Configuration of an Optionally Piloted Vehicle as Flying Laboratory for Aeronautical Research

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ABSTRACT

In the framework of the PRO.R.A. - UAV program the Italian Aerospace Research Centre (CIRA) has planned to carry out the TECVOL Project ("TECnologie del VOLo autonomo"). The scope of TECVOL Project is to integrate, to optimize and to validate Unmanned Aerial System innovative technologies including the Detect, Sense & Avoid functions, based on ATM/ATC (Air Traffic Management & Control) non-cooperative technologies. The integration and validation of these technologies should allow to accomplish a complete autonomous flight mission of an UAV-HALE (High Altitude Long Endurance) flying platform. The in-flight validation of the TECVOL technologies is planned to be performed by utilizing an Optionally Piloted Vehicle (OPV), derived from a commercial off-the-shelf manned Very Light Aircraft, so as to achieve a significant cost and risk reduction, especially in the development and realization costs of a new aircraft. In particular the flying platform, based on a TECNAM P92-Echo S and named FLARE (Flying Laboratory for Aeronautical REsearch), has been selected for its low purchasing and modifications costs and for the good operational flexibility and reliability. This paper describes the overall FLARE-OPV configuration, detailing the modifications on the basic aircraft in order to accommodate the experimental set-up. Moreover a general description of the Ground Control Station and of the on-board sensors/avionics is provided.

1.0 INTRODUCTION

The Unmanned Aerial Systems (UAS) enabling technologies, mainly focused on Mission Automation and Autonomous Obstacle Detect, Sense & Avoid functions, represents the Italian Aerospace Research Centre (CIRA) investigation approach, in the framework of PRO.R.A. Program (Italy's National Aerospace Research Program). The TECVOL project, planned to be carried out inside the PRO.R.A. Program, has the main aim to investigate on innovative UAS technologies, including Anticollision functions based on ATM/ATC (Air Traffic Management / Air Traffic Control) non-cooperative technologies, to be implemented, after validation, on a HALE category UAS. For the in-flight experimentations of the TECVOL technologies CIRA has chosen an Optionally Piloted Vehicle (OPV) platform, derived from a commercial off-the-shelf manned Very Light Aircraft, to drastically reduce research costs and risks.

2.0 TECVOL PROJECT

The TECVOL Project technologies to be validated are based on the following main functions:

- **F1** Autonomous Flight Path Execution
- **F2** Autonomous Obstacle Detection &Tracking

- **F3** Autonomous Collision Avoidance
- **F4** Autonomous Approach & Landing
- **F5** RPV Mode

The Autonomous Flight Path Execution is the system capability to autonomously perform an entire flight mission based on the planned route. During the flight the route re-planning will be possible in order to assure the flight safety (i.e. a very invasive collision avoidance manoeuvre) and the management of the emergencies due to an on-board failure or a data-link loss.

The Autonomous Obstacle Detection & Tracking is the autonomous system capability to detect and track the obstacles in flight during the entire mission.

The Autonomous Collision Avoidance is the autonomous system capability to avoid obstacles collisions in every flight phase, relating to the aircraft manoeuvrability limits and minimizing the flight route deviations.

The Autonomous Approach & Landing is the system feature to autonomously execute aircraft approach, landing and taxing on the well-known runway instrumented or not.

The Remote Piloting Vehicle (RPV) Mode is the capability of aircraft piloting from the Ground Control Station. Two different RPV piloting modes shall be developed: standard and advanced. In the standard one the ground pilot receives, via telemetry, the aircraft status information and external view and, remotely, controls the aircraft using replicated standard devices like stick, pedals and throttle. In the advanced RPV mode the ground pilot external vision is replaced by a stereoscopic video visualized on an Head Mounted Display.

3.0 AN OPTIONALLY PILOTED VEHICLE

A true OPV can be piloted remotely by a ground pilot interfaced directly with the on-board flight control system, or alternatively, sending just high-level commands to the on-board flight control computer that can manage autonomously the flight mission. The flight control computer can be charged to carry out the entire flight mission or just some phases of it. These remotely operations are possible with the means of a wireless radio link between the OPV and the remote flight control station, that can be located or on the ground or on-board another aircraft. A characteristic common to almost all OPV is the possibility to have a pilot placed both in the cockpit as well as in the remote control station. The ability to carry a crew aboard, and then to be a manned platform, is a feature that can prompts the designers to choose off-the shelf certified aircrafts as baseline airframes for OPVs. Sometimes just minor modifications to the aircraft are needed, depending to the amount of functions that the system should accomplish, in order to install the necessary subsystems to transform the manned airplane into an OPV. Starting from an off-the shelf certified aircraft for the research activities and experimental testing, would potentially be a much quicker recertification process instead of designing and developing a new one flying platform to be used as an OPV. The main gains of such a choice are substantial reductions in the project costs and risks.

4.0 BASELINE AIRCRAFT - TECNAM P92-ECHO

The baseline aircraft chosen by CIRA as Flying Test Bed, named FLARE Flying Laboratory for Aeronautical Research (FLARE), is the TECNAM P92-Echo S, VLA category. The mounted powerplant is a Rotax 912 ULS2 100 Hp, four-cylinder, four-stroke. The engine is coupled with a two blade fixed pitch propeller. The P-92 Echo S has been selected:

- for the low costs related to the modifications, operations and maintenance;
- for its excellent VLA flying characteristics that allow it to be operated on very short semiprepared/grass airstrips.

