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ICARUS

INTEGRATED COMMON ALTITUDE REFERENCE SYSTEM FOR U-SPACE

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Abstract

This document defines a preliminary Concept of Operations (ConOps) for three U-space services proposed by the ICARUS project to provide for a common altitude reference system. This system will enable unmanned aircraft systems/urban air mobility vehicles (UAS/UAM) and manned aircraft to share very low-level airspace despite their greatly different methods of calculating their altitudes. These services are:

- the Vertical Conversion Service (VCS);
- the Vertical Alert Service (VALS), and
- the Real-time Geospatial Information Service (RGIS).

They are used in conjunction with three other U-space services that were defined in the U-space ConOps provided by the CORUS project:

- the Geospatial Information Service (GIS);
- the Geo-awareness service (GAW)
- and the Electro-Magnetic Interference Information Service (EMS).

An analysis of the risks and probabilities of various types of encounter, both current and future, shows that the ICARUS services greatly reduce risks in all cases. In fact, an acceptable target level of safety (TLS) for VLOS operations (e.g. $5x10^{-5}$ – the current VFR TLS) in any type of airspace would not be achievable without the use of ICARUS services.

For UAS operations in E-VLOS (i.e. with one or more airspace observers) in the Specific category, ICARUS services would provide a significant improvement in safety if any manned traffic is encountered.

For UAS operations in BVLOS in VLL airspace in the Specific category (e.g. transport of small cargo over urban areas) the impact of ICARUS services depends on the type of airspace (as defined by CORUS). Whereas operations in type Za volumes would be sufficiently safe even without ICARUS services, this would not be the case in type X volumes, unless airborne DAA or procedural mitigation measures beyond the scope of ICARUS were present. Operations in type Y and Zu volumes would not be sufficiently safe without ICARUS and the associated regulatory amendments (i.e. PBA and GAMZ).

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1 Introduction

1.1 Purpose of the document

The purpose of this document is to describe the ICARUS Concept of Operations (ConOps) for a Common Altitude Reference System (CARS) for both manned and unmanned aircraft flying at Very Low Level (VLL) in the same volume of airspace.

The ConOps is based on six U-space services listed in ISO Draft International Standard (DIS) 23629-12. These ICARUS services may be exploited by remote pilots on the ground and by airborne pilots, either on board suitably equipped aircraft or using a portable Electronic Flight Bag (EFB).

1.2 Structure of the document

Following this introduction, section 2 defines the objectives and scope of the ICARUS ConOps, including a description of the current situation and explaining why change is needed. Section 3 gives details of the technical considerations of the ICARUS solution and how these are taken on board by the ConOps.

The ConOps itself forms section 4. It defines the roles and responsibilities of the different players, stakeholders and entities, and the different organisational interactions involved. The regulatory aspects and the rules of the air are also covered.

1.3 Acronyms

Acronym	Meaning
ADF	Automatic Direction Finder
AGL	Above Ground Level
AIP	Aeronautical Information Publication
AMC	Acceptable Means of Compliance
AO	Airspace Observer
API	Application Programming Interface
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Service
ATZ	Aerodrome Traffic Zone
BVLOS	Beyond Visual Line of Sight
CARA	Common Altitude Reference Area (successor of GAMZ)
CARS	Common Altitude Reference System

CAT	Commercial Air Transport
CD	Committee Draft
CONOPS	Concept of Operations
CS	Certification Specifications
CU	Command Unit
DAA	Detect And Avoid
DEM	Digital Elevation Model
DIS	Draft International Standard (ISO)
DME	Distance Measuring Equipment
DOP	Dilution Of Precision
DSM	Digital Surface Model
DTM	Digital Terrain Model
EASA	European Union Aviation Safety Agency
EC	European Commission
EFB	Electronic Flight Bag
EMS	Electro-Magnetic Interference Information Service
ERCS	European (common) Risk Classification Scheme
EU	European Union
EVLOS	Extended Visual Line Of Sight
eVTOL	Electrically powered VTOL
FLTA	Forward Looking Terrain Avoidance
GAMZ	Geometric Altitude Mandatory Zone
GAW	Geo-Awareness
GIS	Geospatial Information Service
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HALB	Horizontal Alert Buffer

ICAO	International Civil Aviation Organisation
IDE	Instrument, Data and Equipment
IFR	Instrument Flight Rules
ISO	International Organisation for Standardisation
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
LFR	Low-level Flight Rules
LoI	Level of Involvement
MoE	Means of Evidence
MS	Member State
NPA	Notice of Proposed Amendment
PBA	Performance-Based Altimetry
PBN	Performance-Based Navigation
PED	Portable Electronic Device
QE	Qualified Entity
QNH	Query Nautical Height
RGIS	Real-time Geospatial Information Service
RMT	Rulemaking Task
RMZ	Radio Mandatory Zone
RNAV	Area Navigation
RNP	Required Navigation Performance
RP	Remote Pilot
RWC	Remain Well Clear
SC	Sub-Committee
SDO	Standards Development Organizations
SERA	Standard European Rules of Air
SJU	SESAR Joint Undertaking
SORA	Specific Operations Risk Assessment
SP	Service Provider

TC	Technical Committee
TMZ	Transponder Mandatory Zone
ToR	Terms of Reference
U-space	Unmanned space
UA	Unmanned Aircraft
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
USSP	U-Space Service Providers (alias UTM service provider)
UTM	Unmanned aircraft system Traffic Management (alias U-space)
VALB	Vertical Alert Buffer
VALS	Vertical Alert Service
VCS	Vertical Conversion Service
VFR	Visual Flight Rules
VLL	Very-Low-Level
VLOS	Visual Line Of Sight
VO	Visual Observer
VOR	VHF Omnidirectional Range
VTOL	Vertical Take-Off and Landing
WALB	Width Alert Buffer
WG	Working Group

Table 1-1: Acronyms list

2 Objective and scope

2.1 Current situation

The common altitude reference problem affects not only UAS flights, but also all kinds of aviation especially manned ultra-light and general aviation (GA) flights, potentially present in the same airspace, as well as transport by manned helicopters (including emergency and medical) or aerial work by any sort of aircraft.

ICARUS aims to address the challenge of common altitude reference in VLL airspace while ensuring high safety levels, through the exploitation of six digital U-space services. Three of these have already been envisaged in draft ISO standard 23629-12. Conversely, three new services (particularly the vertical conversion service) have been proposed by the ICARUS project and are now included in ISO/DIS 23629-12. These six ICARUS U-space services are presented in section 2.3 below.

In November 2018, EUROCONTROL and EASA published a discussion document on a UAS ATM Common Altitude Reference System (CARS) [1]. This document considered the issues related to the sharing of the same airspace by UAS and manned flights.

The study proposed three options:

a) Option 1: barometric measurements for all operations in VLL (no U-space services);

b) Option 2: GNSS measurements for all operations in VLL (no U-space services);

c) ***Option 3: Mixed approach in which each airspace user adopts its approved altimetry system and U-space services are used for conversion***.

The final Concept of Operations for European UTM systems produced by the CORUS project [2] was the fruit of two years of exploratory research to adopt a harmonised approach to integrating drones into VLL airspace.

Two important aspects were provided by CORUS:

a) New airspace classifications (type X, Y, Z_a and Z_u);

b) A list of U-space services, updated with respect to the initial SJU blueprint.

Moreover, a list of requirements related to the U-space ecosystem has been developed by several SJU-funder exploratory research projects. These requirements have been assessed and analysed by the ICARUS consortium to determine a possible set of initial requirements. The result of this was published in document *D3.1 ICARUS Concept Definition*: State-Of-The-Art, Requirements, Gap Analysis.

Furthermore, the DIODE and GOF2.0 very large-scale SJU U-space demonstrators, and the European DACUS, BUBBLES, AMPERE, DELOREAN, 5G!Drones, and SUGUS projects have been considered by ICARUS in terms of lessons learned and/or progress harmonisation.

Finally, ICARUS has ensured close coordination with Sub-Committee (SC) 16 (UAS) of ISO Technical Committee (TC) 20 (Aerospace) which is developing the series 23629-XX of international standards on UTM (called U-space in Europe). Among them, 23629-12 lists 30 digital U-space services, classified as ‘safety-critical’, ‘safety-related’ and ‘operation support’. The list, currently in the Draft International Standard (DIS*) stage, comprises all of the services proposed by CORUS, as well as the three additional services proposed by ICARUS.

ISO Standards		
Stage name	**Product name**	**Acronym**
Preliminary stage	Preliminary work item	PWI
Proposal stage	New proposal for a work item	NP
Preparatory stage	Working Draft	WD
Committe stage	Committe Draft	CD
Enquiry stage	Draft International Standard	DIS
Approval stage	Final Draft International Standard	FDIS
Publication stage	International Standard	IS

Figure 2-1: ISO International Harmonised Stage Codes

**The DIS stage is the enquiry stage during the work related to an ISO standard. It is one of the final stages before the publication of the standard.*

2.2 Drivers for change

ICARUS has identified the following main drivers for change:

a) An expected increase in aviation traffic away from the airports, in particular in the context of Urban Air Mobility (UAM), which encompasses traditional helicopters, new-generation electrically powered and distributed-lift aircraft capable of Vertical Take-Off and Landing (eVTOL) and of course UAS. These last may be used for aerial work, for carrying passengers, or in logistics (the 'last mile');

b) The low accuracy of barometric sensor measurements and generalised regional QNH;

c) The rapidly growing need for the integration of two kinds of sensor: barometric and GNSS-based

d) A set of emerging digital U-space services, for which the most comprehensive list is presently contained in ISO DIS 23629-12;

e) Proportional requirements for safety-critical, safety-related or operation-support U-space service providers, as included in the afore-mentioned ISO 23629-12;

f) The increasing miniaturisation of electronic equipment;

g) The Electronic Flight Bag (EFB) concept that enables the airborne pilot to acquire and manage the digital information necessary during a flight in an easier and more effective way, through the use of small Portable Electronic Devices (PED; e.g. through a tablet). It should be noted that such PEDs are small enough to be carried on-board even the smallest aircraft and that EASA rules[1] allow the use of portable EFBs, thus eliminating the requirement for retrofit, which is usually not possible on the legacy aircraft used by general aviation or in aerial work;

h) Commission Implementing Regulation (EU) 2021/666 of 22nd April 2021 amending Regulation (EU) No 923/2012 as regards requirements for manned aviation operating in U-space airspace (electronic conspicuity to U-space service providers);

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[1] Commission Implementing Regulation (EU) 2018/1975 of 14 December 2018 amending Regulation (EU) No 965/2012 as regards air operations requirements for sailplanes and electronic flight bags

i) Possible introduction of Common Altitude Reference Areas (CARA) based on Article 15 of Commission Implementing Regulation 2019/947.

2.3 ICARUS U-space services

The ICARUS ConOps is based on six U-space services, three of which have already been proposed by CORUS and considered by ISO, and three of which are new services proposed by the project to provide an innovative solution to the challenge of a common altitude reference in VLL airspace. The EMS, GIS and GAW services are already known to EASA, the aviation authorities and Standard Development Organisations (SDOs), and are also listed by CORUS. RGIS, VALS and VCS are the new services proposed by ICARUS.

