Cockpit Simulator Architecture

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Copyright Statement

ICARUS

INTEGRATED COMMON ALTITUDE REFERENCE SYSTEM FOR U-SPACE

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Abstract

This document is ICARUS deliverable D5.2 "Cockpit simulator interface update & prototyping".

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.

The cockpit simulator is a CESSNA 172 1:1 scale cockpit available at TopView laboratories. This resource has been tailored by specific hardware (HW) and software (SW) developments allowing its full integration into the ICARUS testbed and into the Italian D-Flight USSP for real-time tracking.

The development has concentrated on a particular piece of electronic equipment, in the form of an electronic flight bag (EFB), placed inside the airplane's cockpit. This particular equipment provides the GA Pilot with information about the possible presence of drones near the flight (i.e. less than 5 NM) and their altitude with respect to that of the GA. The ICARUS services implemented are presented to the GA pilot in a very simple way through a simple and clear HMI panel. The information presented is the output of ICARUS service for the GA pilot.

On the other hand, the possibility for (autonomous) drones and drone pilots to have a full situational awareness of the surrounding environment, including clear information about the altitude of any possible interfering flight in VLL, is of great relevance. Through the USSP web interface or a tablet app available for drone pilots, it is possible to visualise the tracking data generated by the cockpit simulator flights, inside D-Flight USSP system. The tracking information presented by the cockpit simulator to the USSP interface is used by the ICARUS service with particular reference to the altimeter information, dispatching this information to drone pilots this time.

The final section of this document is dedicated to the specification of the interface control document (ICD) used for connecting the cockpit simulator to the D-Flight USSP and the ICARUS testbed.

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1 Introduction

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

In manned aviation, the methods for determining the altitude of an aircraft are based on pressure altitude difference measurements referenced to a common datum (e.g. QFE, QNH or ISA). UA flights add a new challenge, since a small drone may take off and land from almost everywhere, hence reducing the original significance of the QFE settings, introduced on behalf of manned pilots to display zero height on the altimeter at touchdown on the local runway. In fact, the possibility for n drones to take off at n different places would generate a series of n different QFEs corresponding to different ground pressure heights, the take-off “home points”. Therefore, for a large number of drones, new methodologies and procedures need to be put in place.

ICARUS proposes the use of GNSS receivers with suitable requirements for a vertical UAS-UAS common reference and the definition of a new U-space service (U3) for altitude transformation for a UAS - Manned aircraft common reference, tightly coupled with the interface of existing U-space services (Tracking, Flight Planning services, Navigation Infrastructure monitoring, etc.).

The terrain model information above the ellipsoid datum used in GNSS receivers, including ground obstacles information, is an important element that could be exploited by users of the ICARUS service, and is of particular interest for validation exercises. In fact the users of the ICARUS service are indeed remote pilots competent to fly in VLOS or BVLOS in the Specific category of UAS operations, ultralight and GA pilots who potentially share the same VLL airspace, and the drone itself, considering the increased level of automation and connectivity expected at U-level 3. For this reason, a specific tailoring of the cockpit simulator is also taken into account, for addressing the needs of this new category of user.

1.1 Applicable Reference material

The following documents are considered applicable reference material:

[1] Grant Agreement-894593-ICARUS
[2] ICARUS Consortium Agreement
[3] SESAR 2020 Exploratory Research Call H2020-SESAR-2019-2 (ER4), available at http://ec.europa.eu/research
[4] Project Handbook of SESAR 2020 Exploratory Research Call H2020-SESAR-2019-2 (ER4) (Programme Execution Guidance), edition 03.00.00, 14th March 2019
[5] D3.1 – ICARUS concept definition: state of the art, requirements, gap analysis
[6] D4.1 – Design and Architecture of the ICARUS system & service
[7] D5.1 – UTM Platform architecture
[8] D5.4 – External I/F test
[9] D-Flight USSP ICD - https://www.d-flight.it/new_portal/2021/06/24/nasce-il-manifesto-per-lo-spazio-aereo-dei-droni-d-flight-in-campo-per-il-decollo-del-settore/

1.2 Acronyms

Acronyms	Signification
BVLOS	Beyond Visual Line of Sight
CARS	Common Altitude Reference System
DTM	Digital Terrain Model
E2E	End to End
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European Global Navigation Satellite System
GA	General Aviation
GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
ISA	International Standard Atmosphere
MCMF	Multi Constellation Multi Frequency
QFE	Query Field Elevation
QNH	Query Nautical Height
RGIS	Real Time Geographical Information Service
RNP	Required Navigation Performance
SBAS	Satellite Based Augmentation System
VALS	Vertical Alert Service
VCS	Vertical Conversion Service
VLL	Very-Low-Level
IPT	Integrated Procedures Trainer
FTD	Flight Training Device

Table 1-1 – Acronyms list

2 Cockpit Simulator

The Easy Flight© cockpit simulator is a static flight simulator used as Integrated Procedure Trainer (IPT) and a Flight Training Device (FTD). It is capable of simulating the flight controls, physical characteristics and the performance of a single-engine aircraft of general aviation or ultralight category.

The EasyFlight© system features a real 1:1 scale cockpit; it is used to faithfully emulate the aircraft physics with the original cockpit controls and instrumentation replica. In fact, it replicates the internal environment of a Cessna 172 Skyhawk with the same dimensions. The control panel has been created by combining instruments emulated with multi-touch screens and dedicated controllers, thus allowing the pilot to improve his skills with an outstanding level of realism, the details achieved comparing well with those of a real flight experience.

Figure 2-1 – existing Cockpit Simulator main panel

The actual configuration of the cockpit simulator returns a feeling of great realism, making this simulator an extremely valid and versatile platform that can be used for different purposes that include, but are not limited to:

- ✓ Use of the simulator as a platform for the validation of other aeronautical systems that interact with the flight, with the pilot and / or the aircraft itself;
- ✓ Training sessions for student pilots who are close to their first solo flight;

- ✓ Simulation and training of a real mission with high level of realism and ground details, before real flight operations;
- ✓ IFR training sessions, with the possibility of performing SID/STAR/ILS/VOR/NDB procedures and other phases of instrumental flight;
- ✓ Educational and teaching activities for students from aeronautical academy and flight schools (ATOs) for practical flight experience about the syllabus learned during theoretical lessons;
- ✓ Testbed for experimental activity, including the imminent testing of the Common Altitude Reference System with the help of electronic flight bag devices.

Figure 2-2 –IFR training Session (left); GA pilots invited cockpit simulator qualification (right)

2.1 Core Engine (FSS)

The main core engine used as flight simulator is a comprehensive and powerful flight simulator software (FSS) for personal computers and it offers the most realistic flight model available.

FSS is an engineering tool that can be used to predict the flying qualities of fixed- and rotary-wing aircraft with incredible accuracy. Indeed, it is a great tool for pilots to keep up their currency in a simulator that flies like the real plane, for engineers to predict how a new airplane will fly, and for aviation enthusiasts to explore the world of aircraft flight dynamics.

With this tool, the world of props, jets, single and multi-engine airplanes, as well as gliders, helicopters and VTOLs can be easily explored, also considering upcoming drone taxi applications. Additionally, through Software API, it is possible to Design and use a specific Airplane, Helicopter or VTOL model. For ICARUS scenarios, a specific VTOL Drone Taxi model will be used.

Figure 2-3 – Illustrating the forces acting on a Baron 58

The FSS scenery package covers all the Earth, moreover it is able to create custom airports or custom scenery, customize a local airport, customize the air traffic control flow at an airport. Vertiports could be also generated.

Weather is variable and customizable from clear skies and high visibility to thunderstorms with controllable wind, wind shear, turbulence, and micro bursts. Moreover, Actual weather conditions can be downloaded from the Internet, allowing users pilots to fly in the weather that really exists at their current location.