In Table 1 are reassumed the main features and performances of the basic aircraft, whereas in Figure 1 is reported the three-view drawings of the basic airplane.

DIMENSIONS		
Wing Span	9.6	m
Wing Area	12	m^2
Fuselage Lenght	6.3	m
Fuselage Height	2.5	m
ENGINE		
Manufacturer	Rotax	
Model	912 ULS2	
Power	100	hp
Number of cylinders	4	
PROPELLER		
Manufacturer	Tonini	
Model	GT	
Number of Blades	2	
Type	Fix	
DESIGNED WEIGHT and LOADING		
Designed MTOW	600	kg
Limit Loads	+4/-2	g
Ultimate Loads	+6/-3	g
PERFORMANCE		
SPEED		
Maximum at Sea Level, Gross Weight	235	km/h
Cruise, 75% power	215	km/h
Vne	270	km/h
STALL SPEED		
Flaps Down, power off	65	km/h
Rate of Climb at sea level	6	m/s
Service Ceiling	4500	m
TAKEOFF PERFORMANCE		
Ground roll	110	m
Totale over 50 ft obstacle	205	m
LANDING PERFORMANCE		
Ground roll	110	m
Totale over 50 ft obstacle	260	m
FUEL TANK CAPACITY	45x2	lt
FUEL ECONOMY	17	lt/h

Table 1: TECNAM P92 Echo S features & performances

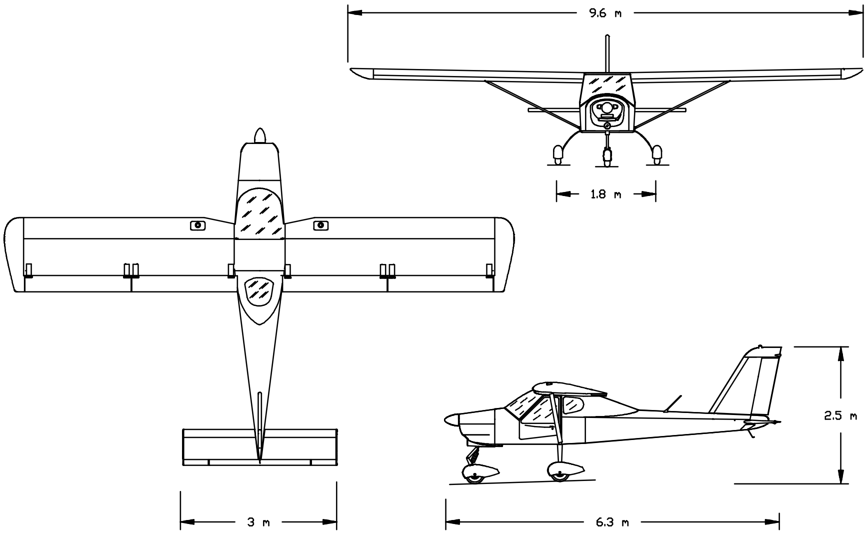

Figure 1: TECNAM P92 Echo-S

5.0 FLARE OPV HIGH-LEVEL ARCHITECTURE

The FLARE OPV High-Level Architecture is presented in Figure 2.

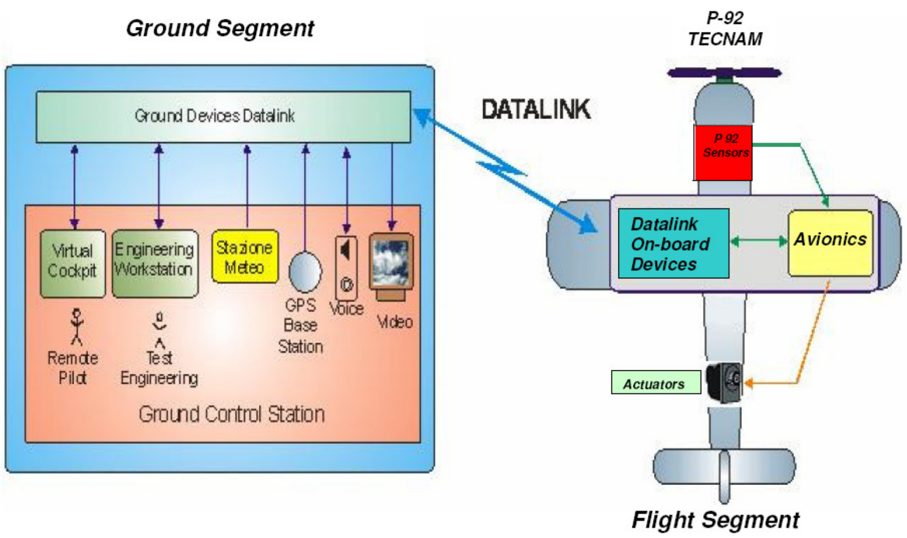

Figure 2: FLARE OPV architecture

The set-up consist of:

- A ground segment, designated to monitor the flight experiments and to interact with the on board systems. A GPS Base Station provides the differential correction for the on board GPS (DGPS).
- A data-link system for the communications between the Ground Control Station and the on board

segment (digital data exchange, the on board video transmission and the vocal communications).