ISO, based on a proposal from ICARUS, now lists all the six services in DIS 23629-12. These are summarised in the following table (new services are highlighted in yellow).

Service		**Description**
Id.	**Safety Criticality**	
Geospatial Information Service (GIS)	Safety-related	Accurate cartography, DTM / DSM, 3D models of the ground obstacle provisioning service during the strategic phase of flight (i.e. flight planning)
Real-time Geospatial Information Service (RGIS)	Safety-critical	Accurate cartography, DTM / DSM, 3D models of the ground obstacle provisioning service during the execution of flight (tactical phase), to provide real-time information of vertical distance to ground
Geo-awareness (GAW)	Safety-critical	An information service warning manned aviation pilot(s) when crossing (or being in proximity of) the limit of a new " Common Altitude Reference Area", and related advice
Vertical Conversion Service (VCS)	Safety-related or critical depending on airspace and flight rules	Provides drone altitude and height with respect to the surface, converting drone altitude into barometric altitude, and converting manned barometric altitude to geometric altitude, to enable entry into a CARA
Vertical Alert Service (VALS)	Safety-critical	Alerts drones and manned aviation about their current vertical distance from ground when this is small
Electro-Magnetic Interference Information Service (EMS)	Safety-related	GNSS Signal Monitoring and Positioning + Integrity service that reports enhanced accuracy, performance estimation and integrity to UAS pilots or drones

Table 2-1: List of ICARUS U-space services

The overall ICARUS architecture, with a particular focus on the architecture of the proposed services, is provided in *D4.1 Design and architecture of the ICARUS system & services*.

3 Technical considerations

3.1 Accuracy

There are many elements to the issue of accuracy. Among them, the following should be mentioned:

3.1.1 GNSS Accuracy

The design of the ICARUS system follows a Performance-Based Navigation (PBN) approach for aspects that concern determining a drone's position [10]. This means that the performance requirements drive the design of the navigation system for the players operating in the designated airspace (VLL zones), introducing concepts like accuracy, integrity, continuity, availability [11]. For definitions and further information, please refer to section 3 of ICARUS D3.1 [10].

The most mature GNSS is GPS, for which much historical data is available, and whose performance is the most stable and consolidated. The accuracy of the GPS and Galileo systems, as stated by official Service Definition Documents (SDD, [12], [13]) and as observed in periodic Performance Reports ([14], [15]), are reported in section 9.3.2 of ICARUS D3.1 [10].

3.1.1.1 Threat analysis

Modern GNSS systems are susceptible to several threats that can undermine the required performance for area navigation. These challenging threats can affect different segments, and require the presence of augmentation systems that provide the necessary integrity:

- Threats affecting the system (either the space segment or the control segment)
    - GNSS satellite hardware, firmware or software fault due to design flaws, memory corruption or random hardware failures, including satellite clock runoffs (unexpected changes in clock phase and/or frequency), and satellite ephemeris errors caused by un-commanded manoeuvres such as leaks in a pressurised fuel tank. Other examples are signal modulation imperfections caused within the circuitry inside a satellite and gamma rays corrupting satellite memory.
    - Operational error by GNSS ground segment staff, including satellite ephemeris errors caused by the failure to set a satellite's health status to "unhealthy" before a satellite manoeuvre.
    - GNSS ground segment hardware, firmware, software errors or design flaws, either at a Master Control Station (MCS) or at Monitor Stations (MSs).
    - Atmospheric and environmental factors that cause range measurement errors at MSs. These include unmodelled ionospheric delays introduced by space weather.
    - GNSS navigation message bit transmission errors, whether the errors occur in terrestrial communications links or in space.
- Threats affecting signal propagation
    - Tropospheric errors (if sufficiently large).
    - Ionopsheric errors (ionospheric storms, anomalies, scintillation).
- Local threats, affecting the environment or the user receiver
    - Undetected cycle slips and half-cycle slips.
    - Radio frequency interference (RFI), if it results in significant errors.

  - Signal multipath reflections in the environment around a user-equipment antenna.
  - User-equipment hardware, firmware, and software errors and design flaws.
  - Ambiguity error

    Until now, the term altitude in various GNSS systems has generally referred to AMSL (Above Mean Sea Level). Due to the nature of GNSS systems, the value of the altitude in most of the cases is referenced to the mathematical model of the ellipsoid. Thus, to be converted to AMSL, information about local undulation is necessary. However, most GNSS chipsets use simplified undulation models, which consequently give an additional, unknown error value. Unfortunately, in addition, most manufacturers of chipsets do not provide information (even in general terms) about conversion systems between the ellipsoid and AMSL.

    It should also be noted that broadcasting information about the type of altitude and conversion methods used at the level of telemetry information exchange protocols (e.g. USSP-USSP, USSP-CISP, etc.) should be mandatory.
  - User-equipment antenna biases.

An analysis of the challenges for satellite navigation has been performed in [16], based on historic GPS data recorded over many years, to define a path to the design of ARAIM and to conceive counter-measures such that the overall integrity risk respects the limits for aeronautic-related safety applications. The threats have been categorised as follows:

1. **Faults** arising from within the GNSS: in recent years, major service faults have occurred approximately three times per year for GPS. Many of these can be attributed to some form of clock runoff, where the signal broadcast by a given satellite is not properly synchronised with the signal from the other satellites in the constellation. Others have been due to an upload of faulty navigation data from the GPS control segment to the GPS satellites for broadcast to users. Either of these types of fault can introduce positioning errors that are hazardous to aviation users. Moreover, in normal operation, GPS may not detect these threats for several hours.

2. **Rare normal** conditions: for satellite navigation, these conditions are frequently associated with adverse space weather that generates ionospheric storms. These storms can persist for hours while introducing dangerous guidance errors. Detection of ionospheric anomalies creates the largest restriction on operating regions and times for today's single-frequency user of GPS-based systems.

3. **Constellation weakness** when too few well positioned satellites are operational in the GNSS constellation relative to the number needed to support key operations. In principle, GNSS users only need four satellites (five for a multi-constellation solution) to estimate their position. However, safety-related applications typically need seven or more satellites to guarantee the performance needed to assure the RNP. The bad geometry can result in a worsened DOP figure that would increase the overall error (see section 9.3.2.2 of [10]).

4. **Radio frequency interference (RFI)**: this can be intentional or unintentional, and can easily result in local GNSS outages. GNSS signals are received at the user background-noise level, so they are weak and readily overwhelmed by any of the multitude of signals emanating from terrestrial sources. RFI events can occur due to scheduled activities (e.g. testing). They can be accidental or unintentional and can cause co-channel degradation. Finally, these RFI events can be malevolent and intended to deny service. In the past few years, several RFI incidents have occurred, and these have taken days or weeks to isolate and mitigate. A truly malevolent

RFI event (i.e. jamming and spoofing) would be very problematic and could deny service for a long time.

The mitigation of the four challenges described above is the underlying driver of integrity techniques and augmentation systems, described in section 3 of [10] and briefly listed below:

1. Single Frequency / Single Constellation (GPS) augmentation systems:
    a. SBAS (EGNOS in Europe, WAAS in North America, SDCM in Russia, GAGAN in India, MSAS in Japan)
    b. GBAS
    c. Traditional ABAS (RAIM)
2. Dual Frequency / Multi Constellation augmentation systems:
    a. Dual Frequency SBAS (under development)
    b. Dual Frequency GBAS (under development)
    c. Advanced RAIM, in its nominal and non-degraded mode (assuming an iono-free combination of the ranging observables)

3.1.1.2 DTM/DSM

Since each type of height conversion requires a specific DTM / DSM field model, information about its accuracy is necessary. Accuracy of field models should be taken into account when calculating the total error value (TSE).

DTM/DSM are necessary to compare the height coming from the telemetry stream into height with respect to the terrain and surface. This is important to provide both manned and unmanned ICARUS users with unambiguous information about their current height above the surface or terrain, especially if the amount of manned and unmanned aircraft traffic will increase in the future, particularly in the urban environment with the advent of the advanced urban mobility and in notably of urban air mobility (UAM).

For ICARUS purposes, DSM with a resolution of 0.6m and a DTM of 1m has been used.

Because DTM / DSM models are, and will be more often, commonly used for safety-critical height/altitude conversions, the development, management, integrity, update and distribution of DTM/DSM models should be subject to authorisation by a competent authority.

3.1.2 Vertical Conversion Services (VCS) Accuracy

In this section, we provide some conceptual considerations related to the evaluation of VCS service accuracy. The service interface is described in deliverable D4.2. The formulas implemented for the first version of VCS may be found along with their related assumptions in section 3.5 of the present document.

3.1.2.1 Data Availability and Undulation Approximation

The VCS service requires two sets of orthometric heights as input: the weather station heights and those of the DTM and DSM.

Since they are all orthometric heights, it is necessary to have both information on the reference geoid and the associated undulation parameter datasets.

The undulation of a geoid is its height relative to a given reference ellipsoid. Therefore, this parameter permits switching from the orthometric to the ellipsoidal reference system [19].

For the Polish case, the geodetic reference system is the “EVRF - west European plus Kron8” one. After some research, it was found that this official implementation most likely uses the PL-geoid-2011 model. The undulation dataset at [17] was downloaded and converted to the required format.

As regards the undulation data, these were treated in the ISG 1.0 Format [18]. In the first version of the VCS algorithm, the undulation value of a given set of coordinates was approximated to the undulation value relative to the centre of the cell that contains it. In the final version, it is calculated using bilinear interpolation of the nearest cell-centre values [19].

3.1.2.2 Complex and Simple Formulas. Weather Station Factor.

As input data for the calculations, it is assumed that data from the weather stations are available for the area where the vehicle is flying.

In the tested scenarios, it was assumed that the elevation of the weather station serving pressure and temperature was known; this is critical for the calculations. A simplification was also made, consisting of the fact that all tests were carried out on flat terrain, using one calibrated pressure and temperature sensor. In the future, the topic of pressure distribution in larger areas, especially mountain and highly urbanised areas, should be investigated, because the differences in pressure used for conversion may be significantly different.

Another important factor will be the analysis of the pressure distribution between the sensors, which will require separate tests and studies.

The first version of the VCS service uses the simple formulas of the algorithm that consider only the effect of pressure variations.

The complex formulas - to be implemented in the final version of the service - not only take variations in pressure into consideration but also those in temperature and gravity.

After the test analysis, the impact of these variations on the final conversion results will be quantified.

3.1.2.3 Access to the QNH data

Access to the QNH pressure is necessary to convert altitudes to the pressure used in aviation. This is important in both of the following cases. Firstly, where the calculated altitude based on the GNSS sensor should reference the QNH pressure (regional, local and contingency), and secondly, where manned aircraft will generally declare that they will fly at a certain altitude (implicitly relative to the QNH pressure).

3.1.2.4 Standard Atmosphere and Ideal Gas Law

As described thoroughly in chapter 5 of the D3.1 document [10], the conversion formula used makes two assumptions: the ICAO standard atmosphere model and the ideal gas law.

To quantify the impact of these assumptions, the conversion service was tested for a set of points, of which we know both barometric and ellipsoidal heights, using a set of weather reference stations.

