# RADIUS

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## Deliverable D3.1

## Analysis of Existing Drone Trajectory Technologies

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|---|---|
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# 1 Executive Summary

The RADIUS project aims to develop an unmanned aircraft system (UAS) technology to improve the maintenance and monitoring activities of railway signalling assets. The project will focus on developing the most effective and efficient solution to enhance railway maintenance, by keeping in consideration the main technical characteristics of the major railway signalling assets, line characteristics, maintenance procedures, and operational procedures of the unmanned aircraft in relation to the asset to be monitored.

In this context, a highly accurate navigation performance is required to ensure a safe integration of drones flying at very low level (VLL) and interacting with critical railway infrastructure.

This paper analyses current state-of-the-art UAS navigation technology, while providing an in-depth analysis of different available levels of automation and human interaction to UAS operations.

Ultimately, the scope of this deliverable is to provide a critical assessment of current trajectory technologies, ranging from man-operated to fully autonomous navigation, to provide a basis to identify the optimal configuration for the project's purpose.

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# 2 Table of Contents

*The project leading to this application has received funding from the European GNSS Agency under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004192*

# 3 Abbreviations and Acronyms

| Abbreviation / Acronym | Description |
|---|---|
| ADS-B | Automatic Dependent Surveillance - Broadcast |
| AI | Artificial Intelligence |
| AMC | Acceptable Means of Compliance |
| BVLOS | Beyond Visual Line of Sight |
| EASA | European Union Aviation Safety Agency |
| EGNOS | European Geostationary Navigation Overlay System |
| EGNSS | European Global Navigation Satellite System |
| FTE | Flight Technical Error |
| GCS | Ground Control Station |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| GSA | European GNSS Agency |
| GUI | Graphic User Interface |
| HIC | Human in Control |
| HOTL | Human out of the loop |
| HITL | Human in the loop |
| NSE | Navigation System Error |
| PDE | Path Definition Error |
| RNAV | Area Navigation |
| RNP | Required Navigation Performance |
| RPAS | Remotely Piloted Aircraft System |
| RTK | Real-time Kinematics |
| SBAS | Satellite-based Augmentation Systems |

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| | |
|---|---|
| SDO | Standard Development Organisation |
| SISE | Signal-In Space Error |
| SORA | Specific Operations Risk Assessment |
| TCAS | Traffic Collision Avoidance System |
| TMS | Traffic Management System |
| TRL | Technology Readiness Level |
| TSE | Total System Error |
| UA | Unmanned Aircraft |
| UAM | Urban Air Mobility |
| UAS | Unmanned Aircraft System |
| UAV | Unmanned Aerial Vehicle |
| UTM | Unmanned Aircraft System Traffic Management |
| VLL | Very Low Level |
| VLOS | Visual Line of Sight |

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# 4 Introduction

## 4.1 Background

The RADIUS project aims to develop an unmanned aircraft system (UAS)-based solution to enhance railway maintenance activities through the monitoring of the physical status and electronic functionality of both non-safety-critical and safety-critical railway signalling assets, as well as the execution of the specific maintenance activities.

The project focuses on identifying of the most efficient UAS technology to be employed in the railway sector, considering the main railway signalling assets to be monitored, the characteristics of the lines, the maintenance procedures to be applied and the distances to be covered by the unmanned aircraft (UA).

Furthermore, the design of the UAS will consider all navigation related technologies and related payloads to integrate:

- sensors and data collection and processing capabilities will allow the monitoring of the signalling assets,
- wireless technology to be used for establishing secure communication channels between the drone and the peripheral post and to allow contact-less diagnostic and SW maintenance,
- EGNSS solutions for navigation and positioning such as EGNOS (SBAS) and GALILEO enabling improved drones' flight control and safe movements in complex railways operational scenario,
- the most secure data transmission solution to guarantee reliable and secure data exchanges,
- embedded data analytics to perform assets monitoring, maintenance prediction analysis, and repairing actions avoiding railway track possession.

In addition, the design of the railway signalling assets will be adapted to allow for drone-friendly maintenance activities. This will include the design of a docking station for the UA.

The project will also consider the interaction with existing Intelligent Asset Management Systems and with current Traffic Management Systems (TMS) to improve the safe movements of drones within the railway.

The planning of drone mission strategies will demonstrate compliance with regulations and with the complexity of the railway environment when flying Beyond Visual Line of Sight (BVLOS), considering the new Commission Implementing Regulation (EU) 2019/947 [1] on the rules and procedures for the operation of unmanned aircraft, and Commission Delegated Regulation (EU) 2019/945 [2] on unmanned aircraft systems and on third-country operators of unmanned aircraft systems.

Ultimately, the project will feature practical demonstrations of a proof-of-concept with Technology Readiness Level (TRL) 6 in a railway relevant environment.

## 4.2 Navigation Performance in UAS Operations

The employment of civil drones in complex applications requires demanding navigation performance, to allow safe integration of drones at very low level (VLL), as well as interaction with other ecosystems and critical infrastructure as that encountered in the premises of railways.

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Such scenarios have already been explored, with GNSS EGNOS technology becoming available for drones. [3] UAS navigation performance is a product of multiple parameters, such as (show in Figure 1):

- Path Definition Error (PDE) occurs when the path defined by the area navigation system (RNAV) does not correspond to the desired path. This may be negligible in manned aviation, while not in VLL drone operations such as in railway applications.
- Navigation System Error (NSE) is the difference between the aircraft's estimated position and its true position. It includes Signal-In-Space Error (SISE) and airborne equipment errors. Hence it is directly proportional to the accuracy of the inputs to the position solution, i.e., the accepted GNSS accuracy.
- Flight Technical Error (FTE) is the difference between the location of the aircraft given by the navigation system and the defined flight path; it is yielded by the capability of a pilot or autopilot to follow a defined trajectory, including any display error.

The Total System Error (TSE) is the combination of the PDE, NSE and FTE.

Despite being applicable to commercial airliners, RNAV/RNP introduce concepts that are useful for drone operation. Area Navigation (RNAV) and Required Navigation Performance (RNP) are navigation specifications enabling a particular level of accuracy and integrity to the aircraft's navigation. Local or on-board systems track navigation performance and ensure the accuracy necessary to fly a specific path with a given maximum deviation.

With the underlying assumption that the true position of the aircraft is not known, the TSE follows a probability distribution evaluated during flight, and compared with a pre-defined threshold to return a warning when the TSE exceeds its limit. This if the result of two requirements related to the TSE distribution:

- RNP accuracy: the TSE shall remain equal to or better than the required accuracy for 95% of the flight time; and
- The probability that the TSE exceeds the specified TSE limit (or two times the accuracy value) is less than $10^{-5}$.

The International Civil Aviation Organization's (ICAO) PBN Manual [4] identifies seven navigation specifications under the RNP family: RNP4, RNP2, RNP1, Advanced RNP, RNP APCH, RNP AR APCH and RNP 0.3. [4] For reference, a value of RNP-1 requires a TSE < 1 nm (nautical mile) throughout 95 % of the flight, and a P(TSE > 2 nm) < $10^{-5}$, as depicted in Figure 2.

The concepts introduced above are applicable and relevant to UAS operations, especially when operating at VLL and in close proximity to critical infrastructure, as is the case with RADIUS. Navigation system error, flight technical error and path definition error, in fact, constitute an important aspect of the navigation performance of the drones employed within the project, due to their dependence on GNSS-predominant navigation technologies.

