INTEGRATED COMMON ALTITUDE
REFERENCE SYSTEM FOR U-SPACE

ICARUS

ICARUS ARCHITECTURE & DESIGN

MAY 2022

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INTEGRATED COMMON ALTITUDE REFERENCE SYSTEM FOR U-SPACE

In manned aviation, an aircraft's altitude is determined using various pressure altitude difference measurements. However, since small drones can take off and land almost anywhere, some of these settings aren't as significant in unmanned aircraft flights.

New methods and procedures are therefore needed for large numbers of drones. The EU-funded ICARUS project aims to introduce an innovative solution for common altitude reference inside very low-level airspace. It will define new U-space services and validate them in real operational environments.

With this approach, the Vertical Conversion Service (VCS) will be embedded in an application programme interface that can be queried by a remote pilot or drone based on the actual positioning of the unmanned aircraft.

The present document describes the architecture and design decisions taken after a critical review of present and past studies of the state-of-the-art of the technological solutions needed to define the ICARUS concept services.

Because of the inherent complexities of the technical and operational issues involved in the definition of a Common Altitude Reference System (CARS), the document also comprehensively describes the key concepts that have to be considered to understand these architecture and design decisions.

To get more information about the project ICARUS, please contact us at:

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INTRODUCTION

GLOSSARY OF TERMS

Acronym	Term
ABAS	Airborne-based augmentation systems
AGL	Above ground level
ANS	Air Navigation Services
ATM	Air Traffic Manangement
ATS	Air Traffic Services
ATZ	Aerodrome Traffic Zone
BVLOS	Beyond visual line of sight (operation)
CARA	Common Altitude Reference Area
CTR	Controlled Traffic Region
DAA	Detect and Avoid
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
FL	Flight Level
FTE	Fligth Technical Error
GA	General Aviation
GBAS	Ground-based augmentation systems
GNSS	Global navigation satellite system
GPS	Global Positioning System
HEMS	Helicopter Emergency Medical Service
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules

Acronym	Term
MSL	Mean Sea Level
NSE	Navigation System Error
PDE	Path Definition Error
PPL	Private pilot license
PPP	Precise point positioning
QFE	QFE altimeter pressure setting
QNE	QNE altimeter pressure setting
QNH	QNH altimeter pressure setting
RGIS	Real-time Geospatial Information Service
RPAS	Remotely Piloted Aircraft System
RTK	Real-time kinematics
SBAS	Satellite-based augmentation systems
SME	Small and medium-sized enterprises
TSE	Total System Error
UAS	Unmanned Aerial System
USSP	U-Space Service Providers
UTM	Unmanned Traffic Management
VALS	Vertical Alert Service
VCS	Vertical Conversion Service
VFR	Visual Flight Rules
VLL	Very low level
VLOS	Visual line of sight (operation)

ABOUT ICARUS

Problem statement

Currently there is **no common altitude reference** in manned vs unmanned aviation, or between different drone manufacturers. Traditional methods to determine altitude, and ensure vertical separation, are **based on pressure altitude** while drones and manned aircraft already **use satellite measurements** (GNSS) for navigation purposes.

What is ICARUS

ICARUS are innovative **U-space services** providing its users accurate **height estimation** and **altitude translation** (geometric to/from barometric) for UAS and General Aviation during both the strategic and tactical phases of the flight. Pilots may use the ICARUS service to obtain the terrain profile and known ground obstacles, keeping a common altitude reference as well as augmenting the"level of confidence" on the vertical position.

ICARUS benefits

The U-space service that ICARUS will develop and validate can be **used by drone and manned aviation** to obtain their current altitude, using a Common Altitude Reference, as well as distance from the ground or known obstacles.

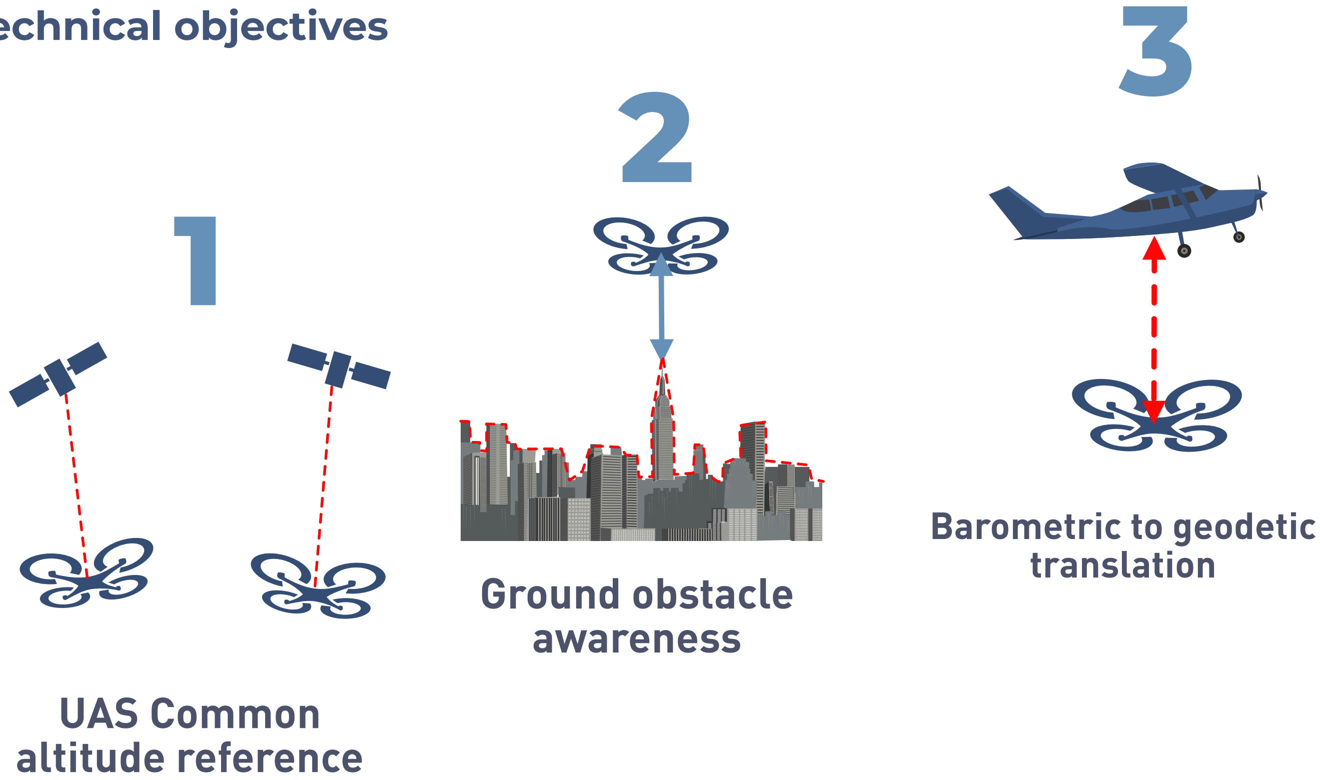
This innovative service will increase the **safety of operations**, boosting long distance (BVLOS) operations, increasing the **capacity of congested low level airspace** and further the **integration of drones** with traditional manned aviation.

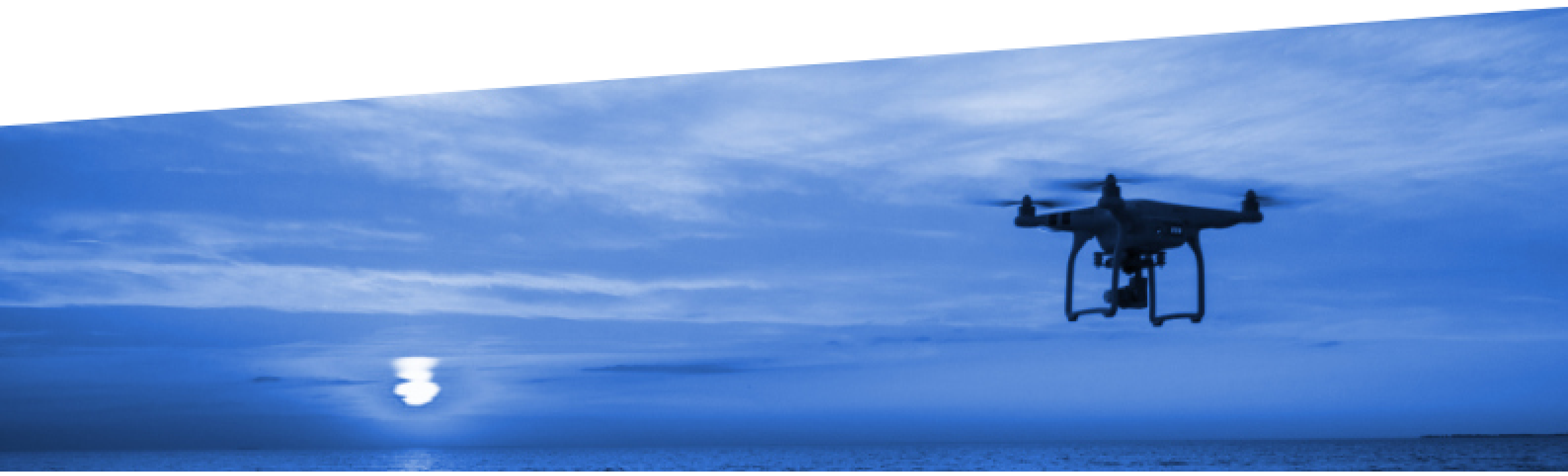
Project timeline

- **May 2020** – Project start
- **Oct 2020** – Online survey
- **Nov 2020** – Prototype service design
- **Apr 2021** – Digital simulation
- **Sep 2021** – Validation
- **May 2022** – ICARUS CONOPS
- **Jul 2022** – Project end

ICARUS addresses the Application area 2: Common altitude reference of the SESAR 2020 Exploratory Research 4 (ER4) call (H2020-SESAR-2019-2)

Technical objectives





THE ICARUS CONSORTIUM

e-Geos

e-GEOS is a leading international player in the Earth Observation and Geo-Spatial Information business. offering a unique portfolio of application services and has acquired leading position within the European Copernicus Program

DiCEA – Sapienza

DICEA, the Department of Civil, Constructional and Environmental Engineering at Sapienza, ensures scientific excellence and quality education in all branches of civil and environmental engineering, architectural design and urban planning

Droneradar

Founded in 2015 by the co-creator of PansaUTM. Developer of Droneradar mobile application, used in Poland by more than 500 000 users. Co-author and co-developer of Data Driven SORA platform. Droneradar is involved in many European VLD and R&D projects.

Eurocontrol

Eurocontrol is a pan-European, civil-military organisation dedicated to supporting European aviation

EuroUSC España

EuroUSC España is an aviation safety consulting company, specialized in Unmanned Aerial Systems (UAS) and Remotely Piloted Aircraft Systems (RPAS). Our services cover the entire workflow of a successful UAS operation

EuroUSC Italia

A consultancy company covering all domains relevant for the civil UAS industry and drones flying under GAT rules. A leading expert in standardisation, regulation, safety assessment and Education on RPAS safety and security

Politecnico di Milano

An Italian technical university, offering courses in engineering, architecture and design. The Department of Civil and Environmental Engineering (DICA) covers many disciplines, also including Geodesy and Geomatics

Telespazio

One of Europe's leaders and world's main players in satellite solutions and services providing also new innovative business solutions for remotely piloted aircraft and supporting the design of the new U-Space platform. Telespazio has its HQ in Rome, Italy, includes e-GEOS, operates worldwide through a wide network of space centres and teleports.