FSS has detailed failure modeling, with multitudes of systems that can either be failed manually at the instructor's command, or randomly when users least expect it. Users can fail instruments, engines, flight controls, control cables, antennae, landing gear, or any of dozens of other systems at any moment.

Figure 2-4 –VR cabin (implemented via software) in Flight Simulator software

2.2 Hardware

The hardware configuration of the Easy Flight© cockpit simulator, available at TopView laboratories is presented In the following paragraphs.

2.2.1 Yokes integrated

A yoke consists of a steering wheel-like control that rotates left and right and also slides back and forth. These are the best option for users primarily interested in flying older-style general aviation planes, business jets, and non-Airbus airliners, since these planes are flown with yokes in reality.

Easy Flight Cockpit integrates two 'Yoko, The Yoke', a double travelling range Yoke, for most precision and accuracy with a solid aeronautical feel, for pitch and ailerons axis control. One is mounted on the right seat and one on the left seat. Custom plug-in SW has been developed to give to the users / instructor the possibility to give controls of the airplane to either the left or right yoke.

Main characteristics and specifications:

- ✓ Double longitudinal course (144 mm)
- ✓ Linear ball guide technology that offers you extra-smooth touch
- ✓ Dumbbell with aluminium alignment
- ✓ Two types of holding mechanism: using 4 lower M6 hollows or via a lower sergeant
- ✓ 6 programmable buttons, of which 4 belong to 2 tilting switches vertical and horizontal trim functions
- ✓ USB connectivity
- ✓ Ultra-resistant, heavy duty range. Construction 90% metallic
- ✓ The force applied to move them is similar to that of real controls

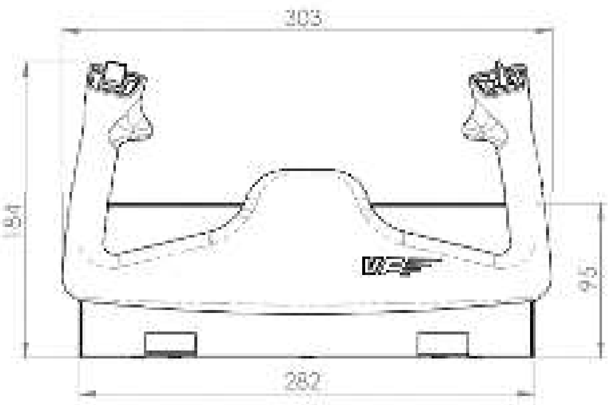

Figure 2-5 – Yoko, The Yoke front view (left); Yoko, The Yoke cutout (right)

2.2.2 Rudder Pedals

Rudder pedals allow users to realistically control the airplane's yaw by pushing the left or right pedal to turn. While in flight, the pedals control the rudder, whereas on the ground they're used to steer. The pedals also control the differential brakes to help the airplane stop or turn sharply while on the ground. (Push the top of the left or right pedal to activate the brakes on that side of the plane.)

The Easy Flight cockpit integrates two Cessna style Flight Rudder Pedals that add precise rudder and braking control. One is mounted on the right seat and one on the left seat.

Physical specifications:

Rudder Pedals (not including heel rests):

- ✓ Length: 31 cm
- ✓ Width: 40.3 cm
- ✓ Height: 16.8 cm
- ✓ Weight 2350 g

Figure 2-6 – Pro Flight Cessna® style Rudder Pedals main features

2.2.3 TPM (Throttle/Prop/Mixture) Integrated

The Easy Flight cockpit integrates a Cessna style TPM System, a trio of durable aluminium rods to smoothly adjust throttle, propeller, and fuel mixture levels. The integrated TPM is precise and smooth in both directions and each push-pull lever provides accurate control over the aircraft. All three levers, replete with color-coded handles, administer accurate travel distances to further enhance realism.

Main features and specifications:

- ✓ 3 Push/Pull Vernier-Style Levers Replicate the Feel of Popular GA Aircraft
- ✓ Aluminium Shafts with Realistic and Accurate Travel for Precise Adjustments
- ✓ Additional Switches Deliver More In-Sim Options

Figure 2-7 – Pro Flight Cessna® TPM integrated in Easy Flight main panel

2.2.4 BENDIX KING style avionics set

The BENDIX KING style avionics set integrated into the Easy Flight cockpit is a set of seven Bendix King style radio/modules that replicate a full avionics set as found in general aviation airplane panels.

The modules included in the set are:

- ✓ 2 x COM/NAV radio module
- ✓ 1 x Audio panel
- ✓ 1 x DME radio module
- ✓ 1 x ADF radio module
- ✓ 1 x ATC radio module
- ✓ 1 x Autopilot module

Figure 2-8 – Bendix King style avionics set integrated in Easy Flight main panel

The seven modules have been daisy chained with a 10 pin connector on flat cable to a central Interface module (CIM) that is needed to connect the instruments to the main Easy Flight computer. The CIM can hold 4 strings of modules. Each string can have up to 16 modules connected, so a total of 64 modules can be attached. The interface is powered by a compact power supply and runs on 5/12 v.

2.2.4.1 COM/NAV Radio module

The BK COM/NAV module is a replica of the Bendix King KX 155A and is equipped with two modules for NAV and COM. Each of them is fully equipped with a dual display, standby and active frequency buttons, dual frequency dials, volume knobs and channel and nav select buttons.

<u>Physical characteristics:</u>

- ✓ height 52 mm
- ✓ width 160 mm
- ✓ depth 23,5 mm
- ✓ mounting 2 screws

Figure 2-9 – Bendix King KX 155A style COM/NAV Radio module

2.2.4.2 AUDIO Panel

The BK AUDIO PANEL closely mimics to the original Bendix King audio panel. The green switch LEDs easily identify which receivers are selected. The module will connect through daisy chain directly with other modules to the central interface. The module also has functional OMI lights.

Figure 2-10 – BK Audio Panel (left); BK Audio Panel cutout (right)

2.2.4.3 DME Radio module

The distance measuring equipment (DME) unit has two concentric frequency selection knobs. The dialed in frequency will display the distance the plane is from the VOR.

Figure 2-11 – BK DME Radio module

2.2.4.4 ADF Radio module

The BK ADF is a replica of the Bendix King ADF radio module that is used to tune in the ADF frequency.

The ADF radio can be set to any ADF frequency in the provided software. The radio has a set of LEDs, one for the active frequency and one for the standby frequency.

The radio module can display either FLT (Flight Time) or ET (Elapsed Time) mode depending on which button was selected. The frequency is tuned in using a dual rotary encoder.

Physical characteristics:

- ✓ height 34 mm
- ✓ width 160 mm
- ✓ depth 24,5 mm
- ✓ mounting 2 screws

Figure 2-12 – Bendix King style ADF Radio module

2.2.4.5 BK style ATC Radio module (Transponder)

The BK ATC is a replica of the Bendix King KT 76C radio module that is used to set a transponder code. The default COM radio can be set to any code for startup (1200, 7777, etc.) in the software provided.

The radio has 2 sets of displays, one for the active frequency and one for the standby frequency. These are set using a dual rotary encoder.