3.1.2.5 Radio Altitude

At present, it is difficult to imagine the use of radio altimeters in UAS. Although radio altimeters are used in commercial aviation, it should be clearly emphasised that their use is considered reliable only in strictly defined cases, during the landing phase, when the elevation of the terrain is known in the final phase of the approach.

The use of radio altimeters by unmanned aerial vehicles, although it seems a good idea, requires the use of DSM / DTM field models to determine a reliable height.

3.1.2.6 Visual reference

Scientific and conference materials mention the topic of determining height with the help of visual systems. In the ICARUS project, we deliberately omitted this measurement technique because: there is a lack of reliable data on the certification and calibration of this type of device; these devices are not able to work in low visibility; and finally, unambiguous determination of the absolute flight altitude would require the use of known field models anyway.

3.2 Services overview

3.2.1 Conversion service formulas

Two services have been developed for the conversion system:

- The **GI service** receives longitude and latitude as input and returns the country code, the heights of the DSM and DTM, and the N undulation value.
- The **VCS service** converts altitudes from the reference system used by airplanes to that used by drones and vice versa.

A detailed description of the GI and VCS and their interfaces are given in chapters 2 and 4 of [20]. Chapter 5 of [10] explains the theory behind the formula implemented inside the services.

Section 3.2.1.1 contains some assumptions and considerations about the implemented services. We will then focus on the formulas implemented in the case of a conversion request from an airplane (3.2.1.2) and a drone (3.2.1.3).

3.2.1.1 Assumptions and considerations

The formulas described refer to the simple conversion algorithm that only takes the pressure variations into consideration.

We potentially need information related to three geoids:

- the geoid used for the orthometric height of the weather station
- the geoid used for the orthometric height of the DTM and DSM
- the chosen reference geoid for the output value.

In these formulas, for the scope of this first prototype, to simplify calculations, we assume that they coincide.

However, a global geoid must be chosen as a reference for the output value of H_P to provide a common reference for all the aircraft regardless of the area in which they are flying and to avoid a mismatch in the border between countries.

The following conventions are used for the annotations:

- capital letter H is used for any orthometric height
- lowercase letter h for any ellipsoidal height

The constants in use for this first version of the algorithm are:

- $T_0 = 288.15\ \mathrm{K}$ (Reference temperature)
- $L = -0.0065\ \mathrm{K/m}$ (Temperature lapse rate)
- $R = 287.05287\ \mathrm{J/Kg\ K}$ (Specific gas constant)

- $g \ = 9.80665\, m/s^2$
- $P_{\mathrm{QNE}} = \ 1013.25\, hPa$

3.2.1.2 Formulas implemented for the airplane case

In the airplane case, the principal input is the observed height over QNE and we mainly aim to retrieve the ellipsoidal height.

For the calculations, as we said, we need the following input values:

- *h_obs_qne,* the observed height over QNE in metres. In the formulas, it will be referred to as $\mathrm{H}_{\mathrm{QNE}}^{\mathrm{obs}}$.
- *p_w,* pressure in hectopascal (hPa) of the weather station nearest to the vehicle that is asking for conversion. In the formulas, it will be referred to as P_{w}.
- *h_w,* height in metres of the weather station nearest to the vehicle that is asking for conversion. It will be referred to as H_{w}.
- *p_qnh_airport,* average QNH value in hectopascal (hPa). This value is calculated for the region where the airport is located by meteorology authorities and broadcast every 30 minutes for the Polish case. In the formulas, it will be referred to as $\mathrm{P}_{\mathrm{QNH,Airport}}$.
- *h_dtm,* the DTM height (in metres). This value is obtained by the GI service. In the formulas, it will be referred to as $\mathrm{H}_{\mathrm{DTM}}$.
- *h_dsm,* the DSM height (in metres). This value is obtained by the GI service. In the formulas, it will be referred to as $\mathrm{H}_{\mathrm{DSM}}$.
- *N,* is the geoid undulation in metres (height of the geoid relative to a given ellipsoid of reference). It will be referred to as N.

3.2.1.2.1 Orthometric height of the airplane

For the orthometric height of the airplane, $H_{\mathrm{P,w}}$, we use the following formula:

$$H_{\mathrm{P,w}} = \frac{T_0}{L}\left[\left(\frac{P_{\mathrm{QNE}}}{P_{\mathrm{QNH,P}}}\right)^{-\frac{LR}{\bar{g}}} - 1\right] + H_{\mathrm{QNE}}^{\mathrm{obs}}\left(\frac{P_{\mathrm{QNE}}}{P_{\mathrm{QNH,P}}}\right)^{-\frac{LR}{\bar{g}}}$$

where:

$$P_{\mathrm{QNH},w} = P_w\left[\frac{T_0}{L\,H_w + T_0}\right]^{-\frac{\bar{g}}{LR}}$$

P_w and $P_{\mathrm{QNH,P}}$ refer to the time t_{P} at which the airplane started the request.

We use the subscript w for H_{P} because this is the orthometric height of the airplane with respect to the geoid used to calculate the height of the weather stations. H_{w}, indeed, is an orthometric height referred to a certain geoid, which should be known.

3.2.1.2.2 The orthometric height of the airplane with respect to the QNH of the runway

For the orthometric height of the airplane with respect to the QNH of the runway, the following formula is taken as a starting point:

$$H_{\overline{\mathrm{QNH}}} = \frac{T_0}{L}\left[\left(\frac{P_{\mathrm{QNH,P}}}{P_{\overline{\mathrm{QNH}}}}\right)^{-\frac{LR}{g}} - 1\right] + H_{\mathrm{P}}\left(\frac{P_{\mathrm{QNH,P}}}{P_{\overline{\mathrm{QNH}}}}\right)^{-\frac{LR}{g}}$$

where $P_{\overline{\mathrm{QNH}}}$ is the average QNH value calculated for the region where the airport is located. This is usually a value calculated and broadcast periodically for a specific region. The airplane must have this value because it is used to calibrate the altimeter before landing.

3.2.1.2.3 The height of the airplane with respect to the DTM

The orthometric height of the airplane with respect to the DTM, named H_{AGL}, is calculated as:

$$H_{AGL} = H_{\mathrm{P}} - H_{DTM} - N_w + N_{DTM}$$

Assuming that $N_w = N_{DTM}$ the formula becomes:

$$H_{AGL} = H_{\mathrm{P}} - H_{DTM}$$

3.2.1.2.4 The height of the airplane with respect to the DSM

The orthometric height of the airplane with respect to the DSM, named H_{ASL}, is calculated as:

$$H_{ASL} = H_{\mathrm{P}} - H_{DSM} - N_w + N_{DSM}$$

Assuming that $N_w = N_{DSM}$ the formula becomes:

$$H_{ASL} = H_{\mathrm{P}} - H_{DSM}$$

3.2.1.2.5 The ellipsoidal height of the airplane

For the ellipsoidal height of the airplane, h_{P}, we use the following formula:

$$h_P = H_{\mathrm{P,w}} - N_w$$

where N_w is the undulation relative to the height H_w of the weather station used to calculate $P_{QNH,P}$ at the very beginning for $H_{\mathrm{P,w}}$.

3.2.1.3 Formulas implemented for the drone case

In the drone case, the main input is the observed height over QNE and we aim mainly to retrieve the ellipsoidal height.

For the calculations, as stated above, the following input values are required:

- *h_ell,* the ellipsoidal height in metres. It will be referred as h_P.
- *p_w,* the pressure in hectopascal (hPa) of the weather station nearest to the vehicle that is asking for conversion. In the formulas, it will be referred as P_w.
- *h_w,* the height in metres of the weather station nearest to the vehicle that is asking for conversion. It will be referred as H_w.
- *p_qnh_airport,* the average QNH value in hectopascal (hPa). This value is calculated for the region where the airport is located by meteorology authorities, and broadcast every 30 minutes for the Polish case. In the formulas, it will be referred as $P_{QNH,Airport}$.
- *h_dtm,* the DTM height (in metres). In the formulas, it will be referred as H_{DTM}.
- *h_dsm,* the DSM height (in metres). In the formulas, it will be referred as H_{DSM}.

- n is the geoid undulation in metres (height of the geoid relative to a given reference ellipsoid). It will be referred as N.

3.2.1.3.1 The orthometric height of the drone

The orthometric height of the drone H_{P} is calculated using the following formula:

$$H_P = h_{\mathrm{P}} + N$$

Here we assume that the drone is able to give ellipsoidal height. The undulation value N is the one with respect to the geoid chosen as reference for the output value.

3.2.1.3.2 The orthometric height of the drone with respect to the DTM

The orthometric height of the drone with respect to the DTM, named H_{AGL}, is calculated in this way:

$$H_{AGL} = H_{\mathrm{P}} - H_{DTM} - N + N_{DTM}$$

Assuming that $N = N_{DTM}$ the formula becomes:

$$H_{AGL} = H_{\mathrm{P}} - H_{DTM}$$

3.2.1.3.3 The orthometric height of the drone with respect to the DSM

The orthometric height of the drone with respect to the DSM, named H_{ASL}, is calculated as:

$$H_{ASL} = H_{\mathrm{P}} - H_{DSM} - N_w + N_{DSM}$$

Assuming that $N = N_{DSM}$ the formula becomes:

$$H_{ASL} = H_{\mathrm{P}} - H_{DSM}$$

3.2.1.3.4 The orthometric height of the drone respect the QNH of the runway

For the orthometric height of the airplane with respect to the average QNH of the runway, we use this formula:

$$H_{\overline{\mathrm{QNH}}} = \frac{T_0}{L}\left[\left(\frac{P_{\mathrm{QNH,P}}}{P_{\overline{\mathrm{QNH}}}}\right)^{-\frac{LR}{\bar{g}}} - 1\right] + H_{\mathrm{P}}\left(\frac{P_{\mathrm{QNH,P}}}{P_{\overline{\mathrm{QNH}}}}\right)^{-\frac{LR}{\bar{g}}}$$

where:

- $P_{\overline{QNH}}$ is the average QNH value calculated for the region where the airport is located, given in input. This is usually a value calculated and broadcast periodically for a specific region. The aircraft must have this during all phases of flight.
- $P_{QNH,P}$ is calculated from h_w and p_w values given as inputs using this formula:

$$P_{QNH,w} = P_w\left[\frac{T_0}{L\,H_w + T_0}\right]^{-\frac{\bar{g}}{LR}}$$

3.2.1.3.5 The orthometric height of the drone respect the QNE

The orthometric height of the drone with respect to the QNE, H_{QNE}, is calculated using the following formula:

$$H_{\mathrm{QNE}} = \frac{T_0}{L}\left[\left(\frac{P_{\mathrm{QNH,P}}}{P_{\mathrm{QNE}}}\right)^{-\frac{LR}{\bar{g}}} - 1\right] + H_{\mathrm{P}}\left(\frac{P_{\mathrm{QNH,P}}}{P_{\mathrm{QNE}}}\right)^{-\frac{LR}{\bar{g}}}$$

where $P_{\mathrm{QNH,P}}$ is calculated from h_w and p_w values given as inputs using this formula:

$$P_{\mathrm{QNH},P} = P_w\left[\frac{T_0}{L\,H_w + T_0}\right]^{-\frac{\bar{g}}{LR}}$$

4 Operational concept

To solve the common reference altitude issue, we have to determine the purposes for which the vertical parameter will be used by the UAS, and the aviation context.