- An on board segment, composed by peculiar avionics to carry out the planned experiments.
- An Intruder aircraft, represented by a second manned P-92, to simulate a non-cooperative flying obstacle, during collision avoidance tests. The Intruder is equipped with a GPS and a radio link to transmit its position data to GCS.

6.0 ON BOARD FLARE OPV ARCHITECTURE

The FLARE on board architecture is presented in Figure 3.

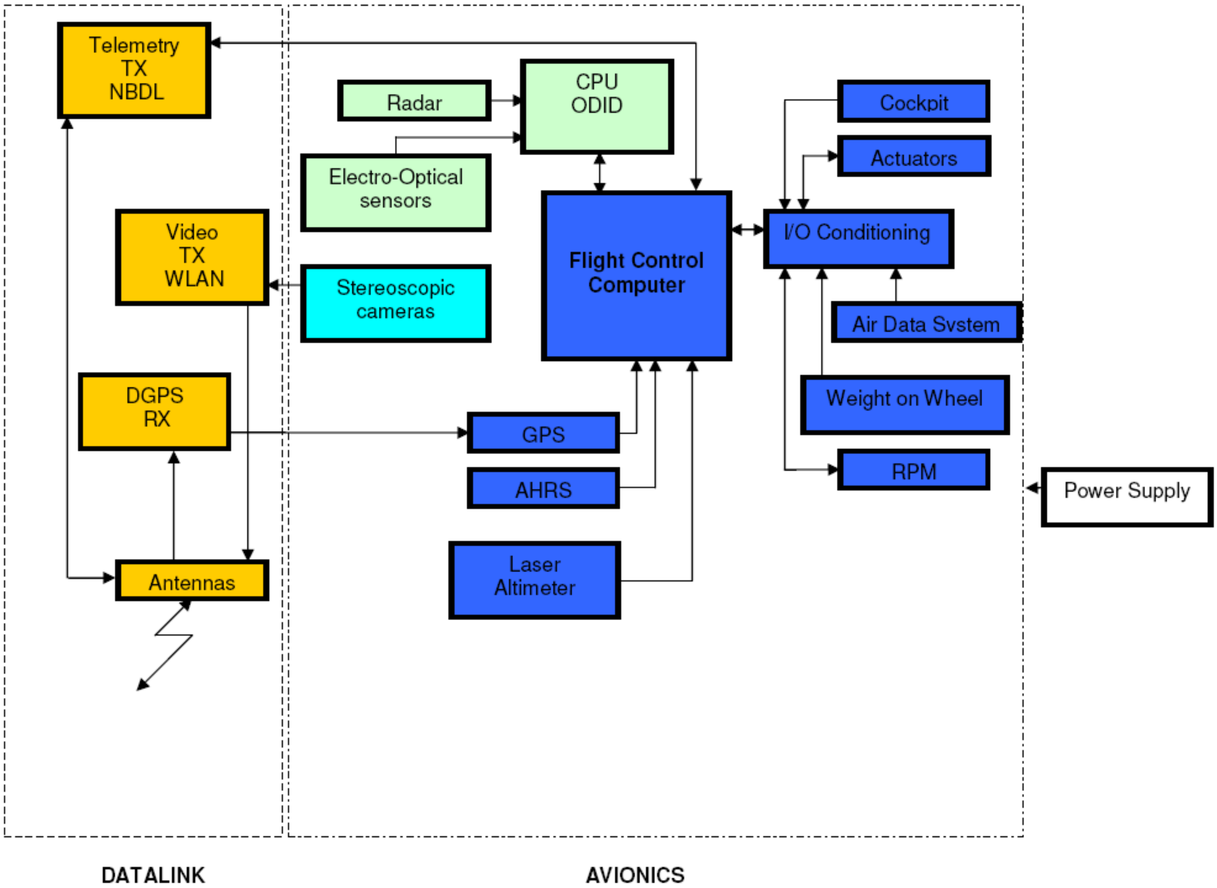

Figure 3: FLARE on-board architecture

In particular is possible to identify the following subsystems:

- **Guidance Navigation and Control (GNC) subsystem**
- **Obstacle Detection and IDentification (ODID) subsystem**
- **Stereoscopic Vision subsystem**
- **Datalink subsystem**

In order to accommodate on board all experimental avionics the left seat has been removed and the baggage bay space has been used too. So it has been possible to allocate the major portion of the equipments inside the cabin for easier installation and maintenance activities. For a more rational installation of the embarked systems two mounting trays have been installed in the cabin: one in place of the baggage bay and the other one on the left seat rails. The ODID sensors (Electro-Opticals, Infrareds and Radar) and related mounting support have been installed on the cabin and, precisely, on the upper side of the wing. The peculiar antennas have been installed: four on the upper wing and three on the bottom fuselage. The mounting of the experimental set-up needed also the installation in the engine bay of an auxiliary alternator to provide the required electrical power. Moreover, in order to minimize the weight growth impact versus the aircraft performances, a new propeller with a reduced blade pitch respect to the baseline one has been installed. All modifications have been made with the aircraft manufacturer formal approval. In Figure 4 is reported a FLARE 3-D view.

