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## Copyright Statement

# 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 ICARU,S were present. Operations in type Y and Zu volumes would not be in the "green" area of the safety matrix without ICARUS and the associated regulatory amendments (i.e. PBA and GAMZ).

In its conclusions, this document recommends:

- the adoption of the concept of a GNSS-Altitude Mandatory Zone (GAMZ) by EASA in amendments to SERA;
- the adoption by the EU of a definition of altitude different from ICAO's, applicable to airspace type Zu, as defined in the CORUS ConOps;
- the development of specific Low-level Flight Rules (LFR) to cover the needs of UAM at VLL;
- transposing the principles of AMC1 ARO.GEN.305(b);(c);(d);(d1) into the U-space context as an AMC to the forthcoming Commission U-space Regulation;
- proposing to include VCS in CD 23629-12 of ISO TC/20 SC/16 WG4;
- the adoption of a performance-based approach to regulation of altimetry in the coming "Part UAM" of AIR-OPS, considering that:
    - the function of a barometric altimeter, especially in areas away from aerodromes where an accurate QNH may not be available, could be replaced by VCS; and
    - the function of the radio altimeter, especially in obstacle-rich environments, could be replaced by RGIS.

Since EASA plans to issue a Notice of Proposed Amendment (NPA) covering this "Part UAM" in AIR-OPS, this recommendation should be forwarded to the Agency immediately.

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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).

This CONOPS is accompanied by a predictive safety assessment based on the European common Risk Classification Scheme (ERCS)[1].

This is a draft version of ICARUS_Preliminary ConOps. Some information is still missing pending the availability of results from the next ICARUS validation and test campaigns. The final release is scheduled for March 2022, when the simulation and demonstration tasks are complete and their results evaluated.

## 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 in the operation of the VCS. The regulatory aspects and the rules of the air are also covered, and the different avionic, UAS and airborne functions necessary for VSC operation are described. The ConOps is completed by a risk analysis, and conclusions and recommendations.

## 1.3 Acronyms

| Acronym | Meaning |
|---|---|
| ADF | Automatic Direction Finder |
| AGL | Above Ground Level |
| AIP | Aeronautical Information Publication |
| AMC | Acceptable Means of Compliance |

[1] Commission Delegated Regulation (EU) 2020/2034 of 6 October 2020 supplementing Regulation (EU) No 376/2014 of the European Parliament and of the Council as regards the common European Risk Classification Scheme (ERCS)

| | |
|---|---|
| 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 |
| 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 including especially ultra-light and general aviation manned 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 SJUblueprint.

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 (alias U-space). 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 kind of sensors: 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) Proportionate requirements for safety-critical, safety-related or operation support UTM 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 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[2] 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;

[2] 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

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 the U-space service providers);

i) Possible introduction of Geometric Altitude Mandatory Zones (GAMZ) 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 3629-12. 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 "Geometric Altitude Mandatory Zone", 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 GAMZ |
| Vertical Alert Service (VALS) | Safety-critical | Alerts drones and manned aviation about their current vertical distance from ground when this is small |

| Service | | Description |
|---|---|---|
| Id. | Safety Criticality | |
| 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 safety assessment in this CONOPS is focused on the three new U-space services proposed by ICARUS.

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 [14]. 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 [15]. For definitions and further information, please refer to section 3 of ICARUS D3.1 [14].

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, [16], [17]) and as observed in periodic Performance Reports ([18], [19]), are reported in section 9.3.2 of ICARUS D3.1 [14].

#### 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.
    - User-equipment antenna biases.

An analysis of the challenges for satellite navigation has been performed in [20], 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 the 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 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 [14]).
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 [14] 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

Due to the fact that for each type of height conversion a specific DTM / DSM field model is required, information about its accuracy is required. Accuracy of field models should be taken into account when calculating the total error value (TSE).

### 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 height 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 [23].

For the Polish case, the geodetic reference system is the “EVRF - west European plus Kron8” one. After some research, we discovered that this official implementation most likely uses the PL-geoid-2011 model. We finally managed to download the undulation dataset at [21] and convert it to the format utilised.

As regards the undulation, the data were treated in the ISG 1.0 Format [22]. 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 will be calculated using bilinear interpolation of the nearest cell-centre values [23].

#### 3.1.2.2 Complex and Simple Formulas. Weather Station Factor.

As input data for the calculations, we 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 is known, which is critical for the calculations. A simplification was also made, consisting in the fact that the entire 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 urbanized 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 - that will be implemented in the final version of the service - take into consideration not only variations in pressure but also in temperature and gravity.

After the test analysis, we aim to quantify the impact of these variations on the final conversion results.

#### 3.1.2.3 Access to the QNH data

Access to the QNH pressure is designed to convert altitudes to the pressure used in aviation. This is important in both cases. The first case in which the counted altitude based on the GNSS sensor should be referred to the QNH pressure (regional, local and contingency), and in the second case, when the most common manned aircraft will declare that it 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 [14], the conversion formula used makes two assumptions: the ICAO standard atmosphere model and the ideal gas law.

To quantify the impact of these assumptions, we plan to test the conversion service for a set of points, of which we know both barometric and ellipsoidal heights, during the test analysis 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 emphasized 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 in order to determine a reliable height.

#### 3.1.2.6 Visual reference

In scientific and conference materials, there is also the topic of determining heights with the help of visual systems. In the ICARUS project, we deliberately omitted this measurement technique due to: the lack of reliable data on the certification and calibration of this type of devices, 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 Operational accuracy

- Accuracy of solution (calculations)
- Probability approach to vertical resolution (Errors)

## 3.3 Revised perception of obstacles

- Point obstacles
- Fixed dimensions obstacles
- Mobile obstacles
- Defined area obstacles (e.g. Crane)

## 3.4 Services overview

T.B.D. *The paragraph will be completed in the final release. It will include information about, at least on:*

- *Communication services*
- *Notification services*
- *Data sources*
- *Conversion system algorithms*

### 3.4.1 Conversion service formulas

As regards the conversion system, two services have been developed:

- The **GI service** receives longitude and latitude as input and returns the country code, the heights of 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 services and their interfaces are given in chapters 2 and 4 of [24]. Chapter 5 of [14] explains the theory behind the formula implemented inside the services.

Section 3.5.1.1 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 (3.5.1.2) and a drone (3.5.1.3).

#### 3.4.1.1 Assumptions and considerations

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

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)

- $R = 287.05287$ J/Kg K (Specific gas constant)
- $g = 9.80665\ m/s^2$
- $P_{\mathrm{QNE}} = 1013.25\ hPa$

### 3.4.1.2 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 $\mathrm{P_w}$.
- *h_w,* height in metres of the weather station nearest to the vehicle that is asking for conversion. It will be referred to as $\mathrm{H_w}$.
- *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 $\mathrm{P_{QNH,Airport}}$.
- *h_dtm,* the DTM height (in metres). This value is obtained by the GI service. In the formulas, it will be referred to as $\mathrm{H_{DTM}}$.
- *h_dsm,* the DSM height (in metres). This value is obtained by the GI service. In the formulas, it will be referred to as $\mathrm{H_{DSM}}$.
- *N,* is the geoid undulation in metres (height of the geoid relative to a given ellipsoid of reference). It will be referred to as $\mathrm{N}$.

#### 3.4.1.2.1 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 $t_{\mathrm{P}}$ at which the airplane started the request.

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

#### 3.4.1.2.2 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:

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

where $P_{\overline{\mathrm{QNH}}}$ is the average QNH value calculated for the region where the airport is located. It 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.

#### 3.4.1.2.3 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:

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

#### 3.4.1.2.4 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:

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

#### 3.4.1.2.5 The ellipsoidal height of the airplane

For the ellipsoidal height of the airplane, $h_{\mathrm{P}}$, 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 $H_{\mathrm{P,w}}$.

### 3.4.1.3 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 $N$.

#### 3.4.1.3.1 The orthometric height of the drone

The orthometric height of the drone $H_{\mathrm{P}}$ 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.

#### 3.4.1.3.2 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:

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

#### 3.4.1.3.3 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:

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

#### 3.4.1.3.4 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. It 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:

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

#### 3.4.1.3.5 The orthometric height of the drone respect the QNE

The orthometric height of the drone with respect to the QNE, $H_{\mathrm{QNE}}$, 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 in the UAS will be used and aviation context:

The following main considerations are to be evaluated:

0. commonality and accessibility of solution

1. mission profile design and mission following

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 are operating in lower band of airspace at present, 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 a mission's object. It is obvious that the legacy aviation pressure sensor with its limitations and accuracies — although 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 (in)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 its 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 that 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 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 (can be an autonomous avoidance algorithm) since all UAS will know their "terrain clearance" and their "ellipsoid altitude", regardless of 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 that 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 Information & Conversion Service safety and regulation

### 4.2.1 Regulatory aspects of ICARUS services

#### 4.2.1.1 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 however not described in the CORUS ConOps.

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

#### 4.2.1.2 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.

<table>
<tr><th rowspan="2"></th><th rowspan="2">X</th><th rowspan="2">Y</th><th colspan="2">Z</th></tr>
<tr><th>Za<br>Controlled by ATC</th><th>Zu<br>Tactical Collision Resolution provided by U-space</th></tr>
<tr><td>Conflict Resolution Service Provision</td><td>No conflict resolution.</td><td>Only pre-flight conflict resolution.</td><td colspan="2">Pre-flight conflict resolution and in-flight separation.</td></tr>
<tr><td>Access Requirements</td><td>• There are few basic requirements on the operator, the pilot or the drone.<br>• The pilot remains responsible for collision avoidance.<br>• VLOS and EVLOS flight are possible.<br>• Other flight modes in X require (significant) risk mitigation.</td><td>• An approved operation plan is required.<br>• The UAS pilot needs to be trained for operation in Y volumes.<br>• A remote piloting station must be connected to U-space.<br>• A drone and a remote piloting station must be capable of position reporting when available.<br>Y volumes may also have specific technical requirements attached to them.</td><td colspan="2">• An approved operation plan is required.<br>• A UAS pilot needs to be trained for operation in Z and/or a compatible, connected automatic drone must be used.<br>• A remote piloting station must be connected to U-space.<br>• A drone and remote piloting station must be capable of position reporting.<br>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.</td></tr>
</table>

**Table 4-1:CORUS ConOps volume definitions**

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.