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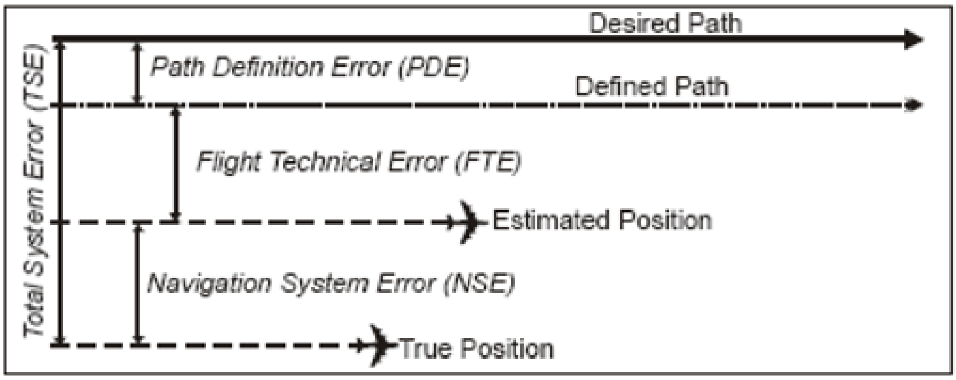


*Figure 1. Graphical representation of TSE, FTE, NSE, PDE. [5]*

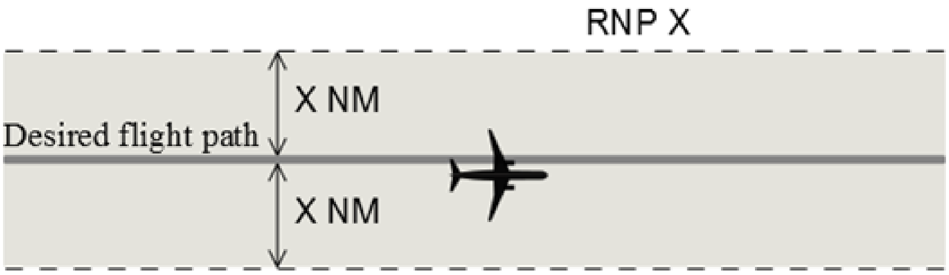


*Figure 2. Graphical representation of RNP. [6]*

## 4.3 Purpose of this document

Work Package 3 of the project considers **communication, mission control and interaction with TMS**, and aims to:

- Develop and implement the communication infrastructure, both locally at the drone (with payloads and other devices) and wirelessly (with the ground station and data management platform and with the assets requiring this feature);
- Develop the framework which will implement the most efficient and safe route until the next target, within the railway infrastructure property (between catenary and railway track), taking into account the different available charging docks and including the management of mission critical faults;
- Interact with the TMS system, to identify time slots for safe flying from departure point to the destination without impacting with the railway operations.

In this context, deliverable D3.1 provides a **preliminary analysis of existing UAS trajectory technologies**, introducing the key aspects of the different levels of automation of currently employed unmanned aircraft navigation technologies. The differences between employing a remote pilot and diverse typologies of ground control stations (GCS) or a fleet manager overlooking the safe operation of cooperative intelligent and autonomous UAS missions is analysed, while also considering the current and future role of Standard Developments Organisations (SDOs) in the performance-based oversight approach adopted by EASA and other aviation authorities.

The project will consider **two different navigation scenarios**:

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1) **Man Operated:** whereby supported by augmented reality a certified UAS pilot will be at a Command-and-Control Station operating the UA between locations, while adhering to rules and regulations.

2) **Automated Navigation:** where the UAS will by its own mechanisms follow a given trajectory.

The document will analyse results from previous and current related projects, evaluating the feasibility of adopting or incorporating them or parts of them into RADIUS navigation systems.

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# 5 Levels of UAS Automation and autonomy and operation

Although the terms of **automation** and **autonomy** [1] are not the same, are closely linked and therefore, it is of interest to represent them according to the levels of autonomy defined for drones. [7]

The following image shows, according to the six levels of autonomy defined for drones, the basic characteristics of each of them, starting from level 0, in which the drone does not include automation and requires a skilled pilot to fly, to level 5, in which the drone is considered fully automated and allows fully autonomous and unattended missions.

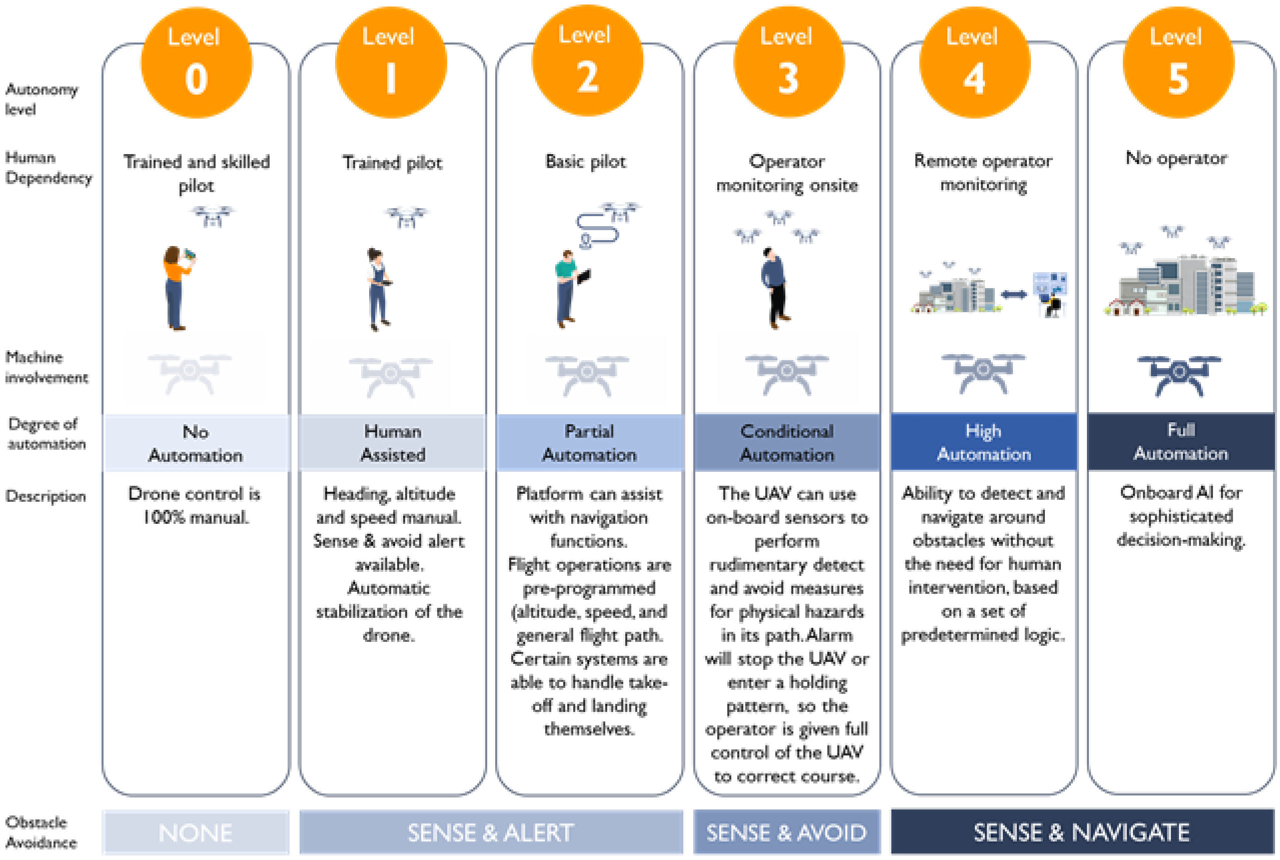


*Figure 3.Types of drone autonomy and degree of automation [8]*

Similarly, the *EASA AI Roadmap* [9] focuses on the oversight of a human with respect to the machine, categorising human-machine interaction in three levels: *Human in Control (HIC), Human out of the loop (HOTL), and Human in the loop (HITL)*. While omitting “Level 0” in which the control of the drone is completely manual, the *EASA AI Roadmap* focuses its degrees of oversight in three macro-categories, as shown below.

[1] **Automation**: the use or introduction of automatic equipment. The more automatic equipment is incorporated into the drone, the more automatic the drone will become and will be able to follow commands but will not make decisions. **Autonomy**: freedom from external control influence. Therefore, the drone will be able to decide his route and destination, having more control over himself.