TopView

An Italian Engineering SME offering drones and IoT based systems tailored for industry and service providers to enhance their processes. TopView has joined several U-space projects as partner and advisory board member

WHY A COMMON ALTITUDE REFERENCE?

Traditional aviation

Traditionally in manned aviation, the acknowledged method of determining the altitude of an aircraft was based on pressure altitude difference measurements referred with respect to to a common datum and using the ICAO standard atmosphere (ISA).

The barometric altitude references **do not provide true heights**, just approximations of height based on the fact that atmospheric pressure decreases with altitude (albeit in a somewhat irregular way).

Within this model, different references are used to define different common altitude references that are used at various stages of the flight, based on the type of flight (visual or instrumental) and the airspace being flown.

Thus, we have three main references, For low level flights there are **QNH** (altitude above sea level) and **QFE** (altitude above airfield elevation) and for high level flights, **QNE** (altitude based on an ideal standard pressure). This complex model has been used since 1928, so it has become an acquired behaviour for manned pilots all around the world.

Even though barometric altimeters do not provide real heights, as long as this system is **followed by all pilots in a consistent way** (i.e. using properly calibrated barometers and selecting the appropriate barometric setting at each point) it provides a common reference to ensure adequate vertical separation. In other words, two different pilots flying near each other will both receive inaccurate height readings, but at least they will use the same wrong values. On the other hand, barometric altitude is not really adequate to ensure vertical separation with obstacles on the ground.

Unmanned aviation

Unmanned Aviation superimposes new challenges. Since a small drone may take off and land almost from everywhere the concept of QFE is not relevant. Also, UAS fly usually between (or even below) certain obstacles on the ground. Finally, Urban Air Mobility (UAM) scenarios have the potential to involve flight densities that are unknown to manned aviation.

For these reasons, a new Common Altitude Reference paradigm such as the one promoted by ICARUS for unnamed aviation is required.

KEY CONCEPTS

WHAT IS U-SPACE

U–space is a set of new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. These services rely on a high level of digitisation and automation of functions. These functions may be on board the drone itself, or be part of the ground–based environment. U–space enables and support routine drone operations, as well as a clear and effective interface to manned aviation, ATM/ANS for service providers and authorities.

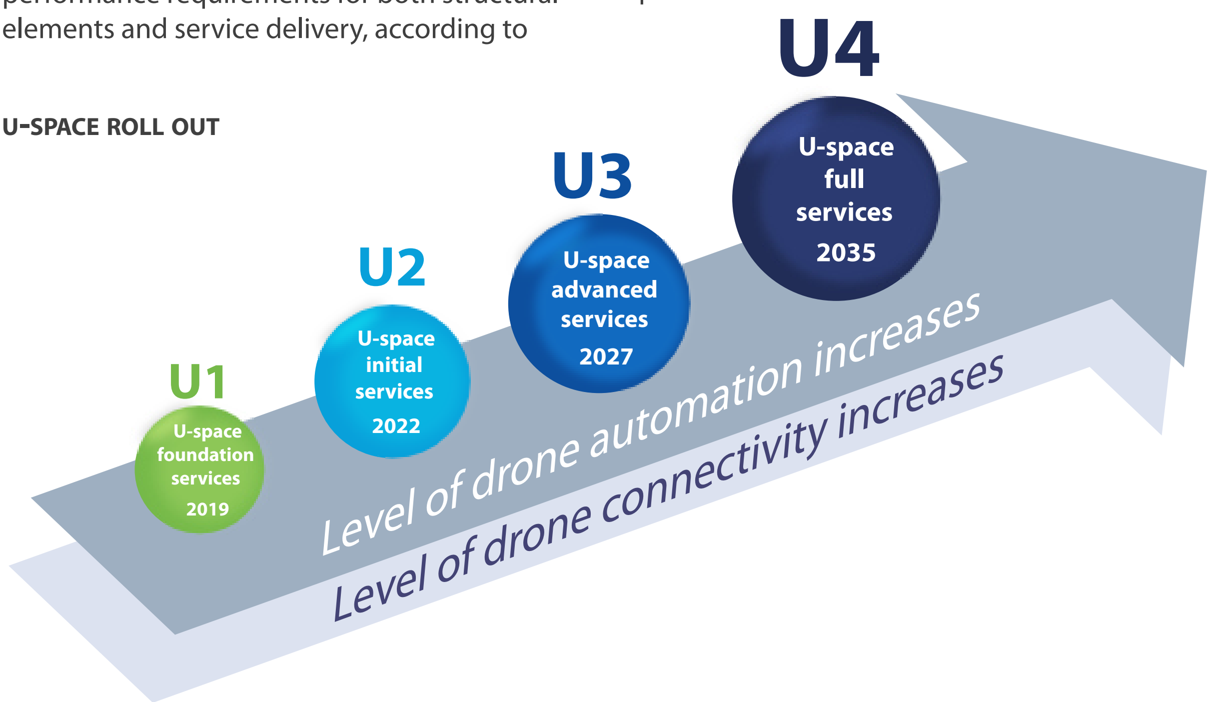
U–space will be capable of ensuring smooth operation of drones in all operating environments, including urban areas, and in all airspaces, in particular in VLL airspace. It will address the need to support the widest possible variety of missions concerning all drone users and every category of UAS operations, as defined by EU Commission Regulation on unmanned aircraft operations. Aviation authorities will establish the performance requirements for both structural elements and service delivery, according to the critical nature of the provided services, and covering safety, security, availability, continuity and resilience.

U–space service providers will deliver the U-space services within the given U–space environment. These services do not replicate the function of ATC, as known in ATM. Instead, they will deliver key services to organise the safe and efficient operation of drones and ensure a proper interface with manned aviation, ATC and relevant authorities.

U–space roll out

The progressive deployment of U–space is linked to the increasing availability of blocks of services and enabling technologies. Over time, U–space services will develop as the level of automation of drones increases, and advanced forms of interaction with the environment are enabled, mainly through digital information and data exchange over a cloud–based platform.

U-SPACE ROLL OUT



- **U1 - U–space foundation services** provide e–registration, e–identification and basic geofencing services.
- **U2 - U–space initial services** support the management of drone operations and may include flight planning, flight approval, tracking, airspace dynamic information, and procedural interfaces with air traffic control.
- **U3 - U–space advanced services** support more complex operations in dense areas and may include capacity management and support for conflict detection. The availability of automated DAA functionalities and more reliable means of communication will lead to a significant increase in the number of operations in all environments. But it will require a more robust framework.
- **U4 - U–space full services**, particularly services offering integrated interfaces with manned aviation, support the full operational capability of U–space. They will rely on top level automation, connectivity and digitalisation for both the drone and the U–space system.

U-space principles

The delivery of U-space relies upon the following key principles:

- Ensure the safety of all airspace users operating in the U-space framework, as well as people on the ground.
- Provide a scalable, flexible and adaptable system that can respond to changes in demand, volume, technology, business models and applications, while managing the interface with manned aviation.
- Enable high density operations with multiple automated drones under the supervision of fleet operators.
- Guarantee fair access to the airspace for all users.
- Enable competitive and cost-effective service provision at all times, supporting the business models of drone operators.
- Minimise deployment and operating costs by building, as much as possible, on existing aeronautical services and infrastructure, including GNSS, as well as those from other sectors, such as mobile communication services.
- Follow a risk-based and performance-driven approach when setting up requirements for safety, security (including cyber-security) and resilience (including failure mode management), while minimising environmental impact and respecting the privacy of citizens, including data protection issues.

U-space is a collection of services that will unlock the full potential of UAS operations

U-SPACE SERVICES

As described in the previous section, U-space is a collection of services. The diagram of the next page shows planned services for U1, U2 and U3 that are related to safety and security. U-space service providers will probably develop additional business-related services and will offer them to drone operators to enhance their operations.

ICARUS U-space services

ICARUS proposes the definition of a new U-space service (U3) for the transformation of geodetic height measurement to the barometric reference system and vice versa. The conversion is based on introducing GNSS-based altitude measurement for drones, tightly coupled with the interface with existing or planned U-space services such as Tracking, and Flight Planning services.

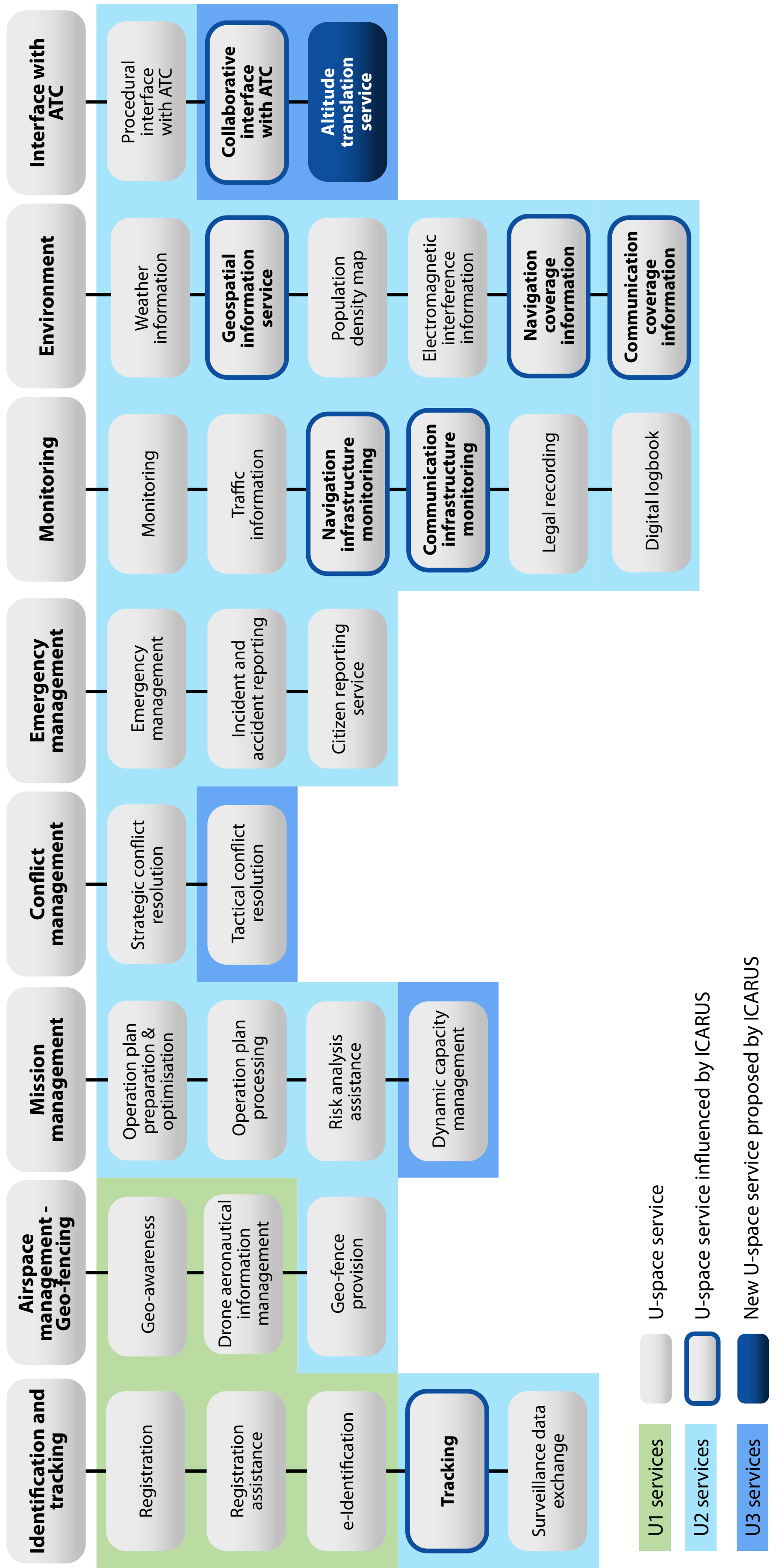
The services provided by ICARUS will allow complex operations to be supported in dense areas. They will facilitate obstacle conflict detection and avoidance, leading to significant increases in operations in all environments. ICARUS will support the most challenging use cases, including those taking place in urban areas.