### 4.2.1.3 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.

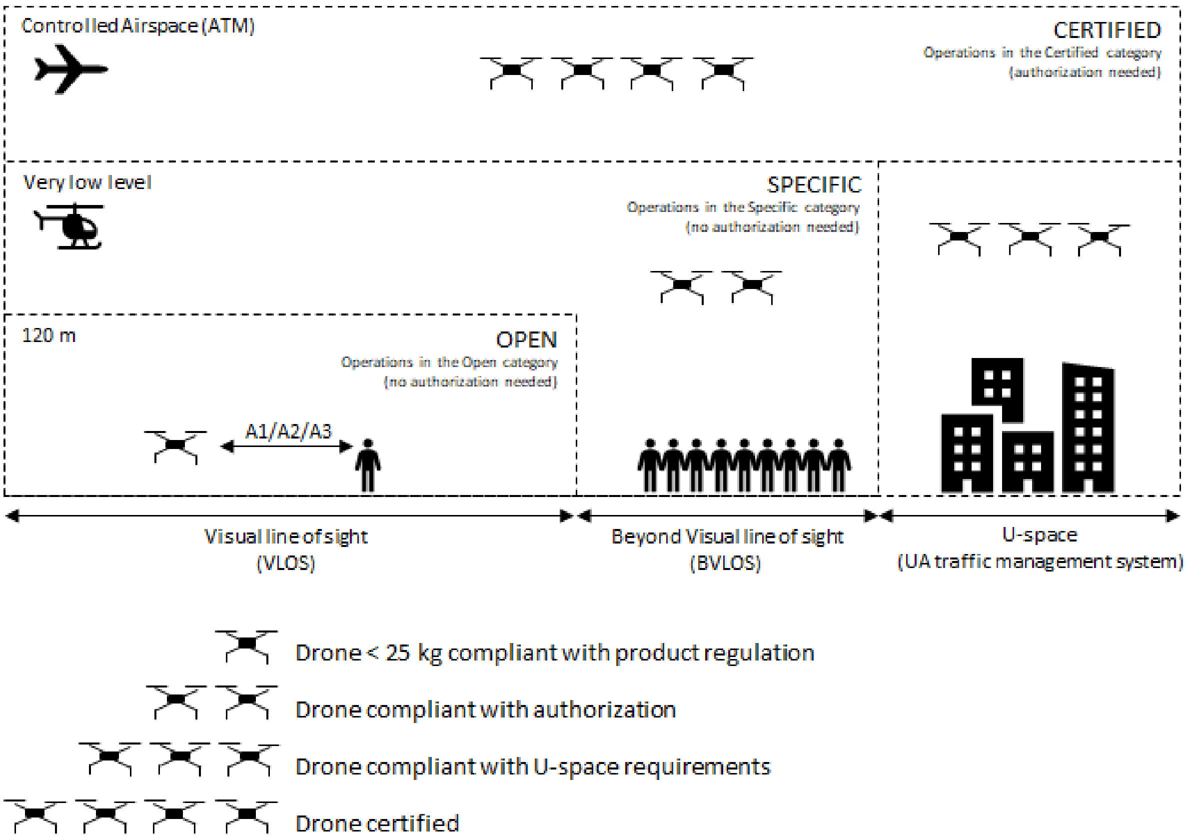

**Figure 4-1:EASA regulations on the certification classifications of UAS**

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.

#### 4.2.1.4 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 "Geometric Altitude Mandatory Zones" (GAMZ). 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 GAMZ in airspace type Zu (over urban areas) it would be necessary to provide VCS to manned aircraft to provide them information about geodetic altitude.

#### 4.2.1.5 Scope

The scope of this section is a preliminarily exploration of regulatory aspects connected to the GAMZ and the new ICARUS services (i.e. RGIS, VCS and VALS), including:

a) Rules of the air;
b) Service Provision; and
c) Required airborne functions for manned aviation.

### 4.2.2 Rules of the Air

Annex 2 (Rules of the Air) to the Chicago Convention has been transposed into EU law through Regulation 923/2012 [7] on Standard European Rules of the Air (SERA). The Commission Implementing Regulation (EU) 2021/666 of 22 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 EU common 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 they 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 [8] 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 even much lower than 500 ft AGL, but it does not provide sufficient common rules or criteria to do so, 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 [9] 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 one side outside the scope of ICARUS and on the other side, at least for UA, already regulated through Commission Regulations 2019/947 and 945 [10] ;
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 navigation 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 [11]).

But, even more important, 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 is planning, through ToR RMT.0230 [12] the integration of UAS operations in non-segregated airspace. The ToR envisage 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 plans to publish 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 currently assumes 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 [13] is not explicit on this. CARS would however still be necessary.

Since UAS traffic density over urban areas is expected to hugely increase 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 Geometric Altitude Mandatory Zones (GAMZ) at least in what CORUS labelled type Zu airspace.

GAMZ 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.

But inside a GAMZ the reference would no longer be mean sea level, but the surface of the planet. The definition of transition altitude would therefore necessitate an amendment.

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 GAMZ could be introduced as well;

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

Based on the above considerations it is therefore recommended that:

a) the concept of GAMZ be proposed to EASA for the 2nd phase of amendment to the SERA and, related to this, the need for the EU to adopt a definition of altitude different from ICAO’s, applicable to airspace type Zu;

b) the development of specific Low-level Flight Rules (LFR) be also proposed, since neither VFR nor IFR are suited to perfectly match the needs of UAM (manned and unmanned) at VLL, as concluded in the mentioned discussion document of 2018 on the subject.

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

### 4.2.3 ICARUS Service Provision

EASA proposed only a subset of the several U-space services proposed by CORUS for certification by aviation authorities, in its Opinion 01/2020. This does not mean that the other services proposed by CORUS are considered infeasible or unnecessary. This may be related to the concept of risk-based regulation introduced for drones by Commission Implementing Regulation 2019/947. In fact, according to this regulation, five different levels of evidence may apply, depending on the level of safety risk perceived by society.

A few examples are provided in the following table:

| Level of safety risk perceived by society | Required Means of Evidence (MoE) | Example |
|---|---|---|
| Negligible | None | Competency of remote pilots of Class C0 (< 250 g) UAS operating in subcategory A1 of the Open category |
| Low | Declaration without attached documents | UAS operations in the specific category, based on standard scenarios, for safety objectives requiring low robustness of safety assurance |
| Medium | Declaration with attached documents verified by applicant | UAS operations in the specific category, based on standard scenarios, for safety objectives requiring medium robustness of safety assurance |
| Medium-High | Declaration with attached documents verified by competent and independent third party[3] | UAS operations in the specific category, subject to authorisation, for safety objectives requiring high robustness of safety assurance |
| High | Certified by aviation authority | UAS operator in the certified category |

**Table 4-2: Levels of safety risk**

ICARUS considers that the same risk based-approach could be used for VCS, observing that this service may be considered:

a) safety related[4] in airspace volumes with a low density of manned and unmanned traffic, such us CORUS airspace types X and Y, but the level of risk would still be medium-high; but

b) safety critical in airspace Za (e.g. ATZ around and above traditional aerodromes, where UAS should also use barometric altitude) and Zu (where GAMZ could be established also mandating manned aircraft to use geometric height), where a much higher traffic density is expected or where much larger aeroplanes would operate and in which case the level of risk would be high.

[3] This third party could be a Notified Body based on EC Regulation 765/2008 or a Qualified Entity based on Article 69 of Regulation 2018/1139.

[4] As defined in CD ISO 23629-12

The proposed regulatory framework should hence encompass the medium-high and high level of risk.

Proposing VCS to be certified by aviation authorities would however further increase the Level of Involvement (LoI) of the authorities, whose resources are not exuberant.

To encompass both risk levels and ensure safety without increasing LoI for the authorities, perhaps an example extracted from existing EASA "soft rules" could help.

In fact, one AMC for air operations[5] refers to the "credit" that aviation authorities may grant if the applicant holds a valid certificate of conformity issued through industry mechanisms.

