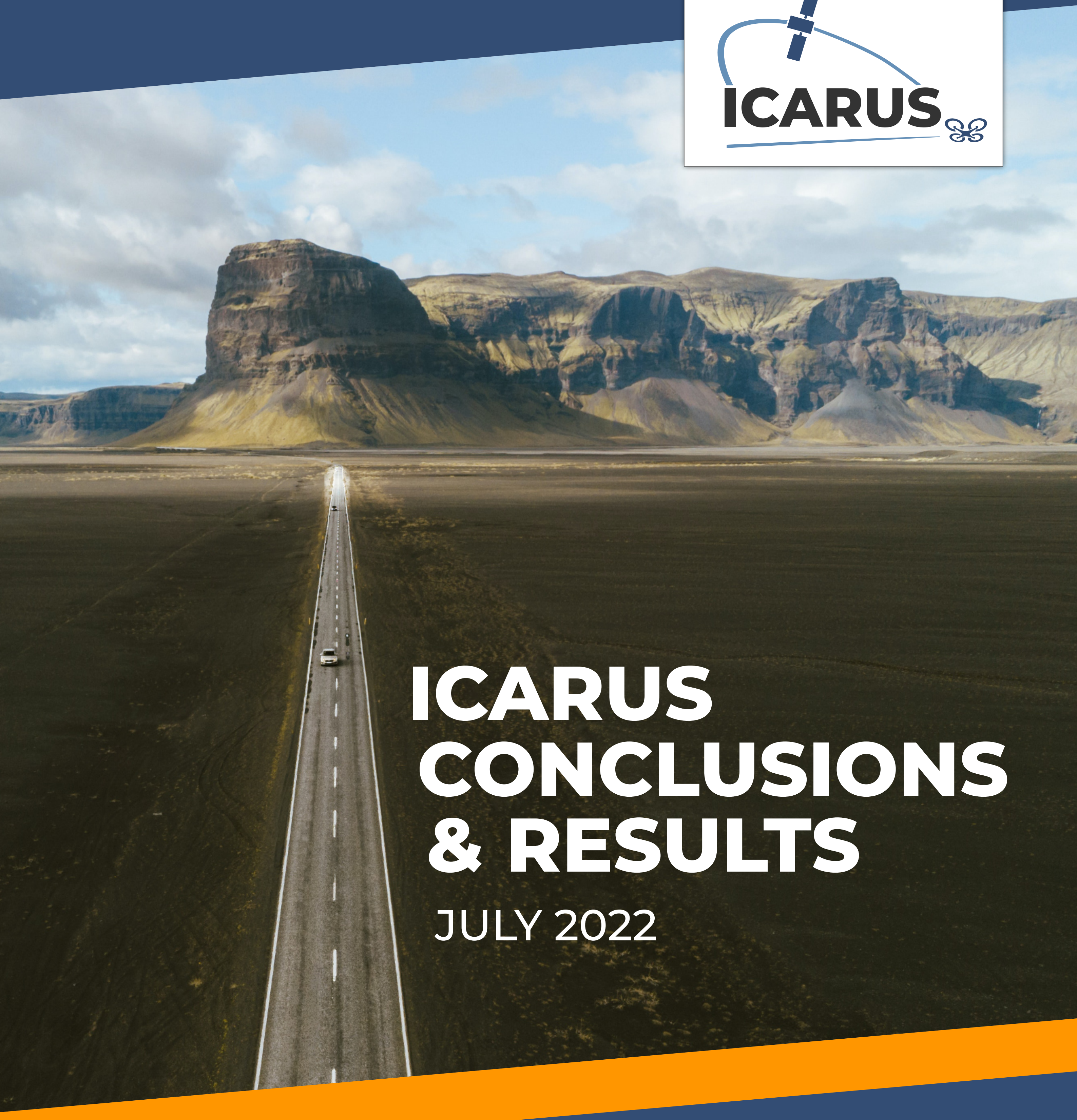
INTEGRATED COMMON ALTITUDE REFERENCE SYSTEM FOR U-SPACE



ICARUS CONCLUSIONS & RESULTS

JULY 2022

ICARUS

INTEGRATED COMMON ALTITUDE REFERENCE SYSTEM FOR U-SPACE

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Issue 1.0

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CONTENTS

ICARUS

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In manned aviation, an aircraft's altitude is determined using pressure altitude difference measurements.

However, small drones use altitude measurements from GNSS satellites that are incompatible with these barometric measurements. New methods and procedures are therefore needed to enable all airspace users, and supervisory systems, to place all aircraft on the same altitude reference system

The EU-funded ICARUS project introduced an innovative solution for common altitude reference inside very low-level (VLL) airspace. It defined new U-space services and validated them in real operational environments.

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

The present document describes the methodology used during the project, in particular the extensive validation exercises carried out to validate the results of the project.

The document presents the key results obtained during the programme execution and recommended practices to the drone and general aviation communities , for them to take advantage of these results to enable safe operations in Very Low Level VLL airspace.

ICARUS is only the first step in creating a Common Altitude Reference System for VLL airspace that can unleash the potential will ensure the safe integration of unmanned aviation. For this to be successfully deployed, additional work needs to be carried out in a future Fast Track for Innovation project.

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

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ICARUS

INTRODUCTION

GLOSSARY OF TERMS

Acronym	Term
ADS-B	Automatic Dependent Surveillance-Broadcast
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

Acronym	Term
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

ABOUT ICARUS

Problem statement

Currently there is no common altitude reference in manned vs unmanned aviation, or between different drone manufacturers.

Traditional methods to determine altitude, and ensure vertical separation, are based on pressure altitude while drones and manned aircraft already use satellite measurements (GNSS) for navigation purposes.

What is ICARUS

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

ICARUS benefits

The U-space service that ICARUS has developed and validated can be used by drones and manned aviation to obtain their current altitude, using a Common Altitude Reference, and the distance from the ground or known obstacles.

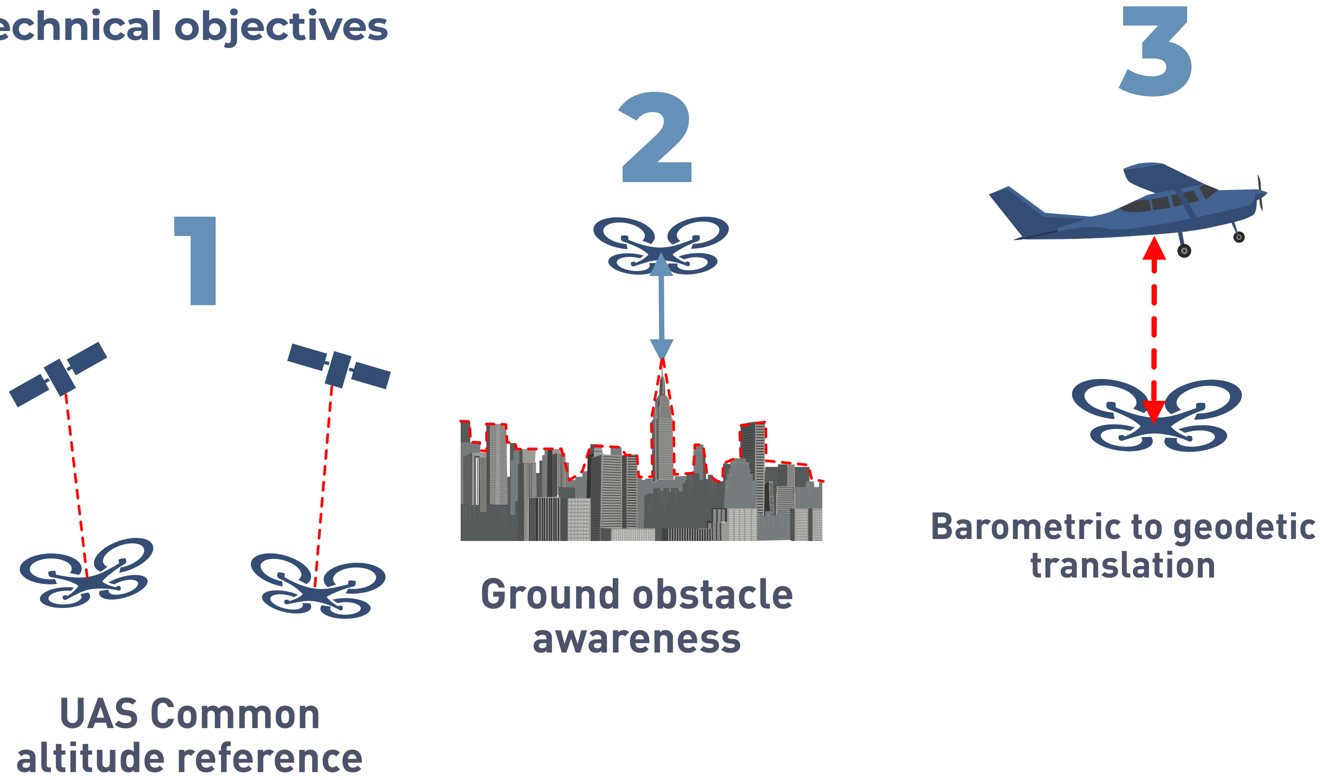
This innovative service will increase the safety of operations, boosting long distance (BVLOS) operations, increasing the capacity of congested low level airspace and further the integration of drones with traditional manned aviation.