The users of the ICARUS services will be remote pilots flying VLOS or BVLOS conducting UAS operations in the Specific category. Also ultralight and general aviation pilots that might share the same VLL airspace. Considering the increased level of automation and connectivity expected at U-space level 3, the drones themselves will also be users of the ICARUS services.

ICARUS will enhance the capacity of the airspace, especially in an urban environment where many promising activities as package delivery and drone taxi applications will take place in Europe in the coming years.

ICARUS will enhance several U-space planned services and proposes a new U3 level custom service

U-SPACE EXISTING AND PLANNED SERVICES



VLL AIRSPACE

U-space divides the whole of VLL airspace into three different volumes. These volumes include the "UAS geographical zones" mentioned in the European UAS regulations.

The motivation for creating these different volumes includes differences in:

- The numbers of flights expected
- The ground risk—and in particular, the population density
- The air risk—the number of other flights in the volume, both manned and unmanned
- Public acceptance factors
- The U-space services that are needed to enable safe operations

These volumes differ in two ways; the services being offered and hence the operation which are possible, and their access and entry requirements.

Three airspace volume types are identified and referred to as X, Y and Z. The totality of VLL airspace is X, Y or Z.

The most significant difference in the three volumes is the provision of conflict resolution services:

- X: No conflict resolution service offered
- Y: Only pre-flight ("strategic") conflict resolution offered
- Z: Both pre-flight ("strategic") conflict resolution and in-flight ("tactical") conflict resolution offered

These differences have a large impact on how UAS should fly in that airspace and what type of operations can be conducted.

X Volumes

There are few basic requirements for the operator, the pilot, or the UAS for accessing airspace type X, but as a result, few services are available.

In X volumes, the pilot remains responsible for separation at all times. VLOS flights are easily possible. Other types of operation in X require significant attention to air risk mitigation.

X volumes are expected in regions with both:

- Low demand for U-space services, either due to there being few flights, or there being a particular focus on Open category operations
- Low ground and air risk

Y Volumes

Access to Y requires an approved operation plan. Y airspaces may have specific technical requirements attached to them. Demonstrating compliance with these requirements is part of the operation plan approval process.

These technical requirements will usually include:

- A remote piloting station connected to U-space
- A UAS capable of position report submission

Y volumes facilitate VLOS and BVLOS flight. In Y volumes, there are risk mitigations provided by U-space which are not available in X. But the effective use of these services will require trained pilots.

In Y airspace, conflict resolution between flights is resolved before take-off, which enhances safety, but reduces flexibility.

There are various scenarios that will dictate the creation of Y volumes:

– Areas where the ground or air risk determined by a SORA or otherwise are too great for an X volume. For example, where there is significant air unmanned traffic or over a densely populated area

– In response to a significant demand to fly BVLOS operations

– To limit access, for example, at a national park

Z Volumes

Z volumes allow higher density operations than Y, and hence are expected in areas where traffic demand exceeds the capacity of Y, or there is a particular risk.

Just as for Y, access to Z requires an approved operation plan, and additionally:

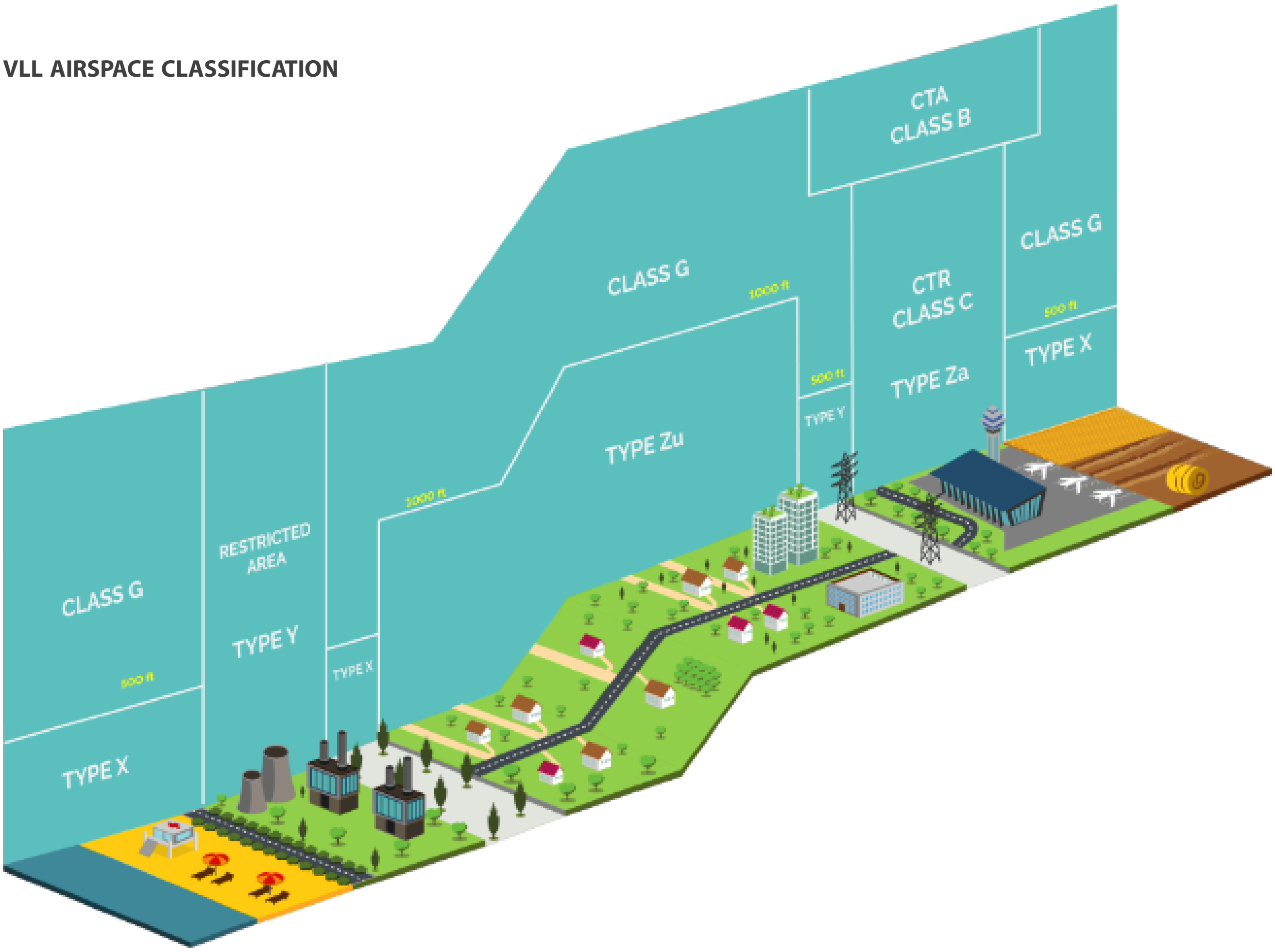
– The pilot continuously connected to U-space

– Position report submission for the aircraft with enough performance to enable tracking

Z airspaces may have specific technical requirements attached to them, and demonstrating that they are met is part of the operation plan approval process.

Z volumes have a tactical conflict resolution service. This may be supplied by U-space in which case the volume is known as Zu, or the volume may be controlled by ATS when it is known as Za.

VLL AIRSPACE CLASSIFICATION



BAROMETRIC ALTIMETRY

Traditionally in manned aviation, there are three acknowledged methods of determining the altitude of an aircraft using a pressure difference with respect to an specified reference, using standard aviation altimeters, calibrated to the International Standard Atmosphere or ISA:

- **QFE** is the atmospheric pressure at a specific point such as an airfield runway threshold. The aviation altimeter estimates the height of the aircraft above the runway from the differential pressure between the QFE setting and the measured static pressure surrounding the aircraft.

  The advantage of QFE is that the altimeter will mark zero when taking off or landing from the corresponding runway.

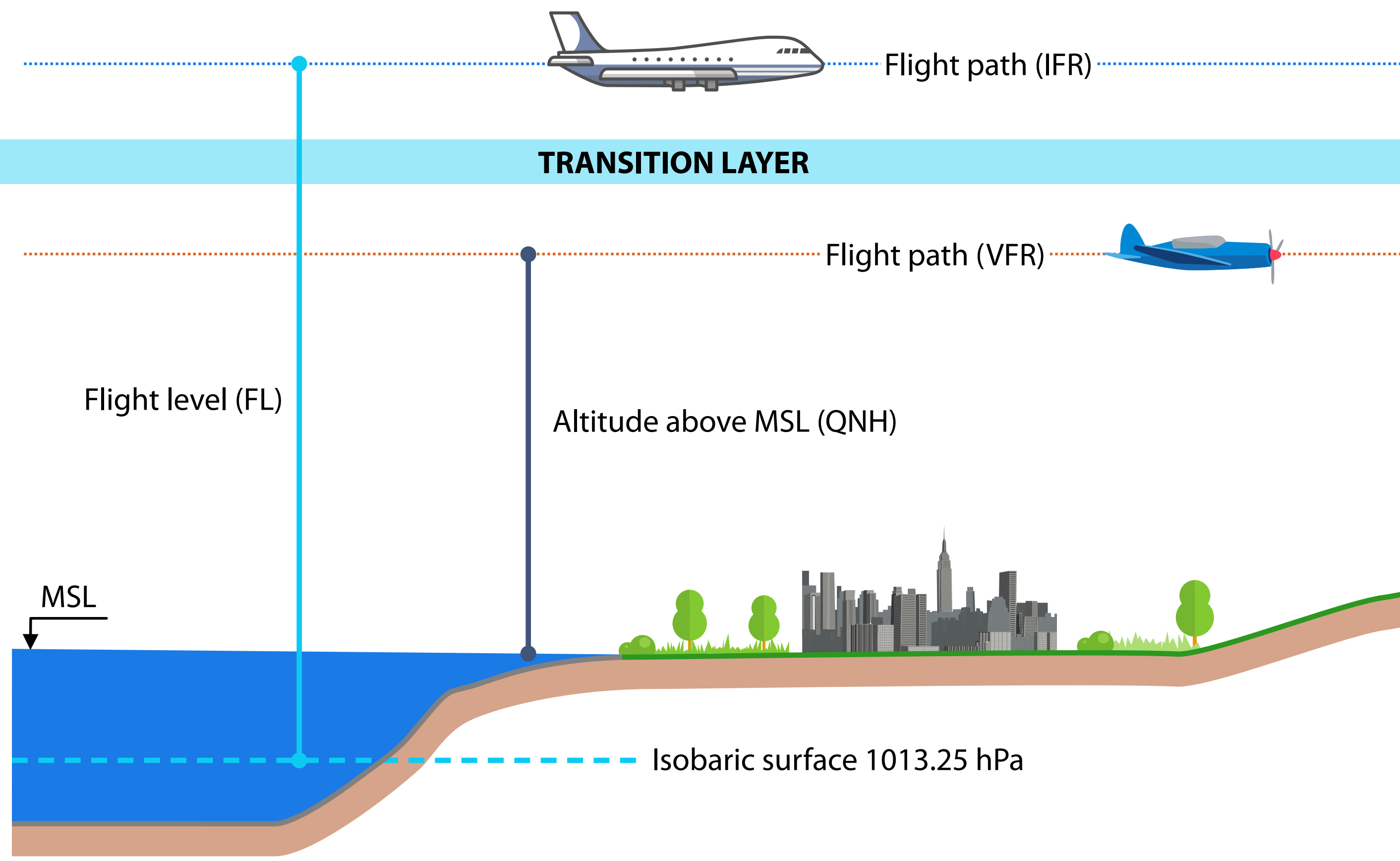
- **QNH** is the atmospheric pressure that would occur at mean sea level in a particular region. Outside of coastal regions it's value is calculated from the elevation and pressure at a wheather station.