The following main considerations must be evaluated:

0. commonality and accessibility of the solution
1. mission profile design and mission management
2. terrain and obstacle avoidance
3. regulation-regulated airspace/zones or airspace restrictions
4. weather-related issues (local weather parameters variations or phenomena)
5. compliance with existing and future aviation safety systems and requirements

Statistics show that most UAS currently operate in the lower band of airspace, in close proximity to the Earth's surface and land features. An adequate altitude reference is therefore required to facilitate missions and to fulfil safety obligations and the object of the mission. It is obvious that the legacy aviation pressure sensor with its limitations and accuracies — although it is the existing standard for manned aviation — cannot deliver an adequate solution for low-level flights in areas where various ground features induce local pressure variations. When added up, local static pressure variations plus the (un)availability of a precise pressure-related datum (used to determine local QNH plus safety margin) plus standard tolerances render the legacy aviation pressure altimeter useless at low operational UAS altitudes. However, UAS must be in a position to "report" their altitude to ATS units in "aviation language" understood by other airspace users, regardless of their vertical parameter value.

In higher airspace volumes it is prudent to make sure that UAS communicates with ATS and other users in an aviation standard (ACAS, ADS-B/C, FL, etc.) This requirement mandates adequate equipment installation and its certification to legal operational and communication standards.

4.1.1 Higher band/volume of airspace:

All UAS designated to operate within, and in close proximity to, manned airspace must be equipped with adequate valid pressure sensors capable of delivering accurate and useful altitude parameters for ATS services, as well as independent safety systems as required (ACAS).

This equipment must be calibrated according to the ISA standard and deliver:

1. altitude based on local or required QNH setting/settings as binding within the operational area(s);
2. flight levels as required by ACAS or other systems
3. a vertical parameter value based on any required or uplinked or designated reference pressure setting (e.g. QFE) as required locally.

It is worth noting that while and when required by ATS or the mission profile, a pressure surface has to be followed to maintain a pressure altitude. In this case, satellite-based altitude should be available but cannot be used for this purpose.

Since the mission profile at low altitudes can interfere with man-made obstacles or terrain while a UAS is following an isobaric plain, adequate safety features must be incorporated into the mission profile design.

This is especially true for low altitude flights.

4.1.2 Lower band/volume of airspace:

At elevations up to 120 m (400 ft) AGL pressure-related altitude measurement is far too inaccurate to deliver a safe solution for terrain, structures or other traffic avoidance. The only available commonly used sensor that is capable of delivering accurate data is satellite navigation. The common reference parameter built-in and used by all users within the accuracy of the applied Earth model is the ellipsoid. As a common denominative, it looks feasible to use the ellipsoid altitude in relation to the present position as the vertical parameter for terrain and UAS-to-UAS traffic avoidance.

There are a few main issues related to using the ellipsoid as a common reference datum for the vertical parameter.

1. Terrain avoidance and mission planning: For this purpose, we have to change our perception of mission design and planning. Everything depends on the type of mission: VLOS or BVLOS. It is obvious that height above the ellipsoid is different from height AGL and from obstacle/structure clearance height. This problem can be addressed by applying a data-derived ground-surface model with the required literacy step to calculate the maximum elevation of the surface in relation to the ellipsoid at a given position. This will allow a profile to be designed that will allow for safe flight with a given margin above the terrain features and safe separation from other missions (this can be an autonomous avoidance algorithm) since all UAS will know their “terrain clearance” and their “ellipsoid altitude”, regardless of the variations and inaccuracies of pressure-sensor altitude. By using this vertical datum and surface model, any mission contingency can be safely accomplished using predetermined and safe horizontal or vertical procedures.
2. UAS traffic avoidance: While within the “ellipsoid altitude” volume, all UAS use a common vertical datum and know their position and velocity vectors as well as the “terrain model margin”. It looks feasible to design proper and safe vertical avoidance manoeuvres that can be activated autonomously when proximity criteria are met. Since the vertical dimensions of UAS and their wake characteristics can be assessed and defined, and seem to be of relatively low impact, the vertical volume of the airspace needed would be much less than one based on pressure-sensor altitude. A manoeuvre can therefore be accomplished within a small airspace volume that does not affect many other users. This feature can also apply to UAS/UAS avoidance in a manned aviation airspace band; it is plausible to design such a manoeuvre with significant accuracy that does not affect other manned flights nearby, at ICAO Annex 2 and Regulation 923/2021 “SERA” Appendix 3 cruising levels. (This will be true at altitudes below sea level as well)
3. Aircraft avoidance: Since aircraft are equipped with transponders that use standard pressure settings, this data must be used for generating ACAS manoeuvres when needed. This “pressure standard altitude” output can be delivered by:
    1. An adequate and valid pressure sensor certified to an aviation standard (can be part of valid ACAS solution)
    2. A calculated and approved mathematical conversion function that enables a standard altitude output based on the ISA model and an uploaded pressure setting valid for given area.
4. Pressure transition level: UAS designed or aimed to be used in close proximity to or within manned aviation altitudes must be able to deliver valid altitude information related to the local pressure setting, as well as standard altitude (ADS-b/C, ACAS usage). By default such a feature must be active when the UAS crosses a height of 120 m (400 ft) AGL or when required by operational or safety reasons (close to instrument approach trajectories, etc.). Since, due to its limitations, a pressure sensor cannot be used with adequate accuracy to determine the vertical transition limit, it seems prudent to use the ellipsoid plus a known, locally determined, static pressure elevation and a conversion function to determine the ellipsoid altitude equivalent of 120 m (400 ft) AGL.

5. Altitude reporting: When away from a pressure-elevation sensor, local QNH might significantly vary from regional QNH. A mathematical model (conversion function) can answer the pressure-altitude problem within the limits of variable inputs. Knowing that there is continuity in pressure change, and if the transition function of pressure changes between sensors is known, the estimated value of the pressure-altitude can be derived as a fixed value and estimated vertical error. This altitude can be reported by ATS to an aircraft as “Block altitude between 1200 and 1400 ft) for UAS altitude 1300 ft +/- 100 ft. Pilots or ATS officers can use this information for traffic purposes.

A digital terrain model provides terrain elevation based on a calculation step that generates a certain probability of accuracy. An operator or mission designer must consciously use the iteration step of calculating altitudes that fulfil the purpose of the mission. The same principle applies to altitude calculation / conversion when applicable; since we cannot physically measure static pressure at each spot and adjust it to the ISA, we have to deliver the altitude with a certain accuracy, as a probability altitude, but in language understood by pilots and ATS officers.

4.1.3 Impact on stakeholders

Finally, the involvement and impact of the following bodies and processes should also be considered:

- Aviation authorities and international organisations
    - ICAO
    - EASA
    - EUROCONTROL
    - National authorities
    - ANSP
- Evolution of regulatory framework
- Emerging industry standards (e.g. ISO 23629-12)
- New service providers (CIS/FIMS/USSP/SSP)
- UAS manufacturers
- UAS operators

4.2 Operational Scenarios

This section gives a summary of the scenarios for the final validation of the concept and the delivery of the service tested during the validation campaign (a detailed description is provided in D6.1 Validation Scenario Design).

4.2.1 Scenario 1: UAS-Manned aircraft CAR service

This validation scenario involves the presence of:

1 small manned leisure aircraft (C-172) departing from an aeroclub in a valley in southern Italy (***simulated flight***).

1 small drone involved in a filming operation, departing from a hill.

This scenario aims to validate the following ICARUS micro-services:

- ✓ Vertical Alert Service (VALS)
- ✓ Vertical Conversion Service (VCS)

in a dynamic scenario (tactical phase).

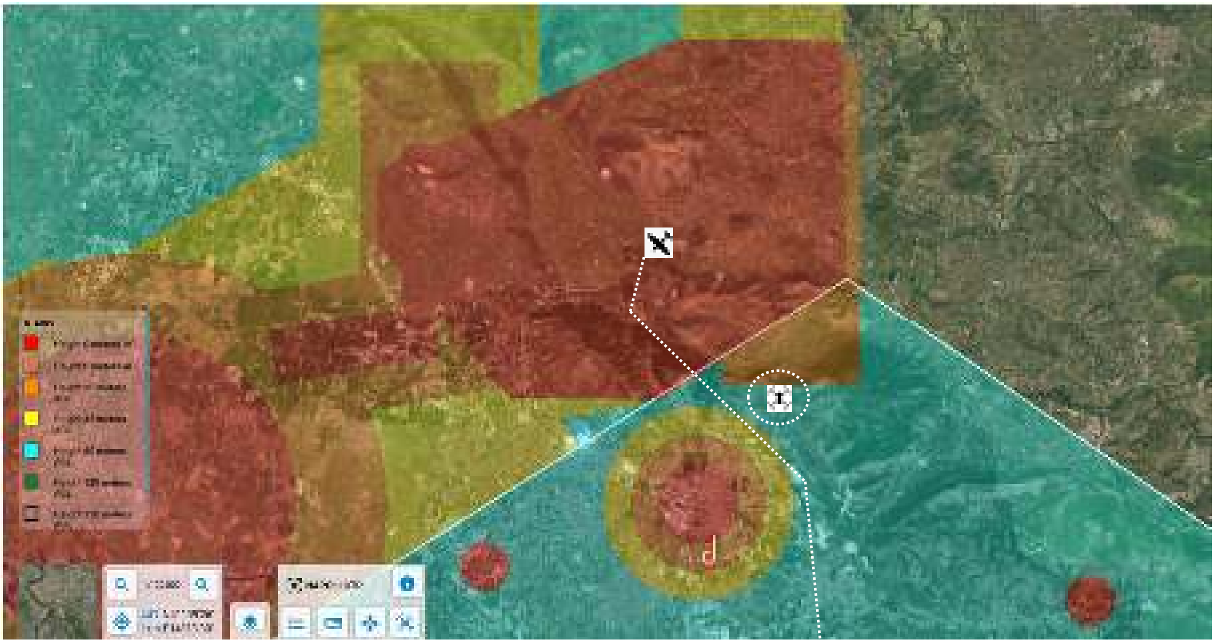


Figure 4-1: Airplane and drone positions on D-flight cartography

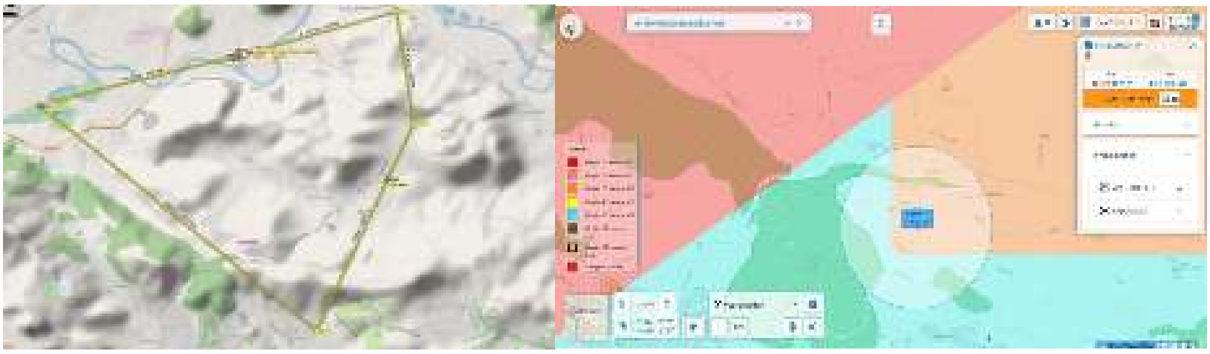


Figure 4-2: airplane and drone mission planning for S1

The mission is designed to provide UAS pilots and GA pilots with suitable tracking information about incoming traffic near their positions, during the flight, by exploiting the value-added services offered by ICARUS, with particular reference to the alerting service and altitude reference.