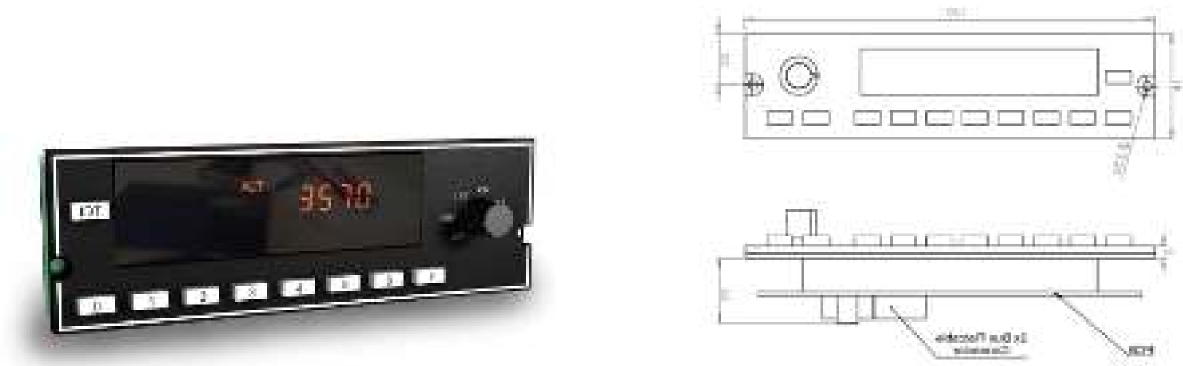

Figure 2-13 – BK ATC Radio module (left); BK ATC Radio module cutout (right)

2.2.4.6 Bendix King Style Autopilot module

The BK Autopilot is based on the KAP 140 manufactured by Bendix King. It has indicators for pitch axis and roll axis, an autopilot engage/disengage button, selector buttons for the heading mode, alt mode, navigation mode, approach mode, back course approach, vertical trim, and rotary knobs for the altitude setting and autopilot barometric setting. This module is made for certified simulators and works as the real KAP-140.

Physical characteristics:

- height 41 mm
- width 160 mm
- depth 27,5 mm
- mounting 2 screws

Figure 2-14 – Bendix King style Autopilot module

2.2.5 GNS 530

The EasyFlight© cockpit is equipped with a high quality and ultra-realistic GNS530 replica. The GN530 used matches as closely as possible to the real thing, including ultra-realistic silicone buttons and knobs. It is the best way to learn the functionality of the Garmin 530, much more realistic than using the mouse or a touch screen.

Main item features:

- ✓ Fully functional knobs and tactile silicone buttons
- ✓ replicated feel and function of the Garmin 530 knobs and buttons, allowing user to learn how to easily navigate the menu system, load a flight plan or approach procedures
- ✓ Change comm radio frequencies quickly and easily
- ✓ GN530 replica allows for the development of muscle memory and improves proficiency needed for instrument flying

This item is especially helpful for learning and practicing instrument flying procedures. When coupled with virtual ATC like *PilotEdge* or *VatSIM*, this provides the most realistic simulation possible. This allows student users to develop familiarity with the Garmin 530 interface and controls so they can be better prepared for actual lessons.

This unit features its own 5" LCD screen that is used to display the Garmin 530 pop out screen from the flight simulator software. It is integrated into the cockpit using USB and HDMI connection to the main computer, plus a 220v power supply.

2.2.6 GNS 430

In addition to GNS530, the EasyFlight© cockpit in equipped with a Garmin GNS430 high-quality replica that provides ultra-realistic buttons and knobs for use with the 430 GPS Nav/Comm simulator software. This is the best way to learn the functionality of the Garmin 430 and is much more realistic than using the mouse or a touch screen. The GNS430 features its own 3.5" LCD screen that is used to display the Garmin 430 pop out screen from the main flight simulator.

Figure 2-15 – GNS530 and GNS430 replica integrated in EasyFlight Cockpit main panel

2.2.7 Switch panel with starter

As in a real Cessna 172, there is the switch panel with the starter switch placed under the left seat yoke. The switch buttons for lights, fuel pump, the generator and battery are faithfully reproduced like the real ones, as well as the double starter switch of the double avionics bus.

All the fuse buttons (in reality intended for fuses) in this panel are assigned to the corresponding fuse as in real life. The starter switches are equipped with a steel spring that ensures the return from the start position.

The peripheral is connected to main computer and flight simulator software through the use of an Arduino Mega2560 board.

The panel is made of 3mm acrylic and all switches and buttons are functional, independent of each other and illuminated for best view in a dark cockpit environment.

Figure 2-16 – Switch panel with starter and fuses

2.2.8 Wing Flap gauge

Flap extension is controlled by the wing flap gauge peripheral replica of the real mechanism of the Cessna C 172. It is equipped with a servo motor that controls the position indicator of flaps extent status.

The peripheral is connected to main computer and flight simulator software through the use of an Arduino Mega2560 board. The product is made of PL and aluminium. The faceplate is made of 3mm acrylic.

Figure 2-17 – Wings Flaps gauge with position indicator

3 Architecture

The internal architecture of the cockpit simulator consists of the following main subsystems:

- **Cockpit Section**
- **Visual System**
- **Audio environment**
- **Local Instructor Operating Station**
- **Simulation Software (ICARUS tailoring)**
- **EFB (ICARUS tailoring)**
- **VTL for UAM (ICARUS tailoring)**