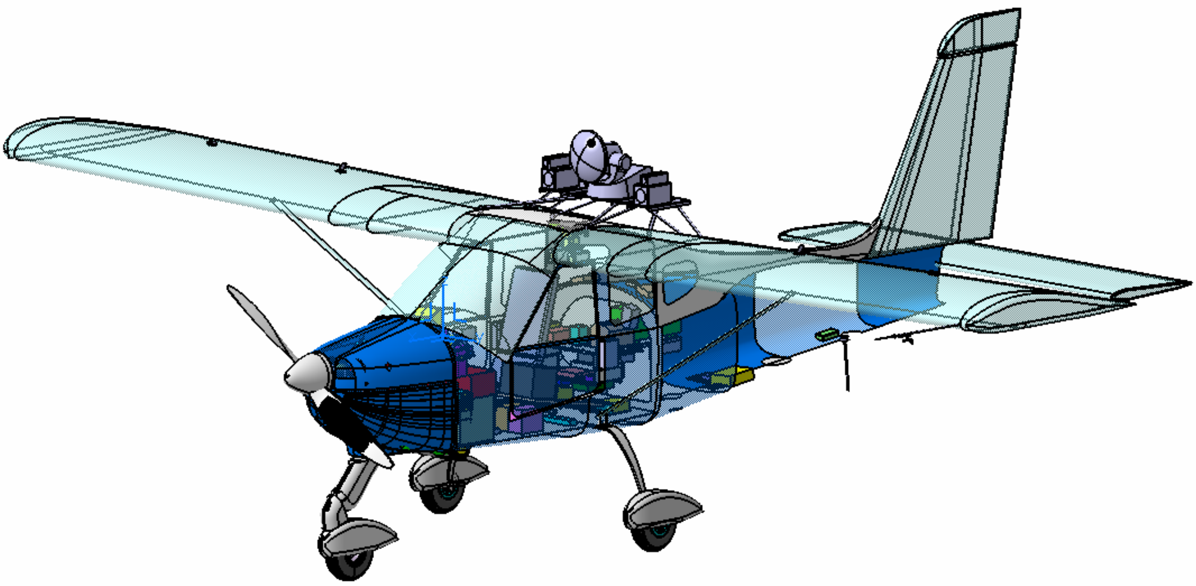

Figure 4: FLARE OPV

6.1 Guidance Navigation and Control subsystem

The GNC subsystem core is the Flight Control Computer (FCC) that controls, in closed loop, the movable surfaces and the engine throttle using the data coming from the Navigation sensors. The Table 2 is a list of the GNC subsystem major components.

GNC ON BOARD SYSTEMS
RUDDER ACTUATOR
AILERONS ACTUATOR
STABILATOR ACTUATOR
THROTTLE ACTUATOR
AIR DATA UNIT
AIR DATA BOOM
LASER ALTIMETER
GPS RECEIVER N.1
GPS RECEIVER N.2
DGPS RECEIVER
DGPS ANTENNA
GPS N.1 ANTENNA
GPS N.2 ANTENNA
AHRS UNIT
FLIGHT CONTROL COMPUTER

Table 2: GNC on board systems

The primary control surfaces and throttle actuators, autopilot type, have been mounted on the existing cinematic chains. In engaged mode each electromagnetic clutch links the actuator to the command chain. In Figure 5 is shown the rudder actuator installation.

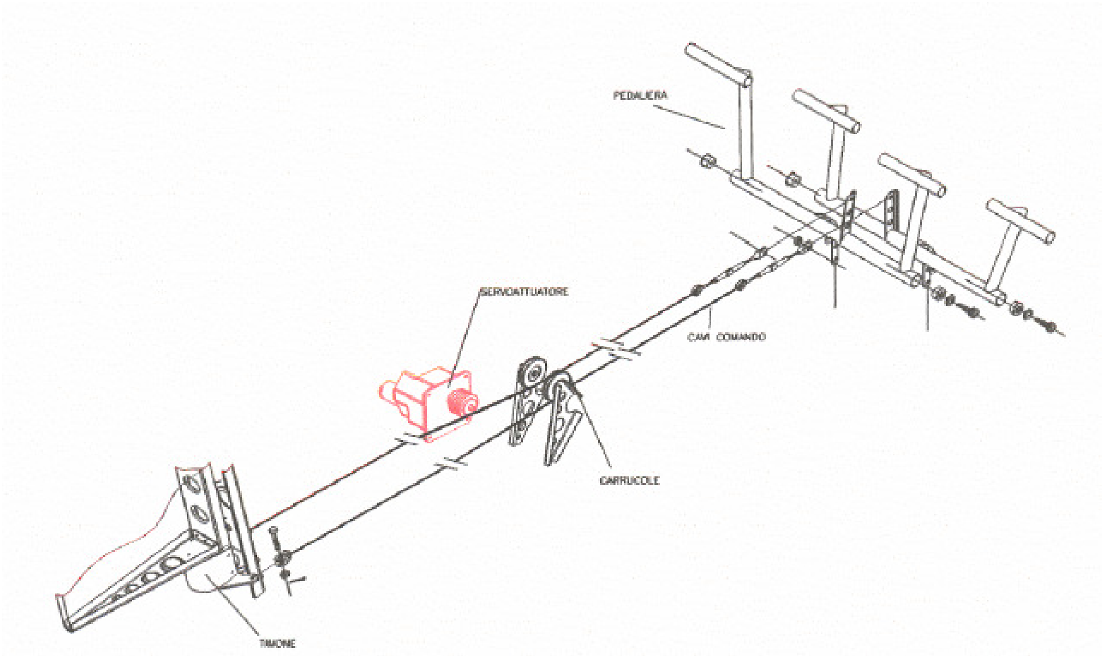

Figure 5: Rudder actuator installation

In Figure 6 is shown the stabilator actuator installation.

