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ICARUS

INTEGRATED COMMON ALTITUDE REFERENCE SYSTEM FOR U-SPACE

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Abstract

This document is part of the ICARUS project (Integrated Common Altitude Reference system for U-space).

The ICARUS project is led by e-GEOS and includes partners Telespazio, TopView, DroneRadar, Eurousc Italia, Eurousc Espania, Eurocontrol, Politecnico di Milano, La Sapienza Roma.

ICARUS is a SESAR Horizon 2020 project supporting U-space, the European vision for the safe, secure and efficient handling of drone traffic and a key enabler for the growing drone market to generate economic and societal benefits.

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

New methods and procedures are therefore needed for large numbers of drones.

The EU-funded ICARUS project aims to introduce an innovative solution for common altitude reference inside very low-level airspace.

It defines new U-space services and validate them in real operational environments.

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

This Final Project Report describes the main achievements of the project, the key results and the final conclusions and recommendations.

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1 Executive Summary

Currently there is no common altitude reference in manned vs unmanned aviation, or between different drone manufacturers. In manned aviation, an aircraft's altitude is determined using pressure measurements while drones generally use GNSS. Moreover, barometric altitude estimation is not very accurate in very low-level airspace, especially over cities, and cannot address the challenges arising from flying very near, or sometimes even lower than ground obstacles.

The purpose of ICARUS project is to deal with problem of how determine the vertical distance between two aircraft using different altimetry systems

The ICARUS solution to these problems is based on U-space services.

The ICARUS project results are related to the study and implementation of new services as well the improvement of existing services:

- **VCS (Vertical Conversion Service):** provides automatic translation between barometric height and GNSS altitude (i.e. conversion from a barometric reference system to a geodetic one or vice-versa);
- **VALS (Vertical Alert Service):** Alerts drones and manned aviation over the common geodetic reference system about the current vertical distance to the ground (or other drone traffic), when such a distance becomes too small.
- **RGIS (Real Time Geographical Information Service)**: provides accurate cartography and 3D DTM / DSM of ground obstacles during the execution of a flight, to provide real-time information on the vertical distance to the ground, including above taller obstacles.
- **GNSS monitoring service:** provides real-time information regarding the drone position and the integrity of the solution achieved to the other ICARUS subsystems. At the same time, the service performs a check of the quality of the GNSS signal in the geographical area of interest, through the monitoring of the progress of the integrity parameters, providing a usability flag to the users.
- **Meteorological service**: provides pressures, temperatures, positions, and orthometric height data of a distributed network of ground weather reference stations. This data will then be exploited to calculate the QNH pressure value for that point, given a certain set of coordinates where an aircraft is flying. Weather Data Providers are needed for accessing the regional average QNH pressure values.

During the verification activities, ICARUS performed some specific tests (both dynamic and static) to provide a clear and accurate assessment about the translation errors from barometric to geometric systems used by UAS and GA airspace users.

This verification and validation activities demonstrated the feasibility of ICARUS approach for the realization of the CAR service, deployed through a scalable architecture.

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The outcomes of ICARUS suggest «corridors dedicated to UAS» inside U-space airspace (EC Regulation 2021/664) providing that a certain navigation performance is achieved, not only in the horizontal plane, but also in the vertical one

ICARUS results can be used as starting point for traffic schemas implementation for future projects helping on:

- A maximum Number of vertical corridors (layers) at VLL for the capacity assessment can now be assessed.
- MFMC GNSS Receiver could be recommended for UAS BVLOS operations in combination with VALS service
- Navigation Monitoring Service Should include CORS (Continuous Operating GNSS Reference station for RTK correction to UASs (identification of a new service provider)
- Proposal for the introduction of CARA (Common Altitude Reference Areas) where VCS (Vertical Conversion Service is expected to operate
- Standardization, best practice and calibration of barometric sensors and certified source on ground (trusted source GIS / METEO)
- DTM/DSM undulation references
- Need to add more data from land pressure stations to reduce the unknown error between real QNH Reference and calculated QNH reference (possible network of ”certified” baro sensors on drones?!)
- Certification of service provider,
- GNSS Integrity algorithms to be further investigated for real time application even with dissimilar technologies and cross check correlation
- Certification of GNSS receivers for UAS operations.

The Common Altitude Reference System proposed by ICARUS is a major element in the integration of unmanned aircraft into the Air Traffic Management system.

This exploratory research project points the way towards future work required for designing a robust vertical reference service.

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2 Project Overview

2.1 Operational/Technical Context

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

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

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

The study proposed three options:

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

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

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

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

Two important aspects were provided by CORUS:

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

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

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

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

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

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

Figure 2-1: ISO International Harmonised Stage Codes

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

2.2 Project Scope and Objectives

ICARUS project proposes an innovative solution to address the challenge of the Common Altitude Reference System for drones inside VLL airspaces with a GNSS altimetry-based approach and the definition of a geodetic-barometric transformation algorithm, implemented by a dedicated U-space service.

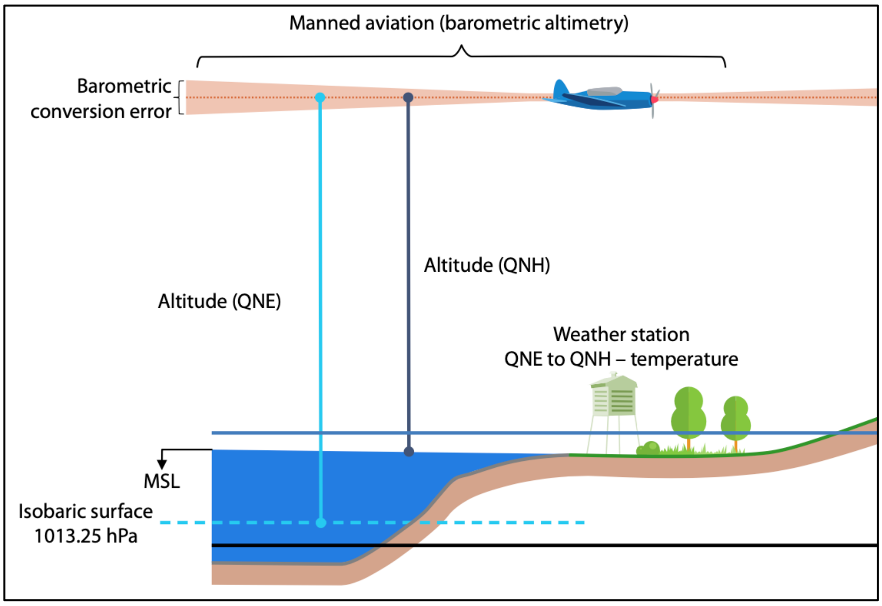

Figure 2-1:manned aviation altitude measurement

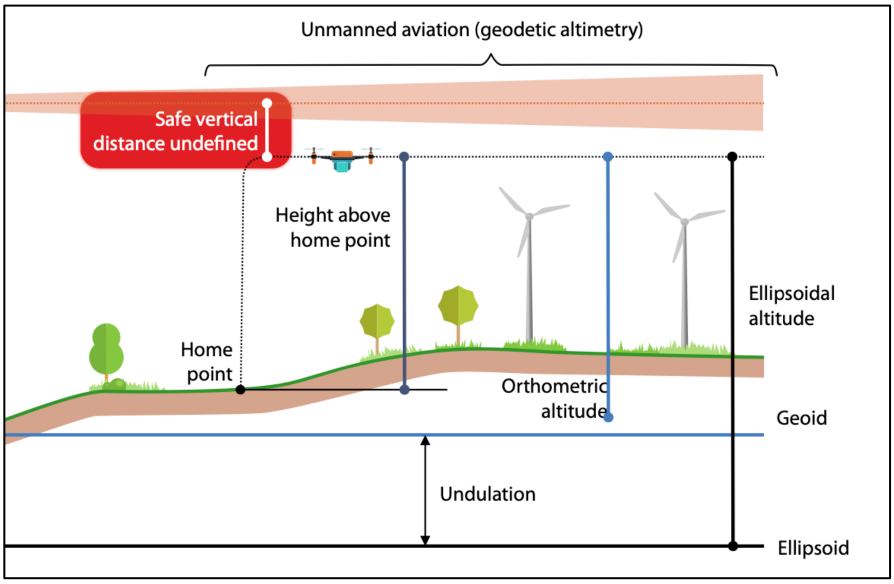

Figure 2-2: drones height measurement

1. Which technology should be used to measure the altitude at which a UAS is flying and to what **precision**, **accuracy** and **integrity** requirements?
2. Which reference **datum** should be used to ensure that every airspace user is flying in the **same altitude/height reference** system?

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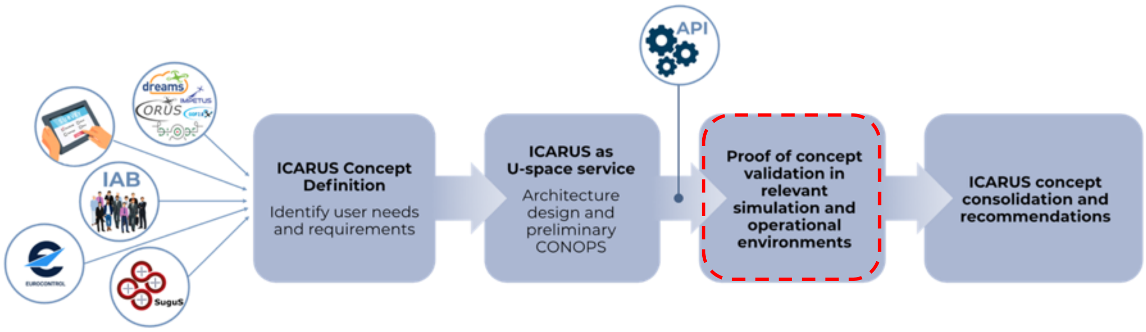
3. Considering the VLL airspace boundaries, which is the **safe vertical distance** to:
    - Higher airspaces;
    - Ground Obstacles
    - **Other drones** or **manned aircraft** in the same **VLL** airspace

2.3 Work Performed

The micro-services designed and developed in ICARUS (VALS, VCS, RGIS, GNSS monitoring) have been defined according to the following methodology:



2.3.1 ICARUS Concept Definition

ICARUS project has performed a critical review of past and concurrent projects, starting from the results obtained by previous and concurrent studies. The possible solution of the challenge of the CARS involved a multidisciplinary approach (Geodesy/ Geomatics / Navigation / ATM Research) not always present in the previous studies. ICARUS consortium being well balanced and composed by all the expertise needed to address this problem, has been able to define the requirements affecting both GNSS-based altimetry approach in terms of accuracy, precision, continuity and integrity of the service and the requirements applicable to the Digital Terrain Model (including Ground obstacles) in terms of resolution needed and accuracy.