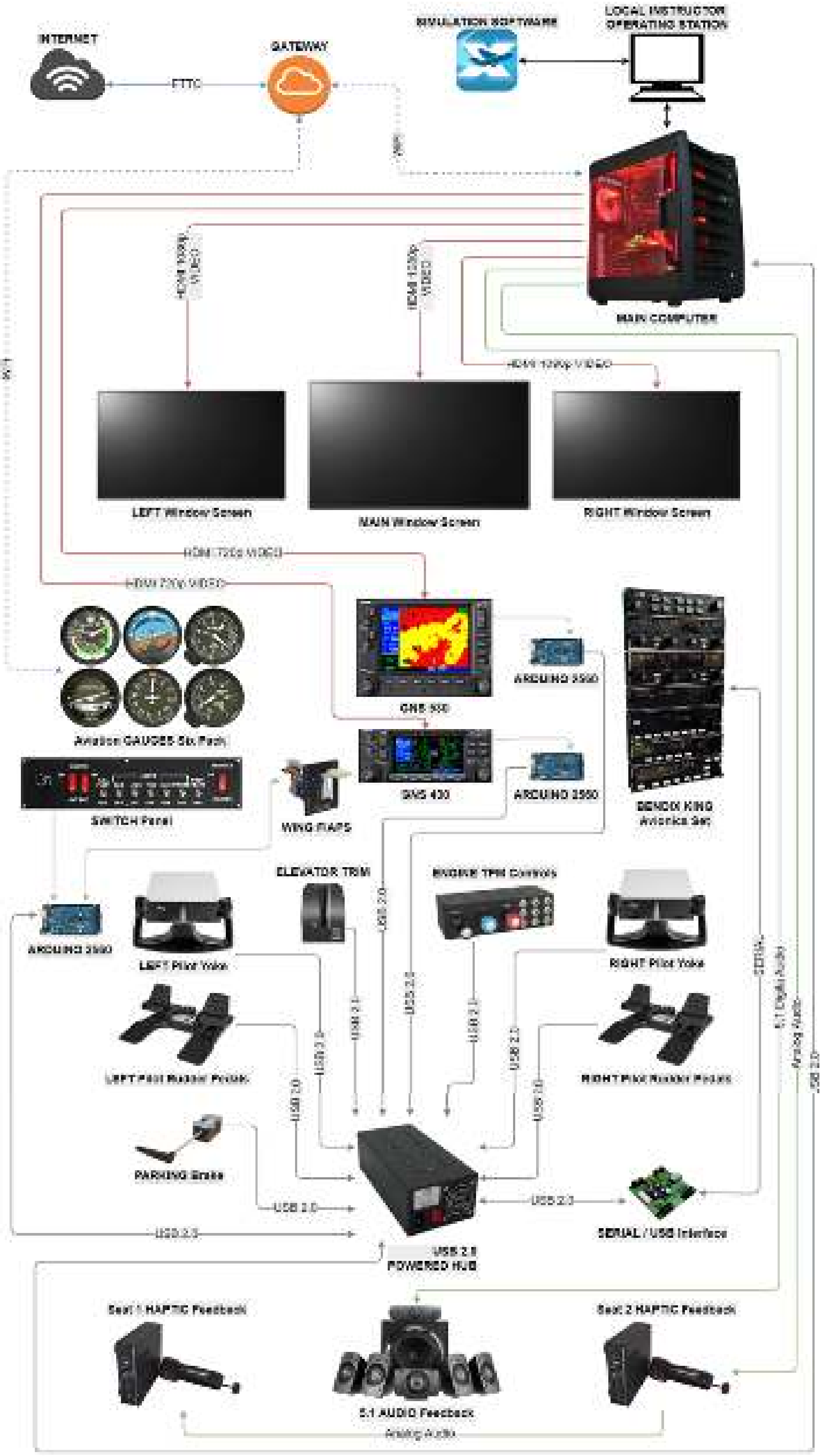

Figure 3-1 – EasyFlight© Cockpit Architecture

3.1 Cockpit Section

The cockpit section reproduces the Cessna 172 cabin, with its characteristic dimensions and equipment (i.e. control panels, instrumentation, throttles, etc.) allowing to interact, during the flight, with the environmental conditions and the aircraft itself, that provides the pilot with consistent indications. The cockpit features a seat shaker system integrated with the front seats (first and second pilot) that, in synergy with the audio environment, is able to emulate and transmit the vibrations of the engine and small shaking (shocks waves, buffeting etc.) to the pilots.

Figure 3-2 –Cockpit Simulator main panel and instruments

3.2 Visual System

The visual System undertakes the simulation of the windshield and the side windows of the cockpit, showing the external environment, in a synchronized way, with a configurable level of detail. Although the importance of the level of detail of the simulated environment is directly linked to the type of training that the pilot is about to accomplish with the simulator, an essential part of the flight simulation is the generation and visualisation of the world outside the cockpit. Even in this case a determined horizon of several nautical miles can be configured for the generation of details and animation of bots driven by AI (cars, other airplanes, people, etc.).

The visual system of the cockpit simulator is fed directly by:

- OSM (Open Street Map), a data source from which the terrain and objects / obstacles information to be simulated and regenerated in 3D (roads, infrastructures, buildings, etc.) are obtained;
- BING Maps High Res Imagery, the data source from which rectified orthogonal aerial images in high resolution are found (from 50 cm to 1 metre per pixel);

Through the following system:

- DVS (Direct View System), a complex set of hardware devices to render perspective, simulating the windshield and the side windows of the cabin projecting a FOV (Field of View) up to 180 °, ensuring that the pilot has the feeling of actually being inside the real aircraft.

Figure 3-3 –Cockpit Simulator during a training session

3.3 Audio environment system

The audio environment is the system dedicated to the reproduction of the typical airplane sounds and noises with particular reference to the main single engine. Such a system helps the pilot to get a complete feeling of the behaviour of the aircraft. In fact, during a simulated failure (engine breakdown, bird-strike, etc.) or particular flight conditions ascribed to the weather (rain, wind, shock waves, buffeting, etc.), the correct sound feedback helps produce immersion near to real operating conditions that the pilot could encounter during the flight.

To achieve a high level of simulator fidelity and meet the training needs of procedures and communications, there is also another essential element, the ATC (Air Traffic Control) audio system, that can simulate voice communications with other pilots and air traffic controllers.

The audio signal is also used for producing a haptic (felt) feedback to the pilot during the flight simulation. This is possible thanks to a special 'subwoofer' that, unlike subwoofer that moves air (and loses accuracy and force), it moves actual mass producing a haptic immersion that's powerful and accurate.

Figure 3-4 –subwoofer for haptic (felt) feedback

It is installed with a clamp mount under the left and right seats of the cockpit simulator, giving the pilots the feeling of the low end without making the room loud, even while using headphones for ATC communications.

3.4 Local Instructor Operating Station

The local instructor operating station is the system, usually manned by an instructor that allows the progress of the flight to be monitored and interaction with the student. From this location flight plans can be created, and a whole series of aspects of the simulation can be managed such as flight conditions and any failures of the aircraft such as:

- engine failure;
- malfunction of navigation systems;
- problems with the electrical, hydraulic and power supply of the motors;
- landing gear failures;
- adverse weather conditions, in flight and on the runway;

This system is implemented through a server connected to the cockpit simulator with a control station dedicated to the instructor.