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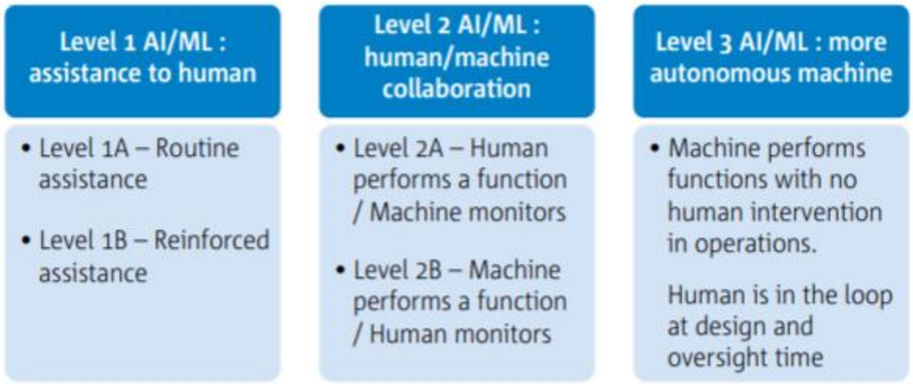


*Figure 4. Possible classification of AI/ML applications [9]*

- **Level 1A** provides human augmentation, aiding the pilot with routine assistance (e.g., aircraft status, stabilisation, etc.)
- **Level 1B** provides cognitive assistance to the pilot to aid the decision making and action selection process (i.e., TCAS audio signal “Traffic! Traffic!”)
- **Level 2** provides enhanced human-machine collaboration, consisting in overseen automating decision-making and action-implementing.
- **Level 3A** consists in overridable automatic decision-making and action-implementing
- **Level 3B** consists in non-overridable automatic decision-making and action-implementing

It is worth stressing that although the previous figures do not graphically distinguish whether the pilot “operates” the drone remotely or locally, for RADIUS project both cases are considered as man operated, where the drone is operated by a pilot. In other words, they correspond to levels of autonomy 1-3 for both cases.

The proposed RADIUS concept foresees the use of a highly automated drone system that will be operated **Beyond Visual Line of Sight (BVLOS)**.

From the RADIUS project approach, three types of operations are defined. The first type, local, corresponds to the pilot operating from the same location as the drone via a radio link. In the second case, the pilot can operate the drone from the field, but the drone can also be commanded through the control centre in a delocalised way. The latter case would allow remote and delocalised operation of the drones from the control centre. In this sense, the project will aim to achieve the highest possible level of automation and remotely.

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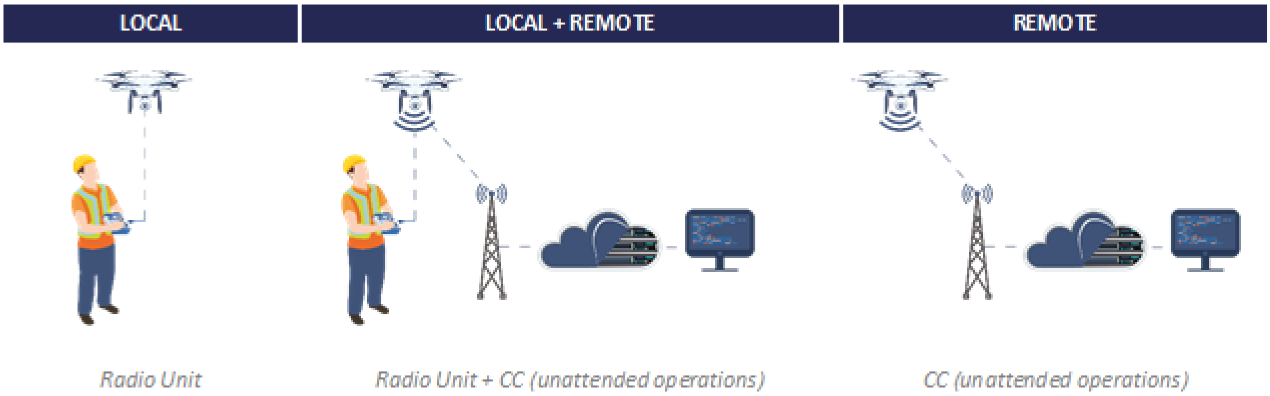


*Figure 5. Types of operations*

Taking into account the previous definitions, RADIUS distinguishes between the two different “navigation scenarios”:

1. ***Man Operated****:* whereby supported by augmented reality a certified Drone pilot will be at a Command-and-Control Centre operating the Drone between locations, while following rules*. This correspond up* to level 2 of autonomy (see Figure 5) as the pilot **operates** the drone although it is located at the command centre and due to the current legislation supported by a pilot on-site.  For drones that lack automation, control always rests with the pilot or operator.
2. **Automated Navigation**: where the drone will by its own mechanisms follow a given trajectory. During this task, results from previous and related projects will be evaluated with the intention of incorporate them or parts of them into RADIUS navigation systems. This corresponds to Levels 4/5 where the operator is just **monitoring** the drone in the command centre.

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# 6 Navigation technologies

## 6.1 Drone positioning and navigation technologies

When talking about **drone positioning and navigation technologies**, according to the EGNSS for Drones operator white paper of the GSA [10], there are two widely used types of drone positioning and navigation technologies, *stand-alone GNSS* and *augmented GNSS*, with the latter being the most commonly used. Besides these GNSS based solutions, local awareness is becoming more common with obstacle detection and avoidance systems allowing a drone to fly around an obstacle before resuming the pre-determined flightpath.

Both these technologies enable the drone to navigate the large landscapes where the railway infrastructure sprawls. However, they lack the finesse and awareness required to navigate close to the cluttered spaces near, e.g., the catenaries, or inside tunnels. These uses will require local based obstacle avoidance systems to override the defined trajectories, and both detect and avoid contact with any obstacles.

**1. Stand-alone GNSS**

Currently almost all drones have a GNSS receiver included to aid navigation. Older models and some recreational drones may not have it implemented, which would correspond to a level 0 autonomy (see Figure 3). Most receivers currently available on the market are multi-constellation and can access signals from different constellations such as GPS, GLONASS, BeiDou or Galileo.

In general, the operation of these devices once mounted on the drone is transparent, i.e., it is the device itself that selects the most suitable constellation at any given moment and provides positional information to the flight control unit.

**2. Augmented GNSS**

There are several systems/methods/technologies to improve the accuracy and reliability provided by GNSS, such as:

- **Satellite-based Augmentation Systems (SBAS)**

SBAS is a system for correcting signals that GNSS transmit to the receiver. The basic architecture of all SBAS systems consists of a network of reference ground stations distributed over a wide geographical area (countries or entire continents) that monitor GNSS satellite constellations. These stations relay data to a central processing facility that evaluates the validity of the signals and calculates corrections to the broadcast ephemeris and clock data from each satellite in view. Areas are shown in Figure 6.

- **Precise Point Positioning (PPP)**

PPP is a technique used to determine the precise position of receiver antenna without requiring communication with a reference station (unlike most RTK techniques). It can retrieve more precise positioning from the carrier phase of each satellite's signal, and the differential delay between signals at different frequencies, as well as benefiting from updated measured ephemerids rather than relying on the estimations provided by the satellite itself. An architecture is shown in Figure 7.

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*Figure 6.SBAS Indicative Service Areas.* [10]

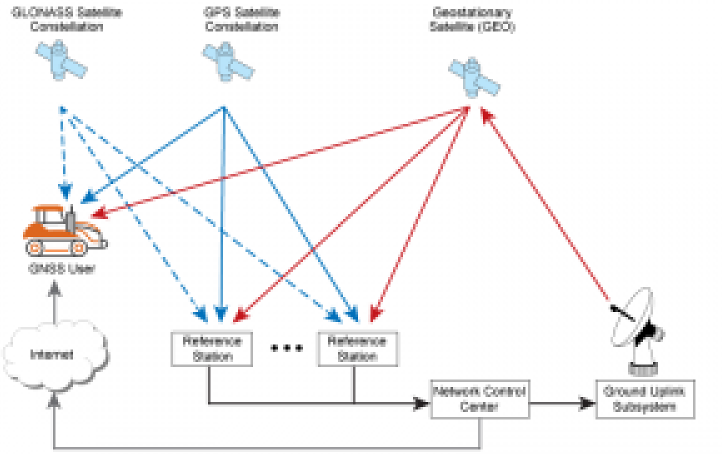


*Figure 7. PPP architecture*

- **RTK (Real Time Kinematics)**

The RTK positioning technique is based on the carrier solution of the signals transmitted by the GPS global navigation satellite systems, achieving centimetre-level accuracy.