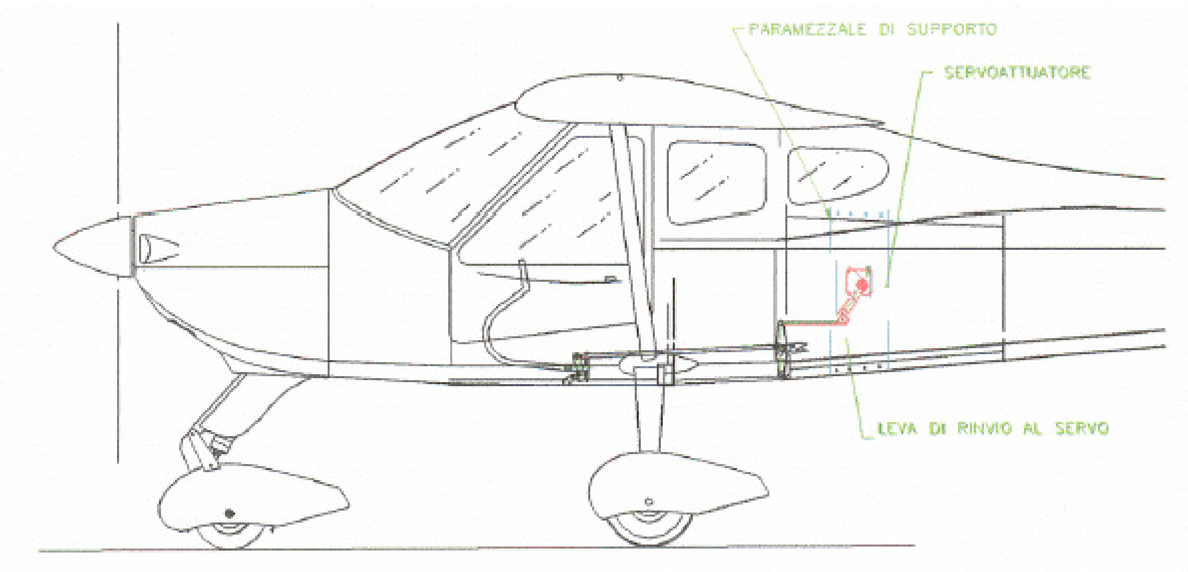

Figure 6: Stabilator actuator installation

In Figure 7 is shown the ailerons actuator installation.

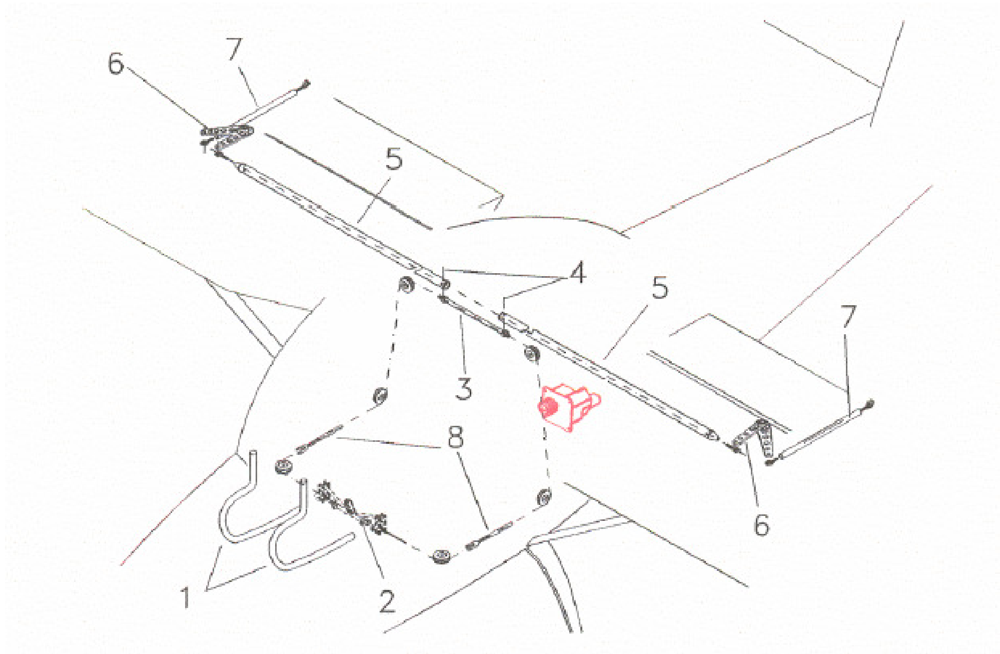

Figure 7: Ailerons actuator installation

In Figure 8 is shown the engine throttle actuator installation.

