance reliability and efficiency in unmanned aviation, the same way that EGNOS SoL does for manned aviation. In this sense, it should be highlighted that EGNOS already delivers solutions and tools that are expected in the provision of a EGNSS Service, such as, SDD, SLAs, an EGNOS Service Performance and Monitoring Tool, or an EGNOS Service Information Tool.

5 EGNOS performance in UAS operations

This section provides an overview of the performances obtained from EGNOS OS and EDAS services in UAS operations. As explained earlier in this document, both services improve the performance of the PVT solution onboard the UAS' GNSS receiver and can be openly used by UAS operators in non-safety critical scenarios, such as the flight operation performed for the obtention of the results depicted in this section. The use of EGNOS in UAS flights improves the Navigation performance in terms of accuracy and reliability with respect to GPS. The use of EGNOS OS corrections provides a lower horizontal and vertical Navigation System Error and protects the operation from potential issues in GPS that are identified and alerted by EGNOS.

Additionally, EGNOS OS can be used in remote identification, providing information about its EGNOS-based position. Using EGNOS OS, the reported position is in line with the EGNOS Open Service committed performance [RD 1] and it could benefit of the some quality information based on its estimated protection levels.

Alternatively, UAS can use EDAS services for low-risk operations to improve GPS solution using a mobile communication to retrieve corrections in real time from a close EDAS reference station. In this case, the pilot should configure the station to be used as reference within the Ntrip configuration panel.

With the aim of demonstrating the EGNOS OS and EDAS benefits, the same flight trajectory has been navigated by an UAS configured with GPS, EGNOS OS and EDAS. Results are presented hereafter.

5.1 Flight description

The flight was performed in the open category in line with the European regulatory requirements described in section 2. Specifically, the operations were performed in A3 sub-category, far from uninvolved persons and away from residential, commercial, industrial, or recreational areas. This category is intended for drones weighing less than 25 kg and the operator must ensure a minimum distance of 150 meters from congested areas and must not fly over uninvolved people.

An EH-1 hexacopter (Figure 9) was commanded to fly the same trajectory in automatic mode during October 2023 in Madrid and Málaga (Spain). The drone was equipped with a GNSS high-end receiver for navigation, which was configured in different GNSS solution types:

- EGNOS OS: It was configured as SBAS using L1 frequency, using automatically the operational SBAS satellites.
- EDAS Ntrip: The reception of EDAS Ntrip corrections in real time was set following the information of the EDAS service Definition Document [RD 2]. For both locations, the Málaga reference stations was configured to receive RTCM

v3 streams to compute RTK position solution by the receiver. Depending on the distance to the reference base distance and the position resolution, the receiver will show RTK-fix (close) or RTK-float[4] (large).

- GPS: The GNSS solution type was configured to use GPS standalone solution based on L1 measurements.