To enforce this actions, it has been envisioned the involvement of the U-space community of UAS Pilots, drone operators, UTM service providers, GA pilots. These actors (including those belonging to the Advisory Board - AB) have been engaged by means of dedicated on-line survey (web questionnaire) aimed at assessing the operational needs related to the common altitude reference issues.

The requirements identified have been taken into account in 5 specific/operational use cases of particular interest to highlight the ICARUS concept and its added value in order to provide a preliminary Safety assessment addressed with state of the art methodologies.

The main output of this phase has been a requirement analysis for the envisioned service; the identification of gaps needed to implement the solution; a preliminary safety assessment of the use-cases envisioned, including a check for compliance of actual EU regulations.

All the work done has been inserted into deliverable D.3.1 ICARUS Concept Definition

2.3.2 ICARUS As U-space Service

The output of the ICARUS concept definition led to the definition and design of ICARUS prototype solution. In this phase a system architecture of the service has been identified and proposed, considering the output of the previous studies, with particular reference to final architecture proposed by CORUS project, for facilitating the integration of ICARUS service in multiple UTM/USSP implementations.

The prototype architecture of ICARUS has been driven by the definition of a new CONOPS that will be proposed in this stage taking into accounts needs and requirements identified.

The architecture proposed has clear software interfaces for the elicitation of service that will be open and interoperable for the facilitating the introduction of the ICARUS prototype service envisioned. For this reason the elaboration of ICARUS concept thought a detailed API has been foreseen. The API will make available ICARUS services to multiple UTM/USSP service providers.

Defined the concept and the architecture, the work proceeded with the development of the ICARUS service through an approach based on microservices and APIs, as well as the design of the right user interface.

Below an overview of the general architecture and the types of interaction:

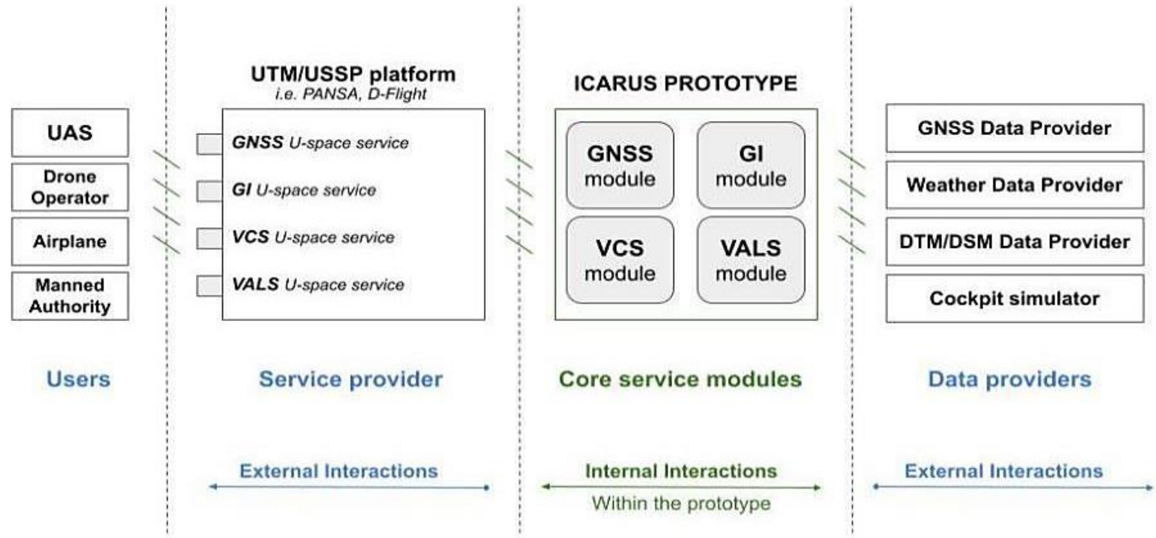


Figure 2-3: Icarus Architecture

The ICARUS prototype is the principal player of the architecture described for this project. It is composed of the following modules:

- Global Navigation Satellite System (GNSS) module
- Geo-Information (GI) module
- Vertical Conversion Services (VCS) module
- Vertical Alert Services (VALS) module

Each of these modules provides one or more **services**: GNSS services, geo-information services (GIS), vertical conversion services (VCS), vertical alert services (VALS). The plan is to make them accessible to the final users as U-space services, in other words passing through a UTM/USSP platform.

The prototype's modules need to interact with external data providers for GNSS, weather, and DTM/DSM data. For validation and testing purposes, the cockpit simulator will also act as a data provider for the prototype.

Given the above, there might be two types of interaction:

- *internal* to the prototype (in and between the modules)
- and from the prototype to the *external* entities.

All the work done has been inserted into deliverables:

a. D.4.1 ICARUS Design and Architecture

b. D.4.2 ICARUS Prototype

c. D.4.3 ICARUS Preliminary CONOPS

2.3.3 Proof of Concept validation

The main objective of this phase was the realization of ICARUS Proof of concept and the preparation of the relative test environment that will be used to validate the functionality of the proof of concept developed in a real operational environment.

The main objective of this phase was the realization of ICARUS Proof of concept and the preparation of the relative test environment used to validate the functionality of the prototype service developed in a real operational environment.

The concept validation followed a stepwise approach starting from the initial requirements set in the first phase of the project, were different simulations and analysis were performed.

During the verification and validation phase of ICARUS project several tests where performed with the final aim to validate the initial proof of concept.

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The requirements and the assumptions made in the first part of the project were verified with the following approach. A second iteration of the requirements was done at the end of the project to adjust conditions not verified or to adjust the performance.

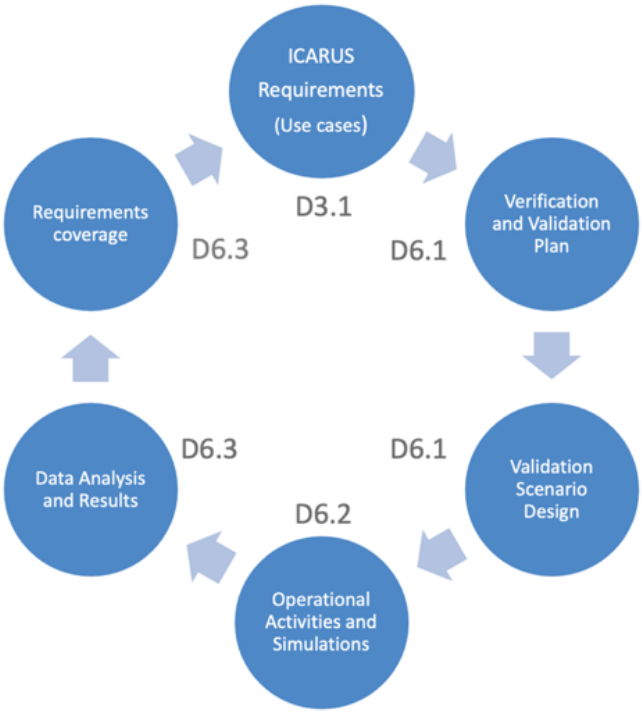


Figure 2-4 – Organisation of information-related verification and validation activities

The organization of the information related to verification and validation activities followed this approach:

1. **ICARUS requirements (Use Cases):** Relevant use cases for ICARUS were defined in Section 6 of D3.1. This set of five use cases was defined to support the definition of the requirements used to drive the design of the ICARUS micro-service architecture and the flight trials (simulated and real) for the assessment of the performance and the validation of the concept. The requirements will be used as the input to the other activities.
2. **Verification and Validation Plan:** This is described in D6.1, taking the project schedule into account. In this section the test cases, the test procedures, and the naming convention will be identified and coded. The Chapter 3 of this document provides the results of the Test cases defined in D6.1 and implemented in this document.
3. **Validation Scenario Design:** The validation scenario design is described in D6.1 where different scenarios (both simulated and real) were described, with particular reference to the ICARUS micro-services that were queried during the validation campaign
4. **Operational Activities and Simulations:** These activities were described in D6.2. This provides operational details about the validation campaigns and exercises that were conducted,

considering the areas where took place. In this document the operational plan for execution of real flights and the **simulation trials** was described.

5. **Data Analysis and Results:** This information is described in this document (D6.3). In this document, all the data collected during the flights (simulated and real) are described and analysed for final results and recommendations. The test results, from the test cases and test procedures defined in Section 2 of the D6.2 document, are finally presented here (D6.3).
6. **Requirements coverage:** The final step is a final check of the coverage of the requirements defined in D3.1. A traceability matrix will be used to support this stage (D6.3), with additional comments and findings.

This process allowed not only to drive with a methodological approach the validation activities, but also to provide recommendations to the U-space Conops and other U-space projects.

Activities concerning the integration and adaptation of existing platforms and simulators and the realization of the subsystem prototypes were performed as well as the production of documents describing the ICD and a test report of the new developed interfaces for facilitate the integration of ICARUS service in multiple UTM/USSP implementations.
Then, at the end of the developments, ICARUS services has been tested during the validation and demonstration activities with a mixed approach involving both simulations and a tests in a real operational scenario, involving two or more drones flying ,starting at different heights (from the slope of a hill, or from the top of a building) with interfering flight plans.

ICARUS has been tested previously in Poland and then in an intensive validation campaign in Italy, involving also GA pilots performing not only a simulated flight but also a real one, making use of ICARUS.