This technique is equipped with a Global Navigation Satellite System (GNSS) receiver and a radio transmitter modem. It is worth mentioning that at least one reference station must be available, and the coordinates must be known for it to work. A comparison of the different positioning techniques is shown in Figure 8.

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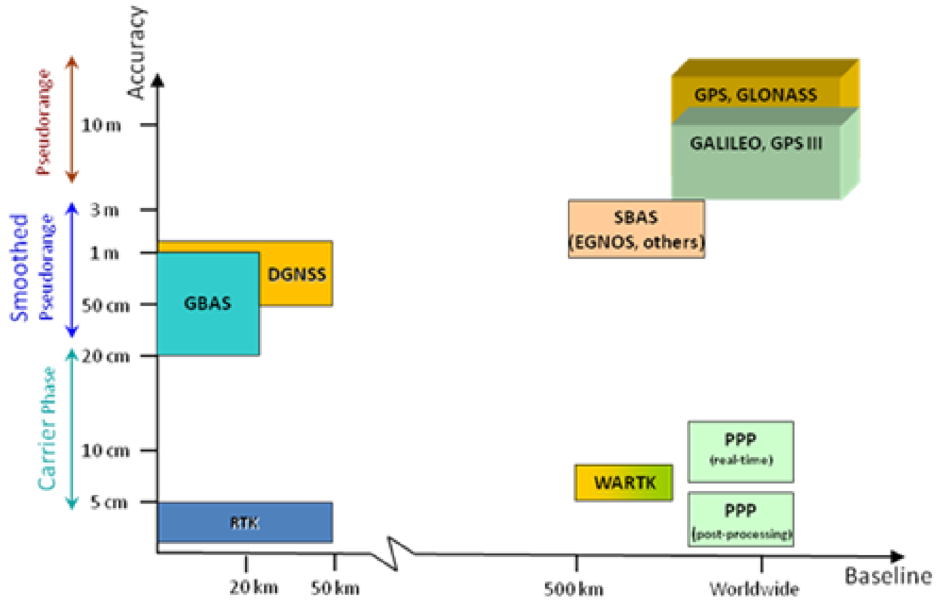


*Figure 8. Positioning techniques comparison* [11]

### 3. Obstacle detection and avoidance

Given the cluttered environment where the drones are expected to work and the proximity required to perform their tasks, **the drones will require local obstacle detection and avoidance system**.

There are currently sonar, radar, and vision-based systems, which take over the navigation of the drone and attempt to release control by returning to the defined flightpath after circumventing the obstacle. These technology offers a local based reference that requires no adaptation of the target, as it can be identified and approached without relying on a GNSS signal and absolute position of target to maintain distance and avoid collisions.

Vision based systems are the most attractive for this project, as the inspection task already requires the visual identification of the object of study. Computer-vision based systems to identify traffic signage are already developed and mature for autonomous driving wheeled vehicles, and these can be adapted to railway specific signals.

Previous weight restrictions limited on-board processing power, and the bandwidth of long-range communication systems did not allow remote processing on a real-time basis. New technologies like 5G could be deployed along the track to provide the range and bandwidth required for an autonomous drone fleet to be in constant communication with a central server that can handle the image processing and send back the metadata required for the drone to safely inspect the signage.

Most commercial drones already feature autonomous static obstacle detection systems, that enable them to get around obstacles before resuming their way to the marked waypoints. A recent state of the art paper list the different methods used for collision avoidance. [12]

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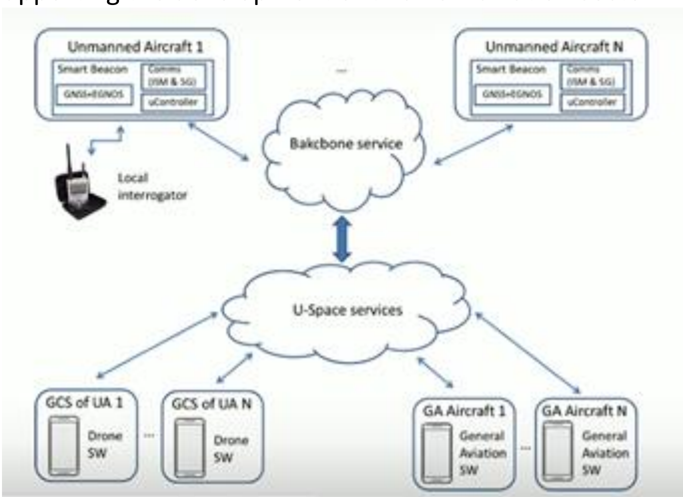
## 6.2 Drone projects with EGNOS

This section contains a set of projects that make use of EGNOS, or at least GALILEO, in their operation.

### 6.2.1 TRACE PROJECT - Smart drone EGNOS-based beacon for U-space

| **Acronym** | **TRACE** |
|---|---|
| **Name** | Smart drone EGNOS based beacon for U-Space |
| **Funding body/Call** | GSA |
| **Execution Period** | 2019 - 2021 |
| **Objective** | The project aims to provide an EGNOS based solution to support drones in its safe and effective integration into U-space, providing services like e-registration, e-identification and pre-tactical geofencing among others.<br>TRACE goals to promote and foster the use of EGNOS in the drone sector by developing a smart beacon that will increase the safety levels of VLL (Very Low Level) operations, supporting the development of this new aviation sector.<br><br>*Figure 9. TRACE smart beacon.* |
| **Related sector** | EGNOS Adoption in Aviation |
| **Link** | [https://www.trace-project.com/](https://www.trace-project.com/) |

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### 6.2.2 REAL (RPAS EGNOS Assisted landing)

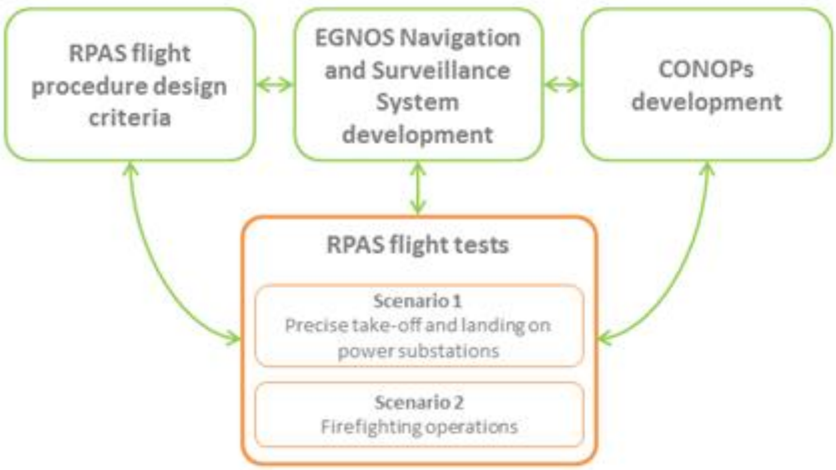
<table>
<tr><th>Acronym</th><th>REAL</th></tr>
<tr><td>Name</td><td>RPAS EGNOS Assisted landing</td></tr>
<tr><td>Funding body/Call</td><td>GSA</td></tr>
<tr><td>Execution Period</td><td>2016 -2018</td></tr>
<tr><td>Objective</td><td>
REAL project has developed an EGNOS-based navigation and surveillance sensor (NSS), which is integrated in two different RPAS vehicles, and coupled to a generic RPAS autopilot and ground station system. Thanks to this new sensor, and to research work in which Concepts of Operations (CONOPs), safety assessments and new adapted design criteria have also been generated, the benefits of using EGNOS-based operations in RPAS field have been demonstrated.<br>
The REAL project aims at four main objectives:
<ul>
<li>develop and integrate an EGNOS navigation and surveillance sensor on two different SAPRs (one for each scenario) in direct support of the navigation function up to a height from which it is possible to carry out the landing using other devices. The position calculated by the EGNOS sensor will also support surveillance functions (for example ADS-B), allowing the remote pilot to maintain awareness of the general operating situation;</li>
<li>develop an operational concept, endorsed by a safety assessment, for the approval of operations, considering the national regulations and the envisaged European roadmap;</li>
<li>perform flight tests to validate navigation and surveillance functions as a support for a safety assessment towards future approval of operations; is</li>
<li>adapt the design criteria of the existing flight procedures considering the dynamic performance of the RPAS systems and the operating environment for each scenario, assuming that, since there are no humans on board, an accident with a drone is not in itself a catastrophe of this study was to highlight the safety benefits provided by the use of EGNOS.</li>
</ul>