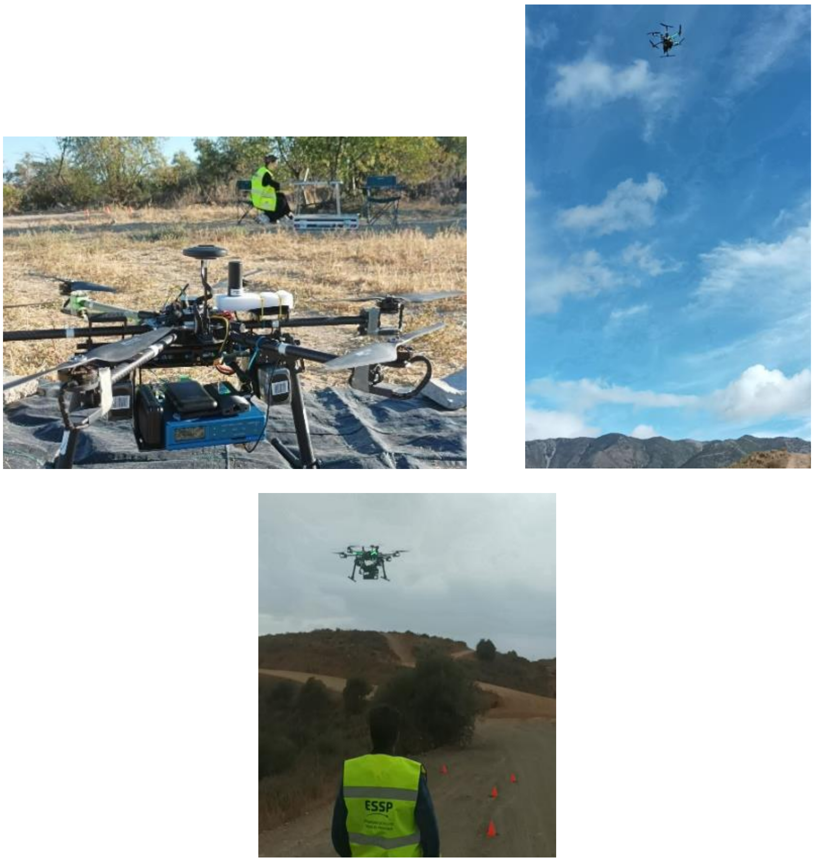


Figure 9. ESSP's EH-1 hexacopter details.

The flight controller was configured with the defined Flight Path, designed through a set of Way Points (WP). Figure 10 shows the defined path uploaded on the drone controller and used for this analysis. The type of flight was set to fly-by and the WP radius was set to 1 m, meaning that the UAS turns to the next course within 1 m radius in the WP. This is known as turn anticipation and the combination of these configuration enhance the battery life (see also Figure 13).

Although the same trajectory was used for each type of position solution, environmental conditions could change from one flight to another. High wind speed or turbulence is presented for each result because it directly impacts the capability of the drone controller to follow the defined path.

[4] Due to large distance the RTK solution is Float RTK: In a Float solution, the receiver algorithm has not been solved and cannot produce an acceptable FIX solution. Since there is no FIX solution, a Float one is provided, which is always a less accurate position than a fixed solution and in general cannot be used for measurements with centimetre accuracy.

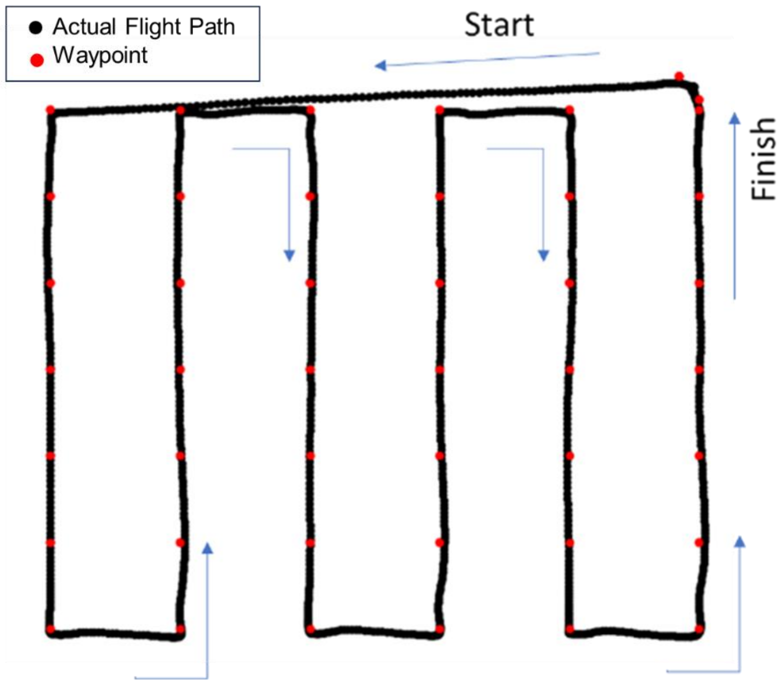


Figure 10 Actual Flight path

5.2 Flight performance results

For this assessment, the navigation outputs of the receiver for each type of solution type (GPS, EGNOS OS and EDAS) were recorded. Additionally, the receiver also gathered GNSS observation measurements to obtain in post-processing the reference "real" trajectory Actual Flight Path (AFP), computed using *Post Processing Kinematics (PPK)* that provides high precision.