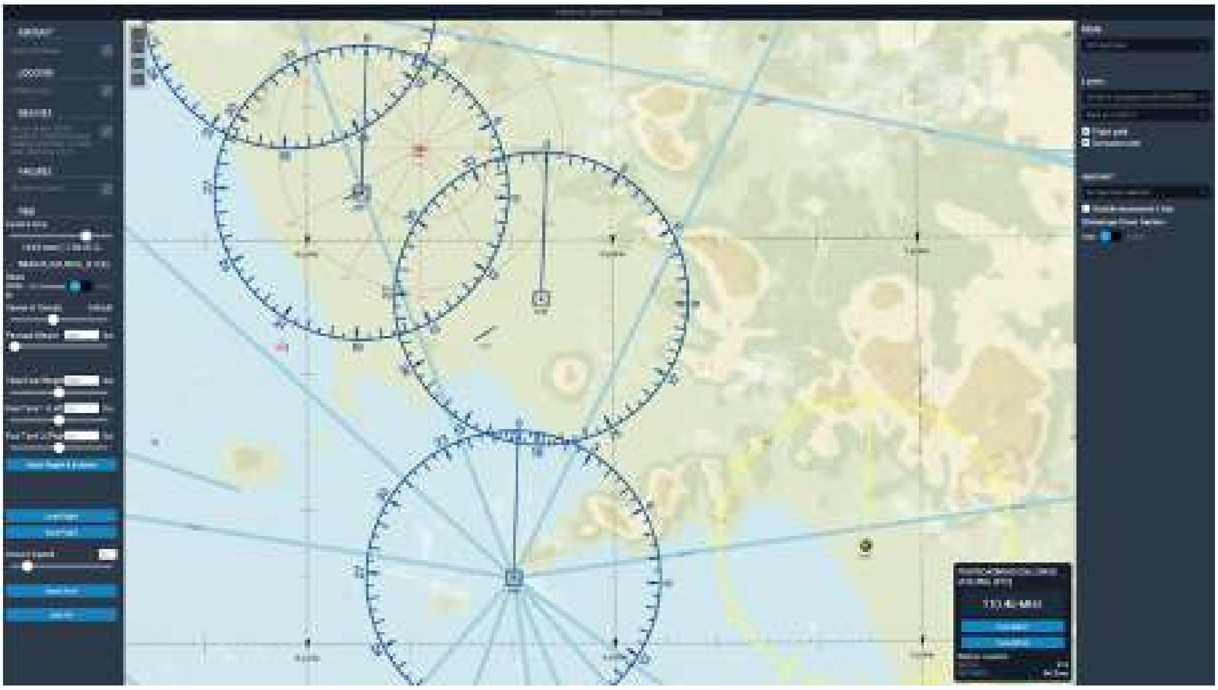

Figure 3-5 – Local Instructor Operating Station

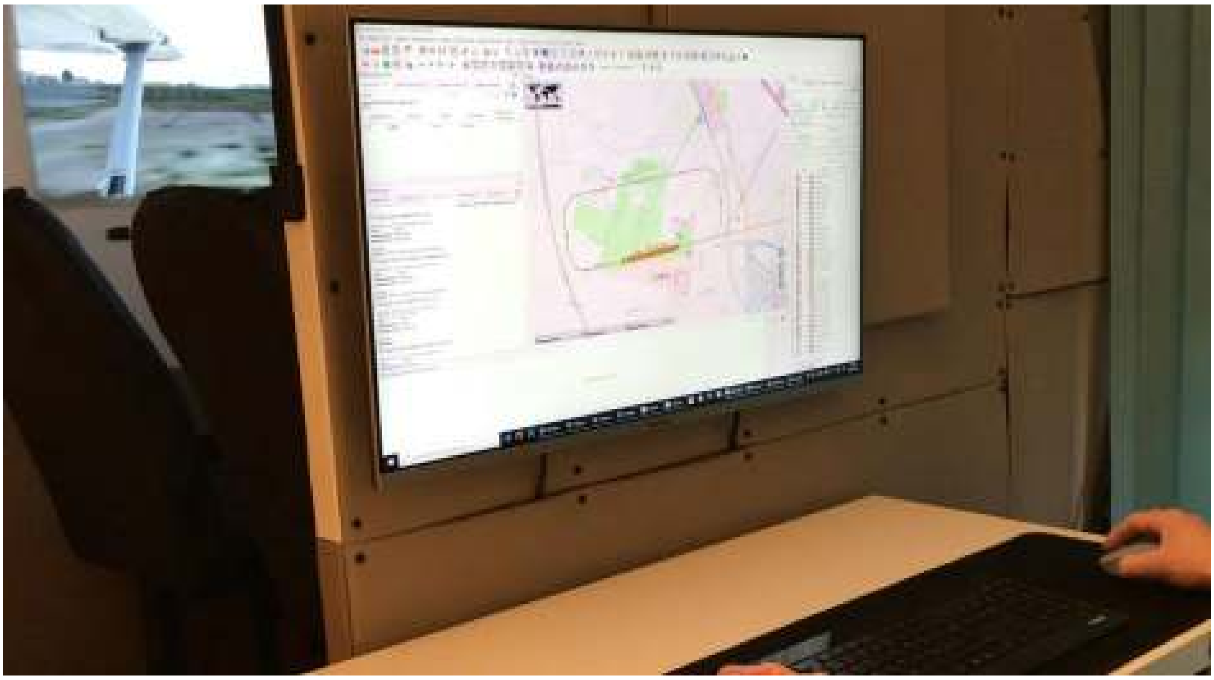

Figure 3-6 – Flight Planning on Local Instructor Operating Station

The simulation software integrated within the cockpit simulator is based on the commercial laminar research X-Plane software. This software implements:

- complete mathematical model of aircraft dynamics;
- mathematical model of the propulsion system;
- mathematical model of the external environment;
- mathematical model of the atmosphere and atmospheric turbulence.

3.5 Tailoring of Architecture for ICARUS

This section presents the software and hardware developments and adaptation needed for the tailoring of the cockpit simulator to ICARUS needs.

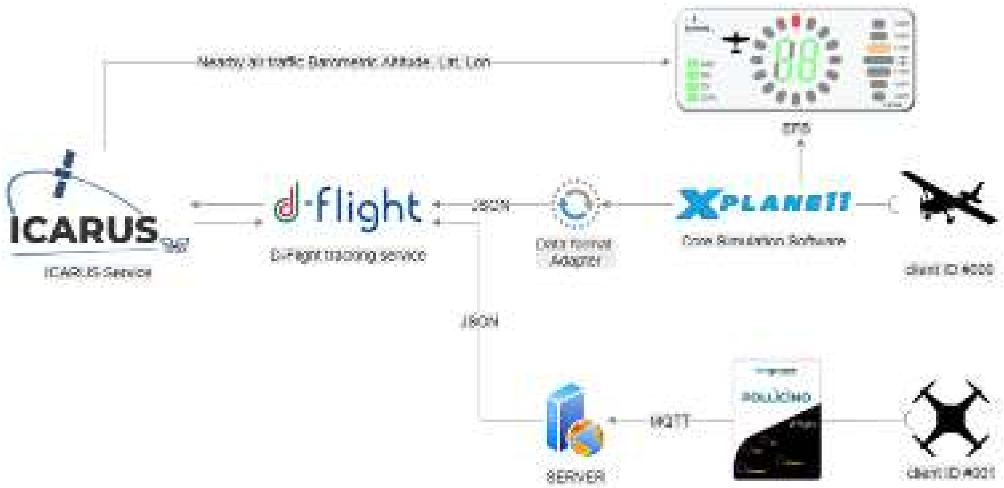

Figure 3-7 – Tailoring of SW architecture of the cockpit simulator for Integration in ICARUS

3.5.1 Simulation Software architecture and interface

This section presents new logical interfaces to exchange data with the cockpit simulator to integrate it with the EFB device, the U-space tracking service made available by D-Flight and the ICARUS VALS, VCS microservices.

A specific Android app, installed on a device (smartphone or tablet) on the command yoke of the cockpit simulator is connected to the Internet via the WiFi network or 4G / LTE. In this way, this application can reach both D-Flight and the ICARUS microservice for the traffic information service and the CCAR service during the flight. The same information can be dispatched through the specific EFB device designed for the purpose.

The surrounding air traffic (manned and unmanned) will be:

- ✓ Entirely simulated using the appropriate SW interface, called *Traffic Plugin,* made available by the cockpit simulator.
- ✓ Injected into the simulator environment flight data from real manned and unmanned vehicles using a dedicated data tracker installed on board (*es*. "*Pollicino*" *UTM-BOX tracker*) and the *Traffic Plugin* to generate and visualise them in the cockpit simulator scenario.

Latitude, longitude, heading, altitude and ground speed are transmitted through an internal plug-in (*traffic plugin*) specifically tailored to interface to the ICARUS service. Thanks to this software interface it is possible to exchange data generated by the flight simulator with the outside world via a UDP Socket connection.

3.5.1.1 Traffic SW Plugin I/F

The Traffic plugin is capable of displaying the presence of other aircraft flying within a well-defined geographical area (in a configurable radius with respect to your actual position) in the cockpit simulator in real time. Latitude, longitude, heading, altitude and ground speed can be simulated or can be received through broadcast via UDP packets.

The received data is decoded and processed by a specific software module and then exposed via an endpoint on a REST server and made available for viewing by the plugin. An example of a JSON message generated by the REST server for a single aircraft is the following:


```
{
"time": 1570807540,
"states": [
["3007d0", "SIO401 ", "Italy", 1570807540, 1570807540, 8.8021, 45.3615, 1135.38, false,
105.33, 349.02, 0, null, 1280.16, "6340", false, 0]
        ]
}
```


The JSON object consists of two elements: "time" which indicates the Unix timestamp relating to the receipt of information on the aircraft and "states" which represents the array containing information on individual aircraft identified in the area of interest.

The detail of the individual fields contained in the "states" array is shown in Table 3-2

Index	Parameter	Type	Description
0	icao24	string	unique 24-bit ICAO address of the transponder in hexadecimal notation
1	callsign	string	aircraft name (8 characters). This can be null
2	origin_country	string	country of origin derived from the 24-bit ICAO address
3	time_position	int	UNIX timestamp (in seconds) relative to the last update of the position. This can be null if no information has been received in the last 15 seconds
4	last_contact	int	UNIX timestamp (in seconds) relative to the last general update. This is updated for every valid message received
5	longitude	float	WGS-84 longitude in decimal degrees
6	latitude	float	WGS-84 latitude in decimal degrees
7	baro_altitude	float	barometric altitude in meters
8	on_ground	Boolean	indicates whether the position refers to an aircraft on the ground or in flight
9	velocity	float	ground speed in m/s

10	true_track	float	true track in decimal degrees calculated clockwise from north (north = 0)
11	vertical_rate	float	vertical rate in m/s
12	sensors	int[]	ID of the receivers and sensors used
13	geo_altitude	float	geometric altitude in metres. This can be null
14	squawk	string	squawk code. This can be null
15	spi	Boolean	flight special purpose indicator
16	position_source	int	position source (eg. 0 = ADS-B)

Table 3-2 – Detail of fields contained in the "states" array in Traffic SW Plugin I/F

3.5.1.2 Weather SW Plugin I/F

In addition to air traffic, during the simulation, the cockpit simulator software interface can also receive and / or generate information relating to the surrounding weather *(Weather plugin)*. The weather plugin is able to both replicate real weather conditions, generated from public weather stations available on the internet, and simulate user-defined weather conditions within the cockpit simulator. In both cases, the METAR weather data format is used weather conditions generated inside the cabin.