The mission described in this scenario contributes to validating the following ICARUS micro-services in the tactical phase:

- **Vertical Alert Service (VALS)**
- **Vertical Conversion Service (VCS)**

In particular in this scenario, the VALS service will be used by the GA pilot for alerting them when in presence of other UAS traffic near the flight. The VCS service, in combination with VALS, will provide the GA pilot with the altitude of the UAS expressed in feet, under the same reference system as used by the aircraft (local QNH). On the other hand, the UAS pilot will receive the altitude of the aircraft under their reference system (WGS-84 or with respect to ground level at the home point).

4.2.2 Scenario 2 UAS-Manned Aircraft CAR performance

This validation scenario involves the presence of:

- ✓ **1 small ultralight leisure aircraft (Tecnam P-92)** departing from an aeroclub in southern Italy (***real flight***).

- ✓ **1 small drone** involved in a training operation near the aeroclub.

This scenario aims to validate the following ICARUS micro-services:

- ✓ Vertical Conversion Service (VCS) performance with low-cost UTM Box and high-end UTM Box (DFMC GNSS Receivers)
- ✓ Vertical Alert Service VALS (VALS)

in the tactical phase.

Figure 4-3: Airplane and drone positions on D-flight cartography

Figure 4-4: airplane and drone mission planning for S2

The second scenario (S2) implements real operations with a real ultralight aircraft and a real UAS flight, flying in a segregated area.

The mission is designed to provide the UAS pilot with alerts about the incoming traffic nearby, during the flight, by using the value-added services offered by ICARUS, particularly the alerting service (VALS).

Moreover, as a secondary objective, the mission aims to verify the radio coverage of the Pollicino Pro tracker, when used by an ultralight aircraft at 1,000 or 2,000 feet AGL.

During the operations, the VCS service, in combination with VALS, will provide the UAS pilot with the height of ultralight expressed in metres, under the same reference system as that used by the UAS (local home point).

4.2.3 Scenario 3 UAM operations

This validation scenario involves the presence of:

1 drone taxi aircraft (*simulated flight*) to simulate an example of passenger transfer for a future Urban Air Mobility scenario in northern Italy (Torino Caselle Airport) considering different aspects such as:

- ✓ QFE setting / GNSS setting procedures (Common Altitude Reference Area - CARA)
- ✓ Vertical Alert Service for ground obstacle awareness

This scenario aims to validate the following ICARUS micro-services in a future scenario of Urban Air Mobility:

- ✓ Real-time Geographical Information (RGIS)
- ✓ Vertical Alert Service (VALS)
- ✓ Vertical Conversion Service (VCS)

in both the strategic and tactical phases of flight.

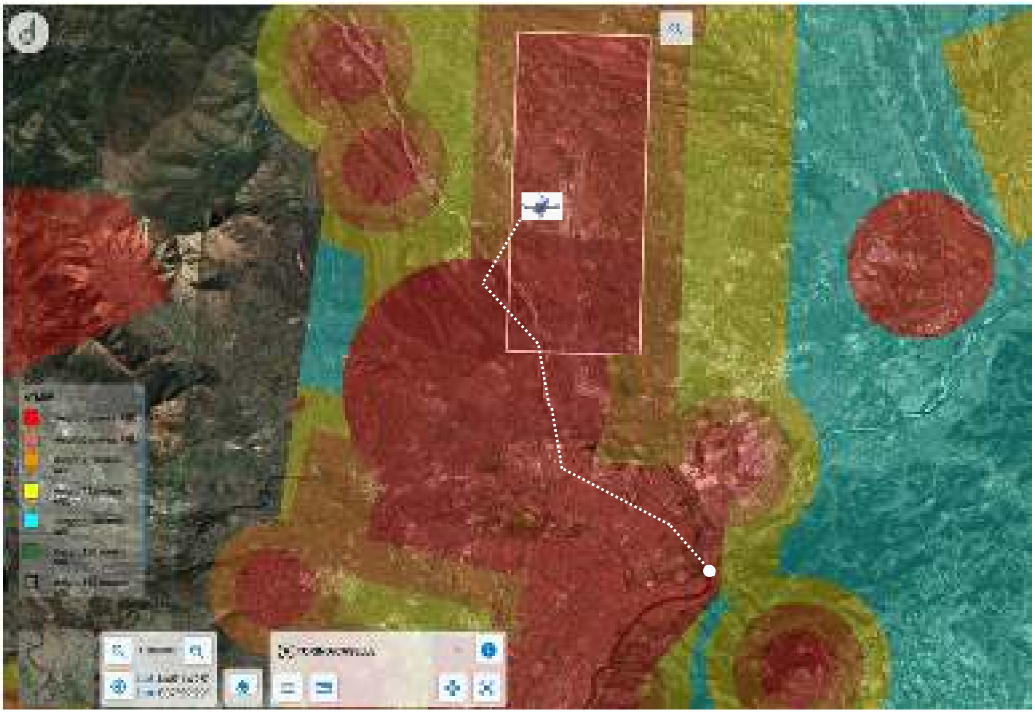


Figure 4-5: Taxi drone Passenger transfer from Torino Caselle Airport

Figure 4-6: S3 Taxi Drone Flight Plan

The simulation aims to show how the remote pilot of a taxi-drone can safely manage the aircraft thanks to accurate ground obstacle information provided by an accurate DSM/DTM service and a system that alerts to both obstacles and other manned and unmanned air traffic. The mission also shows how an aircraft relates to the height and altitude datum when entering a CARA, through using the VCS microservice.

4.2.4 Equipment and ICARUS Microservices involved

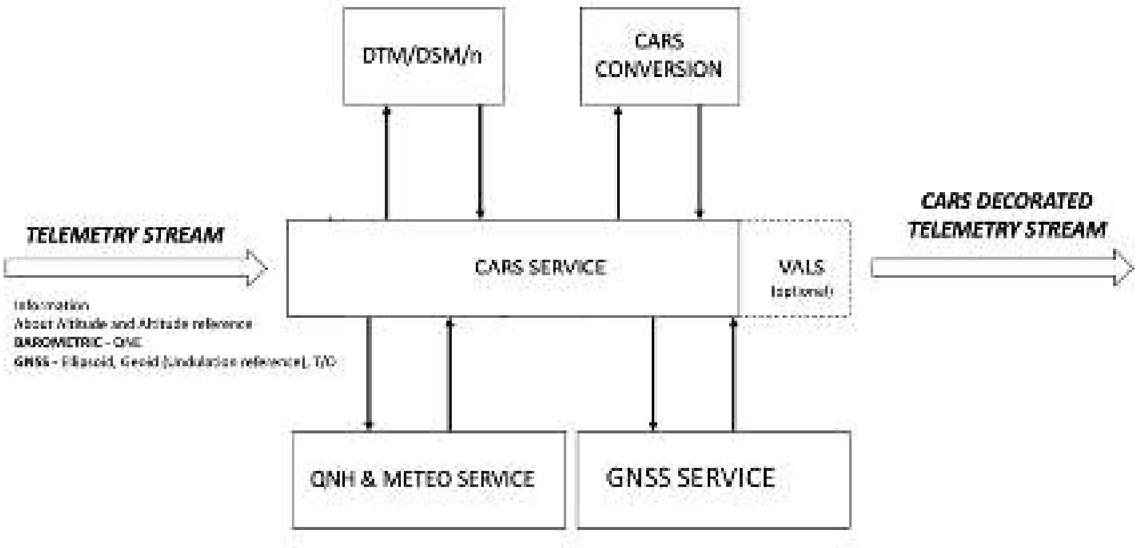


Figure 4-7: High level ICARUS architecture – Conceptual

1. CARS SERVICE

The CARS system acts as an entry point for telemetry decoration. The service performs a three-step conversion, consisting of:

1. collection,
2. conversion,
3. decoration.

The CARS service must provide a real-time conversion. From an IT perspective, it should be horizontally and vertically scaled. Otherwise, if the CARS service is not able to calculate the data in real time, it should inform all connected services (beneficiaries). The system must be use a technology that allows the maximum TTL (Time To Live), which determines the maximum time needed to perform the conversion, to be set. When the TTL is exceeded, the system must announce that it was unable to make requested conversion within the requested time.

CARS supported services:

- Collection of input data:
    - Position (Lat, Long)
    - Lat, Long vectors (for VALS)
    - QNH
    - Local pressure and temperature
    - Elevation and elevation reference of pressure and temperature sensor
    - DTM, and DTM reference
    - DSM, and DSM reference
    - Undulation value (n)
    - EGNOS/EDAS Data

    - VALS Time to Crash, in Seconds
- Real time, two-way calculation of heights and altitudes (GNSS to BARO, and BARO to GNSS)
- VALS.

2. DTM/DSM services

For CARS calculations, the DTM / DSM model should return the point elevation and undulation values.

For VALS calculations, the DSM model should return the maximum elevation of the earth's surface for the polygon derived from the speed, the assumed time "time to crash" parameter and the width of the safety buffer.

3. CARS conversion microservice

Service for two-way height/altitude conversions:

- BARO to GNSS
- GNSS to BARO

4. QNH/METEO Service

- The QNH service should return the value of the actual QNH value for the requested point (LAT/LON from the telemetry service). The QNH service should return QNH for:
    - CTR
    - TMA (when the value of the aerodrome QNH given by METAR has been extended below the TMA)
    - QNH region
    - Contingency QNH Region
- The Meteo service should provide information about the current pressure, temperature and elevation of the sensor along with information about the reference system in which this height was provided. As a rule, the pressure sensor should be laterally as close as possible to the object for which the calculations are made. The details of the maximum "acceptable" lateral (horizontal) distance of the sensor from the flying object (UAS, aircraft, etc.) should be a subject of separate research.

4. GNSS Service

    The ARAIM and EGNOS algorithms are the core elements for providing and comparing different types of augmentation to the drone operators involved in the UAS Operation.

    The telemetry stream is enriched through the computation by information regarding the Horizontal Protection Level (HPL) and Vertical Protection Level (VPL) giving a value for the integrity.

    Integrity is a measure of the trust that can be placed in the correctness of the information supplied by a navigation system. Integrity includes the ability of a system to provide timely warnings to users when the system should not be used for navigation.