The following errors were analysed for each type of navigation solution (EGNOS OS, EDAS and GPS):

- **Navigation System Error (NSE)**: Computed as the difference between the outputted position estimated by the receiver and the UAS actual position.
- **Total System Error (TSE)**: Computed as the difference between the UAS Actual Position and the Desired Flight Path. Assuming that the PDE is negligible (which has to be confirmed anyway), the TSE is a combination of the NSE and the Flight Technical Error (FTE)[5], understood as the ability of the autopilot system to maintain the defined position based on the estimated PVT solution combining measurements from the GNSS source and other positioning sensors such as IMUs (Inertial Measurement Unit), compasses, barometers, etc.

[5] By definition, the TSE is the difference between the actual position and the desired flight path, and it constitutes the combination of the NSE, FTE and PDE. In the analysis described in this document, the latest (PDE) has been omitted for the calculation of the TSE.

Additionally, the following errors are not included as results of the analysis but shown in the below figure for clarification:

- **Flight Technical Error (FTE)**: The difference between the defined flight path and the estimated position is called Flight Technical Error (FTE) and contains aircraft dynamics, turbulence effects, autopilot errors, man-machine interface problems, etc.
- **Path Definition Error (PDE)**: It is the difference between the defined planned route and the intended or desired path, often caused by incorrect waypoint definition, data input errors, or external constraints, and it is constrained through the database integrity and functional requirements on the defined path In order to reduce the PDE, the "home waypoint" is geolocated during 30-40 min using PPK techniques before the flights. The precise location is configured in the drone controller to adjust the measured real position in the field with the path definition. .

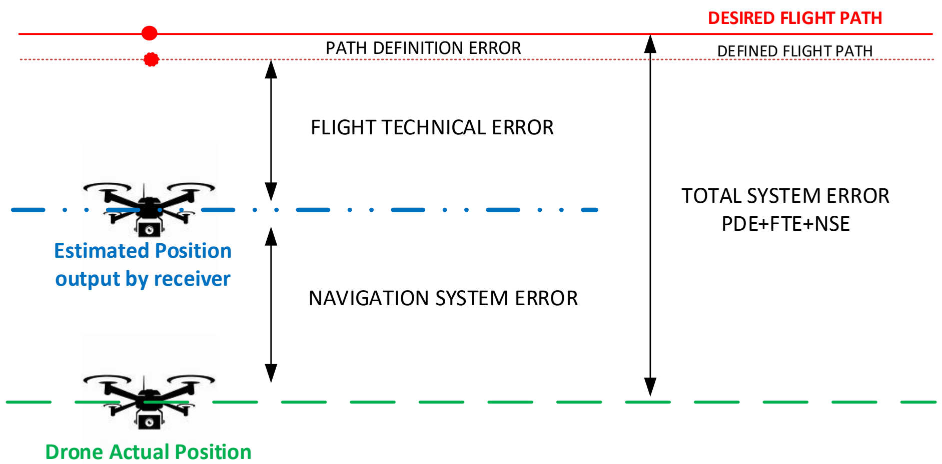


Figure 11. Types of navigation errors

5.2.1 Navigation System Error

The Horizontal & Vertical Navigation System Error (NSE; HNSE and VNSE) was computed as the difference between the estimated receiver´s position and the UAS actual position computed using Post-Processed Kinematic (PPK) algorithms. See Figure 11 for details.

Horizontal and Vertical statistics are shown in Table 1 in two different locations, Madrid and Málaga (far and near location from the EDAS reference station), in order to analyse the UAS positioning using EDAS, due to base distance, see 4.1.2. It shows:

- Horizontal Navigation System Error (HNSE): The percentile at 95% (P-95-th) and the mean.
- Vertical Navigation System Error (VNSE): The percentile at 95% (P-95-th) and the mean.

Location: Madrid Distance from EDAS base: > 400 km Wind speed: 1-2 m/s (3.5 - 7.5 km/h)				
High-end Receiver NSE				
Correction	HNSE		VNSE	
	95%	mean	95%	mean
EGNOS	0.9	0.6	0.5	0.4
EDAS	1.6	0.9	1.5	0.6
GPS	1.9	1.7	3.6	3.2

Location: Málaga Distance from EDAS base: ˜ 35 km Wind speed: 5-7 m/s (18 - 26 km/h)				
High-end Receiver NSE [m]				
Correction	HNSE		VNSE	
	95%	mean	95%	mean
EGNOS	1.7	1.1	2	1.4
EDAS	0.7	0.3	0.7	0.7
GPS	3.2	2.5	5.8	4.9

Table 1. NSE statistics.