Figure 10. REAL project objectives diagram.
</td></tr>
<tr><td>Related sector</td><td>EGNOS Adoption in RPAS sector</td></tr>
<tr><td>Link</td><td>https://www.eurousc-italia.it/en/research-and-development/real/<br>https://sites.google.com/pildo.com/real</td></tr>
</table>

### 6.2.3 REALITY (RPAS EGNOS adoption and liaison with navigation integrity)

| Acronym | REALITY |
|---|---|
| **Name** | RPAS EGNOS adoption and liaison with navigation integrity |

| | |
|---|---|
| **Funding body/Call** | GSA / *GSA/GRANT/06/2017-6* |
| **Execution Period** | 2019 - 2021 |
| **Objective** | The goal of REALITY is to promote the use of EGNOS for safe drone operations, in the short term and in the context of the EU drone operations vision, the U-space.<br>EGNOS could satisfy them.<br>The **REALITY** project will develop an E**GNOS** and **EGNSS** drone navigation activator which will consist of:<br>• **an acquisition of drone navigation data and a real-time performance monitoring system**, hardware / software, to support navigation analysis based on EGNOS;<br>• **a post-processing navigation performance analysis system** to evaluate the error of the EGNOS-based solution supported by the reference system, also calculating integrity and other risk-related figures such as the impact of undetectable errors, instrument errors and **EGNSS** errors;<br>• an automated, cloud-based **post-mission performance monitoring tool** to facilitate massive data management and in-flight performance assessment;<br>• ready-to-use **flight procedures** based on the **EGNOS** instrument and corresponding **RNP** for four applications and operations with relevant and representative drones;<br>• **standard and reference data and demonstrations** collected in more than one hundred flights. This data will be post-processed to provide evidence to industrial stakeholders and to those of the regulatory authorities of the added value of EGNOS and GNSS to drone navigation.<br>The two possible REALITY outputs will be:<br>• new RNP specifications for UAS flight missions tailored for four representative applications of drones;<br>• the analysis of the contribution of EGNOS and EGNSS to drone navigation systems compatible with the specifications of the RNP.<br>Ultimately, the testing campaign of the project demonstrated that RNP 0.01 is achievable in the horizontal plane for slowly moving small UAS at VLL. |
| **Related sector** | EGNOS adoption in aviation |
| **Link** | https://sites.google.com/geonumerics.es/reality-project/home<br>https://www.eurousc-italia.it/en/research-and-development/reality/ |

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### 6.2.4 GAUSS

| | |
|---|---|
| Acronym | GAUSS |
| Name | Galileo-EGNOS as an Asset for UTM Safety and Security |
| Funding body/Call | GSA |
| Execution Period | 2018 - 2021 |
| Objective | GAUSS will aim to use the functionalities and services of EGNOS and Galileo in the field of UAVs with three fundamental goals: improving the positioning, speed, and guidance capabilities of unmanned aerial vehicles; developing detection and mitigation mechanisms for attacks based on jamming (satellite signal interference) and spoofing (fake satellite signal); and applying these improvements to UAVs' air traffic management procedures. |
| Related sector | Positioning system for drones within the U-Space framework |
| Link | https://projectgauss.eu/<br>https://cordis.europa.eu/project/id/776293/es |

### 6.2.5 MULTIDRONE

| | |
|---|---|
| Acronym | MULTIDRONE |
| Name | MULTIple DRONE platform for media production |
| Funding body/Call | Grant agreement ID: 731667 |
| Execution Period | 2017 - 2019 |
| Objective | MULTIDRONE aims to develop an innovative, intelligent, multi-drone platform for media production to cover outdoor events, which are typically held over wide areas (at stadium/city level). The 4-10 drone team, to be managed by the production director and crew, will have: a) increased decisional autonomy, by minimizing production crew load and interventions and b) improved robustness, security and safety mechanisms (e.g., embedded flight regulation compliance, enhanced crowd avoidance, autonomous emergency landing, communications security), enabling it to carry out its mission even against adverse conditions or crew inaction and to handle emergencies. Such robustness is particularly important, as the drone team has to operate close to crowds and may face an unexpected course of events and/or environmental hazards. Therefore, it must be contextually aware and adaptive with improved perception of crowds, individual people and other hazards. As this multi-actor system will be heterogeneous, consisting of multiple drones and the production crew, serious human-in-the-loop issues will be addressed to avoid operator overload, with the goal of maximizing shooting creativity and productivity, whilst minimizing production costs. Overall, MULTIDRONE will boost research on multiple-actor systems by proposing novel multiple-actor functionalities and performance metrics. Furthermore, the overall multidrone system will be built to serve identified end user needs. Specifically, innovative, safe and fast multidrone audiovisual shooting will provide a novel multidrone cinematographic shooting genre and new media production techniques that will have a large impact on the financially important EU broadcasting/media industry. It will boost production creativity by allowing the creation of rich/novel media output formats, improving event coverage, adapting to event dynamics and offering rapid reaction speed to unexpected events. |
| Related sector | Drone fleet autonomy. |
| Link | https://cordis.europa.eu/project/id/731667<br>https://multidrone.eu/ |

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### 6.2.6 5G!DRONES

| | |
|---|---|
| **Acronym** | **5G!Drones** |
| **Name** | Unmanned Aerial Vehicle Vertical Applications' Trials Leveraging Advanced 5G Facilities |
| **Funding body/Call** | N° de convention de subvention: 857031 |
| **Execution Period** | 2019 - 2022 |
| **Objective** | 5G!Drones aim is to trial several UAV use-cases covering eMBB, URLLC, and mMTC 5G services, and to validate 5G KPIs for supporting such challenging use-cases. The project will drive the UAV verticals and 5G networks to a win-win position, on one hand by showing that 5G is able to guarantee UAV vertical KPIs, and on the other hand by demonstrating that 5G can support challenging use-cases that put pressure on network resources, such as low-latency and reliable communication, massive number of connections and high bandwidth requirements, simultaneously. 5G!Drones will build on top of the 5G facilities provided by the ICT-17 projects and a number of support sites, while identifying and developing the missing components to trial UAV use-cases. The project will feature Network Slicing as the key component to simultaneously run the three types of UAV services on the same 5G infrastructure (including the RAN, back/fronthaul, Core), demonstrating that each UAV application runs independently and does not affect the performance of other UAV applications, while covering different 5G services. While considering verticals will be the main users of 5G!Drones, the project will build a software layer to automate the run of trials that exposes a high level API to request the execution of a trial according to the scenario defined by the vertical, while enforcing the trial's scenario using the API exposed by the 5G facility, as well as the 5G!Drones enablers API deployed at the facility. Thus, 5G!Drones will enable abstracting all the low-level details to run the trials for a vertical and aims at validating 5G KPIs to support several UAV use-cases via trials using a 5G shared infrastructure, showing that 5G supports the performance requirements of UAVs with several simultaneous UAV applications with different characteristics (eMBB, uRLLC and mMTC). Using the obtained results, 5G!Drones will allow the UAV association to make recommendations for further improvements on 5G. |
| **Related sector** | 5G usage to communicate with drones |
| **Link** | https://cordis.europa.eu/project/id/857031<br>https://5gdrones.eu/ |