For ease of reference, the above-mentioned AMC is reproduced below:

| **EASA AMC1 ARO.GEN.305(b);(c);(d);(d1) Oversight programme** |
|---|
| INDUSTRY STANDARDS |
| (a) For organisations having demonstrated compliance with industry standards, the competent authority may adapt its oversight programme, in order to avoid duplication of specific audit items.<br><br>(b) Demonstrated compliance with industry standards should not be considered in isolation from the other elements to be considered for the competent authority's risk-based oversight.<br><br>(c) In order to be able to credit any audits performed as part of certification in accordance with industry standards, the following should be considered:<br><br>(1) the demonstration of compliance is based on certification auditing schemes providing for **independent and systematic verification**;<br><br>(2) the existence of an **accreditation scheme** and accreditation body for certification in accordance with the industry standards has been verified;<br><br>(3) certification audits are relevant to the requirements defined in Annex III (Part-ORO) and other Annexes to this Regulation as applicable;<br><br>(4) the scope of such certification audits can easily be mapped against the scope of oversight in accordance with Annex III (Part-ORO);<br><br>(5) audit results are accessible to the competent authority and open to exchange of information in accordance with Article 15(1) of Regulation (EC) No 216/2008; and<br><br>(6) the audit planning intervals of certification audits in agreement with **industry standards** are compatible with the oversight planning cycle. |

In other words, certification by competent accredited and independent third parties, may also apply to safety-critical services.

In the ICARUS case, the "organisation" would be the USSP providing the VCS API.

Key points in this AMC are:

[5] Air Operations in EU are covered by Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council, as lastly amended by Regulation (EU) 2017/363.

a) Independent and systematic verification, which could be implemented through Notified Bodies (NB) based on EU Regulation 765/2008 or Qualified Entities (QEs) based on Article 69 of EU Regulation 2018/1139;

b) Accreditation schemes for NBs or QEs, which are in fact already embedded in the regulations mentioned in a); and

c) Existence of a relevant and published industry standard, which in this case could be ISO 23629-12.

Based on the above considerations, it is therefore recommended to:

a) Propose an AMC to the forthcoming Commission U-space Regulation (following the Agency's Opinion 01/2020) to EASA transposing the principles of AMC1 ARO.GEN.305(b);(c);(d);(d1) into the U-space context. This would allow industry oversight mechanisms to be accredited for VCS, whether the service would in the end be safety-related or critical; and

b) Propose that ISO TC/20 SC/16 WG4 include VCS into CD 23629-12, which is already structured on a comprehensive set of technology-agnostic requirements applicable to the USSP, whether providing safety related or safety critical services.

### 4.2.4 Avionic functions

#### 4.2.4.1 UAS functions for ICARUS Services

The UAS that benefit from the ICARUS services would mainly fly BVLOS in VLL airspace in the Specific category, since BVOLS is not possible in the Open category of UAS operations according to Commission Regulation 2019/947.

This regulation establishes a non-prescriptive and technology-agnostic regime for the specific category of UAS operations. Therefore, the solution proposed by ICARUS is compliant with the EU rules currently applicable in 2019/947.

The corner stone of the regulatory regime in the Specific category is a safety risk assessment, which, when the required integrity robustness is medium or high, would in turn require applying appropriate industry standards.

Since the APIs proposed by ICARUS are based on existing standards for IT, and for networks and communications, their implementation would not require development of new industry standards.

Conversely, emerging UAS certification specifications[6] are objective-based (i.e. performance-based) so allowing UAS designers to integrate functions at the level of the UA or its Command Unit (CU) with sufficient freedom to accommodate VCS.

More complex is the case of emerging aircraft for UAM (e.g. eVTOL carrying passengers at VLL). Traditional rules on instruments (e.g. anemometer), data and equipment (e.g. oxygen), which is not necessary for airworthiness but for operations and thus published in "Subparts IDE" of AIR-OPS rules, have been quite prescriptive (I.e. prescribing mandatory carriage of an instrument based on a given technology) instead of the functionality and performance to be achieved (i.e. performance-based regulation).

In the case of radio-navigation a long process to turn the rules into "Performance-Based Navigation" (PBN) was initiated in 1978 with introduction by ICAO of the "Minimum Navigation Performance

[6] According to Article 40 of Commission Delegated Regulation 2019/945 the UAS may be subject, in certain cases, to airworthiness type approval by EASA, while the operation would still remain in the specific category.

Specification Area" (MNPS) over the North Atlantic. As a result, current rules on radio navigation in AIR-OPS no longer prescribe a list of navigation receivers (ADF, VOR, DME, etc.) but prescribe the accuracy and integrity of the required navigation solution, leaving the designer free to decide which equipment could be fitted on the aircraft.

In the case of altimetry, current EU rules, reproduced in Appendix A, are not yet performance-based but listing only two mandatory technologies: barometric altimeter or radio altimeter. For instance, this is what is required for Helicopters in CAT under IFR at the date of 31 Dec 2020:

| | |
|---|---|
| CAT.IDE.H.130 Operations under IFR or at night – flight and navigational instruments | Helicopters operated under VFR at night or under IFR shall be equipped with the following equipment, available at the pilot's station:<br>(a) A means of measuring and displaying:<br>(1) …<br>(b) **Two means of measuring and displaying barometric altitude**.<br><br>…<br><br>For single-pilot operations under VFR at night **one pressure altimeter may be substituted by a radio altimeter.**<br>… |

No AMC/GM exist to specify that the display of barometric altitude on-board or at the CU of the remote pilot may not necessarily require a barometric capsule to be fitted on-board, since such a capsule could be replaced by the VCS.

Equally, there is no mention of the possibility of using the ICARUS RGIS instead of a radio altimeter, whose usefulness in obstacle-rich environments such as metropolitan areas is doubtful.

In other words, this approach is old-fashioned and should be replaced, at least for UAM, by objective-based rules applicable to UAS in the Certified category, otherwise the development of technology would be constrained by legacy technologies.

In summary, in the Specific category a risk assessment will take the operational scenario in which the drone is intended to fly into account, bearing in mind that geometric height would apply in airspace types X, Y and Zu, while barometric altitude would apply in Za. The assessment will drive any redundancies and software Design Assurance Level (DAL) required, while allowing different technologies (e.g. VCS instead of a classic barometric altimeter) to be used.

Conversely, EASA should be recommended to:

a) Adopt a performance-based approach to regulating altimetry (i.e. Performance-Based Altimetry = PBA) in its future "Part UAM", considering that:

    i. The function of a barometric altimeter, especially in areas away from aerodromes where an accurate QNH may not be available, could be replaced by VCS; and

    ii. The function of the radio altimeter, especially in obstacle-rich environments could be replaced by RGIS.

**Since EASA plans to issue a Notice of Proposed Amendment (NPA) covering a new "Part UAM" in AIR-OPS in 2021, this recommendation should be forwarded urgently to the Agency for inclusion in this.**

#### 4.2.4.2 Airborne functions for ICARUS Services in manned aviation

##### 4.2.4.2.1 Need for preliminary safety assessment

EU rules on airworthiness (e.g. CS-23) do not cover instruments, data and equipment (IDE) including altimetry, since airworthiness looks at structural, aerodynamic and controllability aspects, without considering "operations" (i.e. enabling navigation of a single aircraft) or ATM.

Instead, IDE are a substantial part of the "AIR-OPS"[7] rules applicable to manned aircraft. These rules, an extract of which is reproduced in the above-mentioned Appendix A, always require one or two barometric altimeters in the cockpit for all types of operation (e.g. commercial or non-commercial), under both VFR or IFR in both fixed-wing aeroplanes and helicopters.

Geodetic or geometric height measurement is never contemplated as a possibility, the only allowed exceptions being the possibility of substituting one pressure altimeter by a radio altimeter, for single-pilot commercial air transport helicopter operations under VFR at night.

If EASA proposes moving toward "Performance-Based Altimetry" (PBA) in all "Parts" of the Annex to AIR-OPS, future manned aircraft would allow the use of new instruments fitted on the fleet. However, since mandatory retrofit is nearly always impossible in aviation due to technical or economic difficulties, which results in strong political opposition, the conversion of the fleet would, even in the most optimistic case, last for decades. Keeping the rules unchanged would, however, prevent the evolution from even beginning.

Safety rules have the obvious objective of enhancing safety. Since the safety risk is influenced by several factors including aircraft IDE in the case of VLL, it is deemed necessary to conduct a simplified safety risk assessment in this document, before proposing recommendations for IDE, including for manned aircraft.

##### 4.2.4.2.2 SORA vs ERCS

According to Art. 11 of IR 2019/947, airworthiness and operational requirements for "Specific" category operations are determined as the result of a risk assessment of the operation envisaged. The SORA methodology, developed by JARUS, has been identified by EASA as the recommended Acceptable Mean of Compliance (AMC) to the above-mentioned Art. 11. This methodology applies an assessment process to provide a list of safety barriers (i.e. mitigations) in the form of requirements to be imposed on the operator, on the UAS, on the competency of the remote pilots or on the operation itself.