The METAR information from the various stations can be made available directly within the plugin software interface or via a text file displayed in a URL link. The text file (CSV) may have one or more METAR stations from which the software will fetch the data.

Example file:

```
myStations.csv
LIRI 231550Z 15004KT CAVOK 32/21 Q1015,LIRI,2019-07
23T15:50:00Z,40.62,14.92,32.0,21.0,150,4,,6.21,29.970472,,,,,,,,,,CAVOK,,,,,,,,VFR,,,,,
,,,,,,,METAR,40.0
ICRS 231620Z 30010KT 280V340 CAVOK 32/19 Q1015 NOSIG,DODO,2019-07-23T16:20:00Z,
40.88,14.3,32.0,19.0,300,10,,6.21,29.970472,,,,,,TRUE,,,,,CAVOK,,,,,,,,VFR,,,,,,,,,,,,ME
TAR,72.0
```

Figure 3-8 – METAR information from LIRI weather station in the Weather Plugin

Figure 3-9 – METAR information and weather station nearby LIRN airport in the Weather Plugin

3.5.2 ICARUS EFB for GA pilots

The ICARUS EFB for GA pilots is a specific device designed to be integrated into the cockpit simulator within the ICARUS project. It allows the pilot to visualise the information relating the presence of nearby air traffic through simple LED indicators.

It provides information about the closest manned or unmanned vehicle present in the same or surrounding airspace, near the position of the aircraft it is mounted in, and in particular:

- ✓ **Distance:**
  The distance between the ICARUS EFB position and that of the nearest air traffic (expressed in nautical miles).
- ✓ **Direction:**
  The direction of the nearest air traffic with respect to the heading of the aircraft where it is mounted**.**
- ✓ **Altitude:**
  Altitude information of the nearest air traffic compared with the altitude of the aircraft where the ICARUS EFB is mounted in the same altitude reference as used by the aircraft. The altitude LEDs show the difference with a 100 ft resolution.
- ✓ **Bearing:**
  Angle between the nearest air traffic (manned or unmanned) and the cockpit simulator heading. The bearing LEDs show the differences with a 22.5° resolution in azimuth.

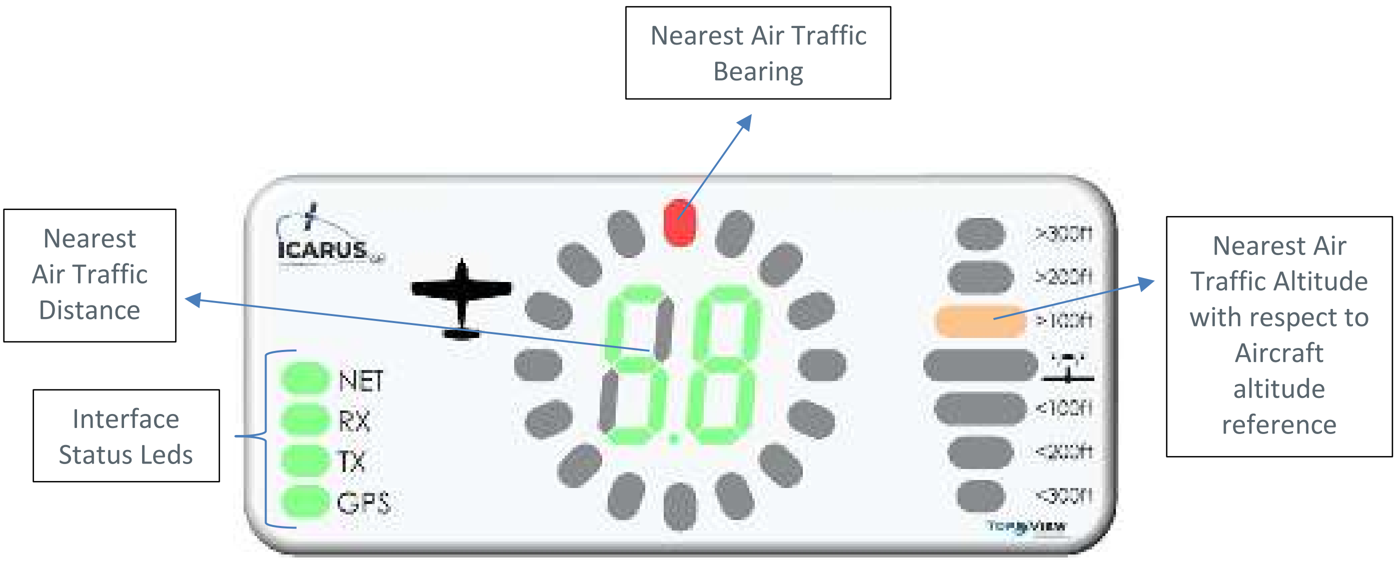

*Figure 3-10 - **ICARUS EFB layout***

3.5.2.1 ICARUS EFB Interfaces

The ICARUS EFB has two communication interfaces that can be used for the scenario validation campaign:

- **Local**: the peripheral is physically connected to the cockpit simulator via a USB 2.0 port through which it is also powered.
- **Remote**: the ICARUS EFB is connected to the internet via a WiFi interface, client of the local gateway and reaches the remote ICARUS services via known network protocols (TCP, UDP)

3.5.2.2 ICARUS EFB Functionality

The ICARUS EFB collects flight information from the simulated Cessna C172 cockpit simulator on which it is mounted and it interpolates the data acquired with air traffic data received from the remote ICARUS microservice available through the internet. In this way it provides to the pilot's "Stay well Clear" information with nearby manned and unmanned air traffic during the flight providing not only the distance and bearing of each track, but also altitude information expressed in the same way the GA pilot is used to reading and understanding it, thanks to the ICARUS microservice.

3.5.3 VTOL for UAM customisation

For air taxi missions (D6.1 - Scenario 3), a major customisation has been implemented in the cockpit simulator with specific reference to the software implementation and tailoring of a particular VTOL taxi drone model and a simplification of the original HMI, which has been redesigned for an autonomous taxi drone.

In particular, on the main cockpit simulator control panel, the user can only see two interactive controls and displays that show:

- A map where the position of the air taxi is visible and updated in real time during the trip.
- Basic gauges for flight monitoring (speed, altitude, battery level, etc.)

A virtual eVTOL UAV software add-on is injected into the flight simulator software core engine to simulate the trip. The eVTOL multicopter is customised for ICARUS Scenario 3.

*Figure 3-11 - **ICARUS tailoring of eVTOL UAV***

3.5.3.1 VTOL Taxi Drone In-Flight Operations

The VTOL taxi drone model control surfaces include elevators located on the horizontal stabiliser, rudders on its vertical stabiliser, and flaperons on its rear pylon. These surfaces operate in synchronisation with the thrust vectoring provided by its four ducted fans and its exhaust air. Due to the location of the CG, located slightly forward of the rear duct, the aircraft's front fans are not the same size and do not produce the same amount of thrust as the rear ducted fans. This relation of differential thrust is automatically calculated by the flight computer and gives a ratio of front to rear rotor thrust that allows the aircraft to safely hover and take off or land vertically. However, for the purpose of long durations of cruise flight with either zero pitch or climb rates of <2,500 ft/sec, it is beneficial to operate the VTOL taxi drone with only forward fans producing thrust.

3.5.3.2 VTOL Taxi Drone Vertical Flight

The category of vertical take-off and landing (VTOL) aircraft includes fixed-wing aircraft that can hover, take off and land vertically, as well as helicopters and other aircraft with powered rotors, such as tiltrotors or in our case tilt fan. Some VTOL aircraft can operate in other modes as well, such as CTOL (conventional take-off and landing), STOL (short take-off and landing), and/or STOVL (short take-off and vertical landing). Others, such as some helicopters, can only operate by VTOL due to their lacking landing gear that can handle horizontal motion.