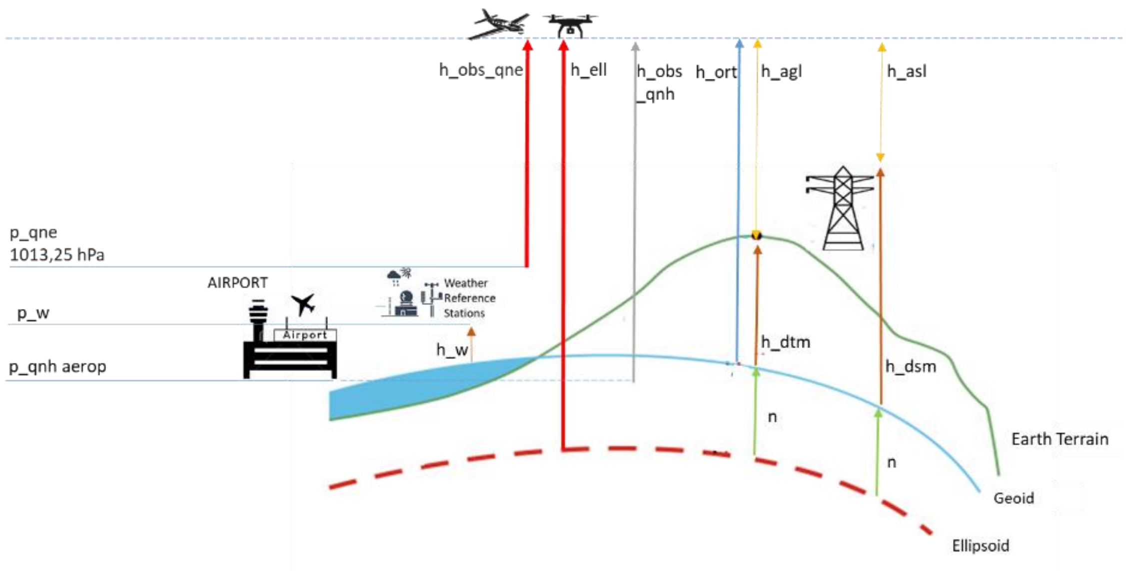
The prototype developed by Telespazio and e-Geos to provide ICARUS services is able to receive the input data necessary for the operation of the 4 implemented microservices (VCS-VALS-RGIS-GNSS).

Data sent by the drone is used to track and provide the GNSS monitoring services necessary for the integrity calculation.

Once the data has been received, coming from the drone or the manned aircraft, the RGIS service is activated, and it calculates the DSM and DTM height value at the point where the manned and unmanned aircraft is located.

VCS service recalls the pressure value from the input barometric sensors and from weather services. At this point The VCS has all the necessary values available to carry out the conversion. From the converted data, VALS is ready, by matching, positions, altitude / height and integrity values, it is able to generate alerts if a collision with the ground, surface or obstacles is possible.

Some details of the parameters in input and output calculated by the platform are presented in the following pictures.



Input:

- `vehicle_type` has to be equal to 0 if the request is coming from a drone, or equal to 1 for airplanes' requests.
- `h_obs_qne` the observed height over QNE in meters *(in case of an airplane request)*
- `h_ell` the ellipsoidal height in meters *(in case of a drone request)*
- `p_w` is the pressure in hectopascal (hPa) of the weather station nearest to the vehicle which is asking for conversion
- `h_w` is the ortometric height of the weather station nearest to the vehicle which is asking for conversion
- `p_qnh_airport` is the average QNH pressure in hectopascal (hPa) for the region in which the airport is located
- `h_dtm` the DTM height (in meters)
- `h_dsm` the DSM height (in meters)
- `n` is the *geoid undulation* in meters (height of the geoid relative to a given ellipsoid of reference)

Output:

- `h_ort` the orthometric height of the requesting vehicle in meters
- `h_obs_qnh` the orthometric height of the requesting vehicle respect the QNH of the runway (in meters)
- `h_agl` the orthometric height of the aircraft respect the DTM (in meters)
- `h_asl` the orthometric height of the aircraft respect the DSM (in meters)
- `h_obs_qne` the orthometric height of P respect the QNE in meters (only for drones' requests)
- `h_ell` the ellipsoidal height of P requesting vehicle in meters (only for airplanes' requests)

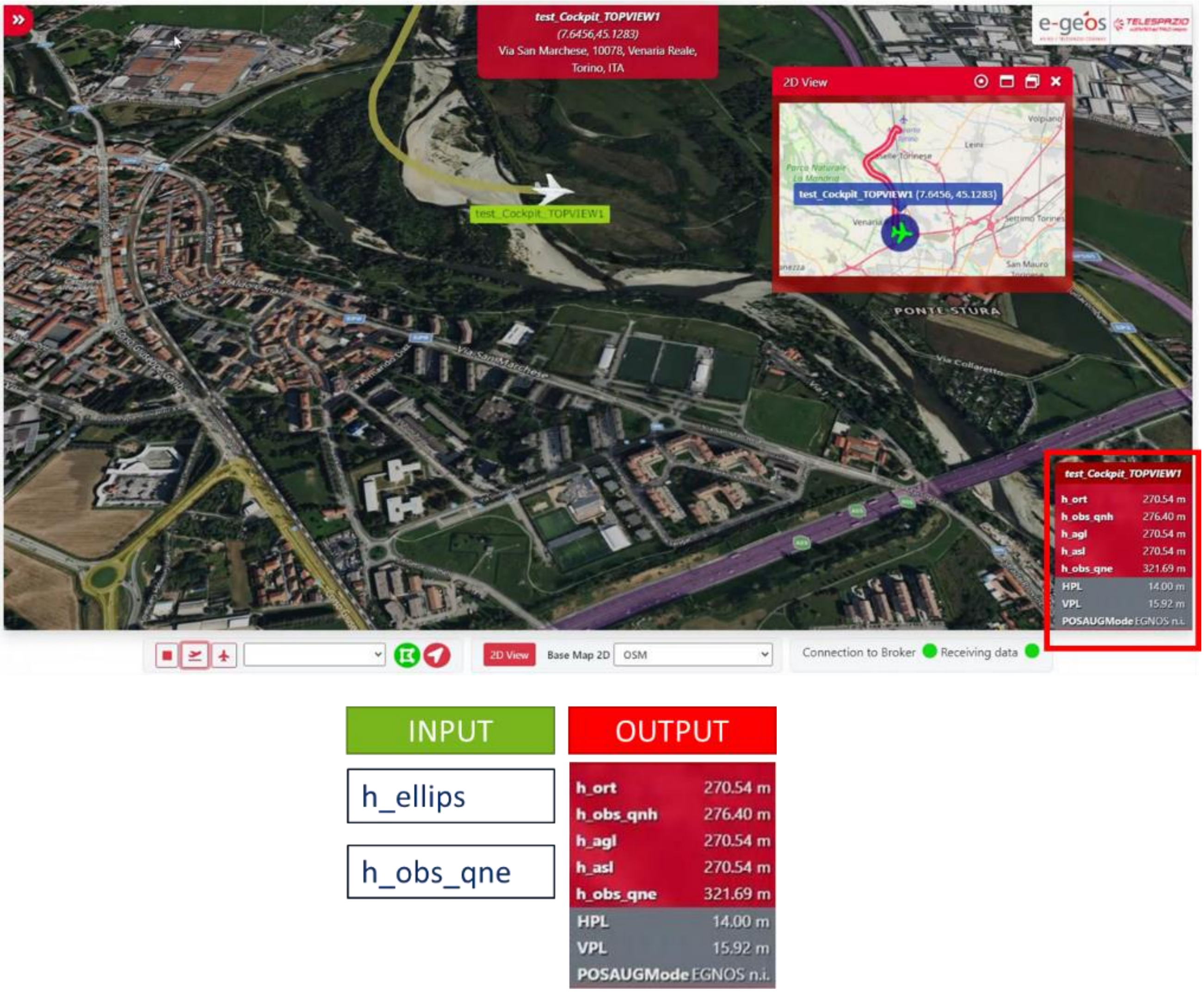


Figure 2-5 –TPZ-E-GEOS SW Platform used for visualization of converted altitudes/heights and data analysis.

In order to verify the system operation correctness as well as to capture the contextual nature of the information, CARS was integrated and visualized on two Droneradar platforms:

- A standalone web application using a WebSocket connection
- The CARS altitude converter was integrated into the PansaUTM/Droneradar UTM within GOF2 project.

For the purposes of smooth visualization the maximum flying object refresh rate was set to 5Hz (5 position updates per second).60 airplanes at the same time. Both the VCS converter used in the project and the Web visualizer (WWW application) were efficient enough to handle online conversions of all aircraft.

Mobile installation was used to perform ad-hoc tests with UAS flying in relatively close vicinity.

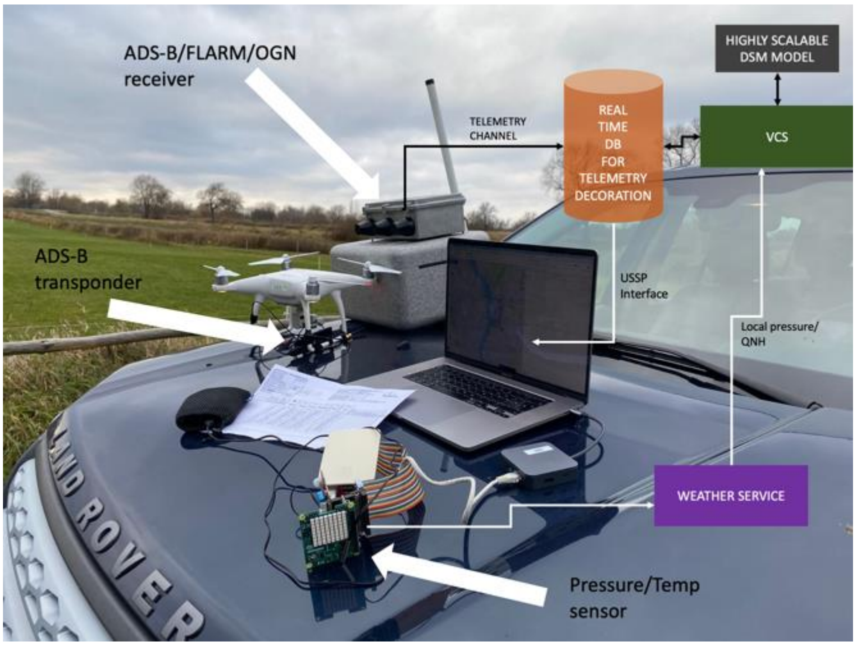


Figure 2-7 – Droneradar Mobile installation: On-site setup including Meteo Station Sensor