The risk related to a possible failure of the common altitude reference system cannot be explicitly addressed through SORA analysis. In fact, the SORA methodology does not take into account possible malfunctions of operations support systems (e.g. a common altitude reference system and U-space services). These malfunctions may lead to collisions or leakage from the operational volume. Moreover, they provide a reduction in the safety margins in the operational scenarios. This leads to the need to use a different risk assessment approach. A risk-matrix approach is chosen for this purpose since it is a more flexible way to cover a wider range of risk areas. Several methods based on risk matrices exist:

- ICAO risk matrix
- EASA risk matrix, reported in the EASA Pre-Regulatory Impact Assessment

[7] Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council, as lastly amended by Implementing Regulation (EU) 2019/1387.

- ESARR4 risk matrix
- EUROCAE risk matrix
- ERCS matrix

The ERCS proposed by Commission Delegated Regulation (EU) 2020/2034 of 6 October 2020 will be adopted in the following sections to determine the safety risk of an occurrence. This regulation became applicable on 1st January 2021.

#### 4.2.4.2.3 Severity Classification scheme

The first step in a risk assessment is to estimate the severity of a possible mid-air collision between a manned aircraft and a drone in one of the four types of airspace envisaged by CORUS.

The new EU regulation[8] on the European safety Risk Classification Scheme (ERCS) in aviation became applicable on 1st January 2021. Six levels of severity applicable to mid-air collision (or collision with obstacles) are standardised in this new regulation. These six levels are reproduced in the table below:

| Severity Class | Description | Number of fatalities |
|---|---|---|
| A | Negligible safety consequences | 0 |
| E | Minor accident involving minor and serious injury (not life changing) or minor aircraft damage | 0 |
| I | Minor accident involving a single fatality, life changing injury or substantial damage accident | 1 |
| M | Major accident with limited number of fatalities, life changing injuries or destruction of the aircraft | 2 to 19 |
| S | Significantly catastrophic accident with potential for several fatalities and injuries | 20 to 100 |
| X | Extremely catastrophic accident with potential for hundreds of fatalities. | More than 100 |

**Table 4-3: ERCS severity class**

#### 4.2.4.2.4 Severity assessment

Based on the ERCS the following severities may be estimated (worst credible case) in each of the airspace types envisaged by the CORUS use cases:

| POSSIBLE MID-AIR COLLISION IN FLIGHT at VLL between a manned aircraft and a drone |
|---|
| SEVERITY (ERCS) |

[8] Commission Delegated Regulation (EU) 2020/2034 of 6 October 2020 supplementing Regulation (EU) No 376/2014 of the European Parliament and of the Council as regards the common European risk classification scheme (ERCS)

| Manned aircraft | UAS | CORUS airspace type | | | |
|---|---|---|---|---|---|
| | | X | Y | Zu | Za |
| under VFR | VLOS (Open category) | **M** (drone of 25 kg colliding with a helicopter with 2 people on board) | **M** (drone of 25 kg colliding with a helicopter with 2 people on board) | **M** (drone of 4 kg colliding with a helicopter with 2 people on board) | **M** (aircraft under VFR not expected to carry more than 20 passengers on board) |
| | EVLOS (Sspecific category) | **M** (as above) | **M** (as above) | **M** (manned helicopters with more than 20 people on board not expected at VLL over urban areas) | **M** (as above) |
| | BVLOS in Specific category | **M** (manned aircraft with more than 20 passengers onboard not foreseen in this type of airspace) | **M** (manned aircraft with more than 20 passengers onboard not foreseen in this type of airspace) | **M** (as above) | **M** (as above) |
| | BVLOS (Part UAM) | **M** (eVTOL at VLL not expected to carry more than 6 passengers) | **M** (eVTOL at VLL not expected to carry more than 6 passengers) | **M** (as above) | **M** (as above) |
| Legacy aircraft under IFR based on current prescriptive rules on altimetry | VLOS (Open category) | **M** (no IFR routes at VLL in this airspace) | **M** (no IFR routes at VLL in this airspace) | **M** (no traditional ATS routes for manned aviation at VLL in this airspace) | **X** (drone in the open category entering airspace where airliners take-off and landing, although this would be beyond the |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | privileges of the Open category) |
| | EVLOS | **M**<br>(as above) | **M**<br>(as above) | **M**<br>(as above) | **X**<br>(large airliners are present in this airspace for take-off and landing) |
| | BVLOS in Specific category | **M**<br>(as above) | **M**<br>(as above) | **M**<br>(as above) | **X**<br>(as above) |
| | BVLOS (Part UAM) | **M**<br>(as above) | **M**<br>(as above) | **M**<br>(as above) | **X**<br>(as above) |
| Future aircraft designed for UAM if the EU common rules on altimetry would evolve towards PBA | VLOS (Open category) | **M**<br>(as above) | **M**<br>(as above) | **M**<br>(as above) | **X**<br>(as above) |
| | EVLOS | **M**<br>(as above) | **M**<br>(as above) | **M**<br>(as above) | **X**<br>(as above) |
| | BVLOS in Specific category | **M**<br>(as above) | **M**<br>(as above) | **M**<br>(as above) | **X**<br>(as above) |
| | BVLOS (Part UAM) | **M**<br>(as above) | **M**<br>(as above) | **M**<br>(as above) | **X**<br>(as above) |

**Table 4-4: Severity assessment for ICARUS concept**

It should be observed that the severity (i.e. the consequences of a mid-air collision) of an accident would not change as a function of the presence or absence of the ICARUS services.

Conversely, the probability of a collision in the air with another aircraft or with obstacles on the ground, might be influenced by the presence of the ICARUS services.

#### 4.2.4.2.5 Probability assessment – baseline

To evaluate the risk, the probability of a collision occurring should of course also be considered.

In our case, the ICARUS "baseline" (the "do nothing" option) is the case of new operations being implemented at VLL, without parallel implementation of the ICARUS services.

In this respect, this document:

a) Only contains qualitative probability assessments, based on the ERCS in 2020/2034;

b) Only focuses on the effect of altimetry on safety, in line with the scope of ICARUS, considering other aspects invariable;

c) Uses six levels of probability: Very High (VH), High (H), Medium High (MH), Medium (MD); Low (L) and Very Low (VL); and

d) Evaluates "Probability" in terms of a "Barrier Score" (from 0 to 9) as per the ERCS.

The ERCS barrier model consists of 8 barriers, ordered in a logical sequence and weighted as per the following table:

| Barrier No. | Barrier | Barrier weight |
|---|---|---|
| 1 | 'Aircraft, equipment and infrastructure design', includes maintenance and correction, operation support, the prevention of problems related to technical factors that could lead to an accident. | 5 |
| 2 | 'Tactical planning', includes organisational and individual planning prior to the flight or other operational activity that supports the reduction of the causes and contributors to accidents. | 2 |
| 3 | 'Regulations, procedures, processes', includes effective, understandable and available regulations, procedures and processes that are complied with (with the exclusion of the use of procedures for recovery barriers). | 3 |
| 4 | 'Situational awareness and action', includes human vigilance for operational threats which ensures identification of operational hazards and effective action to prevent an accident. | 2 |
| 5 | 'Warning systems operation and action' that could prevent an accident and which are fit for purpose, functioning, operational and are complied with. | 3 |
| 6 | 'Late recovery from a potential accident situation' | 1 |
| 7 | 'Protections', when an event has occurred, the level of the outcome is mitigated or prevents the escalation of the occurrence by intangible barriers or providence | 1 |
| 8 | 'Low energy occurrence' scores the same as 'Protections', but for low-energy key risk areas only (ground damage, excursions, injuries). 'Not applicable' for all other key risk areas. | 1 |
| | Max possible Total | 18 |

**Table 4-5: ERCS barriers Model**

According to Regulation 2020/2034, the effectiveness of each barrier must then be assessed, based on defined taxonomy:

| Barrier effectiveness | Definition | Applicable to proactive safety | Applicable in this document (i.e. predictive safety) | To be considered in the probability assessment |
|---|---|---|---|---|
| Stopped | Barrier prevented the accident from occurring | YES | NO | NO |

| | | | | |
|---|---|---|---|---|
| Remaining Known | Known whether the barrier remained between the reported occurrence under assessment and the potential accident outcome | YES | NO | NO |
| Remaining Assumed | Assumed that the barrier remained between the occurrence under assessment and the potential accident outcome | YES | YES<br>(Assumed that the barrier would be available between the hazard and the potential collision) | YES |
| Failed Known | Known that the barrier has failed | Never to be considered | | |
| Failed Assumed | Assumed that the barrier has failed even if insufficient or no information is available to determine this | Never to be considered | | |
| Not Applicable | Barrier is not relevant to the occurrence under assessment | Never to be considered | | |

**Table 4-6: ERCS barrier effectiveness**

Since this document relates to predictive safety assessment (i.e. before the ICARUS services are implemented), only barriers that can assessed as "Remaining Assumed" are considered in the following.

In the ICARUS context, the hazard is that the drone could become too close, vertically, to either obstacles or manned aircraft.