To take off or land vertically, the powerful exhaust streams from a jet engine can be directed downward as well as backwards, and their direction can be changed mid-flight. This allows fixed-wing to take off vertically, fly forward, stop in mid-air, back up, and land vertically. They can also take off and land like a normal airplane. A helicopter's spinning blades create thrust like a large propeller, but the thrust is directed vertically. This allows the vehicle to take off and land vertically and to hover. To move forward, the helicopter tilts slightly to direct some of its thrust forward.

A quadrotor hovers or adjusts its altitude by applying equal thrust to all four rotors. A quadrotor adjusts its yaw by applying more thrust to rotors rotating in one direction. A quadrotor adjusts its pitch or roll by applying more thrust to one rotor and less thrust to its diametrically opposite rotor.

The full physics of the VTOL Taxi Drone concept, including the transition, is reproduced in the cockpit simulator in scenario 3 where a schedule of the flight is given and ICARUS microservices, in particular GIS and VALS, are demonstrated.

4 ICD and SW Interfaces

The external cockpit simulator interfaces are described in the following architecture (from D5.3). In this document a specification of the ICD and SW interface with the D-flight USSP is provided.

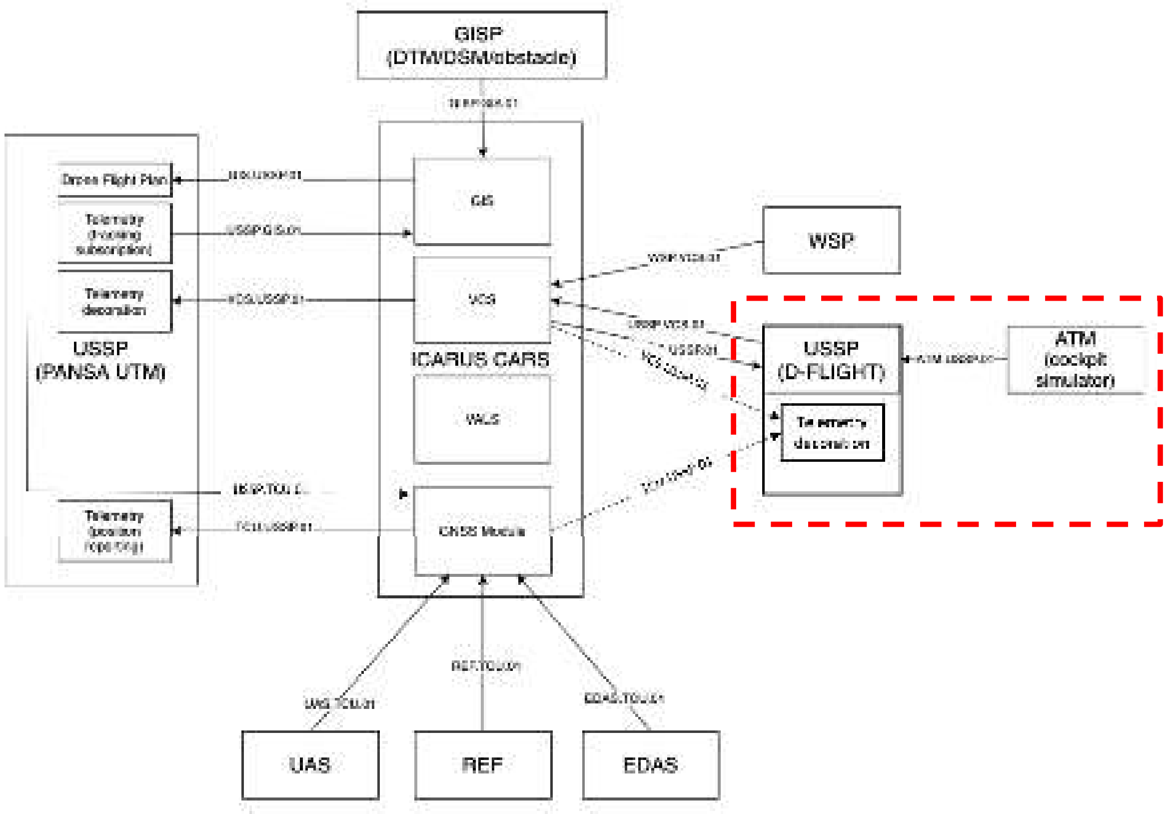

Figure 4-1 – ICARUS testbed architecture and interface ATM.USSP.01 with Cockpit simulator

4.1 ATM.USSP.01 - USSP D-Flight

The cockpit simulator interface that communicates with D-Flight is a one-way interface that is developed specifically to interface with the USSP, according to the D-Flight public ICD [9]. The interface developed to exchange position information of the simulated airplane with D-flight uses the JSON protocol.

The cockpit simulator has a native section with a graphical user interface shown in Figure 4-2 for streaming different typology of useful data including position, height, UTC time and any kind of simulation data.

These data are wrapped in a developed software interface capable of adapting the data generated with the D-Flight ICD using a JSON mechanism for communication.

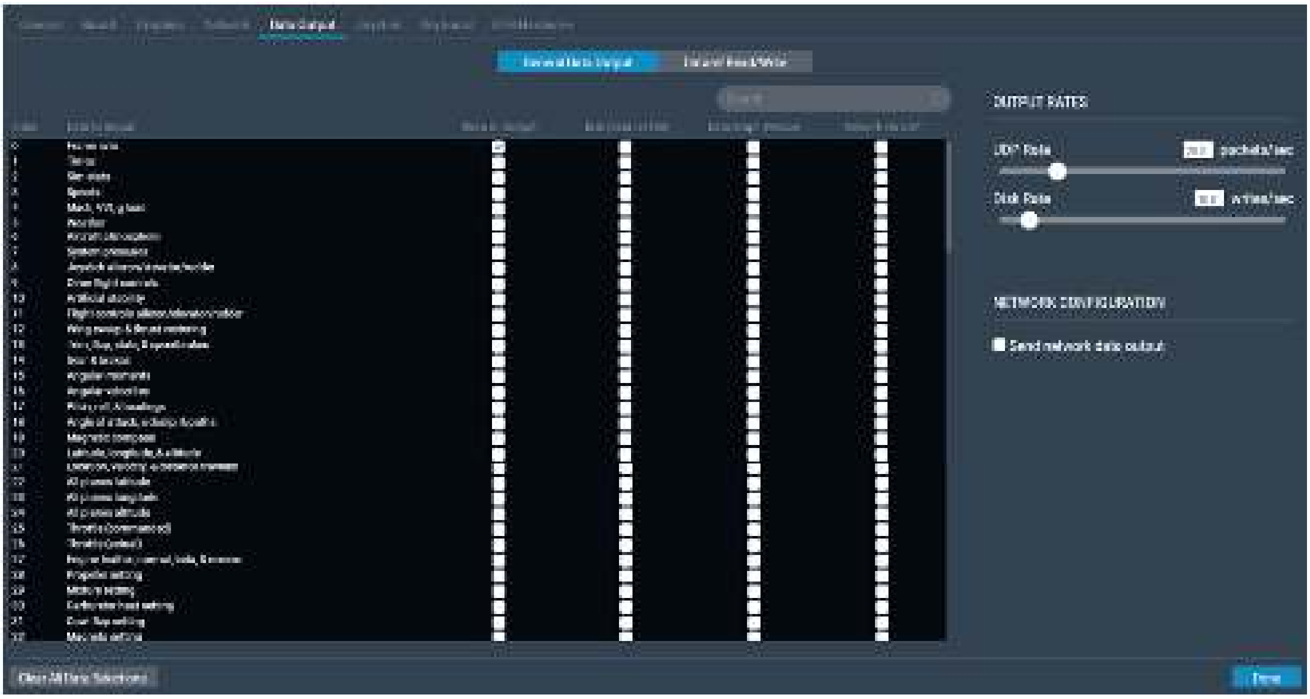

Figure 4-2 – Data output section from the cockpit flight simulator software

Tracking information of an airplane is sent in the same way as for drones that use a physical UTM Box located inside the drone. In this particular case, the data are generated by plugin software developed inside the main computer of the cockpit simulator. Basic telemetry/position information is dispatched from the cockpit simulator, including the height and the ground speed. Additional information cannot be sent with the current version of the D-flight ICD, however an additional release of the ICD (v1.3) is expected at the beginning of 2022.