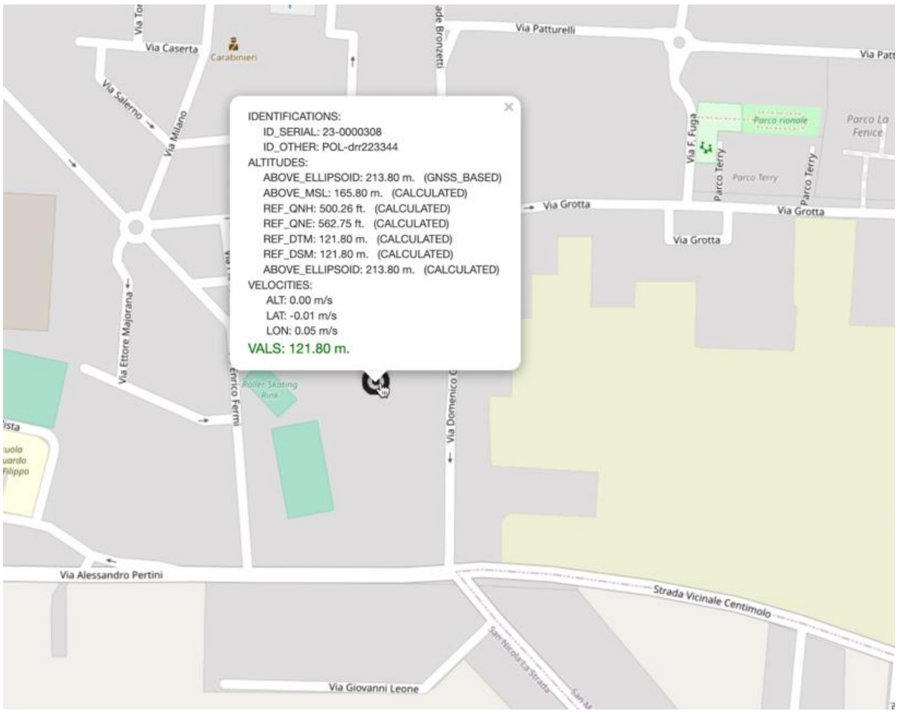


Figure 2-8 – Example of Droneradar standalone visualization. In this example GNSS receiver was used as a source of location and altitude

The output of this phase has been the development of the prototype, the design of the validation scenarios and the simulation and trials execution together with the analysis of the data collected during the activity. The final step has been a final check of the coverage of the requirements defined in D3.1. A traceability matrix has been used to support this stage (D6.3), with additional comments and findings.

To verify the correctness of the CARS algorithm, the ICARUS project performed two parallel UAS test flights at the same place and time.

UAS test flight specification:

- Blue and Orange UAS has been equipped with a calibrated RTK system to determine the exact height above the take-off point (AGL m)

- Blue UAS has been equipped with an ADS-B transmitter with its own barometric sensor that gives the altitude relative to the STD pressure (QNE)

- Orange UAS has been equipped with a 3G / LTE tracker with its own GNSS system that gives the altitude relative to the WGS-84 Ellipsoid

Both UAS flew in the same place, climbing with an altitude step of 10m up to 120m AGL. During the test, measured and converted values were measured.

The final conversion result is presented in the table below.

		CARS Converted Values						CARS Converted Values				
AGL (m)	BLUE ORIG (ft)	AMSL converted from BARO (m)	QNH converted from BARO (ft)	QNE converted from BARO (ft)	DTM/DSM converted from BARO (m)	ELLIPSOID converted from BARO (m)	BLACK ORIG	AMSL converted from ELL (m)	QNH converted from ELL (ft)	QNE converted from ELL (ft)	DTM/DSM converted from ELL (m)	ELLIPSOID converted from ELL (m)
10	**275,59**	59,5	185,45	275,59	15,5	107,5	**101,8**	53,8	166,32	256,44	9,8	101,8
20	**298,55**	66,33	208,41	298,55	22,33	114,33	**112,9**	64,9	203,61	293,75	20,9	112,9
40	**374,01**	88,72	283,82	374,01	44,72	136,72	**131,2**	83,2	265,21	355,39	39,2	131,2
60	**449,47**	111,04	359,23	449,47	67,04	159,04	**151,6**	103,6	334,07	424,29	59,6	151,6
80	**498,68**	125,56	408,41	498,68	81,56	173,56	**172**	124	403,13	493,4	80	172
100	**574,14**	147,76	483,82	574,14	103,76	195,76	**191,8**	143,8	470,36	560,66	99,8	191,8
120	**649,6**	169,89	559,23	649,6	125,89	217,89	**211,4**	163,4	537,09	627,44	119,4	211,4

Figure 2-9 – CARS calculation comparison (based on real tests)

The graphs illustrate the efficiency of the CARS conversion with respect to the conversion of values to the common denominators, which are Ellipsoid, QNH and QNE. It should be emphasised that regardless of what is the source of the height/altitude information, the calculation (decoration) process is performed with respect to every reference pattern.

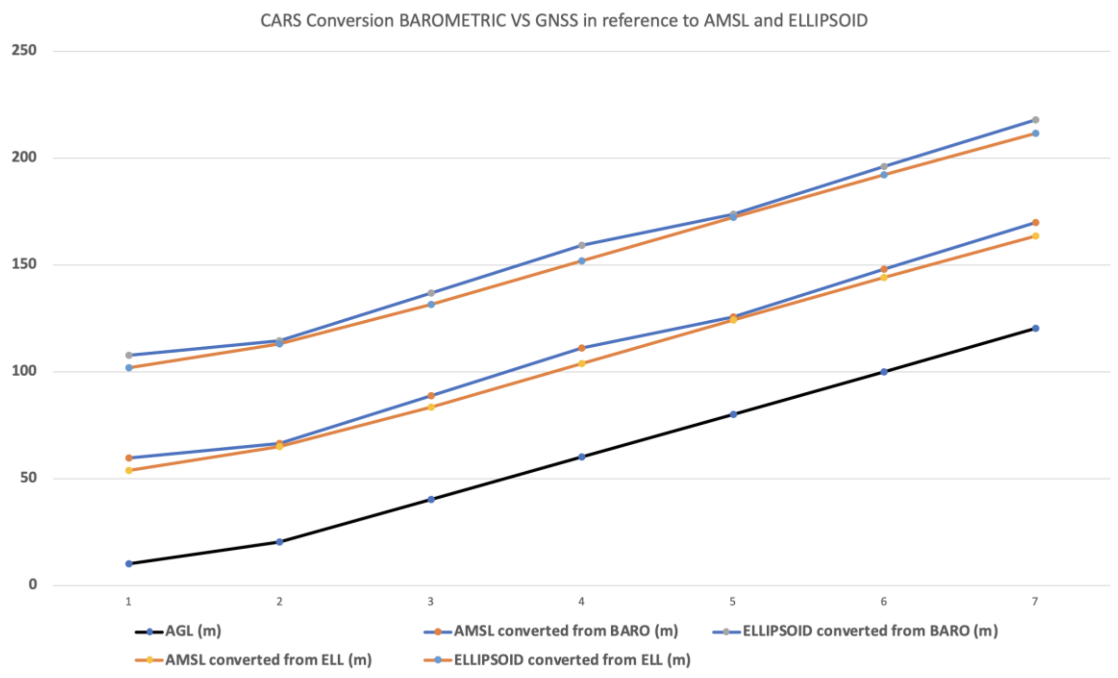


Figure 2-10 – CARS Conversion BAROMETRIC VS GNSS in reference to AMSL and ELLIPSOID

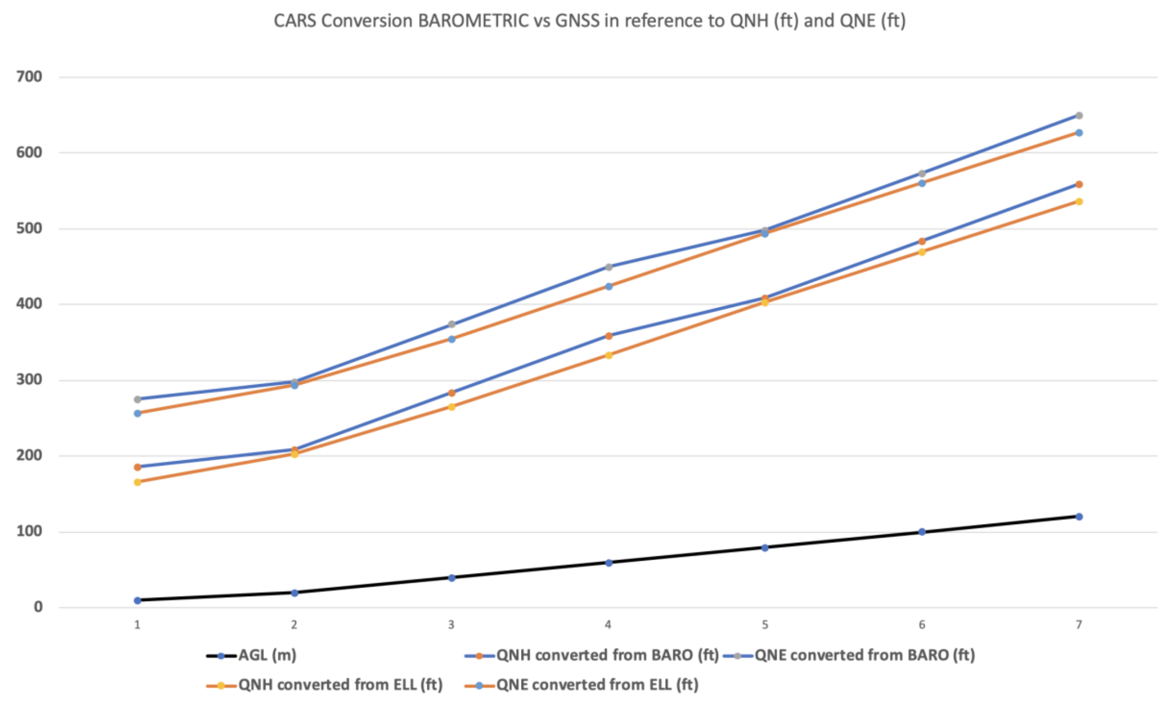


Figure 2-11 – CARS Conversion BAROMETRIC vs GNSS in reference to QNH (ft) and QNE (ft)

All the work done has been inserted into deliverables:

a. D.5.1 UTM Platform Architecture including ICD and integration test report

b. D.5.2 Cockpit simulator Architecture including ICD and updated IF to UTM

c. D.5.3 D-Flight GNSS Augmentation ICD and integration test report

d. D.5.4 ICARUS external I/F test & validation plan

e. D.6.1 Validation Scenario Design

f. D.6.2 Simulation Trials execution plan

g. D.6.3 Simulation trials Data Analysis & Results

2.3.4 ICARUS Concept Consolidation and Recommendations

The final stage of the project has been to show the data acquired during the validation campaign and the results achieved in order to strengthen the ICARUS concept. ICARUS concept has been proposed in the SESAR community and in the U-space / UTM environments with actions of cross fertilization with the other concurrent U-space projects and studies. Such action will be enforced with the presence of ICARUS consortium to events and conferences (e.g. SESAR innovation days, World ATM Congress, etc.).