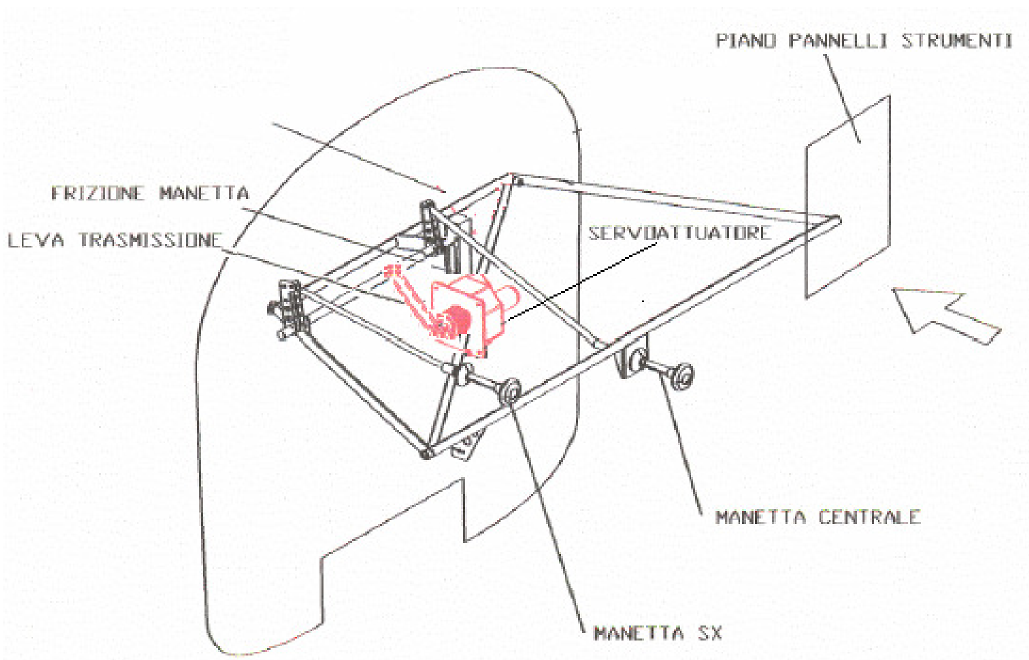

Figure 8: Engine throttle actuator installation

The two secondary actuators, commanding flaps and pitch trim, are P92 basic configuration. They are controlled, only in engaged mode, by the FCC through an electronic interface. FCC and Attitude and Heading Reference System (AHRS) are both installed on the mounting tray located behind the pilot seat, as shown in Figure 9.

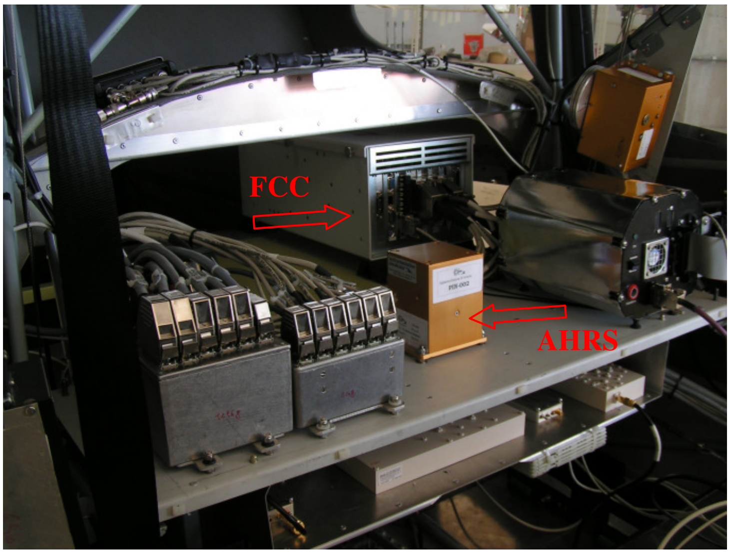

Figure 9: FCC and AHRS installation

The two GPS receivers are mounted in the cabin on the baggage vane structure, just over the FCC, as shown in Figure 10, whereas the laser altimeter is installed under the mounting tray, behind the pilot seat. The GPS antennas are located on the left and right wing upper side and the DGPS receiver is located in the rear fuselage near its own antenna.

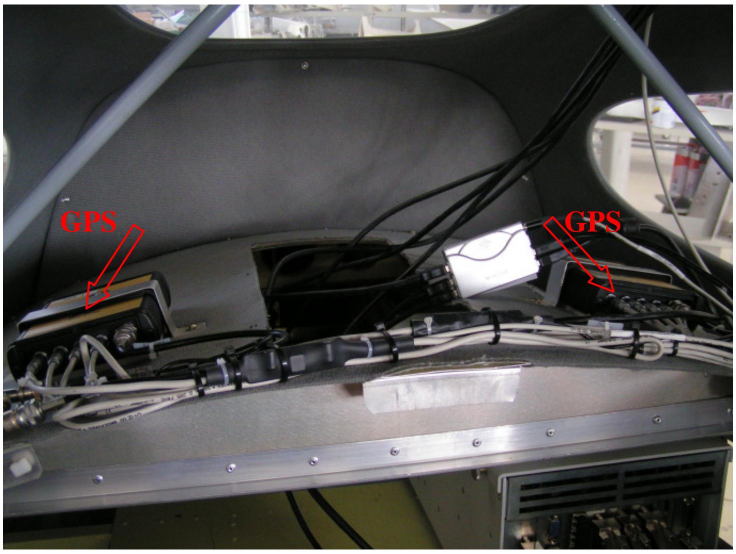

Figure 10: GPS installation

In order to have a better measurement of the aircraft speed, Angle of Attack (AoA) and Angle of Sideslip (AoS), an additional air data system (ADS) has been provided. The pressure and temperature sensors have been assembled by CIRA and the ADS has been equipped with a commercial air data boom, mounted on the left wing tip. Additional sensors were also utilized by GNC subsystems: throttle and control surfaces position, engine manifold pressure, engine RPM, Weight on Wheel (WoW), etc. The throttle and control surfaces position analog transducers are installed close to the control devices. The WoW sensors are installed on the Main (MLG) and Nose (NLG) Landing Gear. The ones installed on the MLG are electrical contact type, whereas for the NLG have been selected an induction proximity sensor sensing the wheel rotation.