In the baseline case (i.e. no ICARUS services), the following barriers might be assumed as "Remaining" to avoid a collision after the hazard has materialised:

| Barrier No. | Barrier | Weight | Remaining Assumed | Resulting weight |
|---|---|---|---|---|
| 1 | 'Aircraft, equipment and infrastructure design', includes maintenance and correction, operation support, the prevention of problems related to technical factors that could lead to an accident. | 5 | NO: Absent in the baseline case (i.e. no ICARUS services) | 0 |
| 2 | 'Tactical planning', includes organisational and individual planning prior to the flight or other operational activity that supports the reduction | 2 | YES, in airspace types Y, Za and Zu | 2 (in Y, Za and Zu) |

| | | | | |
|---|---|---|---|---|
| | of the causes and contributors to accidents. | | | |
| 3 | 'Regulations, procedures, processes', includes effective, understandable and available regulations, procedures and processes that are complied with (with the exclusion of the use of procedures for recovery barriers). | 3 | YES, but only available in Za, or in VLOS or EVLOS | 3 in Za |
| 4 | 'Situational awareness and action', includes human vigilance for operational threats which ensures identification of operational hazards and effective action to prevent an accident. | 2 | Not possible in the absence of CARS, unless VLOS or EVLOS | 2 |
| 5 | 'Warning systems operation and action' that could prevent an accident and that are fit for purpose, functioning, operational and are complied with. | 3 | Not applicable in the absence of VALS | 0 |
| 6 | 'Late recovery from a potential accident situation' | 1 | Always "Remaining Assumed" | 1 |
| 7 | 'Protections', when an event has occurred, the level of the outcome is mitigated or prevents the escalation of the occurrence by intangible barriers or providence | 1 | Not possible in the absence of CARS | 0 |
| 8 | 'Low energy occurrence' scores the same as 'Protections', but for low-energy key risk areas only (ground damage, excursions, injuries). 'Not applicable' for all other key risk areas. | 1 | Not applicable for collisions during flight | 0 |
| | Max possible Total | 18 | As a function of the airspace type | From 1 to 8 |

**Table 4-7: ERCS barrier effectiveness without ICARUS services**

Regulation 2020/2034 then assigns a "score" based on the following table to the total remaining barriers:

| Barrier weight sum | Corresponding barrier score |
|---|---|
| 0 No barriers left.<br>Worst likely accident outcome realised. | 0 |
| 1-2 | 1 |
| 3-4 | 2 |
| 5-6 | 3 |
| 7-8 | 4 |
| 9-10 | 5 |
| 11-12 | 6 |
| 13-14 | 7 |
| 15-16 | 8 |
| 17-18 | 9 |

**Table 4-8: ERCS barrier score**

The resulting barrier score for the baseline (i.e. no ICARUS services) is presented in the following table for the case where manned traffic are under VFR:

<table>
<tr><th colspan="6">POSSIBLE MID-AIR COLLISION IN FLIGHT at VLL between a manned aircraft and a drone</th></tr>
<tr><th colspan="6">Estimated “Barrier Score”, as a function of the altimetry method<br>(Baseline = no ICARUS services)</th></tr>
<tr><th rowspan="2">Manned aircraft</th><th rowspan="2">UAS</th><th colspan="4">CORUS airspace type</th></tr>
<tr><th>X</th><th>Y</th><th>Zu</th><th>Za</th></tr>
<tr><td rowspan="3">under VFR<br>(Barometric altimeter)<br>No ICARUS services</td><td>VLOS (open category)<br>(Geometric Height)</td><td>3<br>(remote pilot able to see manned aircraft in the air and Remain Well Clear (RWC) of them; barrier 3, 4 and 6 are assumed to remain available)</td><td>2<br>(remote pilot able to see manned aircraft in the air and Remain Well Clear (RWC) of them)</td><td>2<br>(Besides RWC by RP, the drone would most likely fly below the height of the obstacles in the area, while manned aircraft would fly above)</td><td>3<br>Unless malicious or inadvertent airspace infringements, made less probable by Geo-Awareness, no drones in the Open category are present in this airspace above the Obstacle Limitation Surfaces)</td></tr>
<tr><td>EVLOS (specific category)<br>(Geometric Height)</td><td>3<br>(beyond the line of sight of the RP, Airspace Observers (AO) would be able to support RWC)</td><td>2<br>(beyond the line of sight of the RP, AOs would be able to support RWC)</td><td>2<br>(in addition to the considerations in the cell immediately above, the AO would not normally extend the E-VLOS range vertically)</td><td>3<br>(Drones in the Specific category not authorised to enter this type of airspace without a barometric altimeter)</td></tr>
<tr><td>BVLOS in specific category<br>(Geometric Height)</td><td>1<br>(no U-space separation services are present in this</td><td>2<br>(Slightly lower than in airspace type X, since,</td><td>2<br>(Two aircraft using different altimetry references in</td><td>6<br>(Drones in the Specific category not authorised to</td></tr>
</table>

| | | | | | |
|---|---|---|---|---|---|
| | | airspace type; therefore, even if traffic density is low, in the absence of on-board DAA, and in the absence of ICARUS services, RWC would be almost impossible) | although traffic density may be higher, U-space provides strategic separation in this airspace; However such strategic separation could not take advantage of CARS and vertical separation would remain uncertain) | an airspace type with high traffic density) | enter this type of airspace without a barometric altimeter; barriers 1, 2, 3 and 6 assumed as remaining) |
| | BVLOS (Part UAM) (Barometric altimeter) | **1** (due not only to low traffic density, but also because drone and manned aircraft would both use barometric altimetry) | **2** (Same as in airspace type X, since, although traffic density may be higher, U-space provides strategic separation in this airspace) | **2** (Full U-space services available and both aircraft using barometric altimetry) | **6** (ATC services and two aircraft using barometric altimetry) |

**Table 4-9: ERCS barrier score without ICARUS services**

In the ECRS, as per Regulation 2020/2034, the same "barrier scores" would apply in the case of an encounter between a drone and a "legacy" aircraft under IFR.

Finally, still in the absence of ICARUS services, the "barrier scores" could be estimated for the future scenario (i.e. Performance-Based Altimetry and GAMZ) as follows:

| **POSSIBLE MID-AIR COLLISION IN FLIGHT AT VLL between a manned aircraft and a drone** | | | | | |
|---|---|---|---|---|---|
| **Estimated barrier score, as a function of the altimetry method (Baseline = no ICARUS services)** | | | | | |
| **Manned aircraft** | **UAS** | **CORUS airspace type** | | | |
| | | **X** | **Y** | **Zu** | **Za** |
| Future aircraft under | VLOS (Open category) | **3** | **2** | **2** | **3** |

| | | | | | |
|---|---|---|---|---|---|
| IFR, designed for UAM if the EU rules on altimetry evolve towards PBA<br><br>No ICARUS services | (Geometric Height) | (barriers 3, 4 and 6 assumed to remain,) | (no IFR routes at VLL in this airspace) | (no traditional ATS routes for manned aviation at VLL in this airspace) | (ATC services and two aircraft using barometric altimetry) |
| | EVLOS<br><br>(Geometric Height) | **3**<br><br>(as above) | **2**<br><br>(no IFR routes at VLL in this airspace) | **2**<br><br>VO mitigates risk of collision even in the absence of ICARUS services | **3**<br><br>(ATC services and two aircraft using barometric altimetry) |
| | BVLOS in Specific category<br><br>(Geometric Height) | **1**<br><br>(no IFR routes at VLL in this airspace) | **2**<br><br>(no IFR routes at VLL in this airspace) | **2**<br><br>(GAMZ cannot be implemented without either retrofit, which is not normally possible, or ICARUS services) | **6**<br><br>(barriers 1, 2, 3 and 6 assumed as remaining) |
| | BVLOS (Part UAM)<br><br>(Barometric altimeter) | **1**<br><br>(no IFR routes at VLL in this airspace) | **2**<br><br>(no IFR routes at VLL in this airspace) | **2**<br><br>(GAMZ cannot be implemented without either retrofit, which is not normally possible, or ICARUS | **6**<br><br>(ATC services and two aircraft using barometric altimetry) |

**Table 4-10: ERCS barrier score without ICARUS services in future scenario**

#### 4.2.4.3 Barrier score – ICARUS services implemented

If ICARUS services were implemented instead, the “remaining assumed” barriers, in the "future scenario” would be:

| Barrier No. | Barrier | Weight | Remaining Assumed | Resulting weight |
|---|---|---|---|---|
| 1 | ‘Aircraft, equipment and infrastructure design’, includes maintenance and correction, operation support, the prevention of problems related to technical factors that could lead to an accident. | 5 | The 4 APIs provided by ICARUS would make this barrier | 5 |

| | | | | |
|---|---|---|---|---|
| | | | "remaining assumed" in any airspace type. | |
| 2 | 'Tactical planning', includes organisational and individual planning prior to the flight or other operational activity that supports the reduction of the causes and contributors to accidents. | 2 | YES, in airspace types Y, Za and Zu (as in the absence of ICARUS services) | 2 (in Y, Za and Zu) |
| 3 | 'Regulations, procedures, processes', includes effective, understandable and available regulations, procedures and processes that are complied with (with the exclusion of the use of procedures for recovery barriers). | 3 | Remaining assumed in Za and Zu, where tactical ATS is available | 3 in Za and Zu |
| 4 | 'Situational awareness and action', includes human vigilance for operational threats which ensures identification of operational hazards and effective action to prevent an accident. | 2 | Remaining assumed thanks to VALS | 2 |
| 5 | 'Warning systems operation and action' that could prevent an accident and which are fit for purpose, functioning, operational and are complied with. | 3 | Remaining assumed thanks to VALS | 3 |
| 6 | 'Late recovery from a potential accident situation' | 1 | Always "Remaining Assumed" | 1 |
| 7 | 'Protections', when an event has occurred, the level of the outcome is mitigated or prevents the escalation of the occurrence by intangible barriers or providence | 1 | RGIS, VCS and VALS would mitigate | 1 |
| 8 | 'Low energy occurrence' scores the same as 'Protections', but for low-energy key risk areas only (ground damage, excursions, injuries). 'Not applicable' for all other key risk areas. | 1 | Not applicable for collisions during flight | 0 |
| | Max possible Total | 18 | As a function of the airspace type | From 12 to 17 |