A final event with the ICARUS advisory board has been set for the end of July 2022 to close the project and to provide feedback on ICARUS consolidated concept and for sharing lesson learnt, recommendations & best practice.

2.4 Key Project Results

ICARUS project demonstrated the feasibility of a CAR system based on WGS-84 for UAS -UAS vertical separations. The information of the Terrain for Ground Obstacle risk is mitigated by the microservices VALS and RGIS.

Finally, the translation for barometric to geometric system is guaranteed by the Vertical Conversion Service, that is proposed to be available in areas called "CARA" – Common Altitude Reference Areas

The main project results and recommendation of ICARUS project can be summarized as follows:

- A proposal of Error Budget for vertical UAS-UAS vertical distance (1 sigma) has been done and validated. This result can be used as starting point for traffic schemas implementation for future projects. The figures proposed are in line with other concurrent and independent studies (i.e. EUSPA). However, additional analysis are still needed for more complex routes and trajectories in UAM environment

- Operational environment and Navigation performance also in the vertical dimension: The outcomes of ICARUS suggest «corridors dedicated to UAS» inside U-space airspace (EC

Regulation 2021/664) providing that a certain navigation performance is achieved, not only in the horizontal plane, but also in the vertical one

- A maximum Number of vertical corridors (layers) at VLL for the capacity assessment can now be assessed starting from the Total System Error calculated and verified on field for both copters and planes.
- MFMC GNSS Receiver Altitude with WGS-84 datum uses as zero altitude are recommended for UAS BVLOS operations in combination with VALS service. On the other hand For VLOS operations, it is recommended to UAS pilots to use their home point Height. Dual Altitude (Home point and WGS-84 altitude) acceptance for pilots should be assessed with a dedicated survey.
- Navigation Monitoring Service Should include CORS (Continuous Operating GNSS Reference station for RTK correction to UASs (identification of a new service provider)
- Proposal for the introduction of CARA (Common Altitude Reference Areas) where VCS (Vertical Conversion Service is expected to operate

However additional R&D activities in some specific areas are still needed:

- Standardization, best practice and calibration of barometric sensors and certified source on ground (trusted source GIS / METEO)
- DTM/DSM undulation references
- Need to add more data from land pressure stations to reduce the unknown error between real QNH Reference and calculated QNH reference (possible network of ”certified” baro sensors on drones?!)
- Certification of service provider,
- GNSS Integrity algorithms to be further investigated for real time application even with dissimilar technologies and cross check correlation
- Certification of GNSS receivers for UAS operations.

KPA	Comment
Safety	The need for a Common Altitude Reference System (CARS) to ensure vertical separation between manned and unmanned aircraft at Very Low Level (VLL) was already highlighted by EUROCONTROL in 2018. The Project has developed new U-space services for this. Improvement of the safety has been demonstrated, based on Commission Regulation 2020/2034.

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Security	The system architecture has been defined taking also security into consideration.
Environment	No impact identified.
Capacity	The Vertical Conversion Service (VCS) does not contribute to enhance capacity at controlled aerodromes and inside related airspace structures. However, it greatly enhances capacity in U-space airspace (e.g. over metropolitan areas), since enabling vertical separation at VLL.
Predictability and Punctuality	Positive impact envisaged for logistic drones at VLL in U-space airspace.
Cost Efficiency	Ensured, since, on-board manned aircraft at VLL under VFR, a portable Electronic Flight Bag (EFB) would be sufficient to exploit VCS and VALS, without the need to modify the installed avionics (i.e. no retrofit necessary).
Flexibility	VALS would allow more flexible drone operations in proximity of obstacles.
Access and Equity	The new services developed by the Project are already listed in ISO 23629-12, which constitutes a world-wide benchmark, ensuring equitable service provisions anywhere.
Human Performance	No adverse effect on human performance assessed during simulations.
Civil Military Cooperation and Coordination	Positive effect, since also MIL aircraft may fly at VLL and they may benefit from VCS.
Cost Benefits Analysis	Not carried out.

2.5 Technical Deliverables

The following table refers to the all ICARUS technical deliverables:

Reference	Title	Delivery Date[1]	Dissemination Level[2]
Description			
D3.1	ICARUS concept definition: state-of-the-art, requirements, gap analysis	21/12/2020	PU
The main objective of WP3 is to collect all the necessary information and analysis to be used for the identification and definition of the services suitable for the ICARUS CAR system, through an in-depth analysis of the requirements of users and all stakeholders, as well as an analysis of the state of the art of each technological component. In this document, the ICARUS concept is established, an analysis is undertaken of the state-of-the-art in height systems, digital terrain models (DTM) and geospatial products relevant to the problem, the requirements of the system/service are derived, and a gap analysis is undertaken on the components to be developed. This wide range analysis is a necessary input for prototyping the system/service.			
D4.2	ICARUS Prototype	14/11/2021	PU
This document aims at finalising and consolidating the design of ICARUS by describing the interfaces of the ICARUS services for each of the four ICARUS modules foreseen. In the introduction, we give an overview of the overall architecture, and we clarify the terminology to facilitate the reader's understanding of the description. The ICARUS prototype will be the central player of the whole discussion. At a high level, this document will show how the prototype interacts with external entities, which can be of two types: *data providers* that act as data sources for the computation, and *service providers* that are intended as the distributors of the ICARUS services. The last section ends the document with the ICD of the cockpit simulator, which is intended as a data provider for testing and validation purposes.			
D4.1	Design and architecture of the ICARUS system & service	02/03/2021	PU
This document specifies the overall ICARUS architecture with a particular focus on the architecture of the proposed micro-services that constitute the ICARUS contribution to the definition of U-space services. Moreover, this document specifies the operational and functional relationship between the ICARUS micro-service components, the other UTM/USSPs and the ATM. This specification is based on			

[1] Delivery data of latest edition

[2] Public or Confidential

the analysis of the ICARUS operational scenarios and use cases, and development of the ICARUS concept definition, that was described in ICARUS deliverable D.3.1

D4.3	ICARUS Preliminary CONOP	26/11/2021	PU

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.

D5.1	UTM Platform Architecture including ICD and Integration Test Report	05/11/2021	PU

This document describes the functional architectures of the USSP (Droneradar), its integration interfaces with the ICARUS CARS system and specify all the interfaces regarding the Weather Service Provider (WSP) and GI Service Provider (GISP) platforms.

D5.3	D-Flight GNSS Augmentation ICD and Integration Test Report	02/11/2021	PU

This document specifies all the interfaces regarding the GNSS microservice. It describes the input and output interfaces that allow the necessary data to be retrieved to be upgraded by the outcomes of the Telespazio computing unit calculations.
Moreover, the document describes the data flows regarding the GNSS microservice through a series of use cases representative of its operations.
Finally, it contains the test to be performed in order to test and verify the communication between the GNSS microservice and the external sources of data (EDAS and Ground Reference Stations) and between the GNSS microservice and the other ICARUS microservices that need its computation

D5.2	Cockpit Simulator Architecture	12/11/2021	PU

The main purpose of this document is to present the architecture of the cockpit simulator that will be used for the validation exercises of the ICARUS project foreseen in WP6. The cockpit simulator is an essential component of the ICARUS testbed as it gives the opportunity to General Aviation (GA) pilots to test the ICARUS services (in particular GIS, VALS, VCS) implemented for the particular scenarios identified, where GA and drones operate concurrently in very low-level (VLL) airspace

D5.4	ICARUS external Interface test and validation plan	04/11/2021	PU

This document contains the inventory of all external interfaces that need to be integrated. It describes the approach to testing and defines the Test Case Descriptor form, which is used to describe test case specifications and document test results. It provides the plan for the integration testing of external systems with the ICARUS CARS platform. Finally, it contains a report on the results of the first tests that the consortium performed

D6.1	D6.1 Validation Scenario Design	14/11/2021	PU

This document, together with D6.2, provides information about the Design of Scenarios envisioned for validation activities and the related testbed including equipment, drones, components, USSPs interfaces that will be used, but also information about the verification of the requirements defined during the Requirements analysis in Document D3.1. The main objectives of D6.1 can be summarized as follows:

- To Identify a suitable scenario for testing ICARUS services (use cases identified in D3.1);
- To provide a verification Matrix of the requirements identified in D3.1 with particular attention to those requirements applicable to the validation activities;
- To design the scenarios for validation activities to be performed with drones and manned flights in Italy and Poland
- To identify verification activities related to the assessment of ICARUS concept accuracy

D6.2		15/11/2021	PU

This document is deliverable D6.2 “Simulation Trials Execution Plan” of the ICARUS project.
The execution plan is defined for each validation scenario regardless of whether its execution is to be performed with real flight activities, simulated trials, or “mixed” trials in a mixed scenario.
In this document, the execution plan for the verification trials is given for both simulation and real flight activities, with a detailed operational plan. The operational plan used considers the typical information needed by an actual UAS operator to perform professional UAS flight activities.
An introductory paragraph on the verification and validation approach is provided to help the reader understand all of the information related to WP6

D6.3	Simulation Trials Data Analysis Results	07/07/20221	PU

This document represents the deliverable D6.3 “Simulation Trials Data Analysis and Results” of ICARUS project. The main objectives of this document can be summarized as follows:

- To report the verification and validation activities of the project addressed in WP6 considering the Test cases identified and the validation scenarios defined in D6.1 and D6.2
- To provide the coverage of the requirements defined in D6.1 document and report any kind of non-compliance / partial compliance and/or findings generated by the verification and validation activities
- To discuss the lesson learned, the problems solved, and the new questions raised
- To summarize the conclusions of ICARUS validation activities.