As presented in above tables, the improvement in Navigation System Error using EGNOS OS position with respect to GPS was quite considerable in both locations. For example, in Madrid, the percentile at 95% improved from 1.9 m down to 0.9 m in horizontal and from 3.6 m down to 0.5 m in Vertical.

With EDAS, the improvement in Navigation System Error was also quite important. The closer the reference station was, the better is the accuracy performance. For example, in Málaga where the station is closer than 40 km, the percentile at 95% improved from 3.2 m in GPS down to 0.7 m in horizontal and from 5.8 m down to 0.7 m in Vertical.

In areas where EDAS reference base distance is higher than 400 km EGNOS is the best solution with lower NSE compared to EDAS and GPS standalone. I.e.: P-95th HNSE 0.9 m, 1.6 m and 1.9 m respectively. In these cases, EDAS can be used as a backup solution when for any reason EGNOS signal is shadowed by any obstacle (i.e.: the time of signal correction increases when any obstacle creates a shadow, therefore this time can be set up to use EDAS when a specific value is reached due to signal shadows: 4 sec, 5 sec, etc) or due to manoeuvring of the UA, providing better results than GPS standalone navigation.

In areas where EDAS reference base distance is lower than 50 km EDAS is the best solution with lower NSE (Figure 12) compared to EGNOS and GPS standalone. I.e.: P-95th

HNSE 0.7 m, to 1.7 m and 3.2 m respectively. The combination of EDAS as primary and EGNOS SiS as a backup solution in the drone receiver is highly suitable for positioning and navigation. As the drone is following the defined path with more accurate approach, it uses less power to the motors. Therefore, it saves more energy than using GPS, where the high positioning errors makes the controller to drive more energy to the motors to reach the defined flight path.

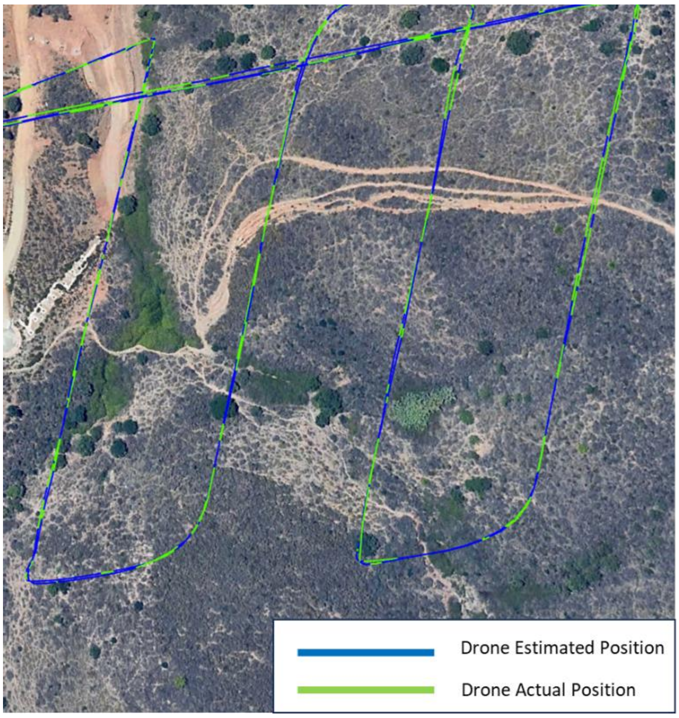


Figure 12. Navigation Trajectory using EDAS in Málaga

5.2.2 Total System Error

The lateral Total System Error (TSE) was computed, assuming a negligible PDE, as the difference between the defined flight path, and the actual position flew by the drone (computed using PPK algorithms). See Figure 11 for details. The Total System Error statistics computed during the flights are shown in Table 2. It shows:

- Total System Error: The percentile at 95% (P-95-th) and the mean.
- Inside radius: the percentage of waypoints in which the UAS was able to turn within the 1 metre radius configured in the design path (see 5.2.2.1 for details).