Project timeline

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

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

Technical objectives



THE ICARUS CONSORTIUM

e-Geos

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

DiCEA – Sapienza

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

Drone Radar

Founded to continue the development of the DroneRadar UTM system in co-operation with the Polish Air Navigation Services Agency. PansaUTM, based on Droneradar concepts and solutions, is the first certified UTM system in the world

Eurocontrol

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

EuroUSC España

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

EuroUSC Italia

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

Politecnico di Milano

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

Telespazio

One of Europe's leaders and world's main players in satellite solutions and services. Telespazio has its HQ in Rome, Italy, includes e-GEOS , operates worldwide and it has a wide network of space centres and teleports

TopView

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

WHY A COMMON ALTITUDE REFERENCE?

Traditional aviation

Traditionally in manned aviation, the altitude of an aircraft is determined based on pressure-altitude difference measurements with respect to a common datum using the International Standard Atmosphere (ISA).

These barometric altitude references do not provide true heights, but rather approximations of height based on known atmospheric pressure gradients. In this model, three different altitude references are used at various stages of a flight: for low-level flights, there are **QNH** (altitude above sea level) and **QFE** (altitude above airfield elevation) and for high-level flights, altitude is expressed in Flight Levels (FL) based on the ISA value of 1013.2HPa at 0 FL (**QNE**). This complex model is in use since 1928, and is standard practice for pilots of manned aircraft around the world.

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

Unmanned aviation

Unmanned aviation brings new challenges. Since a small drone (UAS) may take off and land almost from everywhere the concept of QFE is not relevant. Also, UAS usually fly close to the ground, often below the tops of nearby obstacles. Additionally, drones and Urban Air Mobility (UAM) scenarios have the potential to involve flight densities that are unknown to manned aviation.

Finally, and most importantly, UAS/UAM generally obtain altitude values from GNSS satellites that provide true (within their margin of error) height values with respect to a known geodetic reference – an ellipsoid or a geoid. This is completely incompatible with the barometric altitude used by manned aviation.

For these reasons, a new Common Altitude Reference System (CARS) such as the one promoted by ICARUS is required.

PROJECT METHODOLOGY

METHODOLOGY

The ICARUS work plan included two administrative work packages, four research work packages and a transversal work package devoted to the definition of the business plan, communication, dissemination, and exploitation tasks.

ICARUS concept definition

ICARUS performed a critical review of the results of past and concurrent projects. The workable solution to the challenge of developing a CARS involved a multi-disciplinary approach that included geodesy, geomatics, navigation and ATM research, which was not always present in previous studies.

The ICARUS consortium was well balanced and possessed all the expertise needed to address this problem. It has defined the requirements affecting both a GNSS-based altimetry approach in terms of accuracy, precision, continuity and integrity of service, and the requirements applicable to a Digital Terrain Model, including ground obstacles, in terms of resolution and accuracy.

The involvement of the U-space community of UAS pilots, drone operators, UTM service providers and GA pilots, including those who were members of the Advisory Board, has enabled, through a dedicated web-based questionnaire, an assessment of the operational needs related to common altitude reference issues.

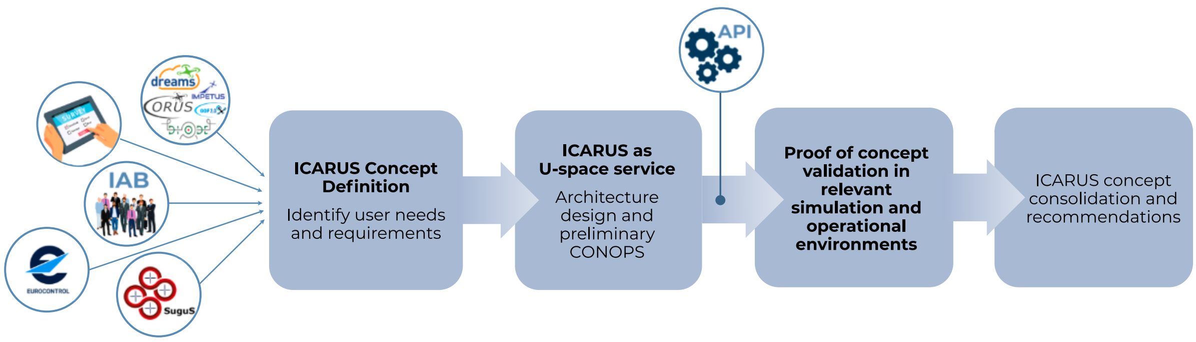
Five specific operational use cases of particular interest embodied the requirements identified, to highlight the ICARUS concept and its added value, and provided the information required to perform a preliminary safety assessment that was undertaken using state-of-the-art methodologies.

The main output of this phase of the project was an analysis of the requirements of the service envisaged by the project, the identification of gaps to be filled to implement the solution, and a preliminary safety assessment of the use-cases, including an analysis of compliance with current EU regulations.

ICARUS as a collection of U-space services

The specification of the ICARUS concept led to the definition and design of a prototype solution. In this phase, a system architecture of the service was developed, that considered the output of previous studies, with particular reference to the final architecture proposed by the CORUS project, to facilitate the integration of the ICARUS services into UTM/USSP implementations.

ICARUS METHODOLOGY



Development of simulated environment

To support the validation of the ICARUS services in the laboratory environment, the ICARUS team implemented a complete simulation of the system to perform preliminary tests.

Concept consolidation and recommendations

The project culminated with the collection and analysis of the data acquired during the validation campaign and the results achieved by the project. We presented the ICARUS concept and the conclusions of the study to the SESAR community and U-space / UTM stakeholders

ICARUS WORK PLAN

WP1 – Ethic requirements

WP2 – Project management

WP3 – ICARUS concept outline definition
- ICARUS concept definition
- Available digital terrain model data products
- Available precision height systems and frameworks
- ICARUS requirement analyses
- Gap analysis and gap filling
- Preliminary safety assessment and regulation compliance

WP4 – ICARUS service solution design and prototype
- ICARUS system and service architecture
- ICARUS system prototype
- ICARUS service preliminary CONOPS

WP5 – Development of simulated environment
- Platform and tablet app update
- Cockpit simulator
- Platform interface design and prototype

WP6 – Validation activities
- Validation scenario design
- Simulation trials execution
- Data analysis and results

WP7 –Exploitation and dissemination
- Cross-fertilisation with concurrent U-space projects
- Dissemination planning execution and review
- Communication planning execution and review
- Exploitation planning and business cases
- Lessons learnt, recommendations and best practices

VALIDATION ACTIVITIES

The primary aim of the validation phase of the project is the proof of the ICARUS concept through validating the functionality of the system in a real operational environment.

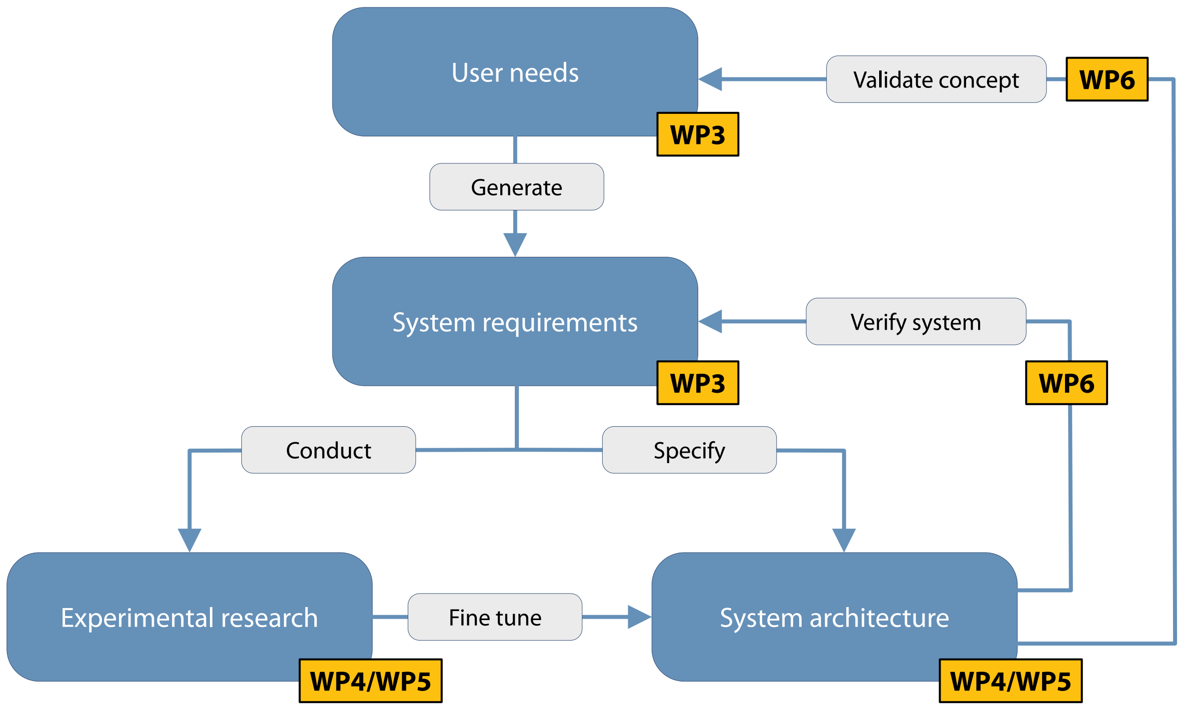
The concept validation followed a stepwise approach, starting with the initial requirements. During the verification and validation phase of the ICARUS project, several tests were performed to verify the requirements and the assumptions made in the first part of the project.