6.2 Datalink subsystem

Two different Line of Sight (LOS) datalink systems will be used for the experimental flight tests. The first one, a Narrow Band Data Link (NBDL), is designed for the telemetry data transmission and for the reception of the telecommands sent from the GCS. The second one, a Wide Band Data Link (WBDL) , is devoted to the transmission of the video acquired by the stereoscopic cameras. The datalink system design is based on flexibility and modularity concepts. The datalink systems and related antenna siting are designed to ensure the communication considering the whole aircraft attitude range. In Figure 11 and Figure 12 are reported datalink logical architectures. The components of the two datalinks are installed inside the cabin on two mounting trays. Each NBDL and WBDL antenna systems are composed by two antennas, one on bottom of fuselage and the other one on the wing upper side. Two different data bus are integrated on FLARE: a multi-point real-time data bus (CAN bus) and an high speed data bus (Firewire 1394a bus). On the CAN bus are connected the FCC, the ODID CPU and the Communication Controller (CC). The high speed data bus is a multi-point bus devoted to transmit, to ODID CPU, the data coming from the infrared cameras. Some relevant features of the two data busses are reported in Table 3.

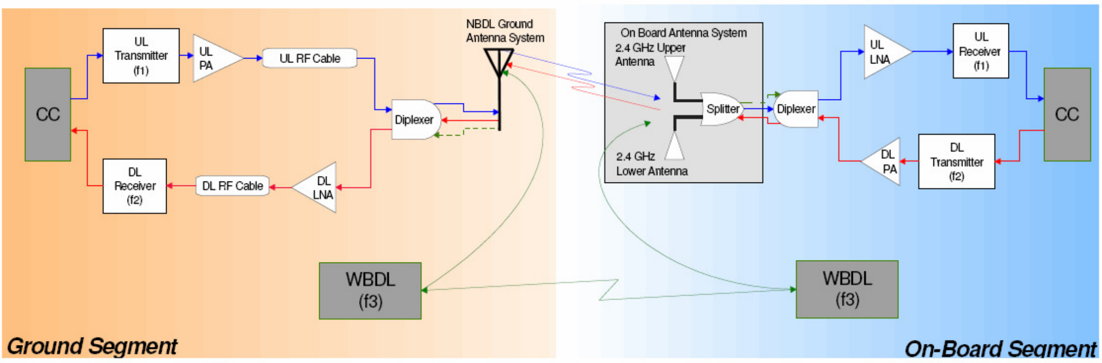

Figure 11: NBDL logical architecture

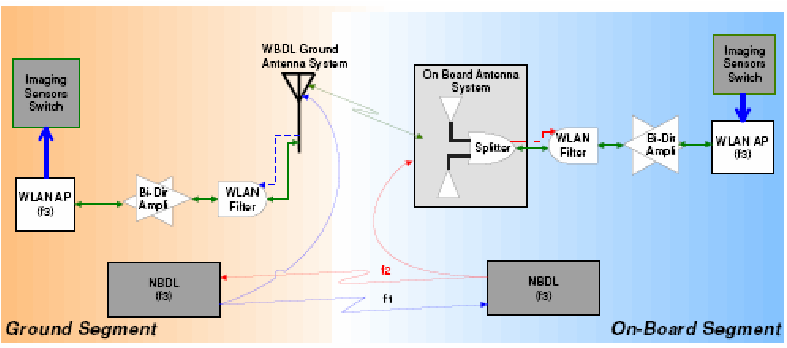

Figure 12: WBDL logical architecture

	CANBUS	FIREWIRE 1394A
Communication	Serial	Serial
Topology	Master-Slave	Peer to Peer
Bus Lenght	40 m	4.5 m
Throughput	1 Mb/s	400 Mb/s
Max n. terminals	No limits	63

Table 3: On board Data Buses features

6.3 Obstacle Detection and Identification subsystem

The ODID subsystem is composed by sensors and processing devices designed and assembled for detection, tracking and identification of non-cooperative flying obstacles. The system is designed to operate in all-weather and all-time operating conditions. The ODID main sensor is an Amphitech AI-130 Ka-band pulsed radar and the secondary sensor group is composed by two FLIR A40V infrared cameras and two AVT F145B2/C2 high resolution cameras. The processing device is based on two CPUs computer unit. One CPU is dedicated to elaborate the images acquired by electro-optical devices (CPU Image), and the other one is devoted to the sensor fusion between the data coming from the radar and from electro-optical sensors, in order to determine the obstacle dynamics. The ODID computer is located in the cabin, installed on the tray mounted on the rails of the left seat. The sensors have been installed externally on the upper side of the wing, above the cabin. In Figure 13 is shown the sensors arrangement and installation.