Table 1: Project Technical Deliverables

3 Summary of Communications and Dissemination activities

3.1 Summary of communications and dissemination activities

3.1.1 Participation in Conferences and Public Events

The original communication and dissemination plan considered the participation in conferences and other public events through presentations, workshops and panels as the primary channel to reach most target groups. Unfortunately, the unprecedented reaction to the COVID-19 crisis will prevent the consortium to achieve their original goals.

In any case, ICARUS has been present in two online events organised by SESAR and four live events.

Conference or Public Event	Type	Date
SESAR Innovation days	Online event	December 2020
SESAR Digital Academy	Online event	May 2021
Mediterranean Aerospace Matching	Conference	September 2021
ENAC National Strategic Plan for the development of Advanced Air Mobility	Conference	January 2022
Amsterdam Drone Week	Hybrid Live / online event	March 2022
World ATM Congress	Conference	June 2022

Table 2 – Conferences and Public Events

3.1.2 Online dissemination strategy

Due to the constraints imposed by the COVID-19 situation mentioned above, the ICARUS consortium implemented an online dissemination strategy as the primary tool to maximise the impact of the dissemination activities.

The plan is based on launching four successive campaigns during the last six months of the project, starting in February 2022. Each of these campaigns involved related documentation and will be announced by posts on the project website, supported by Social Media impacts.

The following table lists the documentation that will be available on each of these campaigns. The highlighted deliverables will be specifically promoted by posts on the website and social media channels, summarizing their contents.

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Public deliverables		White papers	Multimedia
Campaign 1 - General documentation			
D2.4	Data Management Plan		
D7.2	Dissemination and Communication plan – Issue 1	Web survey report	
D7.1	Roadmap & cross fertilization with concurrent U-space projects		
D7.8	Dissemination and communication plan – Issue 2		
Campaign 2 - Design and architecture			
D3.1	ICARUS concept definition: state-of the-art, requirements, gap analysis.		
D4.1	Design and architecture of the ICARUS system & service (including I/F)		
D4.2	ICARUS Prototype		
D4.3	ICARUS Preliminary CONOPS	Design and Architecture Report	
D5.1	U-space Platform Architecture including ICD and integration test report		
D5.2	Cockpit simulator Architecture including ICD and integration test report		
D5.3	D-Flight GNSS Augmentation ICD and integration test report		
Campaign 3 - Validation campaign			
D5.4	ICARUS external I/F test & validation plan		
D6.1	Validation Scenario Design		Validation campaign footage
D6.2	Simulation Trials execution plan		
D6.3	Simulation trials Data Analysis & Results		
Campaign 4 - Project results and conclusions			
D7.4	Communication & Dissemination activity report		
D2.5	Final Project Results Report - Issue 1	Conclusions and Recommen-dations Report	Third ICARUS video
D7.7	Lessons Learnt, recommendation & best practices		

Table 3 – Online dissemination campaigns

3.1.3 Schedule of communication and dissemination activities

The following table lists the schedule of the main communication and dissemination activities conducted during the duration of the Project.

Title	Activity type	Date
Project website	Website and social media accounts	July 2020
Project brochure	Promotional material	September 2020
First Advisory Board Meeting	Online Workshop	October 2020
ICARUS introductory video	Promotional material	November 2020
SESAR Innovation Days	Online Conference	November 2020
ICARUS Survey white paper	Public documentation	February 2021
SESAR Digital Academy	Online Workshop	May 2021
Second Advisory Board Meeting	Online Workshop	June 2021
Mediterranean Aerospace Matching	Conference	September 2021
ENAC National Strategic Plan for the development of Advanced Air Mobility	Conference	January 2022
First online dissemination campaign	Website and social media accounts	Feb-Mar 2022
Amsterdam Drone Week	Conference	March 2022
Second online dissemination campaign	Website and social media accounts	Apr 2022
Third online dissemination campaign	Website and social media accounts	May-June 2022
World ATM Congress	Conference	June 2022
Third Advisory Board Meeting	Meeting	July 2022
ICARUS final video	Promotional material	July 2022
Fourth online dissemination campaign	Website and social media accounts	July 2022

Table 4 – Schedule of communication and dissemination activities

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3.2 Project High Level Messages

Problem description

- There is no common altitude reference (CAR) between manned aviation, nor among UAS
- Traditional methods to determine altitude and ensure vertical separation in manned aviation are based on pressure measurements which are not adequate for Very Low Level (VLL) operations
- Drones already use satellite measurements (GNSS) for navigation
- In VLL conditions GNSS altimetry is the ideal technology due to its accuracy, integrity and continuity, providing much better results than barometric altimetry
- To ensure vertical separation between drones and manned aviation it is necessary to convert altitude between pressure measurements and GNSS

What is ICARUS

- ICARUS is a project that aims to provide an innovative U-space geodetic / barometric altitude translation service for UAS and GA pilots to be used in both the strategic and tactical phases of a flight.
- Drones with sufficient capabilities may use the ICARUS service to obtain the terrain profile from digital terrain models (DTM), the distance from the ground and known ground obstacles, while keeping a common reference altitude datum to that used by manned aviation, using GNSS-based altimetry
- Drones with fewer capabilities may use the ICARUS service for augmenting their "level of confidence" in their vertical position (using a GNSS performance monitoring service), while keeping the same common reference altitude datum

ICARUS benefits

- ICARUS will be implemented as a U-space service that can be provided by any U-space service provider using industry standards
- ICARUS will increase the capacity of congested airspace by reducing the vertical separation requirements imposed by the low-accuracy barometric methods that have been used by traditional manned aviation
- ICARUS will simplify mission planning by providing accurate terrain and obstacle information

- Safe integration of manned and unmanned aviation through the possibility of determination the mutual altitude of different by nature, systems: barometric and GNSS
- Raising the aviation society and regulation awareness of the altitude determination problem
- Identification of new requirements for the remaining provisions related to the U-space and manned aviation regulation

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VASL/CARS movie: https://www.youtube.com/watch?v=5PvYjxk4CTA

4 Links to SESAR Programme

4.1 ATM Master Plan

In the context of this SESAR project, ICARUS has identified a new solution as its main service that is hoped to be deployed together with the U3 set of services. The 4 microservices proposed by the ICARUS project are enablers that could be part of the next edition of the ATM Master Plan (MP) and could help to better integrate the U-space domain with traditional ATM, which is the dominant concern in the MP right now.

It should also be noted that CORUS-XUAM is integrating the ICARUS architecture into its ConOps architecture by using the architectural framework that is used to build the MP.

4.2 Maturity Assessment

Icarus Services has been tested thanks to the prototype developed in a Real Operating Environment.

According to Exploratory Research TRL (min 0- max 2) a TRL 2 has been achieved.

A TRL 7 (Model demonstration in Operational environment), requires the development of documentation, certification, proven highly scalable data models and algorithms.

Below you can find the excel file regarding the maturity assessment:

Foglio di lavoro in
SESAR 3 U-space Fina

5 Conclusions

5.1 Conclusions on maturity of the SESAR Solution(s) and supporting services/capabilities

From the point of view of the prototype made under the ICARUS project, a very high level was achieved. However, it should keep in mind that the commercial implementation of the service, along with the certification, will still require large financial outlays.

Reaching the TRL 7 (Model demonstration in Operational environment), will require the development of documentation, certification, proven highly scalable data models and algorithms. Due to the need to launch many of new services (RGIS, VCS, VALS and EMS), this certification will be demanding in terms of time and investments.

ICARUS project demonstrated the feasibility of a CAR system based on WGS-84 for UAS -UAS vertical separations. The information of the Terrain for Ground Obstacle risk is mitigated by the microservices VALS and RGIS.

Finally, the translation for barometric to geometric system is guaranteed by the Vertical Conversion Service, that is proposed to be available in areas called "CARA" – Common Altitude Reference Areas

The main project results and recommendation of ICARUS project can be summarized as follows:

- A proposal of Error Budget for vertical UAS-UAS vertical distance (1 sigma) has been done and validated. This result can be used as starting point for traffic schemas implementation for future projects. The figures proposed are in line with other concurrent and independent studies (i.e. EUSPA). However, additional analysis are still needed for more complex routes and trajectories in UAM environment

- Operational environment and Navigation performance also in the vertical dimension: The outcomes of ICARUS suggest «corridors dedicated to UAS» inside U-space airspace (EC Regulation 2021/664) providing that a certain navigation performance is achieved, not only in the horizontal plane, but also in the vertical one

- A maximum Number of vertical corridors (layers) at VLL for the capacity assessment can now be assessed starting from the Total System Error calculated and verified on field for both copters and planes.

- MFMC GNSS Receiver Altitude with WGS-84 datum uses as zero altitdue are recommended for UAS BVLOS operations in combination with VALS service. On the other hand For VLOS operations, it is recommended to UAS pilots to use their home point Height. Dual Altitude (Home point and WGS-84 altitude) acceptance for pilots should be assessed with a dedicated survey.

- Navigation Monitoring Service Should include CORS (Continuous Operating GNSS Reference station for RTK correction to UASs (identification of a new service provider)

- Proposal for the introduction of CARA (Common Altitude Reference Areas) where VCS (Vertical Conversion Service is expected to operate

However additional R&D activities in some specific areas are still needed:

- Standardization, best practice and calibration of barometric sensors and certified source on ground (trusted source GIS / METEO)
- DTM/DSM undulation references
- Need to add more data from land pressure stations to reduce the unknown error between real QNH Reference and calculated QNH reference (possible network of "certified" baro sensors on drones?!)
- Certification of service provider,
- GNSS Integrity algorithms to be further investigated for real time application even with dissimilar technologies and cross check correlation
- Certification of GNSS receivers for UAS operations.

5.2 Conclusions on technical design, feasibility and architecture

CARS is a real-time service. For this reason, its final production architecture must be reliable and scalable vertically and horizontally. The vertical development will be realized by increasing the the computing power, while horizontal will be performed server instances multiplication.