**Table 4-11: ERCS barrier effectiveness with ICARUS services**

The probability of a collision could be assessed in terms of 'barrier effectiveness' as in the following table for an encounter with manned traffic under VFR:

| **POSSIBLE MID-AIR COLLISION IN FLIGHT AT VLL between a manned aircraft and a drone** | | |
|---|---|---|
| **Estimated Barrier effectiveness, as a function of the altimetry method**<br>**(ICARUS services implemented)** | | |
| | **UAS** | **CORUS airspace type** |

| Manned aircraft | | X | Y | Zu | Za |
|---|---|---|---|---|---|
| under VFR (Barometric altimeter) Plus ICARUS services | VLOS (Open category) (Geometric Height) | **5** (no ICARUS services available to non-equipped manned aircraft, only barriers 3, 4 and 6 is assumed to remain; but barriers 5 and 7 would be available on the drone) | **5** (as in airspace X) | **5** (Tactical separation available in this airspace, but not based on CARS = as in airspace X) | **7** (drone and manned aircraft using same barometric reference; barriers 1, 2, 3, 4 and 7 available, but not 5 and 7) |
| | EVLOS (Specific category) (Geometric Height) | **5** (as above, since score in this case is driven by absence of equipment to exploit ICARUS services in legacy aircraft) | **5** (as above) | **5** (as above) | **7** (as above) |
| | BVLOS in Specific category (Geometric Height) | **5** (as above) | **5** (as above) | **5** (as above) | **7** (as above) |
| | BVLOS (Part UAM) (Barometric altimeter) | **5** (as above) | **5** (as above) | **5** (as above) | **7** (as above) |

**Table 4-12: ERCS barrier score with ICARUS services**

With ICARUS services implemented, the probability of a collision could be assessed in terms of “barrier score”, as in the following table for an encounter with manned legacy traffic under IFR:

| **POSSIBLE MID-AIR COLLISION IN FLIGHT at VLL between a manned aircraft and a drone** |
|---|
| **Qualitatively estimated Probability Index, as a function of the altimetry method** |

| (ICARUS services implemented) | | | | | |
|---|---|---|---|---|---|
| **Manned aircraft** | **UAS** | **CORUS airspace type** | | | |
| | | **X** | **Y** | **Zu** | **Za** |
| Legacy aircraft under IFR based on current prescriptive rules on altimetry<br>(Barometric altimeter)<br>Plus ICARUS services | VLOS (Open category)<br>(Geometric Height) | **5**<br>(as in the case of an encounter with a manned aircraft under VFR) | **5**<br>(as in the case of an encounter with a manned aircraft under VFR) | **5**<br>(as in the case of an encounter with a manned aircraft under VFR) | **7**<br>(as in the case of an encounter with a manned aircraft under VFR) |
| | EVLOS<br>(Geometric Height) | **5**<br>(as above) | **5**<br>(as above) | **5**<br>(as above) | **7**<br>(as above) |
| | BVLOS in Specific category<br>(Geometric Height) | **5**<br>(as above) | **5**<br>(as above) | **5**<br>(as above) | **7**<br>(as above) |
| | BVLOS (Part UAM)<br>(Barometric altimeter) | **5**<br>(as above) | **5**<br>(as above) | **5**<br>(as above) | **7**<br>(as above) |

**Table 4-13: ERCS barrier score with ICARUS services**

Finally, with ICARUS services implemented, the probability of a collision could be assessed in terms of "barrier score" as in the following table for an encounter with manned traffic under IFR in the future scenario (i.e. PBA and GAMZ in addition to ICARUS services):

| **POSSIBLE MID-AIR COLLISION IN FLIGHT AT VLL between a manned aircraft and a drone** | | | | | |
|---|---|---|---|---|---|
| **Estimated Barrier scores, as a function of the altimetry method**<br>**(ICARUS services implemented)** | | | | | |
| **Manned aircraft** | **UAS** | **CORUS airspace type** | | | |
| | | **X** | **Y** | **Zu** | **Za** |
| Future aircraft designed for UAM if the EU rules on altimetry would | VLOS (Open category)<br>(Geometric Height) | **6**<br>(barriers 1, 4, 5, 6 and 7 assumed to remain) | **7**<br>(barriers 1, 2, 4, 5, 6 and 7 assumed to remain) | **9**<br>(barriers 1, 2, 3, 4, 5, 6 and 7 assumed to remain) | **9**<br>(as in Zu) |
| | EVLOS | **6**<br>(as above) | **7**<br>(as above) | **9**<br>(as above) | **9** |

| | | | | | |
|---|---|---|---|---|---|
| evolve towards PBA<br><br>Plus ICARUS services | (Geometric Height) | | | | (as above) |
| | BVLOS in Specific category<br><br>(Geometric Height) | **6**<br>(as above) | **7**<br>(as above) | **9**<br>(as above) | **9**<br>(as above) |
| | BVLOS (Part UAM)<br><br>(Barometric or geometric height depending on airspace requirements such as GAMZ) | **6**<br>(as above) | **7**<br>(as above) | **9**<br>(as above) | **9**<br>(as above) |

**Table 4-14: ERCS barrier score with ICARUS services in future scenario**

### 4.2.4.4 Risk score – encounter with VFR

Now the tolerability of the safety risk can be classified using the risk matrix in annex to Regulation 2020/2034:

| **Potential outcome** | **Sev.** | **ERCS Score** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Extreme catastrophe (potential > 100 fat.) | X | X9 | X8 | X7 | X6 | X5 | X4 | X3 | X2 | X1 | X0 |
| Significant accident (potential several fat.) | S | S9 | S8 | S7 | S6 | S5 | S4 | S3 | S2 | S1 | S0 |
| Major accident (few fatalities or life changing injuries or aircraft destroyed) | M | M9 | M8 | M7 | M6 | M5 | M4 | M3 | M2 | M1 | M0 |
| Minor accident (single fat. or life ch. Inj. or substantial aircraft damage) | I | I9 | I8 | I7 | I6 | I5 | I4 | I3 | I2 | I1 | I0 |
| Accident (no fatalities; injuries but not life changing, or minor damage to aircraft) | E | E9 | E8 | E7 | E6 | E5 | E4 | E3 | E2 | E1 | E0 |
| No likelihood of accident | A | No effect on safety | | | | | | | | | |

**Table 4-15: ERCS risk score**

Combining the severity scores and the barrier effectiveness scores presented in the above paragraphs for an encounter with manned traffic under VFR, with and without ICARUS services, the following ERCS scores can hence be calculated:

| POSSIBLE MID-AIR COLLISION IN FLIGHT at VLL between a manned aircraft (VFR equipped with barometric altimeter) and a drone | | | | | | |
|---|---|---|---|---|---|---|
| Resulting safety risk classification | | | | | | |
| ICARUS Services | UAS | Indices | CORUS airspace type | | | |
| | | | X | Y | Zu | Za |
| No ICARUS services | VLOS (Open category) (Geometric Height) | Severity | M | M | M | M |
| | | Barrier score | 3 | 2 | 2 | 3 |
| | | **ERCS score** | **M3** | **M2** | **M2** | **M3** |
| With ICARUS services | | Severity | M | M | M | M |
| | | Barrier score | 5 | 5 | 5 | 7 |
| | | **ERCS score** | **M5** | **M5** | **M5** | **M7** |
| No ICARUS services | EVLOS (Specific category) (Geometric Height) | Severity | M | M | M | M |
| | | Barrier score | 3 | 2 | 2 | 3 |
| | | **ERCS score** | **M3** | **M2** | **M2** | **M3** |
| With ICARUS services | | Severity | M | M | M | M |
| | | Barrier score | 5 | 5 | 5 | 7 |
| | | **ERCS score** | **M5** | **M5** | **M5** | **M7** |
| No ICARUS services | BVLOS in Specific category (Geometric Height) | Severity | M | M | M | M |
| | | Barrier score | 1 | 2 | 2 | 6 |
| | | **ERCS score** | **M1** | **M2** | **M2** | **M6** |
| With ICARUS services | | Severity | M | M | M | M |
| | | Barrier score | 5 | 5 | 5 | 7 |
| | | **ERCS score** | **M5** | **M5** | **M5** | **M7** |
| No ICARUS services | BVLOS (Part UAM) (Barometric altimeter) | Severity | M | M | M | M |
| | | Barrier score | 1 | 2 | 2 | 6 |
| | | **ERCS score** | **M1** | **M2** | **M2** | **M6** |
| With ICARUS services | | Severity | M | M | M | M |
| | | Barrier score | 5 | 5 | 5 | 7 |
| | | **ERCS score** | **M5** | **M5** | **M5** | **M7** |