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### 6.2.7 PERCEVITE

| Acronym | PercEvite |
|---|---|
| Name | PercEvite - Sense and avoid technology for small drones |
| Funding body/Call | Grant agreement ID: 763702 |
| Execution Period | 2017 - 2020 |
| Objective | PercEvite will develop a sensor, communication, and processing suite for small drones for autonomously detecting and avoiding “ground-based” obstacles and flying objects.<br>To avoid ground-based obstacles, we aim for a lightweight, energy-efficient sensor and processing package that maximizes payload capacity. Self-supervised learning will allow for a breakthrough in perception range. This will enable effective fusion of stereo vision, motion, appearance, ranging and audio information. Our learning process will allow obstacle detection as far as the camera ‘sees’, rather than the current ± 30 m. For close distances, our solution does without energy expensive active sensors such as lasers or sonar.<br>For collaborative avoidance between drones and other air vehicles, we achieve an interoperable solution by combining multiple communication hardware types (ADSB, 4/5G, WiFi) to exchange information on position, speed, and future waypoints. This will enable drones to successfully avoid other flying vehicles even in a very densely used air space. The probability for a collision in a collaborative scenario will be in the order of 10-9.<br>For non-collaborative avoidance, we rely on sensors and even the communication hardware mentioned above. If a non-collaborative aircraft emits communication signals, for instance to a ground station, this hardware allows to retrieve angular measurements. These measurements can be fused with detection and angle estimations performed with multiple tiny microphones and cameras on board of the detecting drone. We estimate the collision probability in a non-collaborative scenario as 10-6.<br>These performances will be assessed by simulations and extensive real-world tests. The consortium will benefit from the partners’ academic and industrial background with expertise in autonomous flight of very light-weight drones, robust wireless communication, drone design, production, and operation to realize a commercially viable platform. |
| Related sector | Sense and avoid technology |
| Link | https://cordis.europa.eu/project/id/763702<br>https://www.percevite.org/ |

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### 6.2.8 DRONES4SAFETY

| | |
|---|---|
| **Acronym** | **Drones4Safety** |
| **Name** | Inspection Drones for Ensuring Safety in Transport Infrastructures |
| **Funding body/Call** | Grant agreement ID: 861111 |
| **Execution Period** | 2020 – 2023 |
| **Objective** | The Drones4Safety project aims to increase the safety of the European civil transport system by building a cooperative, autonomous, and continuously operating drone system that will be offered to railway and bridge operators to inspect their transportation infrastructure accurately, frequently, and autonomously. The Drones4Safety approach will design energy harvesters to tap energy from the overhead electricity infrastructures of railways and power lines to recharge drones. The project will use satellite and open maps to identify the parts of the transport infrastructure that lays near the electricity infrastructure and feed that information to its drones for scheduling their autonomous missions. The project will develop and improve the state-of-the-art artificial intelligence algorithms to optimize the inspection results onboard of the drone. The project will build a swarm drone system that uses advanced low power long range communication network techniques to inspect different parts of the infrastructure at the same time. Navigation based on advancements in EGNOS/Galileo GNSS will improve accuracy og geo-location of inspection events. The project's outcomes will be offered to the transportation operators in forms of software services and hardware drone system.<br>The project brings together leading industrial, research, and academic experts in infrastructure inspection, energy harvesting, artificial intelligence, communications, and drone technology. Two use cases for bridge and railway inspections will be conducted to evaluate the project outcomes. |
| **Related sector** | Drone usage for railway infrastructure inspection. |
| **Link** | https://cordis.europa.eu/project/id/861111<br>https://drones4safety.eu/ |

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# 7 Ground Control Stations (GCS)

**Ground Control Stations** (GCS) are sets of ground-based hardware and software that allow UAS operators to communicate with and control a drone and its payloads, either by setting parameters for autonomous operation or by allowing direct control of the UAV. [13]

This section describes the most popular GCS platforms and compare their most significant features.

## 7.1 QGroundControl

QGroundControl QGroundControl provides full flight control and mission planning for any MAVLink enabled drone. Its primary goal is ease of use for both professional users and developers, as it is open source. [14]


*Figure 11. QGroundControl GUI. [15]*

### Features:

- Full setup/configuration of ArduPilot and PX4 Pro powered vehicles.
- Flight support for vehicles running PX4 and ArduPilot (or any other autopilot that communicates using the MAVLink protocol).
- Mission planning for autonomous flight.
- Flight map display showing vehicle position, flight track, waypoints and vehicle instruments.
- Video streaming with instrument display overlays.
- Support for managing multiple vehicles.
- QGC runs on Windows, OS X, Linux platforms, iOS and Android devices.

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### Constraints

- **Automatic fleet management is not available**. Although QGroundControl can manage several vehicles at the same time, they have to be managed manually one by one.
- **Lack of security**. QGroundControl is free software, so the developer can have full access to all levels of the UAV, resulting in an event exposure to intruder entering the system itself.
- **Single-drone feed video.** It is only possible to view a single video feed simultaneously in QGrounControl.

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## 7.2 Mission Planner

Mission Planner is a full-featured ground control station application for ArduPilot open source-based autopilots.

Figure 12. Mission Planner GUI (I). [16]

Figure 13. Mission Planner GUI (II). [17]

### Features

- Point-and-click waypoint/fence/rally point entry, using Google Maps/Bing/Open street maps/Custom WMS.
- Select mission commands from drop-down menus
- Download mission log files and analyse them
- Configure autopilot settings for your vehicle
- Interface with a PC flight simulator to create a full software-in-the-loop (SITL) UAV simulator.
- Run its own SITL simulation of many frame's types for all the ArduPilot vehicles.

| Platform | Autopilot | Vehicles | License |
|---|---|---|---|
| Windows, Mac OS X (Using Mono) | MAVLink compatible | - | OpenSource (GPLv3) |

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## 7.3 Horizonmp

HORIZON$^{mp}$ [18]allows both the UAV developer and the end user to access critical information in real time.

### Features:

- Up to eight user-defined sensors can be configured and displayed in three formats: [19]
  - Current sensor values are displayed in an easy-to-read gauge format; warning and danger levels can be set for each gauge
  - The Strip Chart graphs sensor-specific variations over time
  - The Trace Route displays sensor data variations along the UAV's flight path

*Figure 14. Horizon$^{mp}$ GUI.*

| Platform | Autopilot | Vehicles | License |
|---|---|---|---|
| Windows | Micropilot | - | Proprietary |

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## 7.4 DJI Flighthub

DJI's FlightHub software enables the control and organisation of the drone fleet, pilots and flight missions.

### Features

- **Map View**
- **Real-Time View** .
- **Flight Logs and Statistics**
- **Secure Web Access and Cloud Storage**
- **Media Library** transfers flight information including photos and videos directly from the DJI Pilot app into FlightHub.
- **Fleet Management**
- **Team Management** (hierarchy system of Administrators, Captains, and Pilots.)


*Figure 15. DJI Flighthub GUI.*

| Platform | Autopilot | Vehicles | License |
|---|---|---|---|
| Windows | DJI autopilot system | - | Proprietary |

*Intentionally left blank.*

## 7.5 APM Planner

APM Planner 2.0 is an open-source ground station application for MAVLink based autopilots.

**Features**: [20]

- Configuration and calibration of the ArduPilot or PX4 autopilot for autonomous vehicle control.
- Real time monitoring of telemetry information (Quick View & more detailed Status View) and control of UAV.
- Mission planning with GPS waypoints and control events.
- 3DR Radio connection to view live data and initiate commands in flight.