Location: Madrid Distance from EDAS base: > 400 km Wind speed: 1-2 m/s (3.5 - 7.5 km/h)			
Total system Error (xyz)			
Correction	P95 [m]	mean [m]	inside radius [%]
EGNOS	1.6	0.9	78
EDAS	1.9	1.0	77
GPS	3.8	1.7	15

Location: Málaga Distance from EDAS base: ˜ 35 km Wind speed: 5-7 m/s (18 - 26 km/h)			
Total system Error (xyz)			
Correction	P95 [m]	mean [m]	Inside radius [%]
EGNOS	2.9	2.2	30
EDAS	1.6	0.7	55
GPS	7.2	5.7	0

Table 2. TSE statistics.

It is observed an important improvement in the Total System Error using EGNOS OS position with respect to GPS in both locations. Especially for Málaga, the percentile at 95% improved from 7.2 m with GPS down to 2.9 m.

When the receiver used EDAS, the improvement in Total System Error was also quite important. The closer the reference station is, the better is the accuracy performance. For example, in Málaga where the station is nearby, the percentile at 95% improved from 7.2 m in GPS down to 1.6 m.

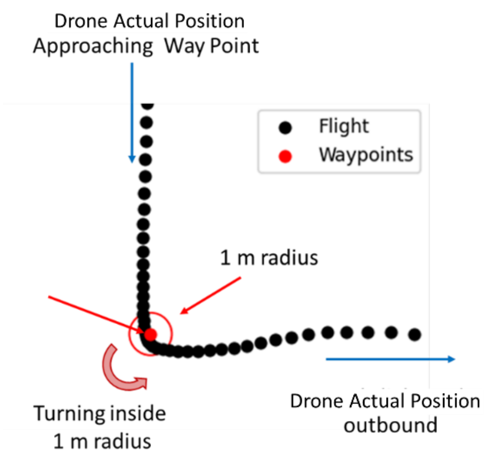
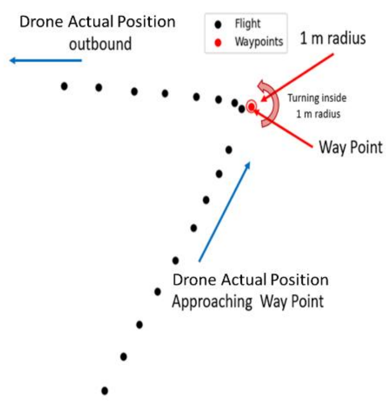
Due to high wind turbulence in the Málaga campaign, the autopilot system couldn´t maintain the drone in the defined path, increasing the FTE that is reflected in the TSE using EGNOS and GPS, as shown in Table 2. Even though P95th values from EGNOS OS and EDAS complies with the EGNOS SDD [RD 1] and EDAS expected performance [RD 2] and both services are very much lower than GPS.

5.2.2.1 *UAS performance in turns*

This section shows an assessment of the flight performance in turns to show that using EGNOS and EDAS the UAS is capable of performing more accurate the challenging defined flight path, such as short turns of 1 meter.

The defined path was configured as “fly-by” and the Way Point (WP) radius was set to 1 m (the minimum acceptable radius by the drone controller), meaning that the UAS controller calculates the best arc of turning to the next course (using the best motor energy) within the 1 m radius in the WP. This is known as turn anticipation and the combination of these configuration enhances the battery life, although the drone decelerates to achieve this task, the use of energy is highly lower than using fly-over configuration. The lower the Total System Error is, the better the UAS is able to follow the defined turns within the defined trajectory.

Figure 13 shows the Actual Flight path in black colour, zoomed in for a turn, showing the Way Point in red and the 1 metre radius configured for the fly-by turning. A typical EGNOS and EDAS (shown in left picture) “fly by” provided a lower Total System Error and the UAS passed inside the 1 m way point radius creating a valid fly-by. When configured in GPS (right picture), the UAS controller was not able to fly-by inside the 1m, the Total System Error was bigger than the configured radius (1 m). In this case the drone tends to approach the waypoint but it cannot enter into the 1 m radius making a not valid way point approach.