It should be remembered that in real-time systems, the weakest element determines the speed of the entire system. Therefore, during the development of the production system as well as certification, the needs resulting from aviation safety will determine requirements They should not be artificially limited to technical requirements. However, should such limitations arise during the operation of the system, fallback and contingency procedures (both technical and procedural) should be defined to inform all users about the limitations of the CARS system in within CARA.

The VCS microservice realized has the possibility to provide in real time 5 heights/altitudes to the consumer of the service. The regional QNH is provided by certified sources

5.3 Conclusions performance and benefit assessments

Determining the performance requirements of the system will be the result of the number of aircraft in a given volume of airspace as well as the frequency of location updates. The typical broadcast frequency of position information varies between 1 and 5 Hz. Thus, system performance should take extreme cases into account and should include a safety buffer in case the amount of information in a given volume of space increases significantly.

5.4 Conclusions on requirements

In this chapter a second iteration of the ICARUS requirements has been done, considering the outcomes of the verification and the validation phase. When relevant some considerations and findings were reported in the field "Remark" of the attached file excel.

Finally, the traceability matrix of test case vs test requirements is hereafter provided.

5.4.1 Test Cases vs requirements

Test Case ID (ref. D6.1)	Test Case Title	Req. ID	STATUS	Note
TEST_OPS.GNSS.10	UAS-UAS altitude reference (urban)	ICARUS-D31-0060 ICARUS-D31-0240 ICARUS-D31-0260 ICARUS-D31-0310 ICARUS-D31-0320 ICARUS-D31-0330 ICARUS-D31-0340 ICARUS-D31-0350	passed*	This test il passed with limitation to the data set acquired and analyzed.
TEST_OPS.GNSS.20	UAS-UAS altitude reference (open sky)	ICARUS-D31-0060	passed*	This test il passed with limitation to the data set acquired and analyzed.
TEST_OPS.GNSS.30	UAS-UAS altitude reference (continuity)	ICARUS-D31-0060 ICARUS-D31-0220	passed*	This test il passed with limitation to the data set acquired and analyzed.
TEST_OPS.GNSS.40	UAS-UAS altitude reference (availability)	ICARUS-D31-0060 ICARUS-D31-0230	passed*	This test il passed with limitation to the data set acquired and analyzed.
TEST_OPS.DTM.10	UAS-Ground Obstacle common reference	ICARUS-D31-0070 ICARUS-D31-0090 ICARUS-D31-0100 ICARUS-D31-0210 ICARUS-D31-0380	passed	
TEST_OPS.BARO.10	static GNSS/BARO conversion	ICARUS-D31-0140 ICARUS-D31-0150 ICARUS-D31-0160 ICARUS-D31-0170	passed	

ReqID	ReqTitle	ReqText	Test Case ID	Remark
ICARUS-D31-0070	UAS-Ground Obstacles vertical Reference at VLL	Ground Obstacles represented in a given DSM shall be reported and referenced by U-space Geospatial Information Service in the same datum used by UAS for Common Altitude Reference System (WGS-84) Remark Gedetic->Geometric transformations of Buldings and obstacles might be needed to ensure the same reference for all airspace users at VLL	TEST_OPS.DTM.10	
ICARUS-D31-0090	AGL Height information in BVLOS	AGL Height (Above Ground Level) information shall be always visible on UAS pilot's Ground Control Station during BVLOS operations in tactical phase Remark during planning, at least each waypoint shall report its AGL height	TEST_OPS.DTM.10	ICARUS service can be can be conceived also as a planning tool capable to convert the panning information of the mission to a common reference (i.e. AGL height). When designing the route, each actor can use their preferred system
ICARUS-D31-0100	Altitude information in BVLOS	Geometric Altitude (above WGS-84 ellipsoid) information shall be always visible on pilot's Ground Control Station during BVLOS operations for Common Altitude Reference with other UAS	TEST_OPS.DTM.10	WGS-84 datum in combination with the RGIS microservice (Providing real time information of distance to ground) and VALS microservice (providing real time infrmation of possibile impact with ground in the next 60 seconds) is the envisioned datum for CARS for drones in BVLOS conditions. It is reccomended to on UAS Pilot GCS to display Heights wrt to Home point for VLOS operations and Altitude (WGS-84) for BVLOS operations
ICARUS-D31-0150	Geometric-Barometric conversion service update	The Geometric-barometric coversion service must calculate the dynamic offset among WGS-84 and local QNH datum at least every 30'	TEST_OPS.BARO.10	During the validation exercises, the conversion service was update with 1 Hz update
ICARUS-D31-0170	Geometric-Barometric conversion service alert	The Geometric-barometric altitude (VCS) service must warn users in case of malfunctioning in less than 6 seconds	TEST_OPS.BARO.10	
ICARUS-D31-0280	ICARUS prototype service	ICARUS prototype service shall be available for verification and valdiation activities to USSPs involved in the project in the form of a microservice that can be queried through a specific Application Program Interface (API)	S1, S2, S3	API tested with 2 different potential USSPs in valdiation exercises S1, S2 and S3
ICARUS-D31-0290	ICARUS demonstrator	ICARUS demonstrator shall be capable of showing during the strategic and tactical phase of the flight the following functionalities: - vertical profile of the planned trajectory with respect to the WGS-84 datum and to the ground (terrain, ground obstacles, buildings); - warnings to the manned-aviation pilots and drones in proximity of "CARA"; - 3D model of buildings, ground obstacles and terrain profile in the defined area of simulation. - Display to airspace users, the conversion of reference datum (QNH/WGS-84) through the dedicated service with a simulated communication mechanism	S1, S2, S3	Functionalities showed in the valdiation exercises S1, S2 and S3. Though most of the them where more concentrated on the tactical phase.
ICARUS-D31-0310	Total System Error (Accuracy)	During BVLOS operations, for a straight trajectory (Waypoint 2 Waypoint), according to PBN ICAO definition, it shall possible for UAS to reach a navigation accuracy performance with TSE of about: - 10 meters for the horizontal accuracy for copters; - 3 to 9 meters for the vertical accuracy for copters; - 14 meters for the horizontal accuracy for planes; - 3 to 9 meters for the vertical accuracy for planes;	TEST_OPS.GNSS.10	The requirment was verified only in straight lines or vertical climbing conditions with success. A more comprehrnsive analysis should be assessed for manouvers (though other studies already addressed this problem with very similar results
ICARUS-D31-0380	Detailed Surface Model Position Accuracy	Detailed Surface Model accuracy must be: - for urban areas, in the range of [0,50-1,00] m; - for rural areas in the range [5,00 – 10,00] m; - for suburban areas [0,50 – 2,00] m, in case of inspection operations; - for suburban areas [5,00 – 10,00] m, in case of transit;	TEST_OPS.DTM.10	

Table 5-1: Requirements vs Test Cases traceability Matrix

6 Recommendations

6.1 Recommendations for concept clarification

6.1.1 Recommendations for updating U-space services and capability definitions

ICARUS develops and validates a new **U3 service - Altitude Translation Service** to be used by drone operators and general aviation pilots that provides current altitude, using a Common Altitude Reference, as well as distance from the ground and known obstacles.

Based on the following NEW/ Update U-space microservices:

Real-time Geospatial Information Service **(RGIS)**	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	UPDATE already existing U-space service
Vertical Conversion Service **(VCS)**	Provides drone altitude and height with respect to the surface, converting drone altitude into barometric altitude, and converting manned barometric altitude to geometric altitude, to enable entry into a CARA. VCS convert any height/altitude input to all possible hight/altitude outputs.	NEW U-space service
Vertical Alert Service **(VALS)**	Alerts drones and manned aviation about their current vertical distance from ground when this is small	NEW U-space service
Electro-Magnetic Interference Information Service **(EMS) / Navigation Coverage Information**	GNSS Signal Monitoring and Positioning + Integrity service that reports enhanced accuracy, performance estimation and integrity to UAS pilots or drones	UPDATE already existing U-space service

6.1.2 Recommendations for updating the U-space architecture

Standardization of the use of (known) Height/Altitude reference system when distributing telemetry in UTM systems

During ICARUS project it was discovered that in the GNSS chipset world there are big uncertainty. GNSS chipset manufacturers use various models for the ellipsoidal to geoidal (AMSL) conversion. In other words, to fit conversion tables in very low memory of chipset, manufacturers make great simplification. In results, generic undulation models which are used for automatic conversion, may have relatively big error (in mountains even dozens of meters). What's worse, from what we've noticed, there are cases when the GNSS chipset manufacturers state that they provide the height relative to the ellipsoid, and in practice they provide the height relative to the geoid based on some unknown undulation model. As a result, there is quite a lot of technical error. **Hence, ultimately, it will be necessary to force the chipset manufacturers to provide two parameters: the reference and the conversion reference model used (need to be included into service specs).**

Standardization of the use of (known) Technical Error Value when distributing telemetry in UTM systems.

TE (Technical Error Value) issue.Each altitude may contain errors, typical for it's nature, for example: the altitude broadcasted by ADS-B transponders has a altitude step of 25 ft. It means that the altitude is given every 25 ft (or about 7.5 m!). In manned aviation it does not matter, but in U-space, where less than 120m is available in total, this error value may be significant. In GNSS, augmented systems like SBAS or GBAS eg EGNOS may provide correction values for known errors in a given area and time. In addition, the computed error may include errors of smaller errors being for instance errors of the system components (eg. DSM approximation, earth temperature and pressure sensors).

6.1.3 Recommendations for elaboration of the U-space concept

- […]ICARUS service can be can be conceived also as a planning tool capable to convert the planning information of the mission to a common reference (i.e. AGL height). When designing the route, each actor can use their preferred system
- WGS-84 datum in combination with the RGIS microservice (Providing real time information of distance to ground) and VALS microservice (providing real time infrmation of possibile impact with ground in the next 60 seconds) is the envisioned datum for CARS for drones in BVLOS conditions. It is reccomended to on UAS Pilot GCS to display Heights wrt to Home point for VLOS operations and Altitude (WGS-84) for BVLOS operations
- Data provided by CAR service should indicate whether it is just measured or it is the result of a conversion.