A second iteration of the requirements was performed at the end of the project to adjust the conditions that had not been verified previously and to adjust the performance of the system in operational conditions.

The diagram on the right-hand page shows the organisation of the information related to the verification and validation activities:

- **ICARUS requirements**: We defined five relevant use cases for ICARUS to support the requirements used to drive the design of the ICARUS micro-service architecture and the flight trials (both simulated and real).
- **Verification and validation plan**: We established test cases, procedures, and the naming conventions to be used during the validation exercises.
- **Validation scenario design**: We described each validation scenario design, with particular reference to the ICARUS micro-services that were queried during the validation campaign.
- **Operational activities and simulations**: We provided significant operational details in advance about the validation campaigns and the exercises that were conducted.

VERIFICATION AND VALIDATION ACTIVITIES



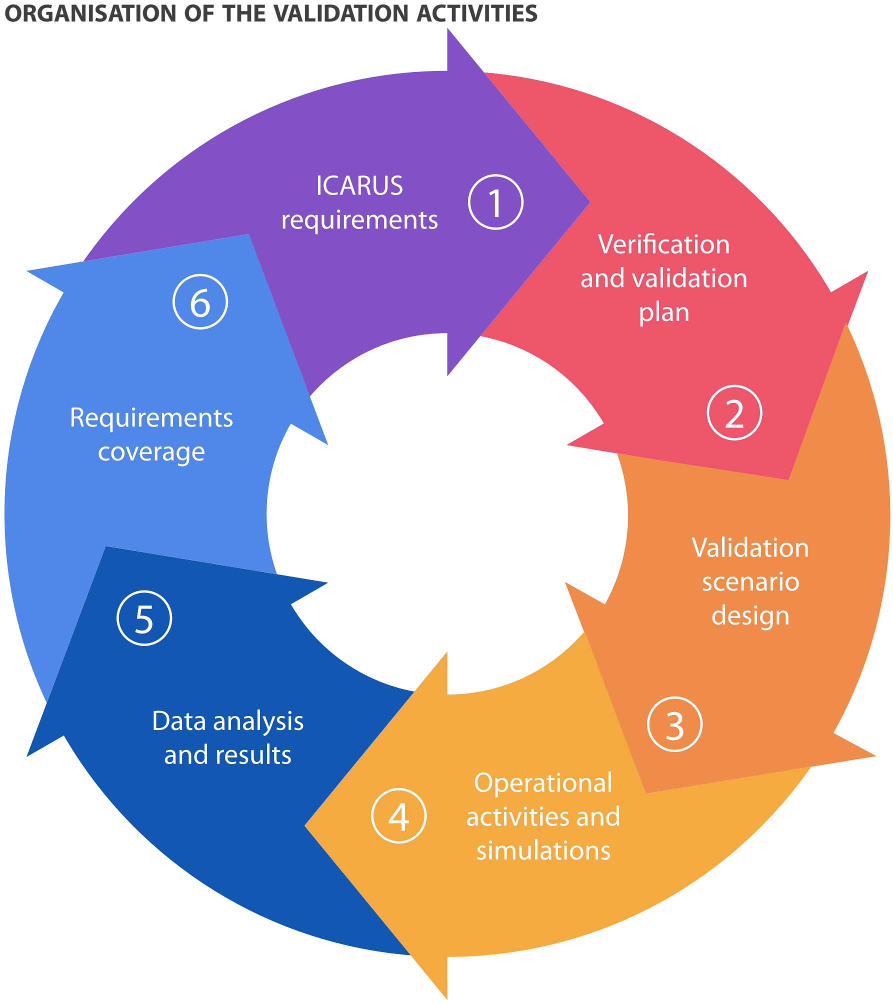
- **Data analysis and results**: We analysed all the data collected during the flights (simulated and real) to get the project results and recommendations.
- **Requirements coverage**: We performed an ultimate check of the coverage of the requirements defined at the start of the process, constructing a traceability matrix with additional comments and findings.

This methodological approach for the validation activities not only allowed the validation of the results of the project, but also provided recommendations for the U-space community.

We conducted preliminary tests in Poland and then performed an intensive validation campaign in Italy, involving actual flights and general aviation pilots.

The ICARUS concept has been proven and validated through a complete validation campaign in simulated and relevant operational environments

ORGANISATION OF THE VALIDATION ACTIVITIES



KEY PROJECT RESULTS

PROBLEM STATEMENT

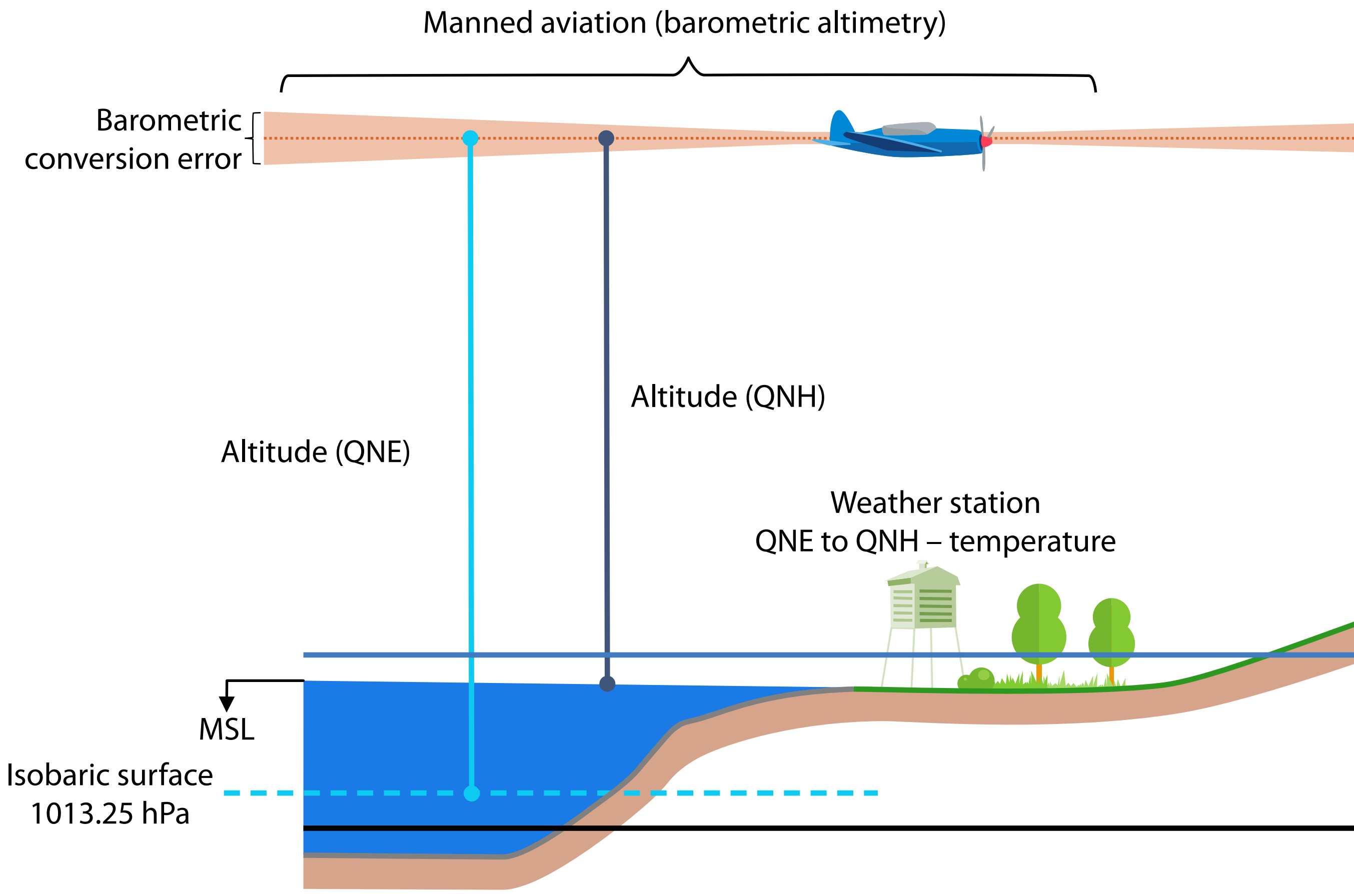
Aircraft use the ISA for defining, reporting and broadcasting vertical information. Above a locally specified "Transition Altitude", this altitude is expressed in Flight Level (FL) based on the QNE of 1013.2HPa at "0 feet". FLs can be used to maintain vertical separation since they refer to a particular standard isobaric surface. However, near the ground they present problems since they are not on the same reference as the real elevation of ground obstacles.