4.1.1 Tracking Message Specification

Tracking Message Specification (JSON) for Interface ATM.USSP.01

The payload forwarded to the U-space platform has a JSON format composed of different basic sections:

1. IDENTIFICATION: the UA or Aircraft identification and the operator identifications;
2. STATEDATA: the position data of the UA at a given time
3. STATUS: the health of the main devices and the accuracy of the position and speed values reported in the STATEDATA section
4. INTENT: the future intention of the UA as the next waypoint position and altitude
5. APPLICATION: data that is only required for certain purposes or applications, and specifically the take-off and the RPS position

6. GEFENCING: the time of last geo-fencing database update

7. AUGMENTATION: information about the GNSS augmentation system used by the aircraft or RPAS (if any) to improve and validate positioning data

8. RAW DATA: raw satellite data information retrieved from the GPS receiver

A single payload is composed of:

- IDENTIFICATION section
- One or more of the remaining basic sections, according to the interface description

This composition makes it easy to specify different rates of transmission for each different section and permits the required throughput to be reduced.

Transmission rates

The frequency of transmission is (recommendation EUROCAE WG-105):

STATEDATA	At a 2 Hz rate as a minimum when airborne At a 1 Hz otherwise
STATUS	As soon as a change occurs At a 0.1 Hz rate as a minimum otherwise
INTENT	2 Hz rate as a minimum when the UA is flown manually 0.1 Hz rate as a minimum when the UA is flown in automatic mode
APPLICATION	At a 2 Hz rate as a minimum when airborne At a 0.1 Hz rate as a minimum otherwise
GEFENCING	As soon as a change occurs At a 0.1 Hz rate as a minimum otherwise
AUGMENTATION	At a 2 Hz rate as a minimum when airborne At a 1 Hz otherwise

Table 4-3 – frequency of transmission

Identification section layout

Element	Description	Mandatory
UAId	Identification of the aircraft or UA according ANSI/CTA-2063	Y
OpId	Operator Identification	N
src	Type of data channel. This can be: 0=Bluetooth, 1=WIFI, 2=Lora, 3=4G/LTE, 4=Satellite	Y
dev	Type of device source. This can be: 0=U-Box On board, 1=U-Box c/o GCS, 2=Virtual U-Box, 3=Reserved, 4=Drone Operation Area	Y

Table 4-4 – Identification section layout

State Data section layout

Element	Description	Mandatory
time	Timestamp of position update Time of day in UTC When transmitted as string, use at least 3 decimal digits	Y
lat	WGS-84 latitude Latitude in decimal format. Unit of measure deg When transmitted as string, use at least 5 decimal digits	Y
lon	WGS-84 longitude Longitude in decimal format. Unit of measure deg When transmitted as string, use at least 5 decimal digits	Y
height	WGS-84 height Height in decimal format. Unit of measure m When transmitted as string, use at least 1 decimal digit	Y
altitudeMSL	Altitude above Mean Sea Level Altitude in decimal format. Unit of measure m When transmitted as string, use at least 1 decimal digit	N
speedNS	Ground speed North axis	N

	Speed in decimal format. Unit of measure m/s When transmitted as string, use at least 2 decimal digits	
speedEW	Ground speed East axis Speed in decimal format. Unit of measure m/s When transmitted as string, use at least 2 decimal digits	**N**
VRate	Climb/descent rate Vertical speed in decimal format. Unit of measure m/s When transmitted as string, use 2 at least decimal digits	**N**

Table 4-5 – State Data section layout

Size of messages

Following the above specification, the JSON message can have an approximate size of 1.4-2.2kB (depending whether the advanced telemetry information is part of the message).

JSON/ZIP format

Compressed data (zip/tgz formats accepted) is supported when sending messages on specific interfaces (see section 3 for more detail). Compression rates are seen to be around 55-66%, resulting in a message file size of around 600-750 Bytes.

Additional information on the ICD used can be found in [9]

4.2 Integration Test Report

The cockpit simulator has been successfully integrated with d-flight using the same mechanism as specified in the public ICD used for the drones.

At this time, the public interface does not consider the possibility of interfacing manned aircraft for the exploitation of U-space services, however this functionality is under development. When available, it will be possible to update the software interface, for additional data exchange and new functionalities including the CAR service.

The integration test was successful: The cockpit simulator track was visible in D-flight, presenting the same information that a UAS shows as per ICD including altitude, position information, tracking information, ground speed, etc.

The only limitation so far is represented by the visualisation; the Icon shown on D-flight cartography represents a drone, however this limitation will be solved with the new ICD 1.3

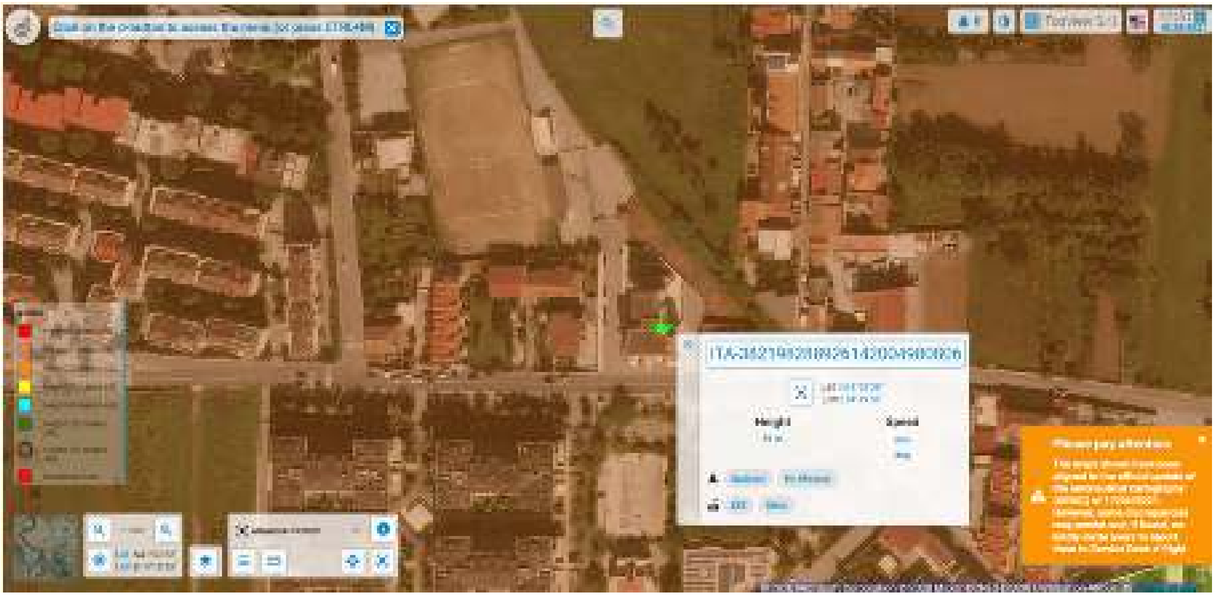

Figure 4-3 – Track generated by the cockpit simulator and injected into d-flight (drone Icon - ICD v1.2 to be replaced by airplane icon in ICD v1.3).