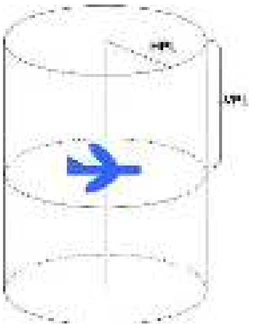
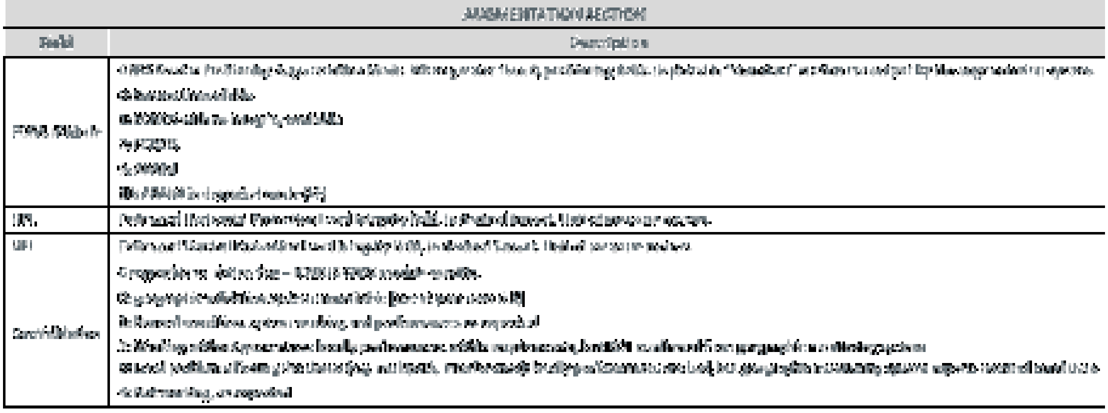


Figure 4-8: graphic representation of HPL and VPL

The GNSS service provides:



AUGMENTATION SECTION	
Field	Description
POSAUGMode	[illegible]
HPL	[illegible]
VPL	[illegible]
GeoValidation	[illegible]

Since it is not possible to know the position error of an aircraft during normal operations, a statistical bound to position error, called protection level, needs to be computed to be able to measure the risk of exceeding the alert limit.

CARS FLOW:

1. GNSS and BAROMETRIC data and references are extracted from the telemetry stream
2. The DTM/DSM provides elevation data and reference for LAT/LON extracted from the telemetry stream
3. The QNH service provides a QNH value for LAT/LON extracted from the telemetry stream
4. The METEO service provides pressure and temperature, as well as the pressure sensor elevation value for LAT/LON extracted from the telemetry stream
5. The GNSS service provides HPL,VPL, geo-validation and POSAUGMode
6. All collected data are forwarded to the CARS conversion service
7. The telemetry stream is decorated by the CARS service with calculated:
    1. QNH Altitude
    2. QNE Altitude
    3. Height above terrain (referenced to the DTM)
    4. Height above surface (references to the DSM)
    5. Altitude above the ellipsoid
    6. Altitude above the geoid
    7. HPL ,VPL, POSAUGMode

h_ort	270.54 m
h_obs_qnh	276.40 m
h_agl	270.54 m
h_asl	270.54 m
h_obs_qne	321.69 m
HPL	14.00 m
VPL	15.97 m
POSAUGMode	EGNOS m.l.

The decorated telemetry and consequently the results of ICARUS microservice computations are provided to the users through the USSP.

Once the drone operator has planned the mission and it has been authorised by the USSP responsible for the U-Space airspace (e.g. D-FLIGHT for Italy), the drone operator can start the mission.

Figure 4-9: Mission approval on USSP (D-Flight)

Once the mission has started, the received telemetry is enriched by ICARUS computations able to calculate QNH altitude, QNE altitude, Height above terrain, Height above the surface, Altitude above the ellipsoid, Altitude above the geoid, HPL, and VPL.

Figure 4-10: Icarus Service Visualiser

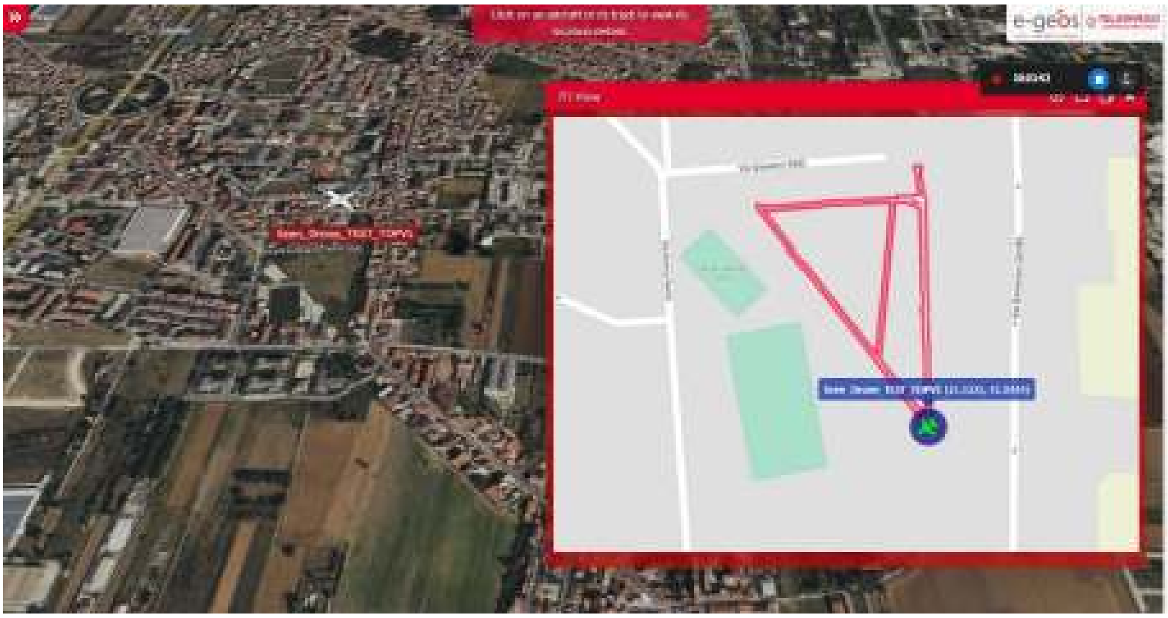


Figure 4-11 : Real time exploitation of Icarus services

Figure 4-12: ICARUS service exploitation for manned aircraft

If the manned traffic is already active and connected to ICARUS services, the same computations are also provided to the manned pilots, thus a harmonisation of manned and unmanned information is possible through the Common Altitude Reference System provided.

Figure 4-13: ICARUS service exploitation for manned and unmanned aircraft

Both manned and unmanned aircraft will have the indication of their current position decorated by ICARUS, so the manned and unmanned pilots will be able to compare their altitude/height using all the necessary information available in real/near-real time.

Figure 4-14: Cockpit simulator and ICARUS EFB used during the validation activities

For the validation of the ICARUS concept on the manned aviation side, a cockpit simulator for general aviation (GA) was used. The pilot used a tailored Electronic Flight Bag (EFB) prototype for cooperative drone traffic information, with indication of azimuth and relative height with respect to the altimeter settings used by the GA airplane.

On the other hand, GNSS raw data and barometric raw data were collected by drones, with a prototype of UTM box transmitting this information in real time to the ICARUS VCS service.

Figure 4-15: ICARUS UTM Box prototype

4.3 DTM/DSM/Undulation information requirements and recommendations

The technical characteristics of DTM/DSM/Undulation constitute a key limit of the vertical accuracy of CARS conversion. The table below provide guidelines for selecting proper datasets. As the highest accuracy data is not available for the entire world, requirements as to recommended and minimum values are provided.

For ICARUS validation activities, ad hoc DTM and DSM have been generated with a resolution of 1m and 0.6 m, to obtain the best conversion results by reducing the amount of total error due to the Geographical Information System (GIS) component.

Property	**Minimum**	**Recommended**
DTM/DSM		
Measurement method	SAR, SGM	LIDAR
Vertical accuracy	Europe: not worse than EUDEM World: not worse than NASADEM	<=0.5m RMSE (measured for the date of data acquisition for man-made objects)
Source grid spacing	Europe: not worse than EUDEM World: not worse than NASADEM	<=1.0m <=0.5m for DSM for urban areas

Validation	For other than EUDEM/NASADEM internal validation required (performed by data provider)	State mapping authorities certified verification
Timeliness	For other than EUDEM/NASADEM, 15 years	10 years
Spatial coverage	Seamless coverage (lack of no-data values) for entire service provision territory	Seamless coverage (lack of no-data values) for entire service provision territory
Planar datum	WGS84 (EPSG:4326)	WGS84 (EPSG:4326)
Vertical datum	EVRF2000 (EPSG:5730)	EVRF2007 (EPSG:5621)
Metadata	As a minimum, metadata for DTM/DSM dataset must describe vertical accuracy and acquisition year.	As a minimum, metadata for DTM/DSM dataset must describe vertical accuracy, acquisition year and data provider.
Other	-	It is recommended to use one provider of DTM/DSM for a given area (e.g.: country, region) to ensure single source of truth for everyone
	-	It is recommended to use the existing data provider most commonly used by the UAS community to ensure smooth implementation and predictable results.
Undulation		
Geoid model	EGM96	EGM2008

Due to the vast cost of high accuracy LIDAR data, its update cycle is usually considerably long (e.g. 10 years). To improve the timeliness of the data, it is recommended that DTM/DSM providers allow local contributions of more up-to-date datasets from other sources e.g. UAS operator/pilot communities. Such data must be provided in an off-line mode only, along with reference data and proper metadata (minimum: vertical accuracy acquisition year) to allow users to carefully analyse it.

4.4 Information & Conversion Service regulation

4.4.1 Regulatory aspects of ICARUS services

4.4.1.1 CORUS ConOps

Section 2.5.2 of vol. II of the CORUS ConOps (CORUS, 2019) stated the need for a Common Altitude Reference System (CARS) and envisaged that U-space might offer services to convert between different altitude systems (i.e. geodetic to barometric and vice-versa). This Vertical Conversion Service (VCS) was not described in the CORUS ConOps, however.

In the ICARUS architecture, the VCS is complemented by the RGIS (Real-time information on vertical geometric distance from obstacles) and the Vertical Alert Service (VALS).

4.4.1.2 Volumes

The CORUS ConOps proposes that U-space airspace be divided into different kinds of volume according to the U-space services provided. The three basic configuration types are detailed in Table 4-1: CORUS ConOps volume definitions.

	X	**Y**	**Z**	
			Za Controlled by ATC	**Zu** Tactical Collision Resolution provided by U-space
Conflict Resolution Service Provision	No conflict resolution.	Only pre-flight conflict resolution.	Pre-flight conflict resolution and in-flight separation.	
Access Requirements	• There are few basic requirements on the operator, the pilot or the drone. • The pilot remains responsible for collision avoidance. • VLOS and EVLOS flight are possible. • Other flight modes in X require (significant) risk mitigation.	• An approved operation plan is required. • The UAS pilot needs to be trained for operation in Y volumes. • A remote piloting station must be connected to U-space. • A drone and a remote piloting station must be capable of position reporting when available. Y volumes may also have specific technical requirements attached to them.	• An approved operation plan is required. • A UAS pilot needs to be trained for operation in Z and/or a compatible, connected automatic drone must be used. • A remote piloting station must be connected to U-space. • A drone and remote piloting station must be capable of position reporting. Z volumes may also have specific technical requirements attached to them, most probably that the drone be fitted with a collaborative Detect And Avoid (DAA) system for collision avoidance.	