Below a locally specified "Transition Level", altitude is again calculated using the ISA, but based on either the pressure at the local airfield (where the aircraft will land) (QFE) or the regional value for the pressure at mean sea level (QNH). These values provide a reference compatible with ground obstacles and the runway.

Since all aircraft in the local airspace use the same QNE/QNH reference datums, these are adequate for achieving vertical separation of traffic.

UAS use ellipsoid-based altitude measurements from satellites. These can enable vertical separation of UAS/UAS traffic, and in combination with appropriate digital terrain or surface models (DTM/DSM), ground-obstacle avoidance. However, they are not compatible the barometric references that manned aviation traffic relies on.

To achieve interoperability and continuity of safe operation near or within manned aviation airspace, there is a need to deliver QNE/QNH-based altitude information to UAS users.



In other words, the ellipsoid altitude used for UAS mission planning and execution must be converted into pressure altitudes understood by manned aviation.

ICARUS provides the solution to these problems with a collection of services that:

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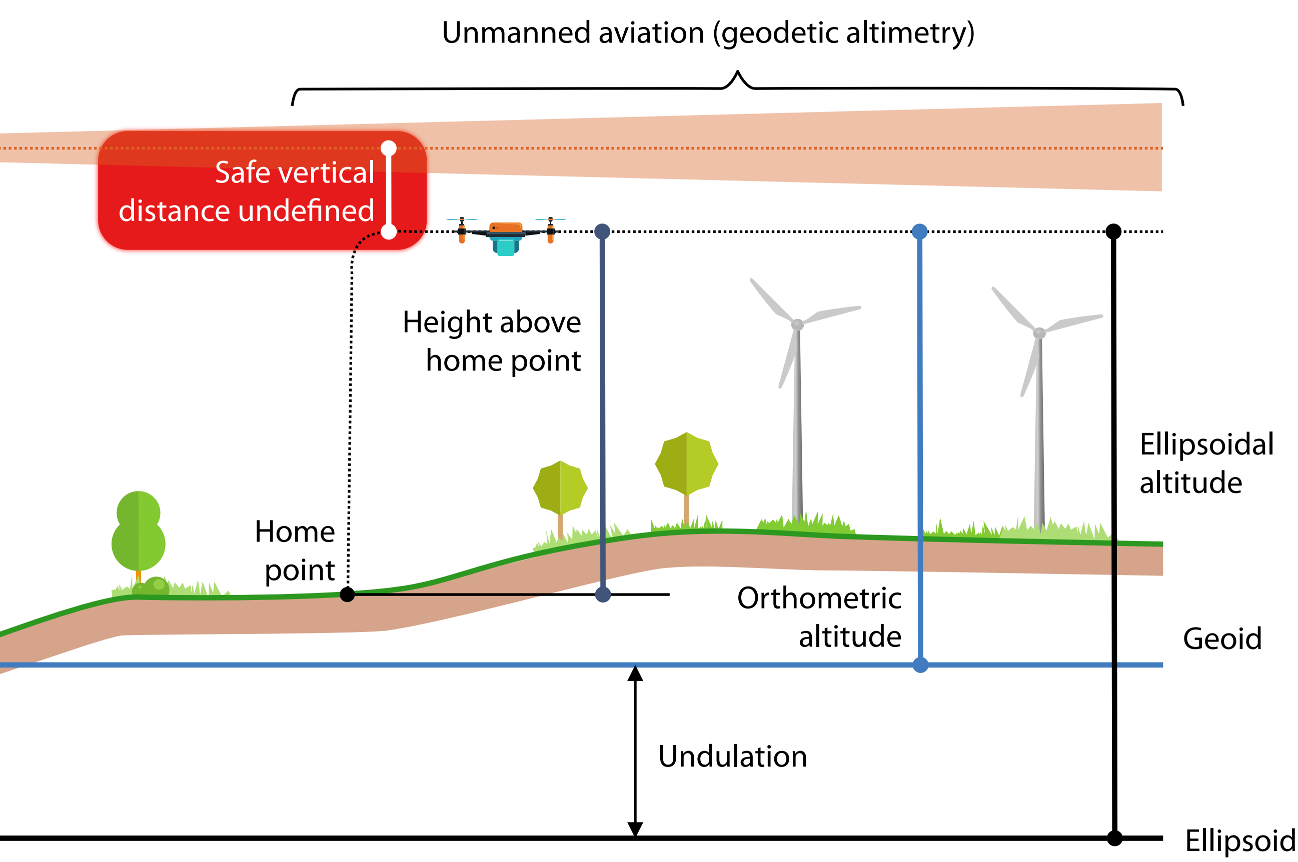
ICARUS provides the solution to these problems with a collection of services that:

- Introduces GNSS-based altitude measurement as a common vertical reference datum for UAS-RPAS
- Provides a tailored U-space service for ground obstacle mapping and terrain profile information
- Provides a two-way height-transformation service for between geodetic measurement and the barometric reference system

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



KEY PROJECT RESULTS

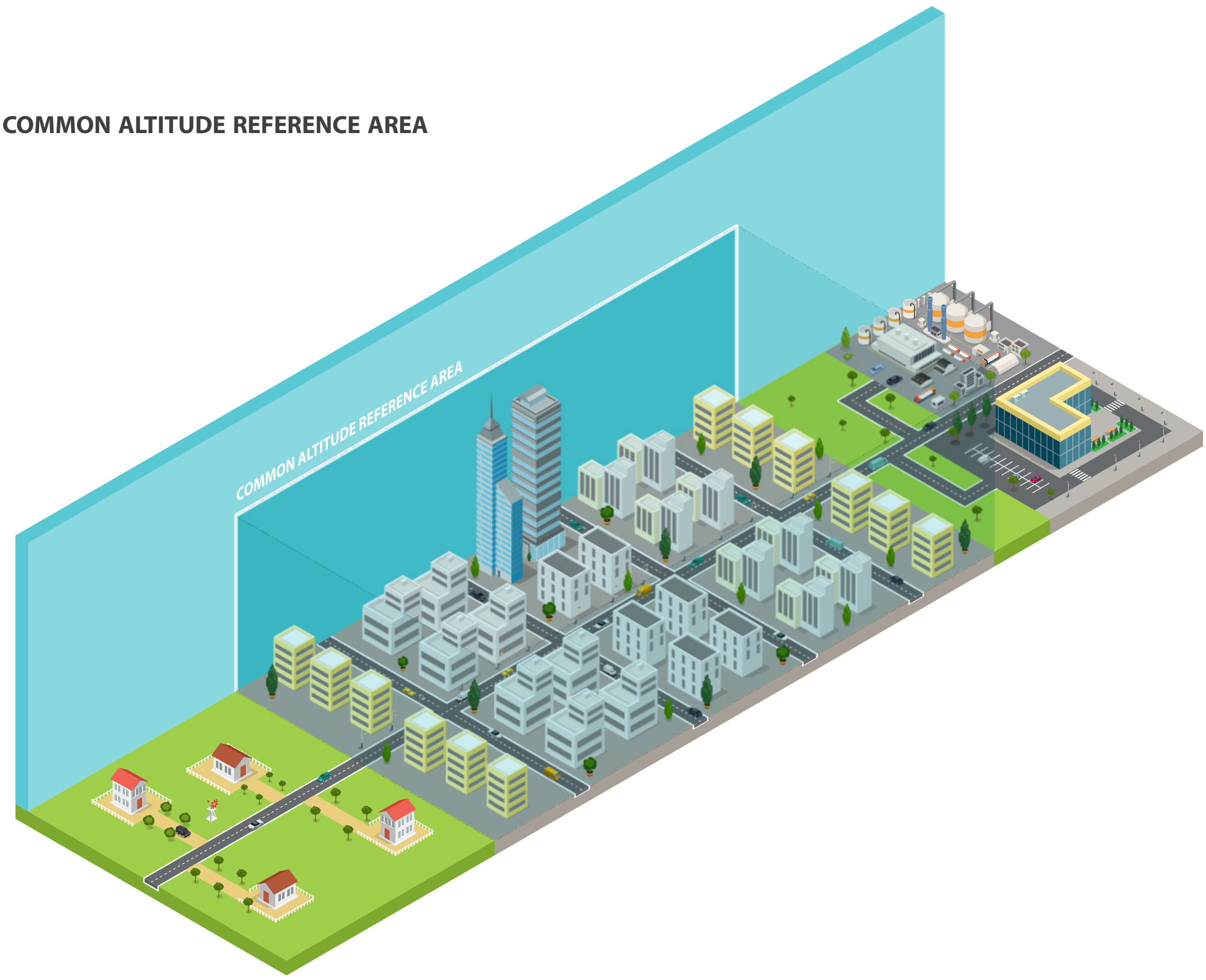
The ICARUS project has shown the feasibility of a CAR system for UAS based on WGS-84 that provides safe and reliable vertical UAS separation. In addition, the VALS and RGIS micro-services mitigate ground obstacle risk.

The Vertical Conversion Service translates barometric to geometric altitudes and vice versa. The project proposes that new areas of the airspace, called Common Altitude Reference Areas (CARA), be defined where the conversion service will be available to all users (not only drones) operating in this area.