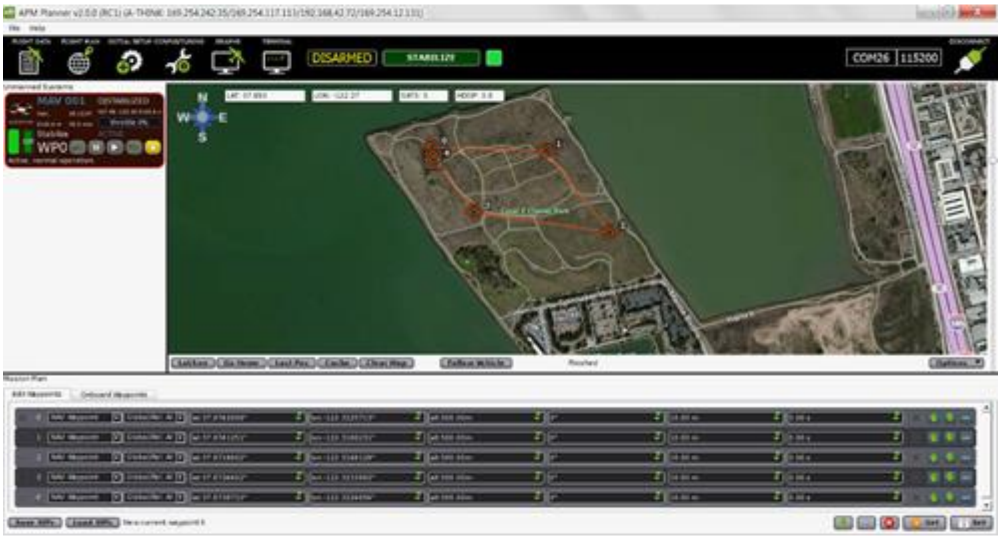


*Figure 16. Planner 2. [21]*

| Platform | Autopilot | Vehicles | License |
| --- | --- | --- | --- |
| Windows, Mac OS X, Linux | MAVLink (APM, PX4,..) | - | Open Source |

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## 7.6 MAVProxy

MAVProxy is a Linux GCS. Primarily a command line interface with graphical modules for map and mission editing.

**Features:** [22]

- It is a command-line, console-based application. There are plugins included with MAVProxy to provide a basic GUI.
- It can be networked and run on any number of computers.
- It is portable; it should run on any POSIX operating system with python, pyserial and select() function calls, meaning Linux, OS X, Windows and others.
- The lightweight design means it can run on small netbooks with ease.
- Supports loadable modules, and has modules to support consoles, moving maps, joysticks, antenna trackers, etc.
- Complete with tabbed commands.

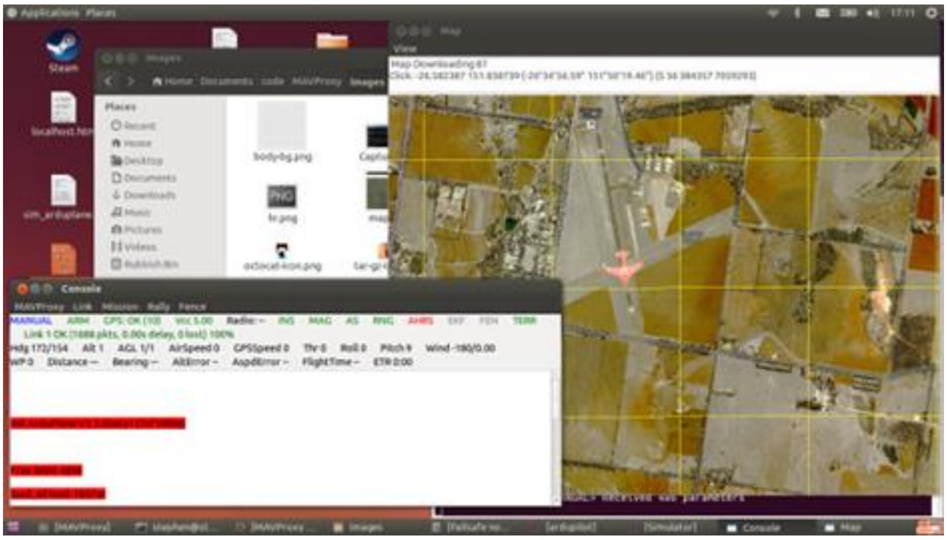

*Figure 17. MAVproxy. [23]*

| Platform | Autopilot | Vehicles | License |
|---|---|---|---|
| Windows, Mac OS, Linux | MAVLink compatible | - | Open Source |

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## 7.7 UgCS – Universal Ground Control Station

UgCS is a safe and efficient toolset for UAV land surveying and industrial inspections. [24]

There are two type of licenses :

1. **UgCS PRO**

Fully functional multi-drone ground control software for professional UAV mission planning. Digital elevation model (DEM) and KML file import enabling map customization, ADS-B receiver support to ensure flight safety.

2. **UgCS ENTERPRISE**

Suitable for companies operating a fleet of different manufacturer drones, requiring a unifying ground station solution. ADS-B transponder support, multinode deployment, enabling operating a central server with unlimited connections to UgCS server.


*Figure 18. UgCS GUI. [25]*

| Platform | Autopilot | Vehicles | License |
|---|---|---|---|
| Windows, Mac OS, Linux | MAVLink compatible (Pixhawk/APM multicopter & helicopter APM Airplane) | DJI M600, M300, M200, Inspire, Phantom 4, Mavic and series, Parrot | Proprietary with a free licence available as well |

## 7.8 Summary of the commercial GCS

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| NAME | PLATFORM | AUTOPILOT | VEHICLE | LICENSE |
|---|---|---|---|---|
| **QgroundControl** | Windows, OS X, Linux, iOS and Android | MAVLink capable autopilots (PX4 Pro, ArduPilot,..) | All vehicle types supported by PX4 Pro and ArduPilot (multi-rotor, fixed-wing, VTOL, etc.) | OpenSource (GPLv3) |
| **Mission Planer** | Windows, Mac OS X (Using Mono) | MAVLink compatible | - | Open source |
| **Horizon MP** | Windows | MicroPilot | Multiple types of UAV including helicopter and fixed-wing | Proprietary |
| **DJI Flighthub** | Windows | DJI autopilots | DJI | |
| **MAVProxy** | Linux | MAVLink compatible | - | Open source |
| **UgCS** | Windows, macOS, Linux | MAVLink compatible (Pixhawk/APM multicopter & helicopter APM Airplane) | DJI M600, M300, M200, Inspire, Phantom 4, Mavic and series, Parrot | Proprietary with a free licence available as well |
| **APM Planner** | Windows, Mac OS X, Linux | MAVLink (APM, PX4,..) | - | Open source |

*Table 1. GCS comparison*

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## 7.9 Fleet Management

Dealing with a large number of drones requires a great amount of paperwork to keep track of their usage and maintenance operations, in order to ensure law abiding safe flights.

Even though the drones will be flying on very well-defined tracks, there are legal requirements that need to be followed, and the proper authorities need to be notified of any operations.

Maintenance operations can also require manual flights, for which licensed pilots are needed.

Future developments in the UAS and UAM sectors will likely see the establishment of key figures to manage fleets of drones when operating at full regime. These may take the form of:

- A Remote Pilot, who can override the automation and take control of the flight if necessary ('human on-the-loop');
- A 'Fleet Manager', equivalent to today's "Flight Dispatcher" ('human out-the-loop') not allowed to take control of the flight, but skilled and equipped to:
    - Plan the flight before take-off;
    - Command flight termination in case of anomalies;
    - Activate the emergency response plan.

In this context, the allocation of tasks proposed by EASA in relation to the levels of automation described in the *EASA AI Roadmap*, as explained in Section 5 , envisages Level 2 of automation to enhance the human-AI collaboration, while maintaining the underlying role of the human-in-the-loop to retain full responsibility. The machine may perform the functions in autonomy, while under active supervision of the human. In Level 3 (A/B) the human is not within the operational loop, but rather in the loop at the design and oversight phases.

A software that helps the user to keep track of the fleet status and keep up with any legal issues limiting their usage would be a great help in operating a fleet of drones.

There are currently several commercially available software packages to manage such drone fleets.