**Table 4-16: ERCS score for ICARUS concept - VFR**

#### 4.2.4.4.1 Risk score – encounter with legacy aircraft under IFR

The safety risk score (ERCS) can also be calculated for an encounter with a legacy manned aircraft under IFR, with and without ICARUS services:

| POSSIBLE MID-AIR COLLISION IN FLIGHT at VLL between a manned aircraft and a drone<br>Legacy aircraft under IFR based on current prescriptive rules on altimetry<br>(Barometric altimeter) | | | | | | |
|---|---|---|---|---|---|---|
| **Resulting safety risk score** | | | | | | |
| **Manned aircraft** | **UAS** | **Indices** | **CORUS airspace type** | | | |
| | | | **X** | **Y** | **Zu** | **Za** |
| No ICARUS services | VLOS (Open category)<br>(Geometric Height) | Severity | M | M | M | X |
| | | Barrier score | 3 | 2 | 2 | 3 |
| | | **ERCS score** | **M3** | **M2** | **M2** | **X3** |
| With ICARUS services | | Severity | M | M | M | X |
| | | Barrier score | 5 | 5 | 5 | 7 |
| | | **ERCS score** | **M5** | **M5** | **M5** | **X7** |
| No ICARUS services | EVLOS (Specific category)<br>(Geometric Height) | Severity | M | M | M | X |
| | | Barrier score | 3 | 2 | 2 | 3 |
| | | **ERCS score** | **M3** | **M2** | **M2** | **X3** |
| With ICARUS services | | Severity | M | M | M | X |
| | | Barrier score | 5 | 5 | 5 | 7 |
| | | **ERCS score** | **M5** | **M5** | **M5** | **X7** |
| No ICARUS services | BVLOS in Specific category<br>(Geometric Height) | Severity | M | M | M | X |
| | | Barrier score | 1 | 2 | 2 | 6 |
| | | **ERCS score** | **M1** | **M2** | **M2** | **X6** |
| With ICARUS services | | Severity | M | M | M | X |
| | | Barrier score | 5 | 5 | 5 | 7 |
| | | **ERCS score** | **M5** | **M5** | **M5** | **X7** |
| No ICARUS services | BVLOS (Part UAM)<br>(Barometric altimeter) | Severity | M | M | M | X |
| | | Barrier score | 1 | 2 | 2 | 6 |
| | | **ERCS score** | **M1** | **M2** | **M2** | **X6** |
| With ICARUS services | | Severity | M | M | M | X |
| | | Barrier score | 5 | 5 | 5 | 7 |
| | | **ERCS score** | **M5** | **M5** | **M5** | **X7** |

**Table 4-17: ERCS score for ICARUS concept - IFR**

#### 4.2.4.4.2 Risk score – encounter in the future scenario

Finally, the safety risk score (ERCS) can be calculated for the future scenario (i.e. PBA and GAMZ), with and without ICARUS services:

| POSSIBLE MID-AIR COLLISION IN FLIGHT at VLL between a manned aircraft and a drone<br>Future aircraft designed for UAM if the EU rules on altimetry evolve towards PBA | | | | | | |
|---|---|---|---|---|---|---|
| **Resulting safety risk score** | | | | | | |
| **Manned aircraft** | **UAS** | **Indices** | **CORUS airspace type** | | | |
| | | | **X** | **Y** | **Zu** | **Za** |
| No ICARUS services | VLOS (Open category)<br>(Geometric Height) | Severity | M | M | M | X |
| | | Barrier score | 3 | 2 | 2 | 3 |
| | | **ERCS score** | **M3** | **M2** | **M2** | **X3** |
| With ICARUS services | | Severity | M | M | M | X |
| | | Barrier score | **6** | **7** | **9** | **9** |
| | | **ERCS score** | **M6** | **M7** | **M9** | **X9** |
| No ICARUS services | EVLOS<br>(Geometric Height) | Severity | M | M | M | X |
| | | Barrier score | 3 | 2 | 2 | 3 |
| | | **ERCS score** | **M3** | **M2** | **M2** | **X3** |
| With ICARUS services | | Severity | M | M | M | X |
| | | Barrier score | 6 | 7 | 9 | 9 |
| | | **ERCS score** | **M6** | **M7** | **M9** | **X9** |
| No ICARUS services | BVLOS in Specific category<br>(Geometric Height) | Severity | M | M | M | X |
| | | Barrier score | 1 | 2 | 2 | 6 |
| | | **ERCS score** | **M1** | **M2** | **M2** | **X6** |
| With ICARUS services | | Severity | M | M | M | X |
| | | Barrier score | 6 | 7 | 9 | 9 |
| | | **ERCS score** | **M6** | **M7** | **M9** | **X9** |
| No ICARUS services | BVLOS (Part UAM)<br>(Barometric altimeter) | Severity | M | M | M | X |
| | | Barrier score | 1 | 2 | 2 | 6 |
| | | **ERCS score** | **M1** | **M2** | **M2** | **X6** |
| With ICARUS services | BVLOS (Part UAM)<br>(Barometric or geometric height depending on airspace requirements such as GAMZ) | Severity | M | M | M | X |
| | | Barrier score | 6 | 7 | 9 | 9 |
| | | **ERCS score** | **M6** | **M7** | **M9** | **X9** |

**Table 4-18: ERCS score for ICARUS concept - future scenario**

#### 4.2.4.4.3 Comparison

Tolerability of risk is indicated by the colours in the ERCS matrix in Annex to Regulation 2020/2034, where:

a) RED means high risk, which is deemed not acceptable to society and hence the operator must either refrain from this operation or mitigations must be applied, some of which could also be implemented at a regulatory level;

b) YELLOW means elevated risk, which is barely acceptable to society and hence the operator should either refrain from this operation or mitigations should be applied, some of which could also be implemented at a regulatory level;

c) GREEN means low risk, which is acceptable to society and hence the operator could undertake this operation, assuming that all relevant mitigations (e.g. ICARUS services) have been implemented and that the operator is also compliant with applicable rules.

The safety risk scores (ERCS) calculated in the previous paragraphs, with and without ICARUS services, can be compared:

| POSSIBLE MID-AIR COLLISION IN FLIGHT at VLL between a manned aircraft and a drone | | | | | | |
|---|---|---|---|---|---|---|
| Conditions | | | Resulting safety risk score | | | |
| ICARUS Services | UAS | Manned aircraft | CORUS airspace type | | | |
| | | | X | Y | Zu | Za |
| No ICARUS services | VLOS (Open category) (Geometric Height) | VFR | M3 | M2 | M2 | M3 |
| | | Legacy / IFR | M3 | M2 | M2 | X3 |
| | | Future | M3 | M2 | M2 | X3 |
| With ICARUS services | | VFR | M5 | M5 | M5 | M7 |
| | | Legacy / IFR | M5 | M5 | M5 | X7 |
| | | Future | M6 | M7 | M9 | X9 |
| No ICARUS services | EVLOS (Specific category) (Geometric Height) | VFR | M3 | M2 | M2 | M3 |
| | | Legacy / IFR | M3 | M2 | M2 | X3 |
| | | Future | M3 | M2 | M2 | X3 |
| With ICARUS services | | VFR | M5 | M5 | M5 | M7 |
| | | Legacy / IFR | M5 | M5 | M5 | X7 |
| | | Future | M6 | M7 | M9 | X9 |
| No ICARUS services | BVLOS in Specific category (Geometric Height) | VFR | M1 | M2 | M2 | M6 |
| | | Legacy / IFR | M1 | M2 | M2 | X6 |
| | | Future | M1 | M2 | M2 | X6 |
| With ICARUS services | | VFR | M5 | M5 | M5 | M7 |
| | | Legacy / IFR | M5 | M5 | M5 | X7 |
| | | Future | M6 | M7 | M9 | X9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| No ICARUS services | BVLOS (Part UAM) (Barometric altimeter) | VFR | M1 | M2 | M2 | M6 |
| | | Legacy / IFR | M1 | M2 | M2 | X6 |
| | | Future | M1 | M2 | M2 | X6 |
| With ICARUS services | | VFR | M5 | M5 | M5 | M7 |
| | | Legacy / IFR | M5 | M5 | M5 | X7 |
| | | Future | M6 | M7 | M9 | X9 |

**Table 4-19: ERCS score with and without ICARUS services**

The following conclusions can be derived from the table above:

a) For UAS operations in VLOS in the Open category, ICARUS services would provide significant benefits in encounters with VFR, legacy IFR or future (PBA) manned traffic, in all considered airspace types;

b) In the absence of ICARUS services, the achieved safety level for VLOS operations in any type of airspace would barely be acceptable to society;

c) For UAS operations in E-VLOS (i.e. with one or more airspace observers) in the Specific category, ICARUS services would still provide a significant improvement of safety in the case of an encounter with any manned traffic;

d) For UAS operations in BVLOS at VLL in the Specific category (e.g. transport of small cargo over urban areas):

   i. Operations in airspace type X would be not acceptable without ICARUS services, in the absence of airborne DAA or procedural mitigation measures, that are beyond the scope of ICARUS;

   ii. Conversely, operations in type Y and Zu airspace would not be in the "green" area of the safety matrix without ICARUS and the associated regulatory amendments (i.e. PBA and GAMZ);

   iii. Operations would be sufficiently safe in Za airspace even without ICARUS services;

e) The same considerations as in d) apply to encounters with an eVTOL used for passenger transport in UAM.