The key project results are:

- A proposal for an error budget for vertical UAS-UAS distance (1σ) has been validated. This result can be used as a starting point for implementation of traffic schemas in future projects. The figures proposed are in line with other concurrent and independent studies (for example, by EUSPA). However, additional analysis of more complex routes and trajectories in UAM environments will be necessary.
- Operational environment and navigation performance in the vertical dimension: the outcomes of ICARUS suggest the creation of "corridors dedicated to UAS" inside U-space airspace (under EC Regulation 2021/664) that ensure a certain navigation performance, not only in the horizontal plane but also in the vertical one.

COMMON ALTITUDE REFERENCE AREA



- The Total System Error (TSE) calculated and verified on the field for both multi-rotors and airplanes will enable the establishment of the maximum number of vertical corridors (or layers) at VLL to increase the capacity of the airspace.
- For BVLOS operations, we recommend using the GNSS receiver altitude with WGS-84 datum as zero altitude in combination with the VALS service.
- For VLOS operations, we recommend UAS pilots use their take off point as their zero altitude with WGS-84 reference.
- To assess the acceptance of these recommendations, we propose to conduct a dedicated survey of UAS pilots.
- The navigation monitoring service should include CORS, Continuous Operating GNSS Reference Station for RTK correction to UAS

SUMMARY OF KEY PROJECT RESULTS

KPA	Comment
Safety	EUROCONTROL in 2018 highlighted the need for a Common Altitude Reference System (CARS) to ensure vertical separation between manned and unmanned aircraft at Very Low Level (VLL) airspace. The Project has developed new U-space services to implement the CARS and showed the improvement of the safety, based on Commission Regulation 2020/2034.
Security	The Project has defined the system architecture taking security issues 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 enhances the capacity in U-space airspace (for example over metropolitan areas), by enabling consistent vertical separation at VLL.
Predictability and punctuality	Positive impact envisaged for logistic drones at VLL in U-space airspace.
Cost efficiency	The solution is cost-efficient because a portable Electronic Flight Bag (EFB) on-board manned aircraft at VLL under VFR would enable to use the VCS and VALS services without the need to change the installed avionics (i.e. no retrofit necessary).
Flexibility	VALS would allow more flexible drone operations in proximity of obstacles.
Access	The new services developed by the project are listed in ISO 23629-12, a world-wide benchmark, that ensures service provisions anywhere.
Human performance	No adverse effect on human performance has been assessed during the simulations carried out by the Project.
Civil–military cooperation and coordination	Positive effect, since also MIL aircraft may also fly at VLL, and thus may benefit from VCS.
Cost–benefit analysis	Not carried out.

Common Altitude Reference Service (CARS)

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

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. All of the results are shown in the table of the next page.

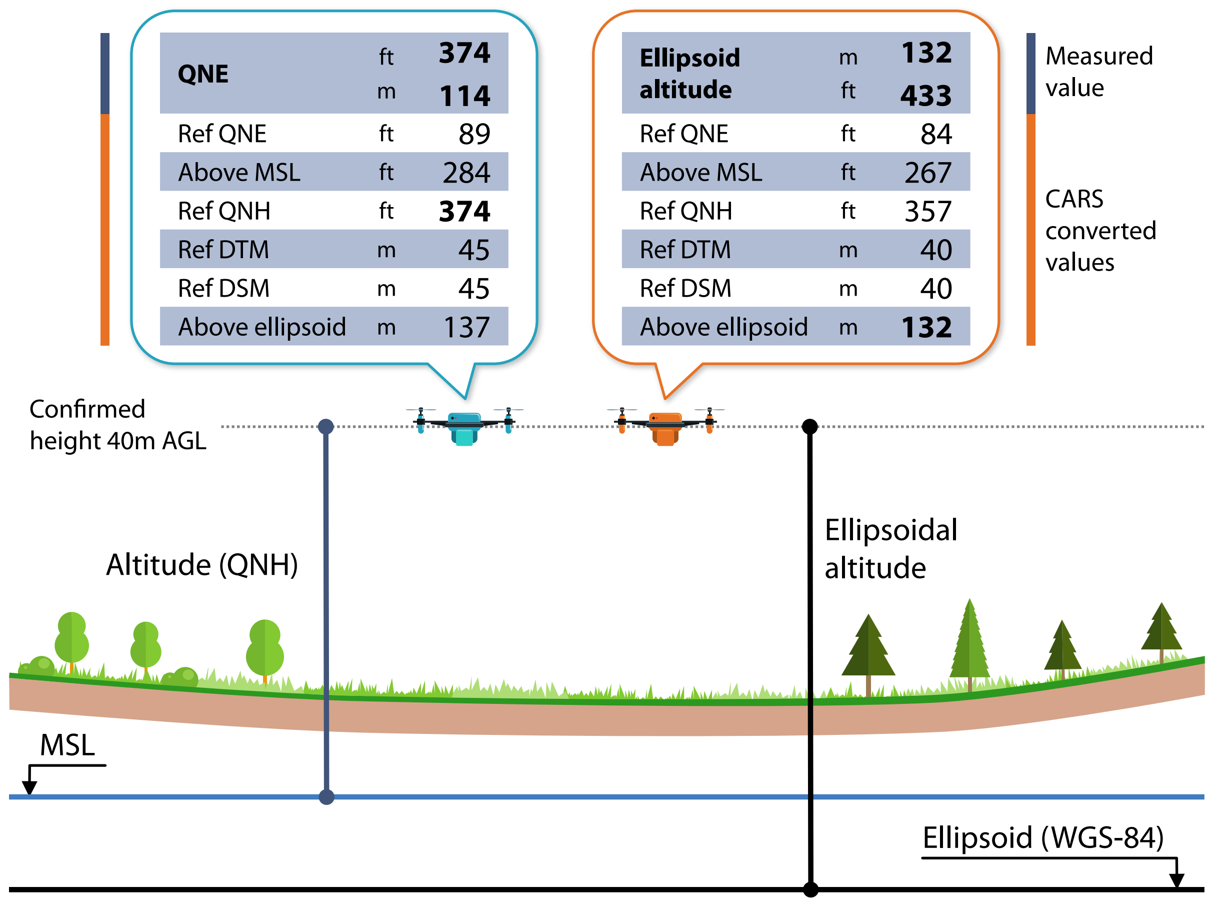
UAS test flight specifications

- Both UAS were been equipped with a calibrated RTK system to determine their exact height above the take-off point (AGL m)
- The blue UAS had an ADS-B transmitter with its own barometric sensor that gave the altitude relative to the standard pressure (QNE)
- The orange UAS has been equipped with a 3G / LTE tracker with its own GNSS system that provides the altitude relative to the WGS-84 Ellipsoid

Test results

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 process is performed with respect to every reference pattern.