  When the altimeter is set to the local QNH, the value corresponds to the altitude of the aircraft above MSL.

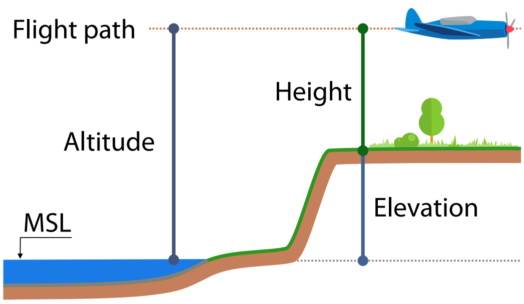
- **QNE** a Flight level (FL) is the vertical distance of an aircraft above the Isobaric Surface of 1013.25 hPa (hectopascals). One FL is the pressure difference of 100 ft of altitude change in the ISA.

  Flight levels only apply to IFR flights above a certain altitude (typically 3,000 ft AGL) and therefore are less relevant to ICARUS.

AVIATION BAROMETRIC ALTIMETRY



Altitude, elevation and height



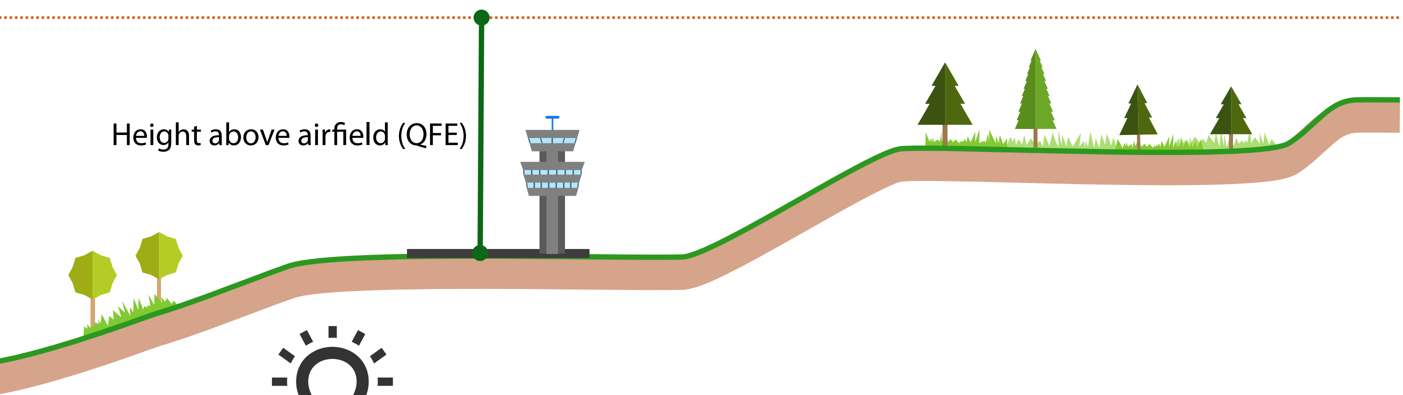
These three terms have a very precise meaning in aviation:

- Altitude is the vertical distance of an aircraft above the MSL
- Elevation is the vertical distance of the terrain or an obstacle above the MSL
- Height is the vertical distance of an object (including an aircraft) above a particular surface (other than MSL)

When all aircraft use the same barometric common reference, they can maintain the minimum separation required between them.

But the pressure references change all the time as the aircraft moves from one place to another, and even at the same place over time.

For that reason, pilots have to adjust the settings of their altimeters to ensure that they are able to maintain their vertical separation at all times.



Traditional aviation has relied in a barometric altimetry paradigm to conduct its operations. Although this system is not adequate for most UAS operations in VLL, drones still need to support it for interoperability with manned aviation

GEODETIC ALTIMETRY

Geodesy and surveying use different height definitions. Before GNSS, orthometric (and normal heights, which are not discussed in this document) were common, since they can be obtained by observing height increments between inter-visible points through levelling.

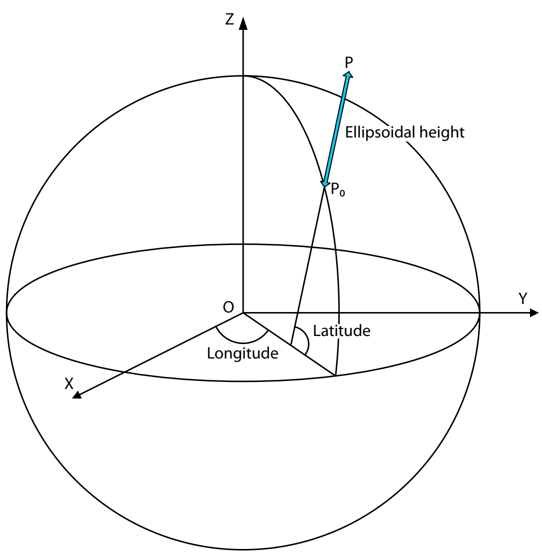
With the advent of the GNSS technology in the 1990s, coherent global ellipsoidal heights have been made available to users. Ellipsoidal heights can be estimated with respect to a given geocentric reference ellipsoid in a fast and precise way using GNSS techniques.

However, especially in aviation applications, flight altitude is also determined through an atmospheric pressure observation that is usually related to orthometric heights.

Ellipsoidal height

Its definition is purely geometric and does not involve the Earth's gravity field as with orthometric and normal heights. It is based on an ellipsoid of reference centered on the Earth's centre that best approximates the Earth's surface.

ELLIPSOIDAL HEIGHT



As shown in the diagram, the ellipsoidal height of a point P is the distance along the normal to the ellipsoid from the point to the intersection of the normal to the ellipsoid (P_0).

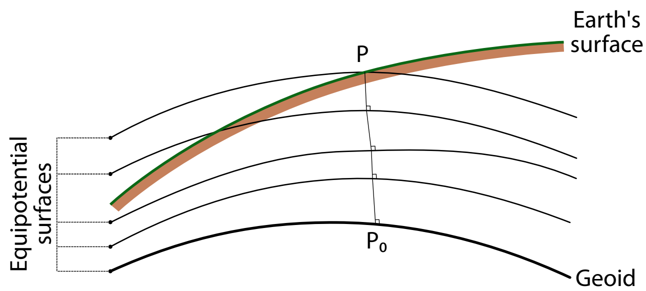
Orthometric height

The definition of the orthometric height is strictly related to the Earth's gravity field. Given the gravity potential, equipotential surfaces join points that have the save gravity potential, and plumb lines are the lines orthogonal to the equipotential surfaces.

The geoid is a particular equipotential surface that coincides with the MSL with a minimum discrepancy (1-2 m at global scale) and extended over land areas by analytical methods.

The orthometric height of a point P is the length of the plumb lines between P and P_0, lying on the geoid.

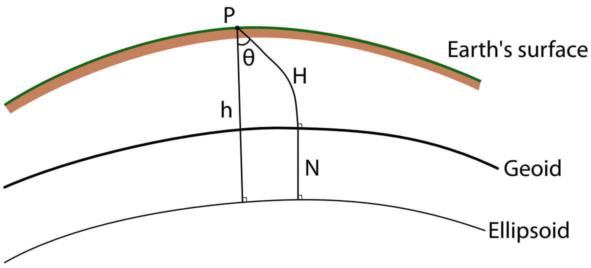
ORTHOMETRIC HEIGHT



Orthometric and ellipsoidal height conversion

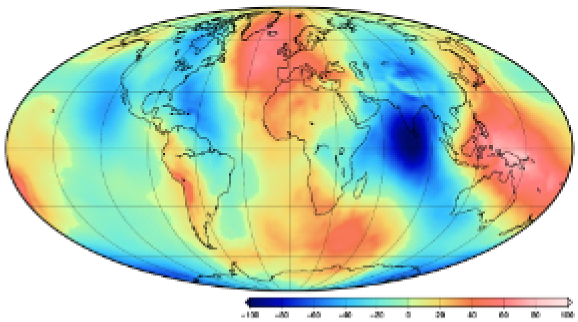
The following diagram shows the relationship between the orthometric height (h) and the ellipsoidal height (H). Note that H is not a straight line and that h and H are slightly rotated.

ORTHOMETRIC AND ELLIPSOIDAL HEIGHT CONVERSION



At each point, the geoid undulation (N) is the distance between the geoid and the ellipsoid. There are global, continental and national geoid models available that provide the values of the geoid undulation on regular grids. Linear interpolation provides the undulation at points that are not in the grid.

GLOBAL GEOID MODEL



Orthometric and ellipsoidal heights can be approximately converted, performing an algebraic sum of the geoid undulation to the orthometric height or the ellipsoidal height respectively. The error introduced by this simple conversion method is of the order of a few tenths of millimetre, that is much lower than the observation accuracy of h, H, and N.

Orthometric height and atmospheric pressure

Strictly speaking, the relationship between atmospheric pressure and orthometric height is not a conversion between two height systems, but it can be aproximated using equations derived from the ideal gas law.

ICARUS will need to convert in real time between the different geodetic and barometric references in order to provide its services

GNSS POSITIONING

Using GNSS for drone positioning is essential, thanks to the worldwide availability and continuity of this technology in the provision of positioning services. The improvement in terms of accuracy of the original GPS system , and the spatial and frequency diversity guaranteed by the new constellations deployed such as Galileo, make this technology even more promising and provide better performance.

Moreover, the existing augmentation technologies allow high levels of accuracy and reliability to be reached. For the safe execution of BVLOS operations, GNSS is the preferred choice for navigation.

Service parameters

To evaluate the suitability of a GNSS solution, the following service parameters have to be considered:

- **Accuracy**: The accuracy is conformance of the reported position with the correct position. Accuracy is a statistical measure of performance and should include a statement of the implied uncertainty. For instance, civil aviation requirements measure accuracy at the 95th percentile and consider accuracy a global system characteristic.