UAS Actual Flight Path: Trajectory making the turn in a Way Point	
Fly by EGNOS	**fly by using GPS**
	

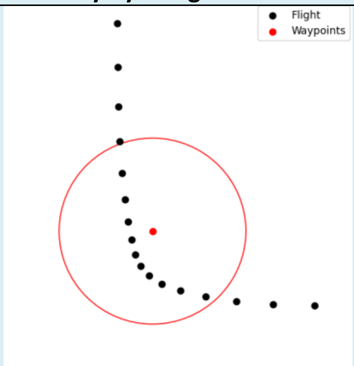
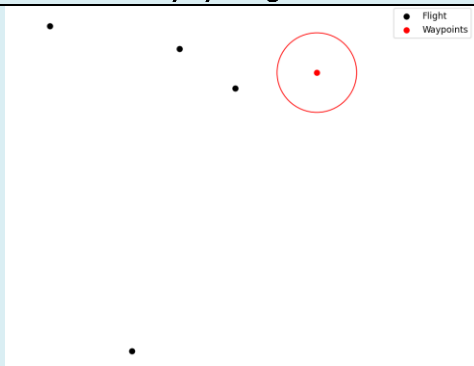
UAS Actual Flight Path position: Trajectory way point zoomed view	
Fly by using EGNOS	**Fly by using GPS**
	

Figure 13 Waypoint radius.

5.3 Outcome

The benefits of EGNOS OS and EDAS for UAS navigation with respect to GPS is shown in the presented performance results.

For both flights, EGNOS OS presented Navigation System Errors at percentile 95^{th} lower than 2 meters in horizontal and vertical planes, showing a significant improvement with respect to GPS only.

Additionally, the Total System Error was considerably improved using EGNOS with respect to GPS position solution, being the UAS able to follow the defined path much closer than with GPS. For example, the Total System Error in Málaga flight, in mean, improved from 5.7 meters in GPS down to 2.2 meters using EGNOS solution. It is noted that in those flights the wind speed was quite high (18-26 km/h) and then, the drone controller presented more difficulties to follow the designed path resulting in higher system errors.

When located close to an EDAS reference station, EDAS can be also a good solution for low-risk operations. To benefit from EDAS, the receiver needs to be Ntrip enabled and requires an active internet connection. Additionally, the receiver should be properly configured to use the mountpoint corresponding to the closest station. In this paper, it is shown the results using EDAS when the reference station is close (~35 km) and far away (>400 km). In areas where EDAS reference station is less than 50 km away, EDAS is the best solution with lower NSE compared with EGNOS and GPS standalone. For example, the analysis showed a HNSE P-95-th 0.7 m using EDAS when located close to the Málaga reference station, compared to 1.7 m with EGNOS and 3.2 m with GPS respectively.

Another important result observed during the flight tests was that thanks to the enhanced accuracy provided by EGNOS and EDAS, the drone was able to flight inside the defined 1 m way point radius creating a valid fly-by as configured in the flight path definition. When using GPS only navigation due to the higher positioning error, the drone controller was not able to perform a proper fly inside the defined radius because the error was higher than 1 m, therefore increasing the distance to the waypoint and creating over/under shooting turns.

The combination of EDAS and EGNOS solutions have proved to be an advantage for UAS positioning and navigation in open category and low-risk operations. A very relevant added value of the combination of EGNOS SiS and EDAS is the continuous provision of an accurate PVT even if the GEOs are not in Line of Sight (LoS) due to obstacles, terrain or manoeuvring of the drone.

6 Conclusions

The definition of UAS operations is continuously evolving, adapting to technology developments and changing regulatory requirements. As part of this evolution, the integration and use of EGNOS services are being tailored to meet the requirements of the different categories and risk levels associated with UAS operations.

As explained in section 4 with the conceptual description of the application of EGNOS to non-safety-critical UAS operations and demonstrated in section 5 with the results of the analysis presented in this document, EGNOS OS and EDAS are suitable and free of charge services that can be used by UAS in the open category and low-risk operations in the specific category over Europe, improving the performance of GNSS receivers onboard UAS' and therefore optimizing the overall execution of its operations.

The assessment of the real performance of an hexacopter operating in the open category provides an overview of the difference in terms of TSE and NSE when enabling GPS-only, EGNOS OS and EDAS for the UAS navigation:

- EGNOS Open Service provides a significant improvement in terms of accuracy with respect to GPS-only, especially in the vertical axis, where the flight tests demonstrate that the NSE could be reduced from several meters to a submeter accuracy (Please consult details in section 5).
- EGNOS EDAS service delivers substantial enhancement in terms of accuracy with respect to GPS-only and EGNOS OS when operations are performed in the vicinity of a RIMS station, as observed in the flights executed at 35km from the Málaga RIMS station, where the NSE 95-percentile and mean remains below one meter for the horizontal and vertical planes (Please consult details in section 5).