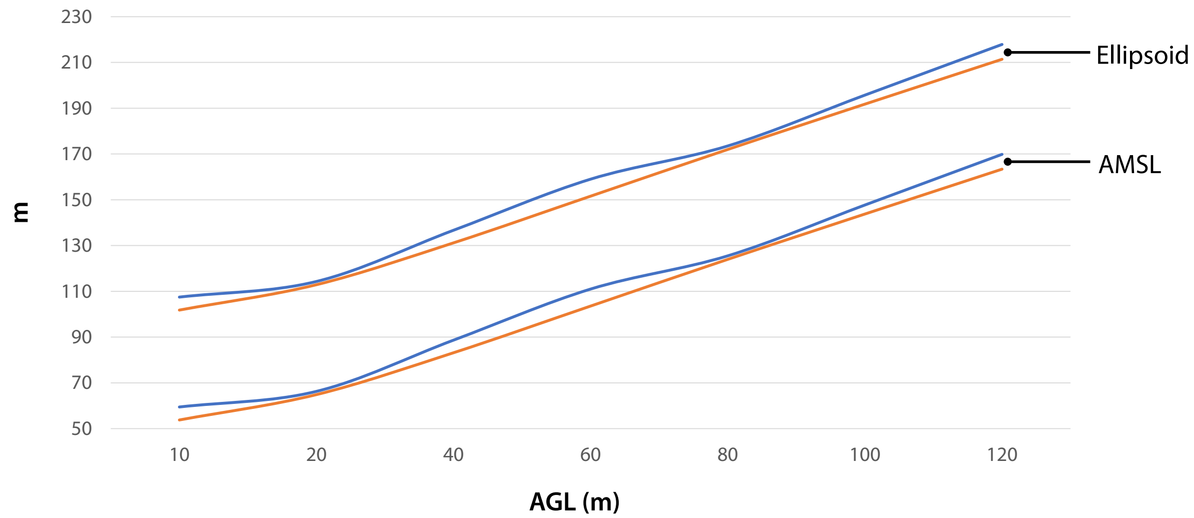
CARS TEST



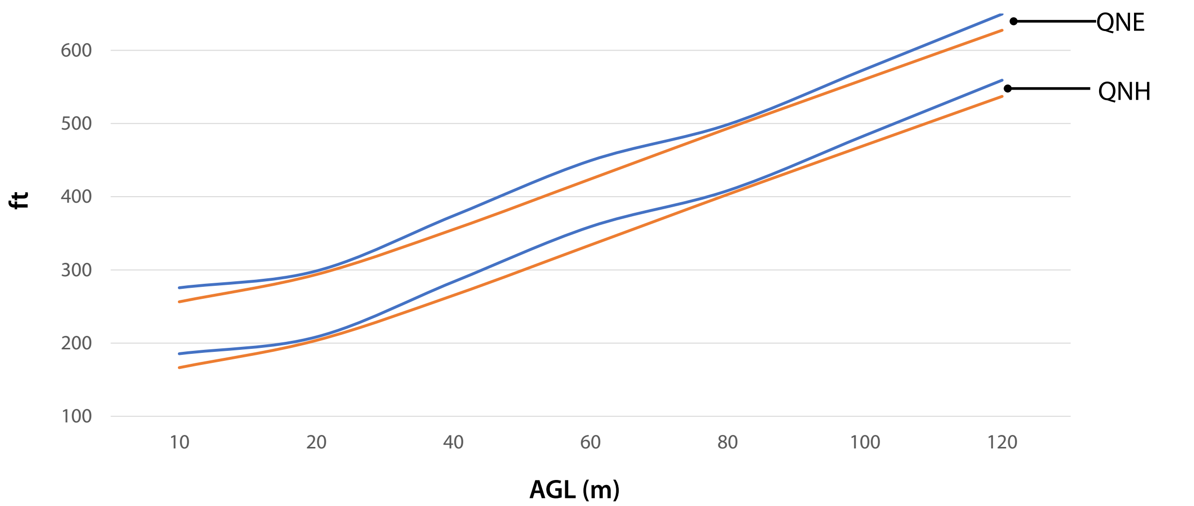
TEST RESULTS

	Blue UAS					Orange UAS				
AGL	AMSL	QNH	QNE	DTM	Ellipsoid	AMSL	QNH	QNE	DTM	Ellipsoid
m	m	ft	**ft**	m	**m**	m	ft	**ft**	m	**m**
10	60	185	**276**	16	**108**	54	166	**256**	10	**102**
20	66	208	**299**	22	**114**	65	204	**294**	21	**113**
40	89	284	**374**	45	**137**	83	265	**355**	39	**131**
60	111	359	**449**	67	**159**	104	334	**424**	60	**152**
80	126	408	**499**	82	**174**	124	403	**493**	80	**172**
100	148	484	**574**	104	**196**	144	470	**561**	100	**192**
120	170	559	**650**	126	**218**	163	537	**627**	120	**211**

CARS CONVERSION BAROMETRIC VS GNSS IN REFERENCE TO ELLIPSOID AND AMSL



CARS CONVERSION BAROMETRIC VS GNSS IN REFERENCE TO QNE AND QNH



Vertical alert service (VALS)

UAS traffic management (UTM) — Part 12: Requirements for UTM service providers ISO/DIS 23629-12 defines VALS as follows:

VALS alerts manned and unmanned aircraft on present vertical distance above the common geodetic reference system from ground, when such distance becomes too small.

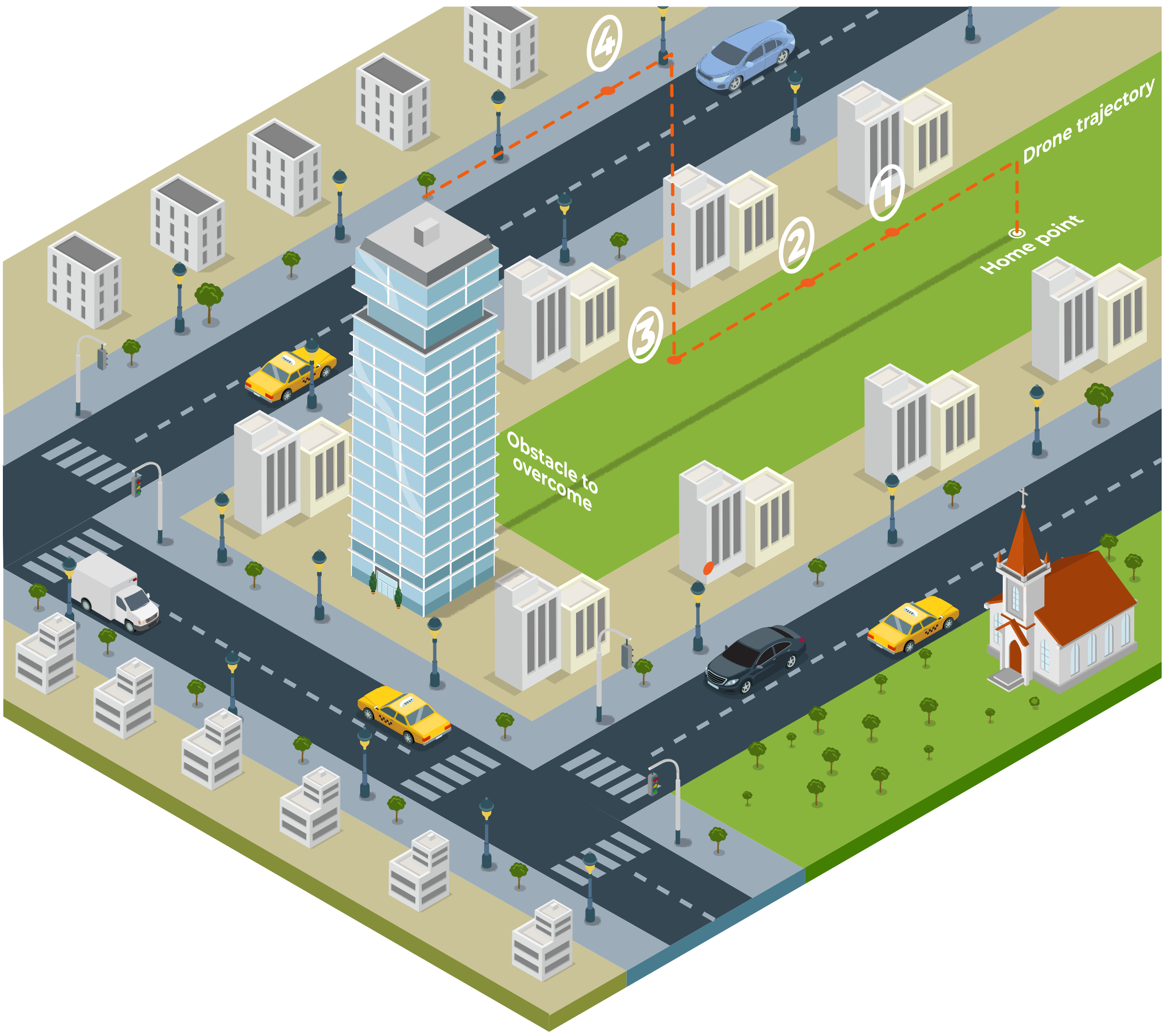
VALS is intended to alert the pilot to a possible collision with known earth surface and obstacles. The source of information about the surface is the DSM model (Digital Surface Model). The undoubted advantage of this solution is the fact that it works independently of current visibility (weather conditions). VALS calculates potential risk of collision in realtime.

It is worth to note that the performance of the VALS function depends on the accuracy of the DSM model. The more accurate the DSM model is, the more VALS will "see".

In the scenario depicted on the diagram below, the sequence of events is as follows:

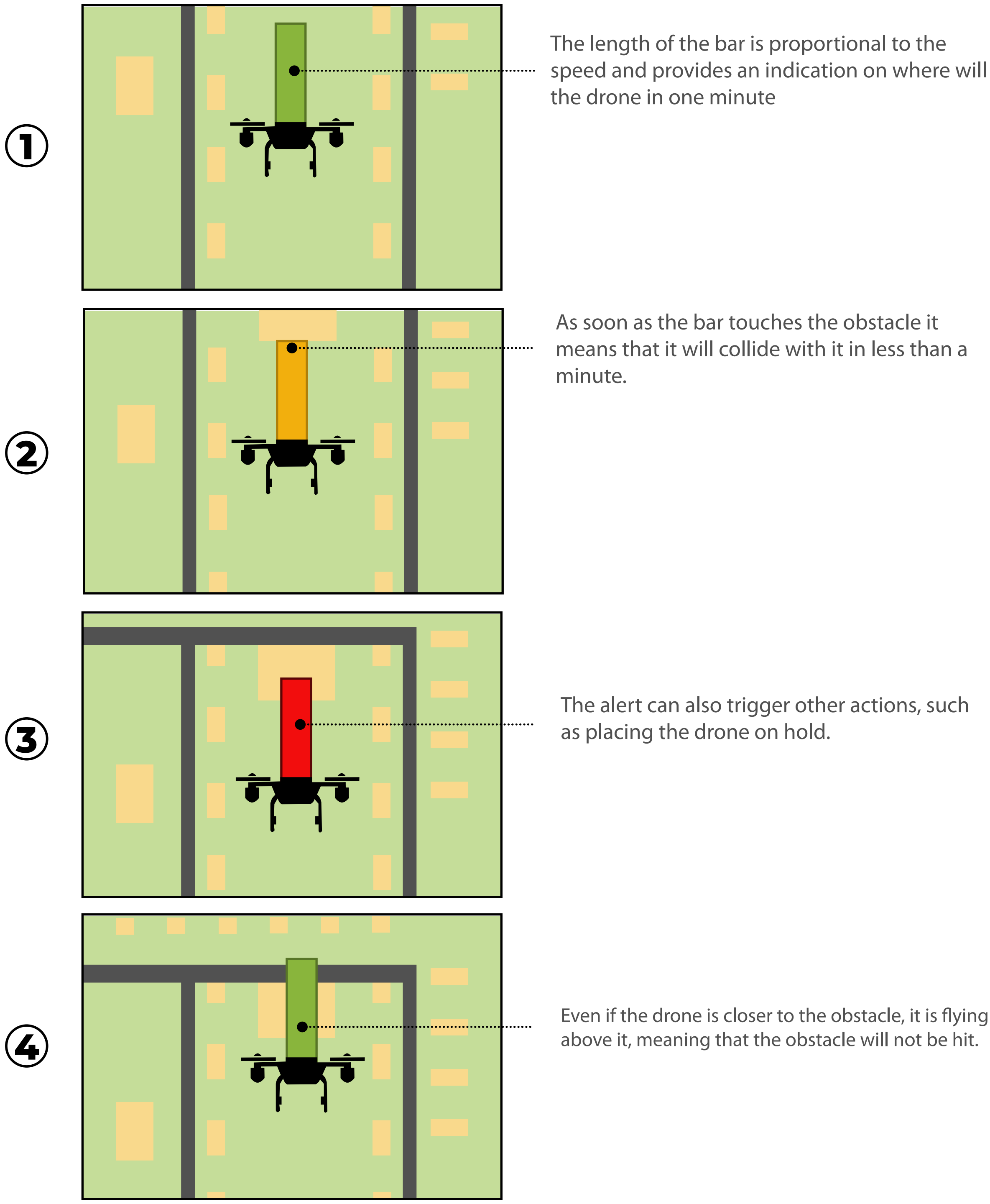
1. VALS is green when the vertical obstacle clearance is more than 5m for the next 60 seconds of flight with current velocity and direction.

THE VERTICAL ALERT SERVICE IN ACTION



2. VALS turns to orange, when the vertical obstacle clearance is between 0 and 5m for the next 60 seconds of flight with current velocity and direction.
3. VALS turns to red, when there is no obstacle clearance within next 60 seconds of flight with current velocity and direction.
4. When the pilot takes the appropriate reaction, such as slow down, change of the direction or, as in this case, climb, VALS in real time will inform when the risk of collision is gone, by changing the colour of VALS bar.

VERTICAL ALERT SERVICE USER INTERFACE



TECHNICAL DELIVERABLES

#	Deliverable
D3.1	**ICARUS concept definition: state-of-the-art, requirements, gap analysis**
	The main objective of WP3 was 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. The ICARUS concept is established in this document, an analysis of the state-of-the-art in height systems, digital terrain models (DTM) and geospatial products relevant to the problem is described, the requirements of the system/service are given, and a gap analysis of the components to be developed was detailed. This wide range analysis was a necessary input for prototyping the system/service.
D4.1	**Design and architecture of the ICARUS system & service**
	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 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
D4.2	**ICARUS Prototype**
	This document finalises and consolidates the design of ICARUS by describing the interfaces of the ICARUS services for each of the four ICARUS modules foreseen. The introduction gives an overview of the overall architecture, and clarifies the terminology to facilitate understanding of the description. The ICARUS prototype is the central player of the whole discussion. At a high level, this document shows how the prototype interacts with external entities, which can be of two types: data providers that act as data sources for the calculation, and service providers that are intended to be 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.
D4.3	**ICARUS Preliminary CONOPS**
	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**
	This document describes the functional architectures of the USSP (Droneradar), its integration interfaces with the ICARUS CARS system and specifies all the interfaces regarding the Weather Service Provider (WSP) and GI Service Provider (GISP) platforms.
D5.2	**Cockpit Simulator Architecture**
	The main purpose of this document is to present the architecture of the cockpit simulator used for the validation exercises in WP6. The cockpit simulator is an essential component of the ICARUS testbed as it gives general aviation (GA) pilots the opportunity 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.

#	Deliverable
D5.3	**D-Flight GNSS Augmentation ICD and Integration Test Report**
This document specifies all the interfaces regarding the GNSS micro-service. It describes the input and output interfaces that allow the necessary data to be retrieved to be upgraded with the outcomes of the Telespazio computing unit calculations. Moreover, the document describes the data flows regarding the GNSS micro-service through a series of use cases representative of its operations. Finally, it describes the test to be performed to test and verify the communication between the GNSS micro-service and the external sources of data (EDAS and Ground Reference Stations) and between the GNSS micro-service and the other ICARUS micro-services that need its calculation.	
D5.4	**ICARUS external Interface test and validation plan**
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	**Validation Scenario Design**
This document, together with D6.2, provides information about the design of scenarios used in validation activities and the related testbed including equipment, drones, components, USSPs interfaces that were used, as well as information about the verification of the requirements defined during the requirements analysis in document D3.1. The main objectives of D6.1 can be summarised as follows: – a suitable scenario identified for testing ICARUS services (use cases identified in D3.1); – a verification matrix of the requirements identified in D3.1 with particular attention to those requirements applicable to the validation activities; – the scenarios for validation activities to be performed with drones and manned flights in Italy and Poland; – verification activities related to the assessment of ICARUS concept accuracy identified.	
D6.2	**Simulation Trials Execution Plan**
The execution plan was defined for each validation scenario regardless of whether its execution was to be performed with real flight activities, simulated trials, or "mixed" trials in a mixed scenario. In this document, the execution plans for the verification trials are 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**
The main objectives of this document can be summarised as follows: – a report on 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; – coverage of the requirements defined in document D6.1 and any non-compliance / partial compliance and/or findings generated by the verification and validation activities reported on; – discussion of the lesson learned, the problems solved, and the new questions raised – a summary of the conclusions of ICARUS validation activities.	

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Conclusions on maturity of the SESAR solutions and supporting services and capabilities

From the point of view of the prototype made under the ICARUS project, we achieved very high level results. However, it should be remembered that the commercial implementation of the service, along with its certification, will still require large financial outlays.

Reaching TRL 7 (Model demonstration in an operational environment), will require the development of documentation, certification, and proven highly scalable data models and algorithms. Because of the need to launch many new services (RGIS, VCS, VALS and EMS), achieving certification will demand a long time and further investment.

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 realised by increasing the computing power, while horizontal development will be performed through the multiplication of server instances.

The VCS microservice developed and tested during the project is able to five heights/ altitudes provide in real time to the consumer of the service. Regional QNH is provided by certified sources.

In real-time systems, the weakest element determines the speed of the entire system. Therefore, during the development of the production system and the process of certification, the needs resulting from aviation safety will determine the requirements, technical or otherwise.

TECHNOLOGY READINESS LEVEL ACHIEVED BY THE PROJECT

1	Basic principles observed
2	**Technology concept formulated**
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment
6	Technology demonstrated in relevant environment
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment

However, to prevent unforeseen limitations arising during the operation of the system, it is necessary to define fall-back and contingency procedures (both technical and procedural) to inform all users about the limitations of the CARS system, specially operating within a CARA.

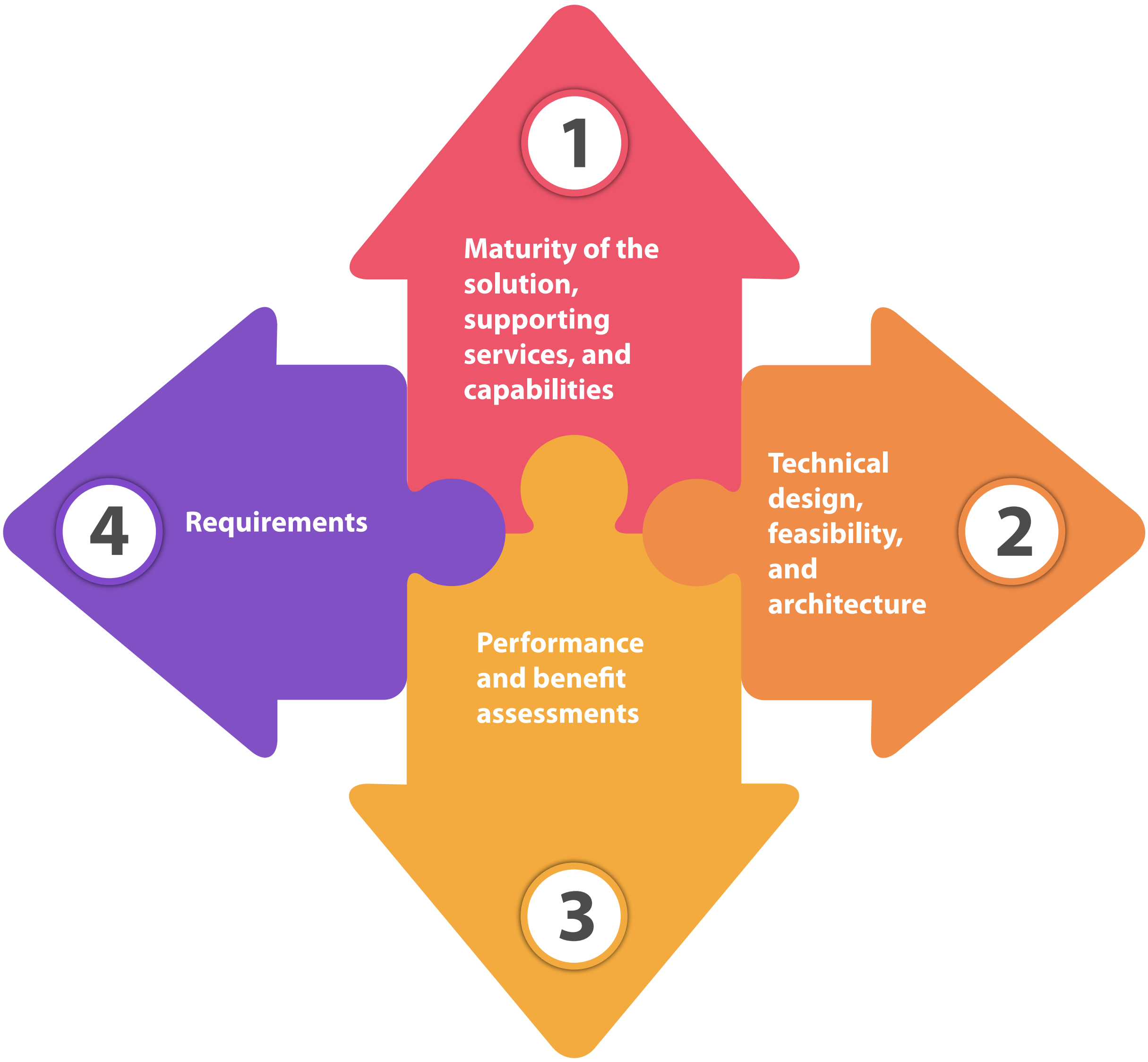
Conclusions on performance and benefit assessments