- **Integrity**: The measure of trust in the information supplied by a navigation system is called integrity. It includes the ability of the system to provide timely warnings to users when the system is not adequate for navigation. Integrity requirements are usually between 99.999% and 99.9999999% and they involve alarms being raised when a system's performance might become risky. Integrity is a real time decision criterion for using or not using the system at a particular moment and is defined by a set of parameters:

  - **Alert Limit**: The error tolerance that should not be exceeded without issuing an alert.
  - **Time to Alert**: The maximum time elapsed from the onset of the navigation system being out of tolerance until the equipment starts the alert.
  - **Integrity Risk**: The probability that, at any moment, the error exceeds the alert limit.
  - **Protection Level**: Statistical error bound computed to guarantee that the probability of the position error exceeding a particular value is less than the target integrity risk.

- **Continuity**: The continuity of a system is the ability of the system to perform its function without interruption during the intended operation. It is measured as the probability that the system will maintain its performance for the duration of a phase of operation, if it was available at the beginning.

- **Availability**: The availability of a navigation system is the percentage of time that the services of the system are usable by the navigator (i.e. the performance of the system is within the requirements.)

Standalone GNSS

Standalone GNSS positioning is the most basic and cheapest solution. It provides free global access to positioning. A GNSS receiver can process single-frequency measurements from a single constellation (typically GPS) or multiple GNSS constellations.

Including the Galileo constellation provides many advantages, such as improved geometry and availability of signals, both in terms of satellite and frequency diversity, better performance and accuracy that rivals that of augmented solutions and the fact that Galileo is a civilian and Europe-controlled system with no political issues, free access, and worldwide coverage.

However, the use of standalone, non-augmented GNSS for drone positioning and navigation is discouraged, since it has many disadvantages and weaknesses:

- GNSS signals, if used without precaution, are vulnerable to malicious actors: jamming, spoofing, etc.
- GNSS signals are vulnerable to multi path and unintentional interference
- Vulnerability to system faults (ground segment faults, satellite failures, signal generation failure) or Signal in Space propagation errors, without provision of timely warning to the user
- Loose guarantees for Signal in Space accuracy
- There are no indications regarding the integrity of the solution, and the guaranteed accuracy is too low, at least for safety-critical and liability-critical applications

Augmented GNSS

There are five different strategies to improve the service parameters of GNSS positioning. They solve many of the disadvantages mentioned above, but they require additional hardware and usually the payment of a fee to access the service. The main augmentation systems in place are:

- Real-time kinematics (RTK)
- Precise point positioning (PPP)
- Satellite-based augmentation systems (SBAS)
- Ground-based augmentation systems (GBAS)
- Airborne-based augmentation systems (ABAS)

ICARUS approach

From a navigation point of view, the main objective of the project is to provide an adequate reliable, accurate and timely drone positioning service to the entities that interact in the operational scenario. In this way, the ICARUS service will guarantee the ability to have full situational awareness, and reliable and accurate control and tracking, providing height measurements through a common altitude reference system.

The main advantages of the proposed ICARUS architecture are:

- Reduced requirements for the equipment on-board the drone
- Relatively low throughput needed for communication and low latency
- The installation of the SBAS state machine on a centralised entity, providing all the advantages at a reduced cost
- All software will run on a ground system with potentially unlimited hardware resources, that are fully scalable
- Changes and upgrades of the algorithm or processing standard will need just one central entity to be upgraded with validated or certified software
- Possibility to certify the positioning data used by the ICARUS users

GNSS positioning is the preferred choice for drone navigation. ICARUS will build on this

DIGITAL ELEVATION MODELS

Digital Elevation Model (DEM) is a generic term, without a particular specification, that applies to the discrete representation of the surface of the Earth using points that are placed on a regular grid (GRID data format) or irregularly (TIN data format).

The horizontal position of each point is expressed in a chosen reference frame (globally WGS84 and ETRF2000 in Europe) and the height is orthometric or ellipsoidal.

- **Digital Surface Model** (DSM) is a discrete representation of the surface of the Earth visible from space, including vegetation, buildings, and infrastructures.
- **Digital Terrain Model** (DTM) is a discrete representation of the surface of the bare ground.

A filtering process to remove all objects can derive a DSM from a DTM. The resulting DTM depends on the algorithm used and its vertical accuracy gets degraded from that of the original DSM.

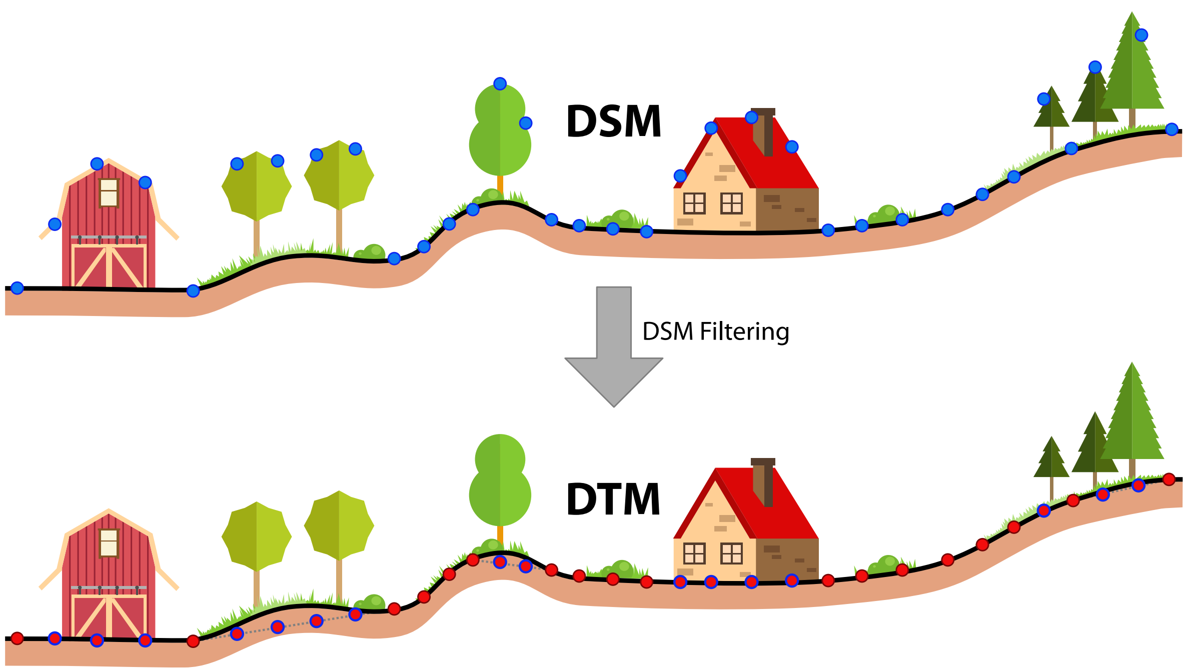
Obstacles

Obstacles in aviation terms are features with a vertical significance compared with the surrounding terrain or surrounding features that constitute a potential hazard to aircraft operations.

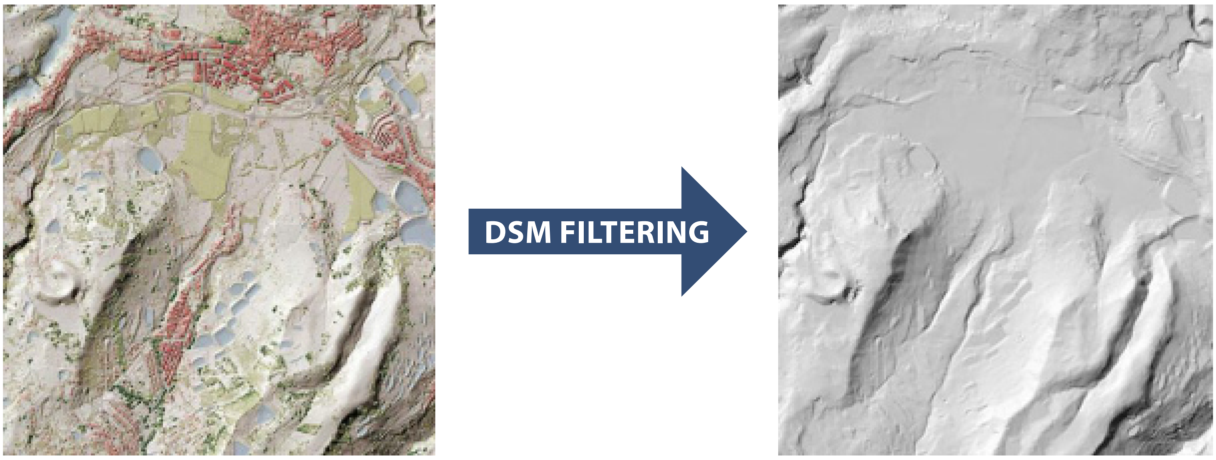
According to ICAO, obstacles are both fixed (whether temporary or permanent) and mobile objects, or parts thereof, that:

- Are located on an area intended for the surface movement of aircraft
- Extend above a defined surface intended to protect aircraft in flight
- Stand outside those defined surfaces and have been assessed as being a hazard to air navigation

DSM AND DTM



DSM FILTERING TO DERIVE DTM



Therefore, the DSM is the discrete representation of the surface, defining the physical boundary for aeronautic purposes, that contains the obstacles that are permanent or were present at the moment of compilation of the DSM.

ICARUS will use Digital Surface Models for its obstacle alert service

ICARUS ARCHITECTURE

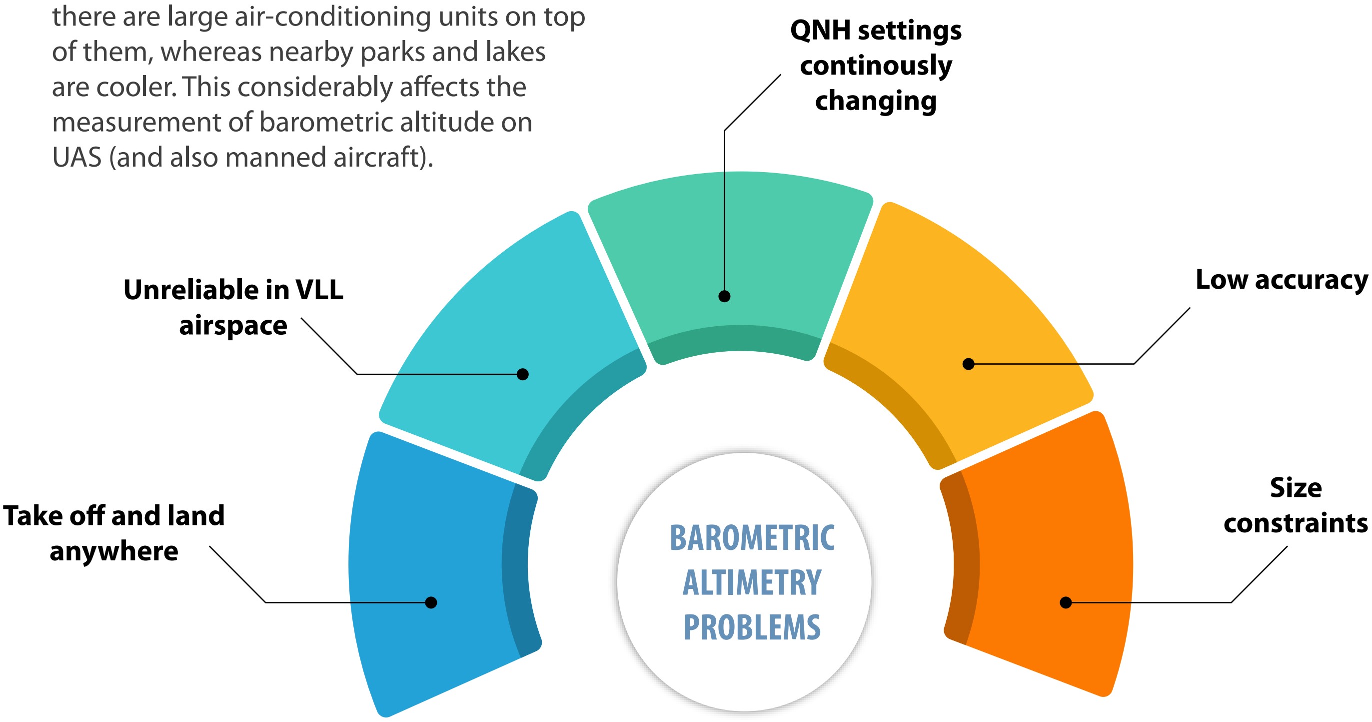
PROBLEM STATEMENT

Barometric altimetry limitations

Barometric altimetry is a legacy system that is only maintained because of the conservative nature and the extremely low density of traffic that is characteristic of traditional manned aviation.