In light of this, the combination of EDAS and EGNOS OS solutions have proved to be an advantage for UAS positioning and navigation in open category and low-risk operations in the specific category, nevertheless, **for safety critical operations it would be highly valuable the provision of an appropriate EGNSS service based on EGNOS and tailored to UAS operations akin to the current EGNOS SoL Service for manned aviation.**

Annex A: Reference documents

RD	Title
RD 1.	EGNOS Open Service (OS) – Service Definition Document Issue 2.3
RD 2.	EGNOS Data Access Service (EDAS) - Service Definition Document Issue 2.3
RD 3.	EGNOS Safety of Life Service (SoL) - Service Definition Document Issue 3.5
RD 4.	ICAO Annex 10 - Aeronautical Telecommunications - Volume I - Radio Navigational Aids
RD 5.	REGULATION (EU) 2018/1139 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111/2005, (EC) No 1008/2008, (EU) No 996/2010, (EU) No 376/2014 and Directives 2014/30/EU and 2014/53/EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552/2004 and (EC) No 216/2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922/91
RD 6.	COMMISSION IMPLEMENTING REGULATION (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft
RD 7.	COMMISSION DELEGATED REGULATION (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems
RD 8.	COMMISSION IMPLEMENTING REGULATION (EU) 2021/664 of 22 April 2021 on a regulatory framework for the U-space
RD 9.	COMMISSION IMPLEMENTING REGULATION (EU) 2017/373 of 1 March 2017 laying down common requirements for providers of air traffic management/air navigation services and other air traffic management network functions and their oversight, repealing Regulation (EC) No 482/2008, Implementing Regulations (EU) No 1034/2011, (EU) No 1035/2011 and (EU) 2016/1377 and amending Regulation (EU) No 677/2011
RD 10.	TERMS OF REFERENCE RMT.0230: Introduction of a regulatory framework for the operation of unmanned aircraft systems and for urban air mobility in the European Union aviation system.

Table 3: Reference documents

Annex B: Acronyms and abbreviations.

Acronym	Definition
AFP	Actual Flight Path
AMC	Acceptable Means of Compliance
ARC	Air Risk Class
CE	Conformité Européene, "European conformity"
CIS	Common Information Service
DGNSS	Differential GNSS
EASA	European Union Aviation Safety Agency
EDAS	EGNOS Data Access Service
EGNOS	European Geostationary Navigation Overlay Service
ESSP	European Satellite Services Provider
EU	European Union
FTE	Flight Technical Error
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRC	Ground Risk Class
HNSE	Horizontal Navigation System Error
HPE	Horizontal Positioning Error (= HNSE)
IAM	Innovative Air Mobility
ICAO	International Civil Aviation Organization
LPV	Localizer Performance with Vertical guidance
NLES	Navigation Land Earth Stations
NSE	Navigation System Error
Ntrip	Networked Transport of RTCM via Internet Protocol
OS	Open Service
OSO	Operational Safety Objective
PBN	Performance Based Navigation
PPK	Post-Processed Kinematic
PRN	Pseudorandom Noise
PVT	Position, Velocity, and Time
RIMS	Ranging and Integrity Monitoring Stations

Acronym	Definition
RNP	Required Navigation Performance
RTCM	Real Time Correction Message
RTK	Real-Time Kinematic
SAIL	Specific Assurance and Integrity Level
SARPs	Standards and Recommended Practices
SBAS	Satellite-Based Augmentation System
SDD	Service Definition Document
SIS	Signal In Space
SLA	Service Level Agreements
SoL	Safety of Life
SORA	Specific Operations Risk Assessment
STS	Standard Scenario
TSE	Total System Error
UAS	Unmanned Aircraft Systems
USSP	U-Space Service Provider
VCA	VTOL-Capable Aircraft
VLOS	Visual Line Of Sight
VNSE	Vertical Navigation System Error
VPE	Vertical Positioning Error (= VNSE)
VTOL	Vertical Take-Off and Landing
WP	Waypoint

Table 4: Acronyms and abbreviations