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- Integrity information can be provided also by dissimilar technologies to simplify the complexity of the system. As an example, Transponders equipped with barometers my cross check GNSS and Barometric information and raise an integrity warning in case of discrepancies of height measures
- Navigation Integrity information resulted to complex to be calculated onboard small UAS. Ground services for ARAIM Calculation can be an option
- When operating in Network Remote Identification, 6 seconds of buffering during Telephone cells handover, is acceptable. However, Transponders may implement mechanisms to filter their position for mitigate frozen tracks as much as possible
- For vertical accuracy only some configruation of receivers presented an acceptable accuracy on the veritcal axis. In general high end receivers in DFMC met this condition. On the horizontal accuracy the requirement was always met.
- ARAIM technicques is excluded for small drones. RAIM is still viable. Navigation data fusion seems to be the most promising technique for integrity monitoring. U-space services for integrity calculation is still viable
- Path Definition Error cannot be neglected for drone operations unless a very detailed cartography is available and a very detailed DTM/DSM model.
- vegetation differences (winter / summer) should be also taken into account in DSM

6.2 Recommendations for standardisation and regulation

The recommendations for standardisation and regulation as follow:

- the adoption of the concept of a CARA (Common Altitude Reference Area) 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;
- 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.

It should be remembered that:

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

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

The safe and harmonised deployment of the U-space needs a solid performance-based and risk-based regulatory framework. These frameworks are considered in the Regulation (EU) 2019/947 and 2021/664.

Privileges, high-level requirements and responsibilities for all the stakeholders operating or providing services in the U-space (e.g. UAS operators, U-space service providers, authorities, …) are defined by the legally binding regulations. Performance-based and risk-based approaches should be as much as possible independent from technological solutions and, consequently, complemented by industry standards.

Some U-space services have been identified in regulation, standard or EU project:

Document	EC U-space Regulation	CORUS CONOPS	ISO 23629-12
No. U-space services	6 + 1	25	30
Website	https://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupMeetingDoc&docid=48688	https://www.eurocontrol.int/project/concept-operations-european-utm-systems	https://www.iso.org/standard/78962.html

… 30 services certified by Authority?

RGIS, VCS and VALS introduced by ICARUS project have been inserted in the list of U-space services listed by ISO 23629-12.

EASA should establish an AMC referring to ISO 23629-12 in support of oversight of U-space services, in particular for the ones other than safety-critical. EASA should invite the SDOs, through the EUSCG to develop minimum performance specifications for all U-space safety-critical and safety-related services listed in ISO 23629-12, beyond the work currently underway in EUROCAE WG 105. See [1].

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6.3 Recommendations for further R&D needs

List of further R&D needs:

- Definition of the certification methods and standards for UAS Static Pressure sensor calibration, especially in multirotors with estimation of TE depending of phase of flight
- Insight into aerial pressure and temperature distribution to be able to plan network of on ground METEO sensors in different types of places: rural, low and highly urbanized
- Amendment of the “general” CARS telemetry Service Specification to be exchanged within U-space between systems (USSP, CISP, GSC, etc.) which will include strained references, errors, and all necessary other details
- Definition of “UAS RVSM” (Reduced Vertical Separation Minimum) areas with safe limits
- Perform feasibility study to create NOSA - Network of Sensors in the AIR to reduce Technical Error of CARA
- Provide further recommendations to known standardisation bodies and authorities (ICAO, EuroCAE, ISO, etc.) as a result of this R&D activities

7 References

7.1 Project Deliverables

The project deliverables are available on STELLAR platform at the link:

https://stellar.sesarju.eu/

A description of all technical deliverables is reported in §2.5

7.2 Other references

[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] 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.

[4] 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.

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

[6] 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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[13]GLOBAL POSITIONING SYSTEM STANDARD POSITIONING SERVICE PERFORMANCE STANDARD, 5th Edition, April 2020.

[14]U.S. Federal Aviation Administration, “Global Positioning System Standard Positioning Service Performance Analysis Report”, July 2020.

[15]European GNSS (Galileo) Services Open Service Quarterly Performance Report, April-June 2020.

[16] Phase II of the GNSS Evolutionary Architecture Study, February 2010.

[17] http://www.asgeupos.pl/index.php?wpg_type=dwnld&sub=gnsstools

[18] “The ISG-format (version 1.0)” https://www.isgeoid.polimi.it/Geoid/ISG_format_v10_20160121.pdf

[19] ICARUS D3.1, “ICARUS Concept Definition: State-Of-The-Art, Requirements, Gap Analysis”, Section 5.4.1 “Orthometric height and Ellipsoidal height”

[20] ICARUS D4.2, “ICARUS Prototype”

[21] ICARUS D6.3 “Simulation Trials Data Analysis Results”

Appendix A Standardisation & regulation

No.	ID	Facts	Considerations	Conclusion	Recommendation
1.	Credit for industry standards	• According to several sources, resources inside CAAs are not sufficient to cope with increasing demand for oversight, including in case of UAS (e.g. Commission COM 613 of 2015) • Even SORA, for several OSOs recommends verification of compliance by independent and accredited third parties • EU Regulation 965/2012, so called AIR-OPS is accompanied by a 'catch-all' AMC, reproduced in Annex A, establishing criteria for crediting verification of conformity by industry	A similar 'catch-all' AMC could facilitate oversight even in relation to Commission Regulations 2019/947 and 2021/664	A general AMC establishing criteria to credit audits by industry is missing in 2019/947 and 2021/664	EASA should complement 2019/947 and 2021/664 with an AMC similar to AMC1 ARO.GEN.305 (b);(c);(d);(d1) Oversight programme
2.	Oversight of U-space service providers	• Regulation 2021/664 lists 4 + 2 + 1 U-space services • CORUS had proposed 25 of them • ICARUS proposed three additional ones • ISO 23629-12, approved on 21 June 2022, lists 30 possible U-space services	ISO classifies these services into 'safety-critical', 'safety-related' and 'operation support. To establish risk-based oversight, only the safety-critical	For safety-related and 'operation support' U-space services, industry certification can alleviate the burden on UAS operators to comply with OSO #13	EASA should establish an AMC referring to ISO 23629-12 in support of oversight of U-space services, in particular for the

No.	ID	Facts	Considerations	Conclusion	Recommendation
			services could need to be certified by the authority. For the others, the UAS operator should take responsibility though OSO #13, which does not exclude taking advantage of industry certification		ones other than safety-critical
3.	Performance requirements for RGIS, VCS and VALS	• ICARUS has proposed three additional U-space services • These services have been accepted by ISO and are listed in ISO 23629-12 • However, while that ISO standard is exhaustive for the requirements on the service provider, it does not contain minimum performance specifications for each service • EUROCAE WG 105 is currently working on minimum performance requirements only for the services listed in 2021/664	For safety of U-space services, both the organisation of the SP and the performances of the service need to be under oversight. There is a gap for the performance specification of several U-space services	All U-space services require minimum performance specifications, to complement the requirements for the SP in ISO 23629-12	EASA should invite the SDOs, through the EUSCG to develop minimum performance specifications for all U-space safety-critical and safety-related services listed in ISO 23629-12, beyond the work currently underway in EUROCAE WG 105

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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.
(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.
(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**:

(1) the demonstration of compliance is based on certification auditing schemes providing for **independent and systematic verification**;
(2) the existence of an **accreditation scheme** and accreditation body for certification in accordance with the industry standards has been verified;
(3) certification audits are **relevant** to the requirements defined in Annex III (Part-ORO) and other Annexes to this Regulation as applicable;
(4) the scope of such certification audits can **easily be mapped** against the scope of oversight in accordance with Annex III (Part-ORO);
(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
(6) the audit **planning intervals** of certification audits i.a.w. industry standards are compatible with the oversight planning cycle.

A.1 Glossary of terms

Term	Definition

Table 2: Glossary

A.2 Acronyms and Terminology

Term	Definition
ATM	Air Traffic Management
SESAR	Single European Sky ATM Research Programme
S3JU	SESAR3 Joint Undertaking (Agency of the European Commission)
ADS-B	Automatic Dependent Surveillance-
AGL	Above Ground Level
AMSL	Above Mean Sea Level
ARAIM	Advanced RAIM
ATM	Air Traffic Manangement
BVLOS	Beyond Visual Line Of Sight (operation)
CARA	Common Altitude Reference Area
CARS	Common Altitude Reference System
CISP	Common Information Service Provider
ConOps	Concept of Operations
CORS	Continuous Operating GNSS Reference Station
DEM	Digital Elevation Model
DFMC	Dual Frequency Multiconstellation SBAS
DSM	Digital Surface Model
DTM	Digital Terrain Model
EASA	European Union Aviation Safety Agency
EC	European Commission
EDAS	External Sources of Data
EGNOS	European Geostationary Navigation Overlay Service
EMS	Electro-Magnetic interference information Service
EUROCAE	European Organisation for Civil Aviation Equipment

EUSPA	European Union Agency for the Space Programme
FL	Flight Level
GA	General Aviation
GBAS	Ground-Based Augmentation Systems
GISP	Geodetic Information Service Provider
GNSS	Global Navigation Satellite System
ICAO	International Civil Aviation Organization
ICD	Interface Control Description
ISA	International Standard Atmosphere
ISO	International Organization for Standardization
LTE	Long Term Evolution (to 3G)
MSL	Mean Sea Level
NOSA	Network of Sensors in the Air
QFE	QFE altimeter pressure setting
QNE	QNE altimeter pressure setting
QNH	QNH altimeter pressure setting
RAIM	Receiver Autonomous Integrity Monitoring
RGIS	Real-time Geospatial Information Service
RTK	Real-Time Kinematics
RVSM	Reduced Vertical Separation Minimum
SBAS	Satellite-Based Augmentation Systems
SME	Small and medium-sized enterprise
TE	Total Error
TRL	Technology Readiness Level
TSE	Total System Error
UAM	Urban Air Mobility

UAS	Unmanned Aircraft System
USSP	U-Space Service Provider
UTM	Unmanned Traffic Management
VALS	Vertical Alert Service
VCS	Vertical Conversion Service
VFR	Visual Flight Rules
VLL	Very Low Level
WGS	World Geodetic System
WSP	Weather Service Provider

Table 3: Acronyms and technology

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Appendix B Requirements