For unmanned aviation operating in VLL, barometric altimetry is not adequate, for the following reasons:

- A small drone may take off and land almost from everywhere ("Home Point"), reducing in this way the original significance of QFE settings.
- Barometric pressure altitude is not very accurate in VLL airspace, atmospheric pressure is difficult to measure over cities because of high temperature gradients: buildings radiate heat, in particular when there are large air-conditioning units on top of them, whereas nearby parks and lakes are cooler. This considerably affects the measurement of barometric altitude on UAS (and also manned aircraft).
- Air pressure is not constant but changes over time, so the (regional) QNH does as well. When using barometric altimetry for de-confliction between different airspace users, UAS need to know the evolution of QNH and change their QNH setting during the flight.
- The certified resolution of the barometric measurement in manned aircraft is 25 ft, which is very coarse for VLL. In addition, such accuracy is only possible using equipment whose size is unfeasible for small drones.
- In traditional aircraft, the sensors are far away from the propellers, while in a drone the rotors could be quite close to the pressure sensors causing constant changes in pressure and thus difficulties in measuring air pressure.



SOLUTION

GNSS-based common vertical reference

Ground obstacle avoidance U-space service

Geodetic to barometric height conversion

ICARUS approach

Taking these considerations in mind, the ICARUS project aims to answer the following questions:

- What technology is more appropriate to measure the altitude at which a UA is flying, and to what precision, accuracy and integrity values?
- What procedural mitigations are possible to harmonise the common altitude reference problem for drones and other users of the same VLL airspace?
- What reference datum ensures that every user of an airspace is flying using the same altitude/height reference system?

ICARUS aims to address the Common Altitude Reference challenge by proposing a new approach based on GNSS-based altimetry, providing information to UAS pilots and GA pilots on the real vertical distance to the ground, translation between barometric and GNSS-based altitude and information regarding ground obstacles and buildings during the flight planning and execution phases.

ICARUS provides the answer to the previous questions with a collection of services based on:

- Introducing GNSS-based altitude measurement for the challenge of a UAS-RPAS vertical common reference datum
- Provision of a tailored U-space service for ground obstacle mapping and terrain profile information
- A height transformation service (geodetic measurement to barometric reference system and vice versa) as a solution for UAS-GA flight integration into VLL airspace.

ICARUS solves the main problems and limitations imposed by both barometric and geodetic height estimation paradigms

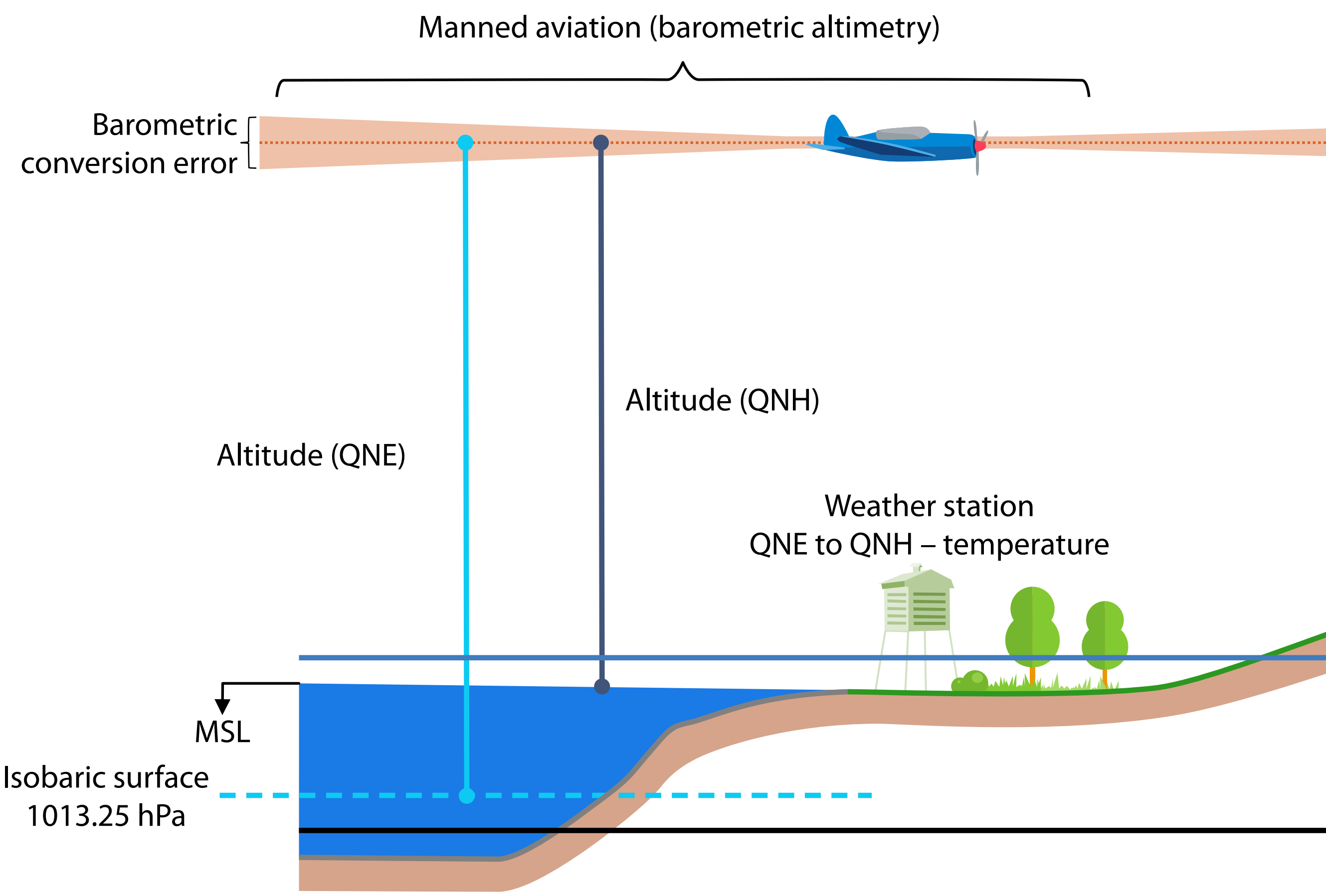
COMMON ALTITUDE REFERENCE

Aircraft airborne surveillance systems use QNE settings for reporting and broadcasting vertical information. Ground-based traffic management systems convert this vertical information to local QNH value for traffic below the Transition Altitude and left it unconverted above the Transition Level. Transponders always provide altitude information based on QNE reference pressure (Flight Levels). Altitudes based on QNE remain accurate regardless of the distance from pressure sensors, since they refer to a particular standard isobaric surface only. Since the system is calibrated to a constant set of standard values derived from the ISA model, all the sensors in the same area have the same errors, thus vertical QNE/QNH separation parameters are adequate for achieving vertical spacing of traffic.

Vertical parameters based on the ellipsoid can optimise the use of airspace, solving vertical segregation of UAS/UAS traffic, and in combination with appropriate DTM/DSM, avoid obstacles on the ground.

However, this reference cannot be used for manned aviation traffic purposes that rely on barometric references for vertical separation.

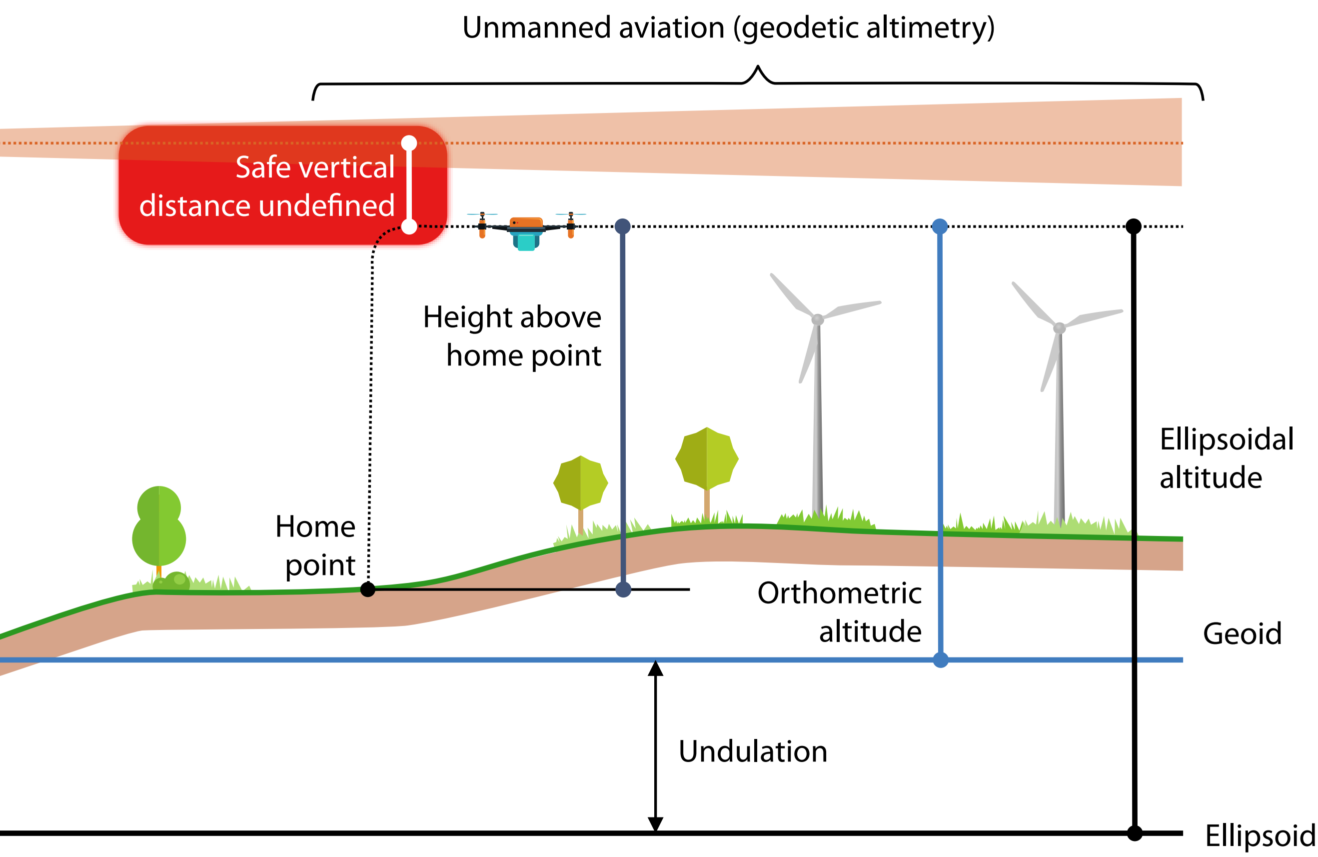
In order to achieve interoperability and continuity of safe operation when close or within manned aviation airspace, there is a need to deliver aviation standard altitude information (QNE, QNH based) to UAS users.