Table 4-1: CORUS ConOps volume definitions

These definitions may change slightly in the upcoming CORUS-XUAM update to the ConOps. For example, there is the possibility of a variant of the Y volume where a plan is required, but no services are offered. Similarly, Zu may be split into two, with one part having tactical separation instructions, and the other just having tactical separation advice.

ICARUS is based on the possibility of GNSS-based altitude measurement for drones combined with a tailored U-space service for height transformation (geodetic measurement to the barometric reference system and vice-versa) to be provided to manned and unmanned users of VLL airspace to provide a common way of determining the vertical distance to the ground in both barometric and geodetic values. In this way, manned and unmanned users can be aware of their altitude and height with both expressed with respect to the same reference.

At VLL, below a given "transition altitude" established by the local civil aviation authorities, both drones and manned flights can use the ICARUS services for altitude determination, but ONLY outside ATZs and CTRs, in the airspace volumes defined as X,Y and Z_u by the CORUS project.

This concept may enhance the capacity of the airspace, while giving a common altitude reference for airspace users, especially in the urban environment where package delivery and drone taxi applications may be promising disruptive businesses in Europe in the coming years.

4.4.1.3 Categories of UAS Operations

The CORUS ConOps mapped 'Open', 'Specific' or 'Certified' category operations to airspace volumes. Both the access conditions and the CORUS volume mappings are summarised below:

- UAS operations in the 'Open' category will not be subject to any prior operational authorisation, nor to an operational declaration by the UAS operator before the operation takes place.
    - Regions of X volumes will be dedicated to 'Open' class operations.
    - They are also possible in Y and Z if all conditions are met
- UAS operations in the 'Specific' category will require:
    - an operational authorisation issued by the competent authority (pursuant to Article 12 of Commission Implementing Regulation 2019/947 (European Commission, 2019))

    or

    - an authorisation received for UAS operations in the framework of model aircraft clubs and associations (in accordance to Article 16 of Commission Implementing Regulation (EU) 2019/947 (European Commission, 2019))

    or, for an operation complying with a standard scenario (as defined in Appendix 1 of Commission Implementing Regulation (EU) 2019/639 (European Commission, 2020))

    - a declaration to be made by a UAS operator, in which case, the UAS operator shall not be required to obtain an operational authorisation.

  These types of operation can occur in X, Y and Z volumes. A risk assessment is required before the operation.
- UAS operations in the 'Certified' category will require the certification of the UAS pursuant to Delegated Regulation (EU) 2019/945 (European Commission, 2019) and the certification of the operator and, where applicable, the licensing of the remote pilot.
    - Certified operations can occur in all X, Y and Z volumes.
    - Some Y and Z airspaces may mandate the use of certified drones only.

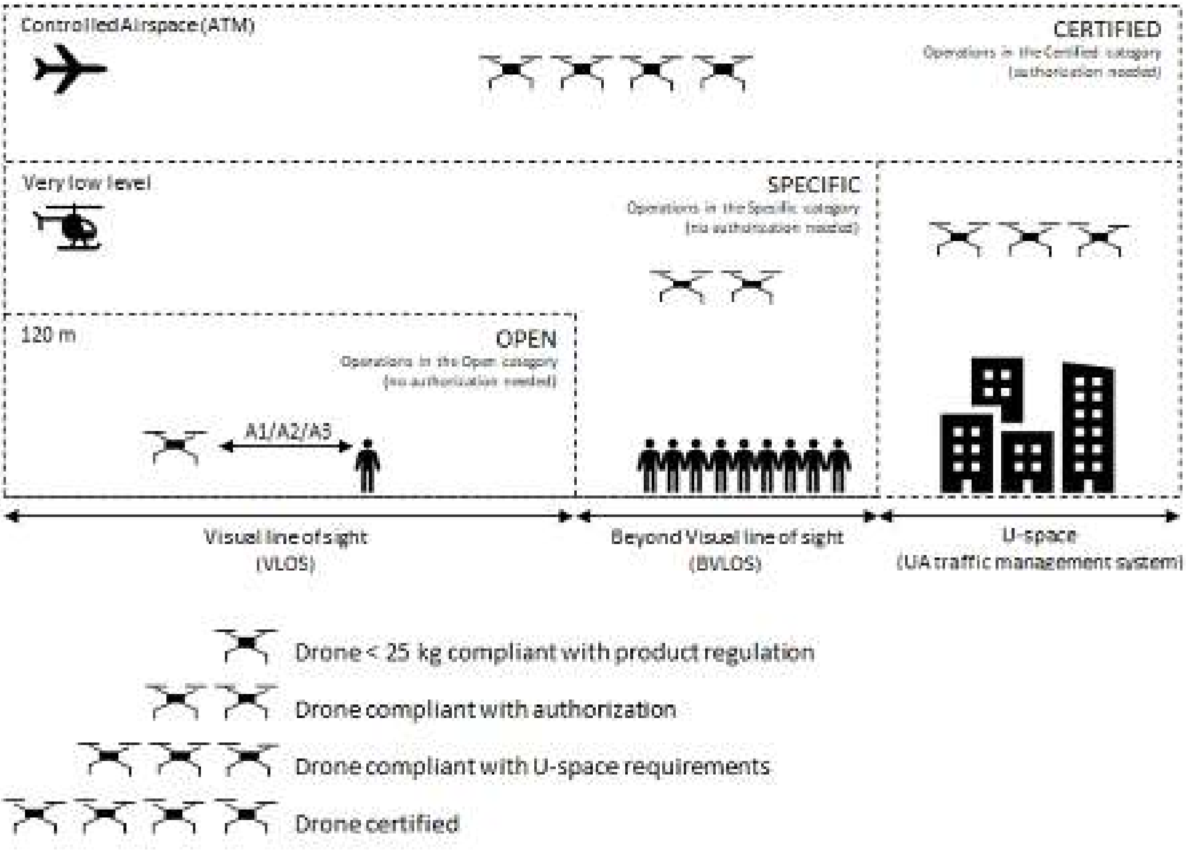


Figure 4-16:EASA regulations on the certification classifications of UAS

EASA regulations on the certification classifications of UAS (European Commission, 2021) provide an illustration (repeated in Figure 4-1) of how the current regulations impact the types of operation and UAS certification classification permitted in different regions of airspace.

ICARUS' work is very important for operations in VLL airspace, especially for the Specific and the Open categories where there is supposed to be the greatest increase in activities.

4.4.1.4 ICARUS CONOPS

When stating the problem, section 2.3 of the first iteration of ICARUS D3.1 says that:

> ICARUS services, will be made available to third parties (e.g. U-space service providers) through specific Application Programming Interfaces (API) and open and interoperable protocols with the following main elements:
>
> - ✓ GNSS-based altimetry as a common reference datum for vertical UAS separation in VLL airspace;
> - ✓ In strategic and tactical phases, a U-space service capable of providing
>   - information on the vertical distance to the ground (terrain, ground obstacles, buildings) and warnings to the manned-aviation pilots near "Geometric Altitude Mandatory Zones";
>   - **conversion of reference systems for general aviation users**;
>   - …

Furthermore, ICARUS D3.1 proposes the concept of "Common Altitude Reference Area" (CARA). However, a few "gaps" to be filled in this have been identified. There is a lack of common technical solutions necessary for manned and unmanned aviation to ensure a mutual vertical alert in VLL airspace. At least in certain scenarios, a simple ATM/UTM interface, invoking the barometric–geodetic Vertical Conversion Service (VCS) can be defined for reporting manned traffic position and height information to remote UAS pilots. Conversely, in a CARA in airspace type Zu (over urban areas) it would be necessary to provide VCS to manned aircraft to provide them information about geodetic altitude.

After collecting experience from the ICARUS project, it was decided to change the previously proposed name GAMZ to CARA (Common Altitude Reference Area). The rationale for the name change and a detailed description of the concept are given below.

GAMZ drawback

Presence of UAS performing different missions in a given volume of airspace requires coordinated effort to achieve safe traffic segregation while maintaining safe clearance from terrain and its features. One of proposed solutions was the introduction of a Geometric Altitude Mandatory Zone (GAMZ). All traffic within the horizontal boundaries of a GAMZ should use the same "zero reference" thus the vertical solution based on a common reference suits this purpose. This approach leads to the establishment of many GAMZs with different "zero references" and in certain cases areas that might even overlap or protrude, and cannot accommodate long distance missions.

It is prudent to realize that some UAS missions (e.g. BVLOS) can either block a significant volume of airspace within a single mission-established GAMZ or cross through various GAMZs. These cases require significant effort to set a "zero-reference-location" that suit the mission profile so that the correct vertical solution for the terrain and its features in reference to that "zero-elevation" can be achieved. Crossing GAMZs brings an additional set of problems: one of these is where to switch to another/next "zero-reference". It is unwise to assume that a UAS that reaches the boundary of its own GAMZ will *hang* (if it is able to) at that fix/position and adjust its vertical mission parameter and/or "zero-reference" to the one of the adjacent GAMZ before continuing, or that there is a need to establish a "transition area" on both sides of a GAMZ border for "smooth" transition between GAMZs. This is significant complication and the increased level of vertical uncertainty within these areas brings the risk of collision. All these imply that the vertical solution to UAS traffic segregation cannot be effectively achieved for the entire volume of unmanned missions by using GAMZ concept.

Manned aviation operating on low altitudes (below the Transition Altitude) uses a QNH altimeter setting for finding a solution to safe obstacle and terrain clearance as well as for segregation from other manned airspace users. The GAMZ concept not not enable vertical information of UAS traffic to be available and understood by pilots. UAS operating at the upper band of a GAMZ airspace volume will not be able to use ACAS or pressure coded vertical information as supplied by advanced on-board surveillance systems (e.g. ADS-B) to achieve safe vertical segregation. In some cases due to atmospheric pressure variations, the upper limit of a GAMZ, or even in general GAMZ cruising altitudes, might be in conflict with pressure altitudes used by pilots due to the various "zero-reference" and lapse rates of the vertical parameter used.

It is clearly evident that the GAMZ concept does not fulfil the continuity, adequacy, safety and manageability principles as perceived by the aviation world and that are commonly known as set of standards and recommended practices.

CARA (Common Altitude Reference Area) born of CARS

Aircraft airborne surveillance systems use QNE settings for reporting and broadcasting vertical information. This vertical information is converted to altitude by ground based traffic management system software using the local QNH value for traffic below the Transition Altitude and left unconverted when 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 the pressure sensor 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 sensors are prone to the same errors when in particular area and thus altitude parameters are true and enable vertical spacing of traffic to be achieved.

Altitude derived when an altimeter is set to QNH refers to the elevation AMSL of the QNH sensor at its position. This implies that altitudes reported when close to the QNH sensor are more accurate than altitudes reported when far away from the reference sensor position. This is due to the horizontal distribution of pressure and various horizontal gradients. Thus, when away from the pressure sensor, altitude reported based on QNH is less accurate. It is worth noting that QNH is used to determine safe obstacle clearance and determines flight altitudes since all terrain and obstacle elevations are referenced to AMSL.

The problem of lateral pressure distribution in different types of area (open, urban, forest, mountain, etc.) has been identified, but not recognised. For example, there is no known "system" accuracy limit for wide (e.g. > 50 km) QNH regions, or contingency ones (such as beyond CTR and TMA) that would provide a known error value. In other words, topic recognition and its impact on TSE, should be evaluated and tested.