The performance of the system will depend on the number of aircraft present in a volume of airspace and 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 volume of space increases significantly.

Conclusions on requirements

After the validation activities were completed, we performed a requirement coverage exercise to analyse if the requirements had been met. The result of the exercise is that all the test cases had been successful, although in some cases the results were limited to the particular data sets used (and therefore the tests might have failed in other conditions.)

ICARUS CONCLUSIONS



RECOMMENDATIONS

Recommendations for updating U-space services and capability definitions

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

A number of recommendations are proposed based on the new or updated U- space micro-services shown in the table below.

Recommendations for updating the U-space architecture

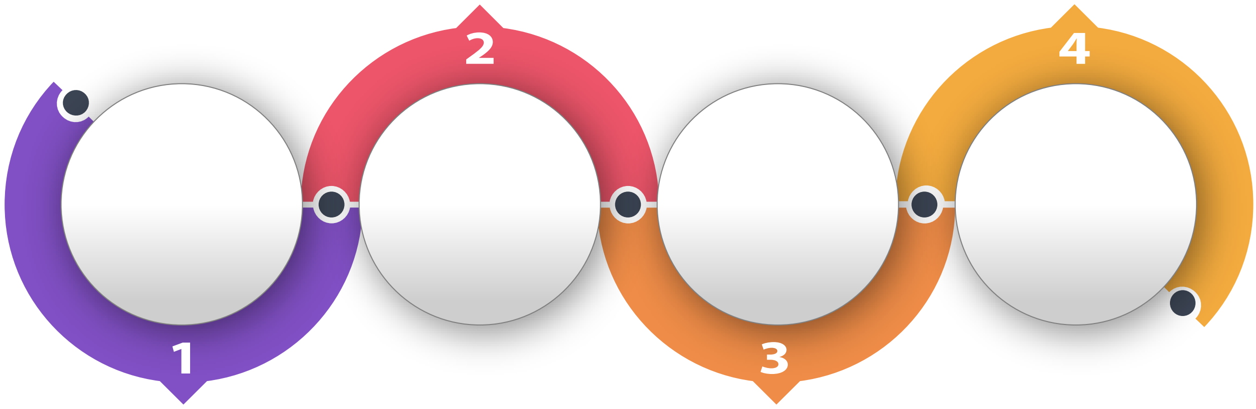
Standardisation of the use of (known) height/altitude reference system when distributing telemetry in UTM systems

During the ICARUS project, we discovered that there are major uncertainties in the GNSS chipset world. GNSS chipset manufacturers use various models for conversion between the ellipsoid to the AMSL geoid. To fit conversion tables in very small memory of chipsets, manufacturers simplify greatly. For example, generic undulation models used for automatic conversion may have relatively large errors (even dozens of metres in mountainous areas). More importantly, we have observed that there are cases where GNSS chipset manufacturers state they provide the height relative to the ellipsoid, whereas in practice they provide the height relative to the geoid

ICARUS SERVICES

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 height/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
Electromagnetic 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

ICARUS RECOMMENDATIONS



based on some unknown undulation model. As a result, there are potentially large technical errors. Hence, ultimately, it will be necessary to force the chipset manufacturers to provide two parameters in their service specifications: the reference and the conversion reference model used.

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

Each altitude presented may contain errors; for example, the altitude broadcast by ADS-B transponders has an altitude step of 25 ft. This means that they provide altitude in steps of 25 ft (or about 7.5 m). In manned aviation, this does not matter much, but in U-space, where less than 120 m is available, this error value may be significant. In GNSS, augmented systems like SBAS or GBAS (such as EGNOS) may provide correction values for known errors in an area and time. In addition, the computed error may include other errors, for instance, errors in system components, such as DSM approximations, earth temperature and pressure sensors.

Recommendations for elaboration of the U-space concept

The ICARUS services constitute a planning tool capable of converting the planning information of the mission to a common reference height (AGL). When designing the route, each actor can use their preferred system.

The WGS-84 datum in combination with the RGIS micro-service, that provides real time information on the distance to the ground, and the VALS micro-service, that provides real-time information of possible impact with ground in the next 60 seconds, are the envisaged datum for CARS for drones in BVLOS conditions. We recommend that UAS ground control stations display heights in relation to the home point for VLOS operations and altitude (WGS-84) for BVLOS operations.

Data provided by the CAR service should show whether it is measured, or if it results from a conversion.

To simplify the complexity of the system, the integrity of the information can also be provided by dissimilar technologies. For example, transponders equipped with barometers may cross check GNSS and barometric information and raise an integrity warning in case of discrepancies in the height measurements above a certain threshold.

Navigation integrity information is too complex to be calculated on-board small UAS. Ground services for ARAIM calculation could be an option.

When operating in Network Remote Identification, 6 seconds of buffering during telephone-cell handover is acceptable.

However, transponders may implement mechanisms to filter their position to mitigate frozen tracks as much as possible.

For vertical accuracy, only certain receiver configurations presented an acceptable accuracy on the vertical axis. High-end receivers in DFMC met this condition. For horizontal accuracy, this requirement was always met.

Small drones do not implement ARAIM techniques, although RAIM is still viable.

Navigation data fusion seems to be the most promising technique for integrity monitoring. U-space services for integrity calculation are still viable.

Drone operations cannot neglect Path Definition Error, unless very detailed

Recommendations for standardisation and regulation

The adoption of the CARA (Common Altitude Reference Area) concept 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:

- SERA enshrines the seven airspace classes (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). In principle, it could introduce CARA (Common Altitude Reference Area) as well.

- Furthermore, nothing in the current text of Article 15 of Commission Implementing Regulation 2019/947 prevents introducing a CARA.

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

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

- ISO 23629-12 includes the RGIS, VCS and VALS services introduced by the ICARUS project.

- EASA should establish an AMC referring to ISO 23629-12 to support oversight of U-space services, in particular for those that are not 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.

FUTURE WORK

The partners of the ICARUS consortium have identified a number of topics that will need to be addressed to finalise the ICARUS concept.

- Definition of the certification methods and standards for UAS Static Pressure Sensor calibration, especially in multi-rotors with estimation of the Total Error depending on phase of flight
- Insight into aerial pressure and temperature distribution to plan the required network of METEO sensors on the ground in different ground types: rural, and lightly and heavily urbanised
- Amendment of the general specification of the CARS telemetry service for exchanges between systems (USSP, CISP, etc.) within U-space. This will include strained references, errors, and all other necessary details
- Definition of UAS RVSM (Reduced Vertical Separation Minimum) areas with safe limits
- Perform a feasibility study to create a Network of Sensors in the AIR (NOSA) to reduce the Technical Error of CARA
- Provide further recommendations to known standardisation bodies and authorities (ICAO, EUROCAE, ISO, etc.) because of these research & development activities

ICARUS has demonstrated a CARS system that is suitable to unleash the future high-scale drone operations. To deploy it, further work is required

Definition of the certification methods and standards for UAS static pressure sensor calibration

Insight into aerial pressure and temperature distribution

Amendment of the CARS telemetry service specification

Definition of UAS Reduced Vertical Separation Minimum

Perform feasibility studio to create Network of Sensors in the Air (NOSA) to reduce the Technical Error

Provide further recommendations to standardisation bodies

Notes

Notes

Notes

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

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