Or, in other words, convert the ellipsoid altitude —used for UAS mission planning and execution— into pressure altitudes understood by manned aviation.

ICARUS proposes to establish **Common Altitude Reference Areas** (CARA) in which a conversion service based on accurate pressure values at a location can translate planned ellipsoid mission altitudes to the pressure altitude system. This allows for verification and consistency with known airspace structure, while conforming to DTM/DSM and providing much higher accuracy.

ICARUS proposes to establish Common Altitude Reference Areas (CARA) in which UAS users can take advantage of advanced vertical information services, while being compliant with aviation standards

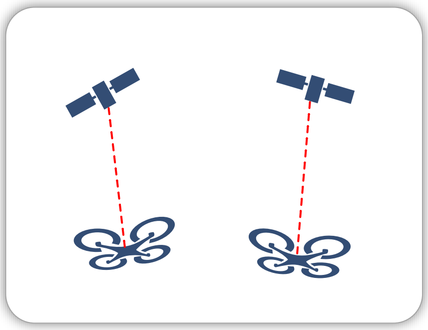


HIGH LEVEL OBJECTIVES

ICARUS proposes the use of GNSS receivers with suitable requirements for the common UAS-UAS vertical reference, and the definition of a new U3 U-space service for altitude transformations for common UAS-manned-aircraft reference, tightly coupled with the interface of existing U-space services (e.g. Tracking, and Flight Planning services).

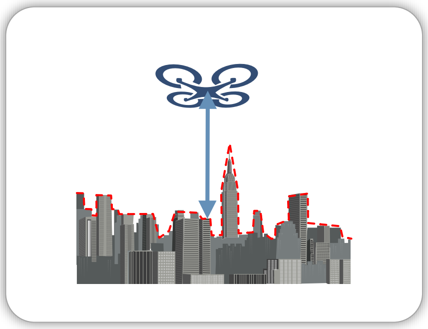
Finally, the terrain model information above the ellipsoid datum used in the GNSS receivers, including ground obstacle information, will also be an important element of the study. The users of the ICARUS service will be remote pilots competent to fly UAS operations in VLOS or BVLOS in the Specific category, ultralight and GA pilots potentially sharing the same VLL airspace, and also the drone itself, considering the increased level of automation and connectivity expected at U-space level 3.

Objective #1
UAS-UAS: Common reference at VLL



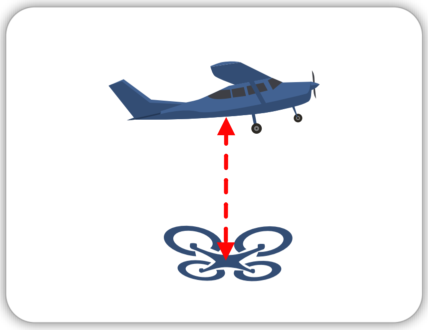
Define the technical requirements for high accuracy GNSS-based altitude measurement for drones, allowing a reliable and accurate common vertical reference (UAS-UAS)

Objective #2
UAS-Ground: Obstacle awareness



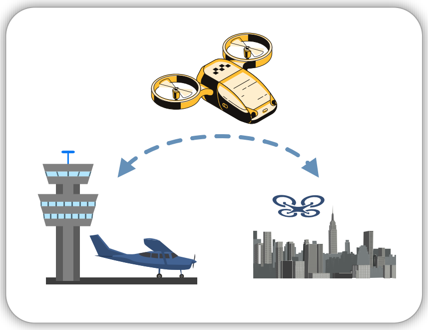
Investigate the vertical accuracy and resolutions achievable by the actual DTM/DSM services for ground obstacle and terrain profile, with respect to the geodetic WGS-84 datum

Objective #3
UAS-Manned: Common reference



Design a tailored U-space service for altitude translation between geometric to barometric altitude for UAS and manned aircrafts

Objective #4
UAM: Enhance VLL capacity



Foster the safest possible system for a common altitude reference system to address the needs of UAS, manned flights and new Urban Air Mobility actors , paving the way for the enhancement of the VLL capacity and UAS separation for future BVLOS applications

ICARUS has established four clear technical objectives that solve the current altitude related problems suffered by UAS operations in VLL airspace

ICARUS ARCHITECTURE

The following diagram shows a high level view of the proposed architecture of the ICARUS system.

Inputs

ICARUS consumes and maintains permanently updated data from GNSS, GIS and weather sources to support its conversion and alert algorithms. The data is obtained in raw format and needs to be processed before using it in the functional modules.

Application Programming Interface

ICARUS exposes APIs and open and interoperable protocols that are used by U-space service providers to query the system on behalf of U-space and GA users.

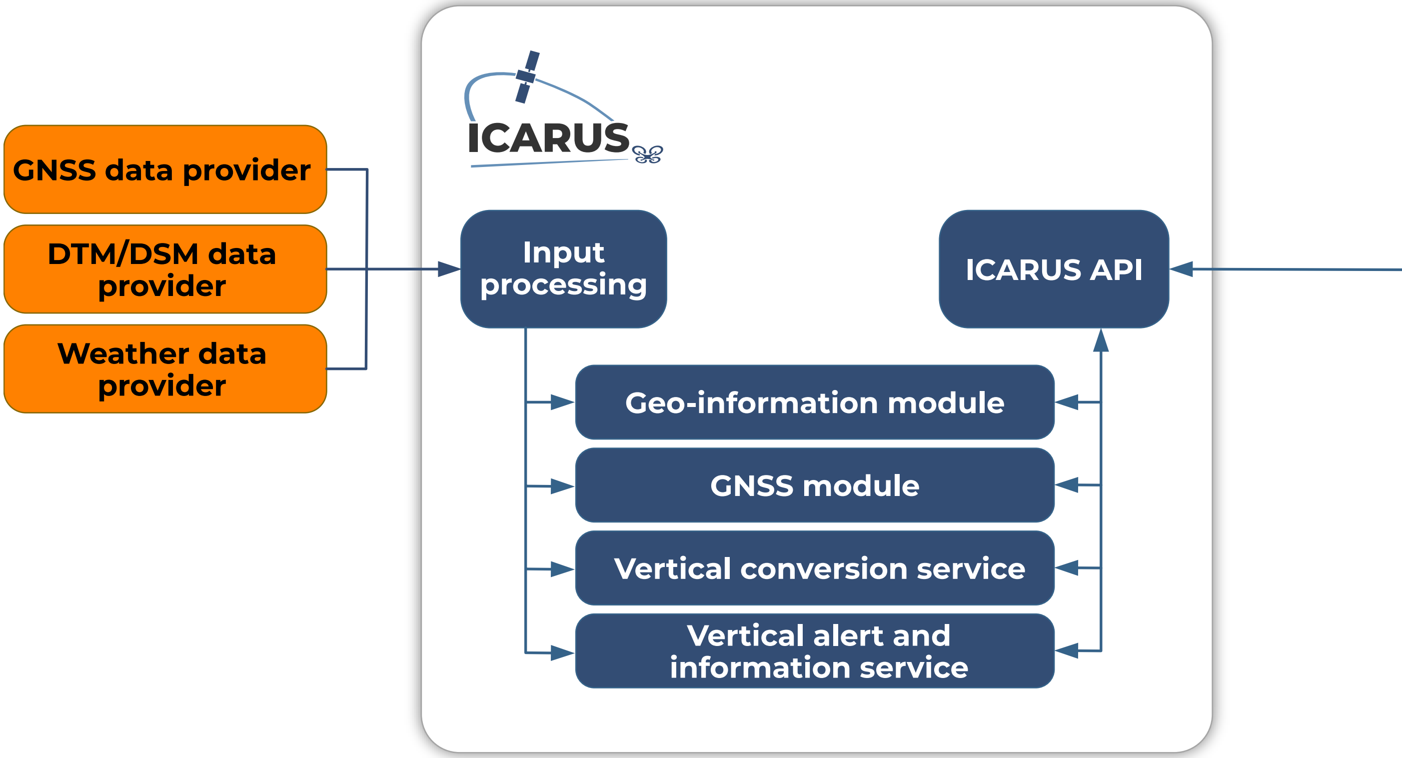
Computational services

- **Geo-information module**: The Geo-information module provides a set of services to support all the other subsystems by providing geographical information, typically associated with DSM, DTM and obstacle data.

  The Geo-information service receives input data from external data providers. Data ingestion is triggered when mission planning is scheduled. Data is physically transferred from external interfaces and stored in local memory.

- **GNSS module**: The GNSS module provide the real-time information regarding the drone position and the integrity of the solution achieved to the other ICARUS