There are two different demands for QNH settings:

- QNH-based altitudes must be accurate when in close proximity to airports (pressure sensor location) due to the demanding airspace structure and the accuracy required for manoeuvring in vertical plane (instrument procedures like SID, STAR, IAP).
- Area QNH must service a wide area and its primary purpose is to provide safe clearance from terrain and obstacles. Such a QNH incorporates add-ons for an expected or experienced drop in pressure at the most distant point from the altimeter setting area (lack of local sensor) which caters for maintaining safe terrain clearance.

As can be seen, vertical segregation is achieved by using discrete altitude values that refer to a common altimeter pressure setting applicable within a given volume of airspace.

All aviation altimeters used for altitude readout are calibrated according to the standard model of the International Standard Atmosphere vertical pressure lapse rate.

Based on practical analysis with interoperability, continuity, manageability, safety and economy concepts in mind, the following principles have been set as a basic framework of a future vertical solution to UAS operation within geo-zones (in the meaning of ED-269, containing both AIM and UAS specific airspace volumes).

1. Use known-to-all and common altitude reference for terrain /obstacle/structure avoidance.
2. Use known-to-all and common reference for UAS / UAS avoidance within geo-zones.
3. Use the pressure concept for manned aviation interference.
4. Set the conversion system to make current and valid pressure setting available for altitude reference used for air traffic service purposes/vertical segregation for all users.

As an outcome of various ideas, it was established that the only feasible and plausible reference system for local and wider area UAS operation is vertical reference to a valid mathematical GNSS Earth model reference line, namely the Earth ellipsoid. This is the only reference to provide precise vertical and commonly understandable information. The ellipsoid model is embedded in all GNSS or 3-D positioning systems. One of the most commonly used models of Earth is the World Geodetic System '84 – known as WGS84. It defines set of models such as the World Magnetic Model (WMM) or the Earth Gravitational Model (EGM), and defines a geoid which is mathematically idealised as an ellipsoid. Thus WGS84 parameterises a reference Earth ellipsoid. This provides continuous and valid reference information that when combined with a DTM/DSM (e.g. GREY) enables mission planning and execution even where the ground features congested areas (cities, mountains, etc.), at this same time giving a valid reference for vertical manoeuvres and UAS/UAS segregation. Ellipsoid-altitude values might be negative in some areas while still valid and true.

The Earth geoid cannot be used for this purpose since by definition the geoid refers to the Earth's constant gravitational acceleration surface, which varies by the value of undulation from the mathematical ellipsoid model at the given location, thus introducing addition vertical error.

It can be seen, therefore, that the vertical parameter based on the ellipsoid can be used to segregate UAS/UAS traffic vertically, taking unmanned vehicle dimensions and manoeuvring capability into account (while also taking DTM/DSM into account) thus optimising the use of airspace. However, this reference cannot be used for manned aviation traffic purposes. The only operationally proven solution to this problem is the use of the existing pressure-referenced system for vertical trajectory management. Advance UAS are already equipped with a certified pressure-altitude determination capability as per the international standard, and their operation in common use airspace mirrors the rules for manned aviation. Since it cannot be expected to incorporate a viable and certified pressure-altimeter system in most of UAS categories in the near future, especially low-end technology UAS, other approaches are required. It is worth mentioning that a change of 1 mbar (1 hPa) of pressure represents approximately 28 ft vertical distance; it is obvious therefore that use of a pressure system for UAS/UAS or UAS / terrain /DTM/DSM is not possible due to horizontal or local pressure variations (temperature, pressure and wind effects, etc.).

To achieve interoperability and continuity of safe operation when close to or within manned aviation airspace, there is need to deliver QNE or QNH-based aviation-standard altitude information to appropriate users. Or in other words, convert ellipsoid altitude (used for UAS missions) into pressure altitudes understood by manned aviation.

The reverse conversion can be used to determine safe mission planning and execution when in a given geozone.

By establishing a conversion service that is based on accurate pressure values at a given location (CARA), the converter is able to "translate" planned ellipsoid mission altitudes to the pressure-altitude system. This allows for verification and consistency with the known airspace structure while conforming to the DTM/DSM.

This conversion system, enhanced by additional pressure sensors and a pressure distribution algorithm, provides increased accuracy and outputs pressure-altitude values based on local or area QNH settings or QNE settings. This allows safe segregation of UAS from manned aviation to be achieved. By extending the number of meteorological (pressure, temperature) sensors, more accurate pressure information can be transferred to ATS services, which significantly increases vertical awareness by reducing uncertainty and the need for conservative pressure distribution models.

The topic of lateral pressure distribution and a later change to lapse or crucial parameters will be addressed separately. An additional point of interest is local temperature and pressure variation on technical error for the CARS altitude solution.

4.4.2 Rules of the Air

Annex 2 (Rules of the Air) to the Chicago Convention has been transposed into EU law through Regulation 923/2012 [3] on Standard European Rules of the Air (SERA). Commission Implementing Regulation (EU) 2021/666 of 22nd April 2021 amended (EU) No 923/2012 as regards requirements for manned aviation operating in U-space airspace. This regulation introduces an additional point to SERA.6005 in Section 6 of the Annex regarding electronic conspicuity in U-space airspace.

According to SERA rule 5050 (f), "*except when necessary for take-off or landing, or except by permission from the competent authority, a VFR flight, during daylight hours, shall not be flown below 1,000 ft AGL over urban areas or below 500 ft in rural areas*". This is consistent with current standards in ICAO Annex 2.

For flights under IFR, SERA 5015 (b) prescribes, again in line with ICAO Annex 2, that, "*except when necessary for take-off or landing, or except when specifically authorised by the competent authority, an IFR flight shall be flown at a level which is not below the minimum flight altitude established by the State whose territory is overflown, or, where no such minimum flight altitude has been established:*

1) *over high terrain or in mountainous areas, at a level which is at least 600 m (2 000 ft) above the highest obstacle located within 8 km of the estimated position of the aircraft;*
2) *elsewhere than as specified in (1), at a level which is at least 300 m (1 000 ft) above the highest obstacle located within 8 km of the estimated position of the aircraft.*"

Consequently, although competent authorities may (and in fact do) authorise flights below such heights/altitudes, no common EU rules yet exist in the SERA for flights at Very Low Level (VLL).

Article 15 of the common EU rules for UAS operations [4] empowers each EU Member State to establish "UAS geographical zones" but:

a) Without mentioning any common criteria;
b) Removing the notion of "minimum height", but not mentioning which rules of the air would apply (i.e. VFR, IFR or else?);
c) Without providing any guidance on the possible presence of manned aircraft in such zones.

In other words, this Art. 15 removes the prescription of minimum heights, so enabling drones to fly much lower than 500 ft AGL, but it does not provide sufficient common rules or criteria for so doing, which would inevitably result in a lack of uniformity across the EU member states and possibly also in safety concerns.

It may therefore be useful to consider a joint EASA/EUROCONTROL Discussion Document [5] of 2018, which concluded that:

a) In 2018, due to absence of specific common flight rules for VLOS and BVLOS and their coexistence with manned aviation, it was possible to safely integrate drones at altitudes below the lowest VFR altitude only through either segregation of airspace or through the use of procedures enabling drones to remain clear of manned aircraft;
b) Conspicuousness is one of the corner stones of the traditional flight rules' aspect of "see and avoid", but this is very difficult, as manned aircraft are not able to detect smaller drones. The issue might indeed be eased through Direct Remote Identification, but this topic is on the one hand outside the scope of ICARUS and on the other hand, at least for UA, already regulated through Commission Regulations 2019/947 and 945 [6] ;
c) Among the issues to be solved there was a CARS and in fact a UTM system providing "translation between several altitude reference systems";
d) Apart from the vertical aspect, horizontal navigation requirements also require attention. Therefore, a navigation specification similar to the PBN specifications will have to be

developed to ensure a certain level of accuracy and integrity, which again is not the prime scope of ICARUS, but covered by other projects (e.g. REALITY [7]).

But, even more importantly, this discussion document deemed it essential to incorporate VLOS and BVLOS into SERA through development of specific Low-level Flight Rules (LFR) without which full integration of manned and unmanned aviation at VLL would not be possible.

In fact, EASA has planned the integration of UAS operations in non-segregated airspace through ToR RMT.0230 [8]. The ToR envisages a progressive update of SERA in this regard:

a) in a 1st phase, reviewing SERA to identify potential issues that could hamper the development of UAS and introducing limited rule changes or guidelines to resolve these issues; and

b) in the 2nd phase, introducing more comprehensive changes to the EU standard rules of the air, including (whenever available) requirements (e.g. mandatory on-board functionalities) for the safe integration of UAS into the airspace.

In the 1st phase, EASA published a Notice of Proposed Amendment (NPA) in 2021, to enable Urban Air Mobility (UAM) operations by UAS/VTOL following predefined routes/areas/corridors in VLL airspace. Even this limited innovation, would however require a CARS.

In the 2nd phase, EASA assumed that U-Space services for tactical de-confliction would be available or Detect And Avoid (DAA) capabilities would have been demonstrated to be suitable for UAM. In this 2nd phase, new flight rules are not excluded, but the current EASA CONOPS [9] is not explicit on this. CARS would however still be necessary.

Since UAS traffic density over urban areas is expected to increase greatly, according to several market studies, and since new concepts for UAM involving manned aircraft (e.g. small seaplanes, hybrid car-gyroplanes, manned eVTOL multicopters, etc.) are emerging, it is considered highly desirable for safety reasons to introduce Common Altitude Reference Areas (CARA), at least in what CORUS labelled type Zu airspace.

CARA would of course apply below a "transition altitude" established by the authority and possibly published in the relevant AIP.

However, such an altitude is currently defined in Annex 11 to the Chicago Convention as "the vertical distance of a level, a point or an object considered as a point, measured from mean sea level", not as vertical distance from the ground. Using barometric altimetry, the altitude is hence based on the QNH.

It should be remembered that:

a) SERA enshrines the seven airspace classes (i.e. A to G) standardised by ICAO in Annex 11 to the Chicago Convention into EU legislation, but, in addition, it has already introduced "Transponder Mandatory Zones" (TMZ) and "Radio Mandatory Zones" (RMZ) and therefore in principle CARA could be introduced as well;

b) Nothing in the current text of Article 15 of Commission Implementing Regulation 2019/947 prevents introducing a CARA.

Lastly, the Commission Implementing Regulation (EU) 2021/664 of 22nd April 2021 on a regulatory framework for the U-space lays down rules and procedures for the safe operations of UAS in U-space airspace, for the safe integration of UAS into the aviation system, and for the provision of U-space services.

5 Applicable and reference documents

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[3] Commission Implementing Regulation (EU) No 923/2012 of 26 September 2012 laying down the common rules of the air and operational provisions regarding services and procedures in air navigation and amending Implementing Regulation (EU) No 1035/2011 and Regulations (EC) No 1265/2007, (EC) No 1794/2006, (EC) No 730/2006, (EC) No 1033/2006 and (EU), as lastly amended by Commission Implementing Regulation (EU) 2017/835 of 12 May 2017.

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[20] ICARUS D4.2, “ICARUS Prototype”

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