#### 4.2.4.5 Conclusions and Recommendations

Based on the above considerations it is recommended to:

a) propose the concept of GAMZ to EASA for the 2nd phase of amendments to the SERA and, related to this, the need for the EU to adopt a definition of altitude different from ICAO's, applicable to airspace type Zu;

b) equally propose the development of specific Low-level Flight Rules (LFR), since neither VFR nor IFR are suited to perfectly match the needs of UAM (manned and unmanned) at VLL, as concluded in the Discussion Document of 2018 on the subject.

c) Propose an AMC to the forthcoming Commission U-space Regulation (following Agency's Opinion 01/2020) to EASA transposing the principles of AMC1 ARO.GEN.305(b);(c);(d);(d1) into the U-space context. This would allow industry oversight mechanisms for VCS to be accredited, whether the service is safety-related or critical in the end; and

d) Propose that ISO TC/20 SC/16 WG4 include VCS in CD 23629-12, which is already structured on a comprehensive set of technology-agnostic requirements applicable to the USSP, whether it provides safety related or safety critical services. After proposing VCS during the CD stage, VCS has been included in the current Safety-related UTM Services list in ISO DIS 23629-12.

e) Adopt a performance-based approach to regulation of altimetry in the future "Part UAM", considering that:

   i. The function of a barometric altimeter, especially in areas away from aerodromes where an accurate QNH may not be available, could be replaced by VCS; and

   ii. The function of the radio altimeter, especially in obstacle-rich environments could be replaced by RGIS.

**Since EASA plans to issue a Notice of Proposed Amendment (NPA) covering a new "Part UAM" in AIR-OPS, this recommendation should be forwarded urgently to the Agency for its inclusion.**

# 5 Applicable and reference documents


[1] UAS ATM Common Altitude Reference System (CARS): https://www.eurocontrol.int/publication/uas-atm-common-altitude-reference-system-cars

[2] CORUS project final ConOps: https://www.eurocontrol.int/project/concept-operations-european-utm-systems

[3] Article 2(26) of Commission Implementing Regulation 2019/947, as lastly amended by Regulation 2020/746, states that: 'Command Unit' ('CU') means the equipment or system of equipment to control unmanned aircraft remotely as defined in point 32 of Article 3 of Regulation (EU) 2018/1139 which supports the control or the monitoring of the unmanned aircraft during any phase of flight, with the exception of any infrastructure supporting the command and control (C2) link service.

[4] ISO TC/20 SC/16 Committee Draft CD 23629-12.

[5] CORUS Concept of Operations (CONOPS) Enhanced Overview, Edition 01.01.03 of 04 Sept 2019.

[6] Opinion 01/2020.

[7] 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.

[8] Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft, as lastly amended by Commission Implementing Regulation (EU) 2020/746 of 4 June 2020.

[9] EASA, EUROCONTROL, Discussion Document on UAS ATM Flight Rules. Edition: 1.1 of 27 November 2018.

[10] Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems, as lastly amended by Commission Delegated Regulation (EU) 2020/1058 of 27 April 2020.

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[24] ICARUS D4.2, "ICARUS Prototype"

# 6 Appendix A

Extract from EASA Easy Access Rules for Air Operations - Revision 14, October 2019:
https://www.easa.europa.eu/document-library/easy-access-rules/easy-access-rules-air-operations.

| Type of Operation | Aircraft category | Flight Rules | Rule | |
|---|---|---|---|---|
| | | | ID | Text |
| Commercial Air Transport (CAT) | Fixed wing aeroplane (A) | VFR | CAT.IDE.A.125 Operations under VFR by day – flight and navigational instruments | (a) Aeroplanes operated under VFR by day shall be equipped with the following equipment, available at the pilot's station:<br>(1) A means of measuring and displaying:<br>(i) …<br>(ii) …<br>(iii) Barometric altitude;<br>(iv) …<br>… |
| | | IFR | CAT.IDE.A.130 Operations under IFR or at night – flight and navigational instruments | Aeroplanes operated under VFR at night or under IFR shall be equipped with the following equipment, available at the pilot's station:<br>(a) A means of measuring and displaying:<br>….<br>(b) Two means of measuring and displaying barometric altitude.<br>… |
| | Helicopter (H) | VFR | CAT.IDE.H.125 Operations under VFR by day – flight and navigational instruments | (a) Helicopters operated under VFR by day shall be equipped with the following equipment, available at the pilot's station:<br>(1) A means of measuring and displaying:<br>(i) …<br>(ii) …<br>(iii) Barometric altitude;<br>(iv) …<br>… |
| | | IFR | CAT.IDE.H.130 Operations under IFR or at night – flight and navigational instruments | Helicopters operated under VFR at night or under IFR shall be equipped with the following equipment, available at the pilot's station:<br>(a) A means of measuring and displaying:<br>(1) …<br>(b) Two means of measuring and displaying barometric altitude.<br><br>For single-pilot operations under VFR at night **one pressure altimeter may be substituted by a radio altimeter.** |

| Type of Operation | Aircraft category | Flight Rules | Rule | |
|---|---|---|---|---|
| | | | ID | Text |
| | | | | … |
| Non-Commercial with Complex aircraft (NCC) (e.g. business jet or turbine-powered helicopter) | Fixed wing aeroplane (A) | VFR | NCC.IDE.A.120 Operations under VFR – flight and navigational instruments | (a) Aeroplanes operated under VFR by day shall be equipped with a means of measuring and displaying the following:<br>(1) …<br>(2) …<br>(3) barometric altitude;<br>(4) … |
| | | IFR | NCC.IDE.A.125 Operations under IFR – flight and navigational instruments | Aeroplanes operated under IFR shall be equipped with:<br>(a) a means of measuring and displaying the following:<br>(1) …<br>(2) …<br>(3) barometric altitude;<br>(4) … |
| | Helicopter (H) | VFR | NCC.IDE.H.120 Operations under VFR – flight and navigational instruments | (a) Helicopters operated under VFR by day shall be equipped with a means of measuring and displaying the following:<br>(1) …<br>(2) …<br>(3) barometric altitude;<br>(4) … |
| | | IFR | NCC.IDE.H.125 Operations under IFR – flight and navigational instruments | Helicopters operated under IFR shall be equipped with:<br>(a) a means of measuring and displaying the following:<br>(1) …<br>(2) …<br>(3) barometric altitude;<br>(4) … |
| Non-Commercial operations with non-complex aircraft (NCO) (e.g. light piston engine aeroplanes) | Fixed wing aeroplane (A) | VFR | NCO.IDE.A.120 Operations under VFR – flight and navigational instruments | (a) Aeroplanes operated under VFR by day shall be equipped with a means of measuring and displaying the following:<br>(1) …<br>(2) …<br>(3) barometric altitude;<br>(4) … |
| | | IFR | NCO.IDE.A.125 Operations under IFR – flight and | Aeroplanes operated under IFR shall be equipped with:<br>(a) a means of measuring and displaying the following:<br>(1) …<br>(2) … |

| Type of Operation | Aircraft category | Flight Rules | Rule | |
|---|---|---|---|---|
| | | | ID | Text |
| | | | navigational instruments | (3) barometric altitude;<br>(4) … |
| | Helicopter (H) | VFR | NCO.IDE.H.120 Operations under VFR – flight and navigational instruments | (a) Helicopters operated under VFR by day shall be equipped with a means of measuring and displaying the following:<br>(1) …<br>(2) …<br>(3) barometric altitude;<br>(4) … |
| | | IFR | NCO.IDE.H.125 Operations under IFR – flight and navigational instruments | Helicopters operated under IFR shall be equipped with:<br>(a) a means of measuring and displaying the following:<br>(1) …<br>(2) …<br>(3) barometric altitude;<br>(4) … |
| Special Operations (SPO) i.e. aerial work carried out by civil operators. State flights excluded. | Fixed wing aeroplane (A) | VFR | SPO.IDE.A.120 Operations under VFR – flight and navigational instruments | (a) Aeroplanes operated under VFR by day shall be equipped with a means of measuring and displaying the following:<br>(1) …<br>(2) …<br>(3) barometric altitude,<br>(4) … |
| | | IFR | SPO.IDE.A.125 Operations under IFR – flight and navigational instruments | Aeroplanes operated under IFR shall be equipped with:<br>(a) a means of measuring and displaying the following:<br>(1) …<br>(2) …,<br>(3) barometric altitude,<br>(4) … |
| | Helicopter (H) | VFR | SPO.IDE.H.120 Operations under VFR – flight and navigational instruments | (a) Helicopters operated under VFR by day shall be equipped with a means of measuring and displaying the following:<br>(1) …<br>(2) …<br>(3) barometric altitude,<br>(4) … |
| | | IFR | SPO.IDE.H.125 Operations under IFR – flight and navigational instruments | Helicopters operated under IFR shall be equipped with:<br>(a) a means of measuring and displaying:<br>(1) …<br>(2) …<br>(3) barometric altitude, |

| Type of Operation | Aircraft category | Flight Rules | Rule | |
|---|---|---|---|---|
| | | | ID | Text |
| | | | | (4) … |