ICARUS ARCHITECTURE



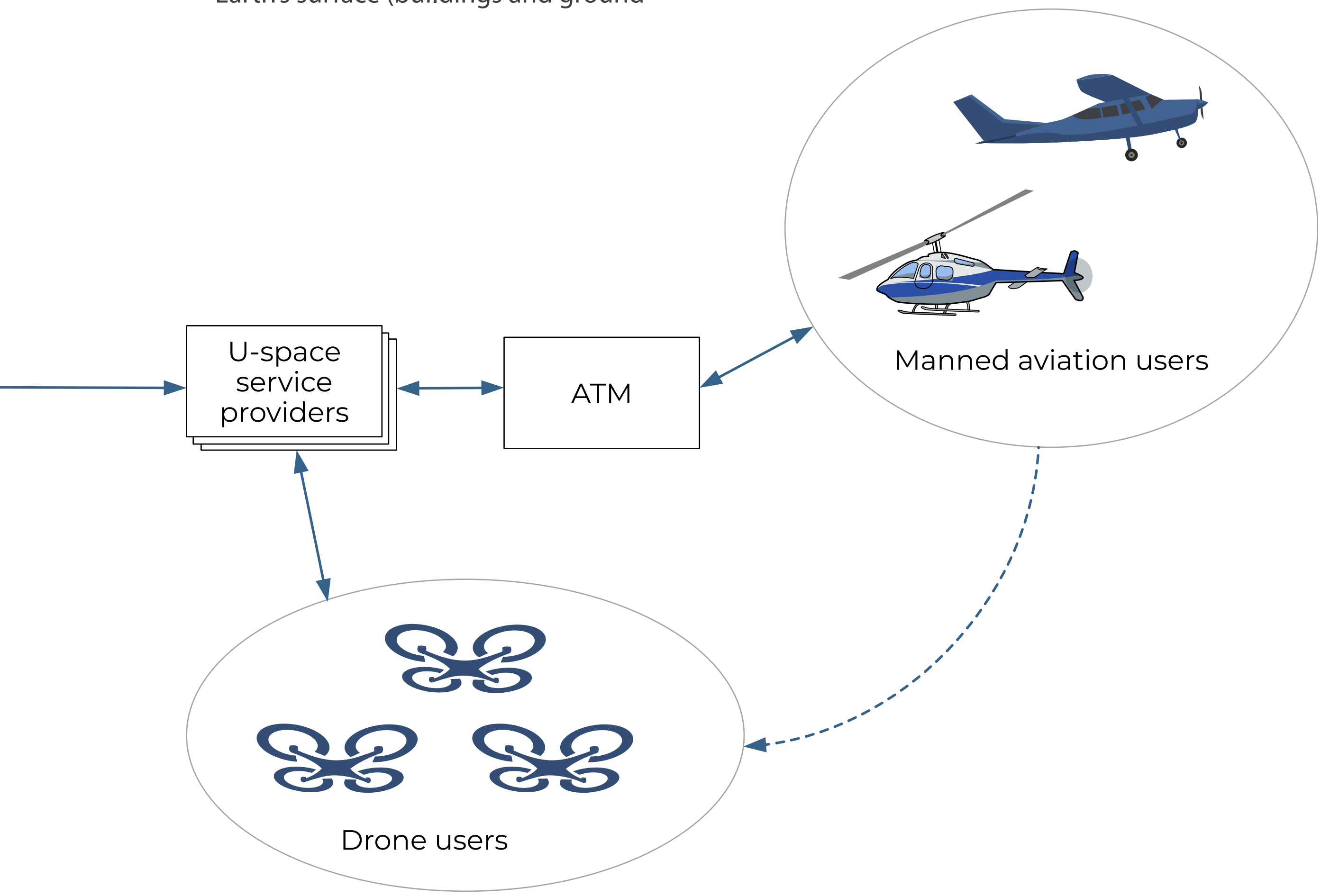
subsystems. The unit performs a check of the quality of the GNSS signal in the geographical area of interest, through the monitoring of the progress of the integrity parameters, providing a usability flag to the users.

- **Vertical Conversion Service module**: The VCS module provides the Vertical Conversion Service, which converts the heights provided as input from a barometric to a geometric reference system, and vice versa.

  It directly interacts with the U-Space Service Provider, with the other internal ICARUS modules, and with the Weather Data Provider that gets data from a set of distributed weather reference stations.

  The VCS module can determine and share current aircraft altitude with respect to the Earth's surface (buildings and ground obstacles), terrain, mean sea level, ellipsoid and geoid model.

- **Vertical alert service module**: The VALS is a system that provides the UAS Pilot with information and alerts on detection of a potentially hazardous terrain situation, so that the UAS pilot may take effective action to prevent a crash event. The main idea is to define a 3D safety-space buffer, called the Forward-Looking Terrain Avoidance volume (FLTA), and raise an alarm whenever any type of obstacle breaches the defined FLTA.



USE CASES

The use cases considered in the design phase of the ICARUS concept have contributed to the definition of the high-level requirements of the system. Their purpose is to present nominal situations where drones are likely to be involved in flight operations, and establish the typical interactions with other drones, ground obstacles, or manned aircraft.

The first use case corresponds to the current state-of-the art of the operations that are performed currently with small drones, while the last envisages a future drone taxi scenario (UAM).

Use cases cover both uncontrolled and controlled airspaces, urban and non-urban scenarios, and consider different typologies of drones with different capabilities. Finally, a detailed specification of the GNSS receivers expected on each case ensures that ICARUS will be operative in real-world applications, without requiring additional equipment.

We summarize the five use cases in the diagram below.

ICARUS USE CASES

	Industrial ski-lift inspection	Spare parts delivery to offshore platform	Industrial power line inspection
Scenario	Mountains / Rural	Above the sea	Rural / Suburban
Population density	None to low	None to low	Low
Conflicting traffic	None	Ultralight and GA in neigh. airspace	UAS / Helicopter / Other leisure GA
Airspace	X only Adjacent: G	Y only Adjacent: G	Y only Adjacent: G
Altitude data	WGS-84 Home points	UAS : WGS-84 Ultralight: WGS-84 GA: QNH	UAS: WGS-84 Ultralight: WGS-84 GA: QNH

The five use cases considered in the design of the ICARUS concept ensure that ICARUS will be relevant in real world operational scenarios

Bio sample delivery	Airport-vertiport passenger transport	
Urban / Suburban	Airport /Rural / Suburban / Urban	Scenario
Medium to high	Medium to high	Population density
Other UAS / HEMS	Commercial flights / Other UAS	Conflicting traffic
Zu only (CTR) Adjacent: G	ATZ (Za), CTR, Zu Adjacent: G	Airspace
UAS: WGS-84 HEMS: QNH / ADS-B	Taxi UAS: QFE (or QNH) in ATZ, WGS-84 inside GAMZ	Altitude data

ERROR BUDGET

To estimate the accuracy of the ICARUS system, we have evaluated all the sources of error, following the Performance-Based Navigation methodology defined by ICAO.

The **Total System Error (TSE)** is the deviation of a flight's actual position away from the desired path. It is the sum of three major errors:

- **Path Definition Error (PDE):** This error occurs when the path defined in the flight plan differs from the actual path reported to U-space. Traditional aviation usually neglects the PDE, because it is not relevant for their operations. With drones, especially when planning missions that require a high level of detail, the PDE can be relevant.

  It originates in errors present in the cartographic system used by the ground control station and, in particular, the DSM used. Updating the DTM value by entering a "Home Point fix" before take-off can be a good mitigation strategy to limit this error.

- **Navigation System Error (NSE):** Corresponds to the difference between the UAS position as estimated by the navigation sensor, the GNSS receiver in this case, and its actual position.

  We can use the error values provided by the GNSS service providers, applying the corrections discussed in the GNSS positioning section.

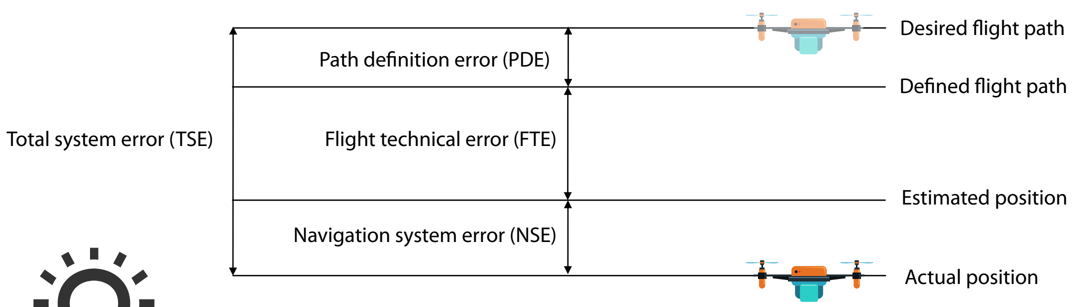
- **Flight Technical Error (FTE):** Refers to the ability of the autopilot to follow the defined path or track, including any display error.

  The FSE can be determined using numeric simulation applied to representative models of a multi-rotor and fixed wing UAS in varying conditions of flight and wind speeds that are normal in real-world operations.

We assume that these three errors are independent, have a zero-mean (i.e. they don't have any systematic error), and have a Gaussian distribution. Therefore, the distribution of the TSE is also Gaussian, with a standard deviation equal to the root sum square of the standard deviations of these three errors.

The TSE determined in this way corresponds to the total error budget for the UAS-UAS service.

COMPONENTS OF THE TOTAL SYSTEM ERROR



The initial assessment performed confirms that ICARUS satisfies the requirements for aviation height estimation

UAS-Ground separation

Besides the TSE of the involved drone, the use of digital elevation models, digital surface models, and ground obstacles introduce another source of error that affects the total error budget.

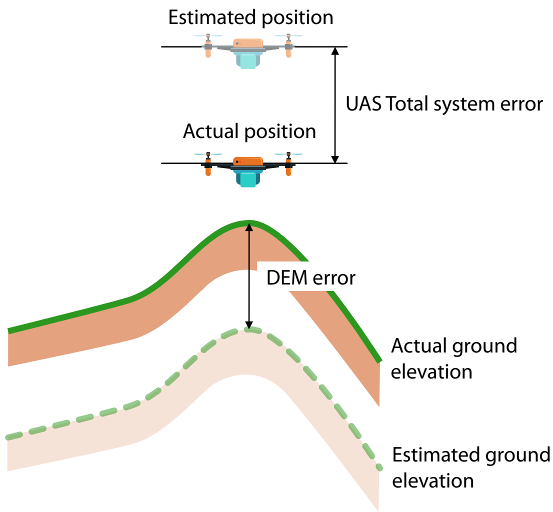
The error introduced by a low quality digital elevation model can be substantial. For that reason ICARUS should use DSM of the highest quality.

UAS-Manned separation

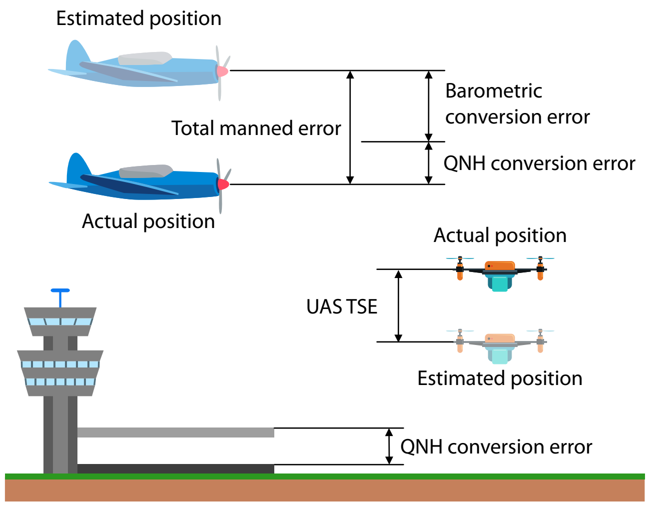
For the common altitude reference for manned and unmanned aviation, the conversion between the different altimetry systems introduces two additional errors:

- The conversion from the DEM used to reference the barometric station used to determine the QNH or QFE references to make them compatible with GNSS height observations.
- The barometric to geodetic conversion required to transform the barometric reading from the manned aircraft to the geodetic height used by the drone.

UAS-GROUND ERROR



UAS-MANNED ERROR



ICARUS ERROR BUDGET

Service	System	Horizontal error (95% CI)	Vertical error (95% CI)
UAS-UAS	Fixed wing	14.5 m	3.0 m
	Multi-rotor	10.0 m	3.0 m
UAS-Ground	Fixed wing	14.5 – 33.0 m	3.0 – 20.0 m
	Multi-rotor	10.0 – 31.5 m	3.0 – 20.0 m
UAS-Manned	Fixed wing	14.5 m	4.5 m
	Multi-rotor	10.5 m	4.5 m

Notes

To get more information about the project ICARUS, please contact us at:

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