### 7.9.1 Aloft

Offers a central place to plan and review drone operations, keeping track of authorizations and permits for each flight. Allows flights planning and reports with all necessary documentation attached. Provides real time video streaming from the drones, with manual control available if necessary. [26]

### 7.9.2 vHive

Manages several drones to perform tasks cooperatively. Allows mission planning with obstacles and no-flight zones created by the user. Already incorporates AI based identification of assets that need inspection. [27]

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### 7.9.3 Altitude Angel

Provides an API that helps defining no-go areas, and manage multiple drones sharing the airspace with each other and even other man-piloted devices, and fleet management software to keep auditable records of every flight and operation. [28]

### 7.9.4 Alaris Pro

This software helps keeping track of every equipment and gives recommendations on replacing and maintenance of the drones. Although it is not a mission planner, if greatly helps with fleet availability and maintenance record keeping. It also helps keeping track of pilots. [29]

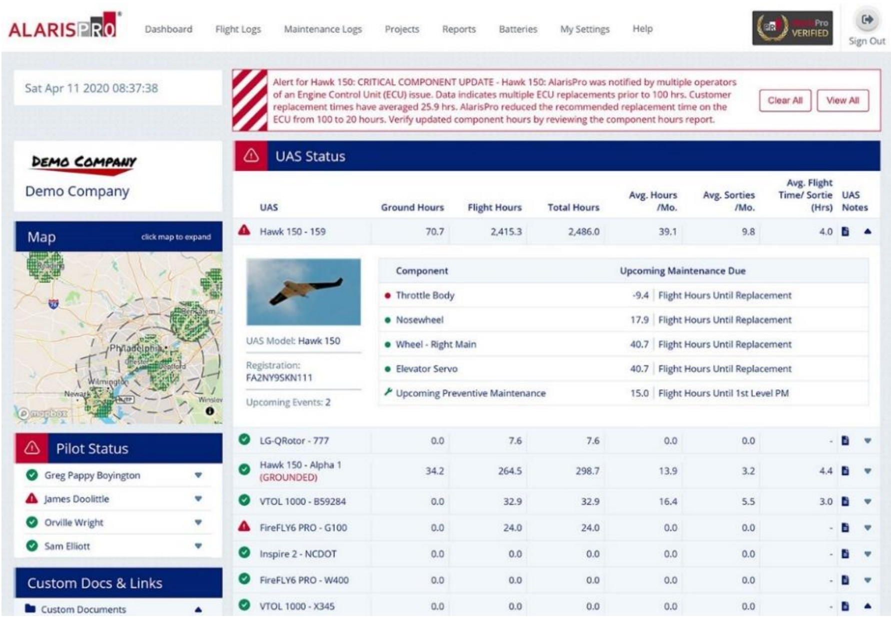


*Figure 19 Alaris Pro GUI example.* [30]

### 7.9.5 Skyward

Personnel and aircraft management tool, with automatic flight logging and records. Includes flight planning and logging. [31]

### 7.9.6 UAVIA

Mission scheduling, collaborative operations, allows running machine learning or computer vision models directly on-board. [32]

# 8 Emerging Industry Standards

With the fast pace of development of UAS technology, aviation authorities recognise consensus-based standards developed by industry and limit scope of their legally binding rules. “Performance-Based Regulation” is the regulatory process through which legally binding rules on the administrative procedures are complemented by detailed consensus-based voluntary standards developed by industry. Consensus-based industry standards may be accepted by aviation authorities as Acceptable Means of Compliance (AMC).

Navigation performance is a crucial aspect of a UAS operation, whose robustness must guarantee to ensure its safety. The reliability and performance of the navigation system directly influences the capability to accurately follow the intended flight trajectory, as well as the accuracy of the geofencing and geocaging functions.

Robust GNSS tracking technology with high reliability and accuracy is therefore essential to minimise operational risks, and, within the context of the project, allow for safe BVLOS operations. GNSS performance is highly dependent on multiple external factors (meteorological conditions, etc.). Moreover, different GNSS performance levels are required in relation to the operation that is being conducted. For example, BVLOS operations in area with complex orography, such as within urban environments and in close proximity of critical infrastructure require a higher performance than operations held in sparsely populated environments, such as over rural areas or above the ocean. Additionally, geofencing and geocaging functions, essential for maintaining the UA within the premises of the railway infrastructure, are highly dependent on GNSS.

It follows that an absence of technical standards defining adequate, operation-specific metrics hinders the operators’ ability to evaluate if the GNSS performance is suitable for the intended operation.

Currently, there is a clear shortage of technical standards adapted specifically for drone operations in this domain, as well as a lack of guidelines to assess the suitability of a specific performance for a certain operation. [33] At present, all existing standards related to navigation performance are designed specifically for manned aviation (i.e., RTCA DO-316: Minimum Operational Performance Standards (MOPS) for Global Positioning System/Aircraft Based Augmentation System Airborne Equipment). While performance parameters (integrity/availability/accuracy) are analogous, specific requirements and test methods show a discrepancy to those applicable to the UAS domain, due to differences linked to operating procedures (flight altitude, applications, speed, etc.).

Other technical standards taken from other sectors (i.e., road) may initially provide a starting point to draft levels of accuracy that may be applicable to drone missions at low altitude, due to the comparable operational restrictions (urban orography and dynamics, etc.).

In a sector such as that of UAS, with an ever-increasing number of applications, it is essential to work on technical standards which provide operation-specific performance requirements, mapped out to typical-use cases and to diverse environments and ecosystems, to avoid having operators developing in-house, case-by-case performance levels.

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At present, Sub-Group 62 ("GNSS for UAS") of Working Group 105 of EUROCAE is developing an important set of standards to fill the aforementioned gaps, having published in 2019 the "Guidelines for the use of multi-GNSS solutions for UAS". These guidelines represent a robust starting point to lay the foundations to the standardisation of GNSS applications tailored specifically for UAS operations, recommending multiple performance levels for GNSS for drone applications (low, medium and high integrity level, in line with the SORA requirements for safety assessments in the EASA Specific Category). Moreover, values for integrity, continuity, availability are also given, alongside causes for GNSSS performance degradation and dependency to external conditions.

While the document only presents initial guidance material, it is expected that the EUROCAE working group will work to expand on MOPS (Minimum Operational Performance Standards) for GNSS in the UAS domain, and it is therefore advised to track the activity of the working group, as the emerging standards will likely correspond to the needs of the project's navigation performance levels.

Finally, the activity of ISO TC 20/SC 16 (UAS) [34] is also to be monitored. "ISO 24355: General requirements of flight control system for civil small and light multirotor UAS", [35] still in Committee Draft stage at the time of drafting of this deliverable, may provide a robust contribution to the technical standard scenario of UAS navigation. The document identifies the composition, functional and performance requirements of flight control for multirotor drones between 150 g and 150 kg, hence being of interest for RADIUS.

# 9 Conclusions and Critical Review

Navigation performance is an essential aspect of UAS operations at VLL to enable safe BVLOS operations, especially when operating within complex environments such as that of the project. Consequently, it is of paramount importance to ensure a very high precision and accuracy, thus entailing low RNP levels. While industry standards are still immature and cannot currently contribute to covering the needs of the project, this document has demonstrated, as have other R&D projects (i.e. REALITY), that commercial off-the-shelf products in combination with currently available technology may provide adequate navigation performance levels to guarantee safe drone operations within a railway ecosystem.

There are already available solutions for fleet management, mission planning, drone navigation, obstacle avoidance, visual based signage identification and even water carrying. As systems integrators we are in the position to pick the most suitable solutions for each and implement or adapt them, as necessary.

For instance, the easiest way to fulfil the objective to not only identify the signage and its state but also being able to perform basic washing as needed, is to adapt an existing agricultural spraying drone. The DJI T16 or T20, for example, should be able to perform these tasks with minimal changes to their spraying systems. Both already support mission planning and can identify and avoid fixed obstacles on the defined pathway. [36]

Other heavy-duty rotor drones could also be used to carry the cleaning system. [37] However, the extra weight of the water that must be carried, as well as the size of the drone itself needed to carry it makes using such drones for scouting operations highly ineffective. Thus, a mixed fleet of smaller, lighter, scout drones to monitor the infrastructure, and heavier, water-carrying cleaning drones, should be used.

The information gathered by the scouting drones can be used to evaluate the need to use the larger cleaning drones only where they are needed, optimizing their usage. Other issues that could require human intervention can also be identified more efficiently and flagged on the same system, where the operator should be able to see the identified issues and make decisions on them.

Algorithms and systems to identify signage are already developed. [38] [39] [40] [41] Vision based obstacle detection and specially rugged drones to allow for small bumps are also becoming available. [42] [43] [44]

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