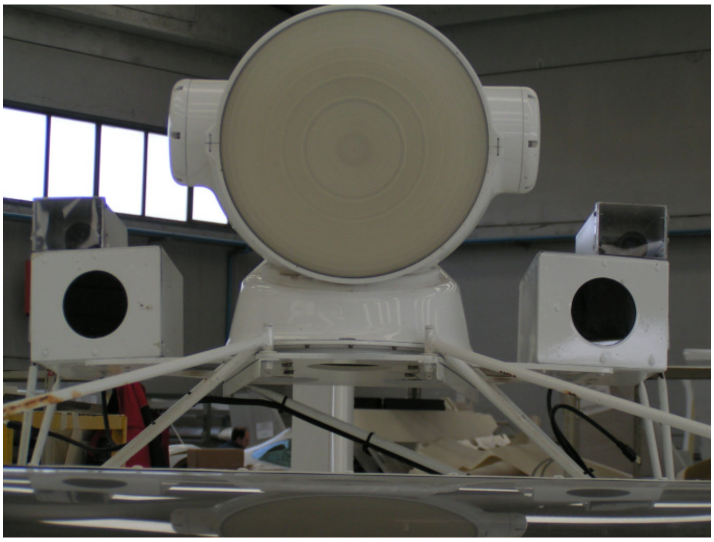

Figure 13: ODID sensors installation

The obstacle dynamics data are provided to the FCC to be processed by the Collision Avoidance decision making algorithm. A scheme of the hardware architecture of the ODID subsystem is presented in Figure 14.

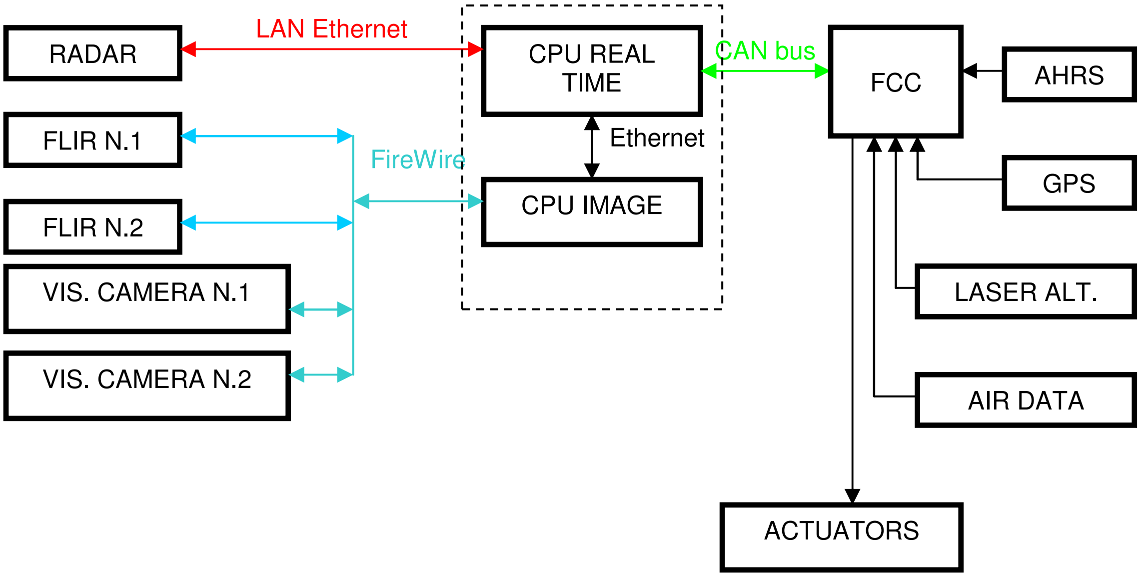

Figure 14: ODID hardware architecture

6.4 Stereoscopic Vision subsystem

The stereoscopic vision subsystem is intended to provide the video for the remote piloting of the vehicle. It makes use of two Ernitech Varicam 23" cameras installed in the piloting cabin, in correspondence of the left side piloting point of view. The cameras are mounted both on an apposite support, connected to the pan tilt unit that allows the movement around the lateral and vertical axis. The pan tilt unit is then directly linked to the piloting cabin ceiling through a specific support. The two acquired video are compressed by two Smart Sight S1500 Ext video devices in order to be sent to the GCS via the WBDL. In Figure 15 is shown the two cameras and the pan tilt unit as installed in the aircraft cabin.

Figure 15: Stereoscopic cameras installation

6.5 On-board Piloting Interface

To allow to the pilot the control and monitoring of the on-board experimental set-up the cockpit has been modified taking in the account the pilot workload. In Figure 16 is shown a snapshot of the cockpit where are identified the pilot interface panel, radar control panel and additional three switches. The auxiliary alternator control switch is located in the middle of the cockpit, whereas the automatic control system engage/disengage switch is installed below the radio comm panel near the engine right throttle command. In engage position the FCC controls directly the aircraft. Advisories panel, with eight annunciation lights, has been installed on the cockpit in front of the pilot (six annunciations are devoted to actuators status, one is devoted to indicate the set-up critical failure and the last one informs the pilot about the end of the automatic piloting test). The third switch, located under the pilot interface panel, is used, in flight just for emergency, to shut off the electrical power to the on-board set-up.

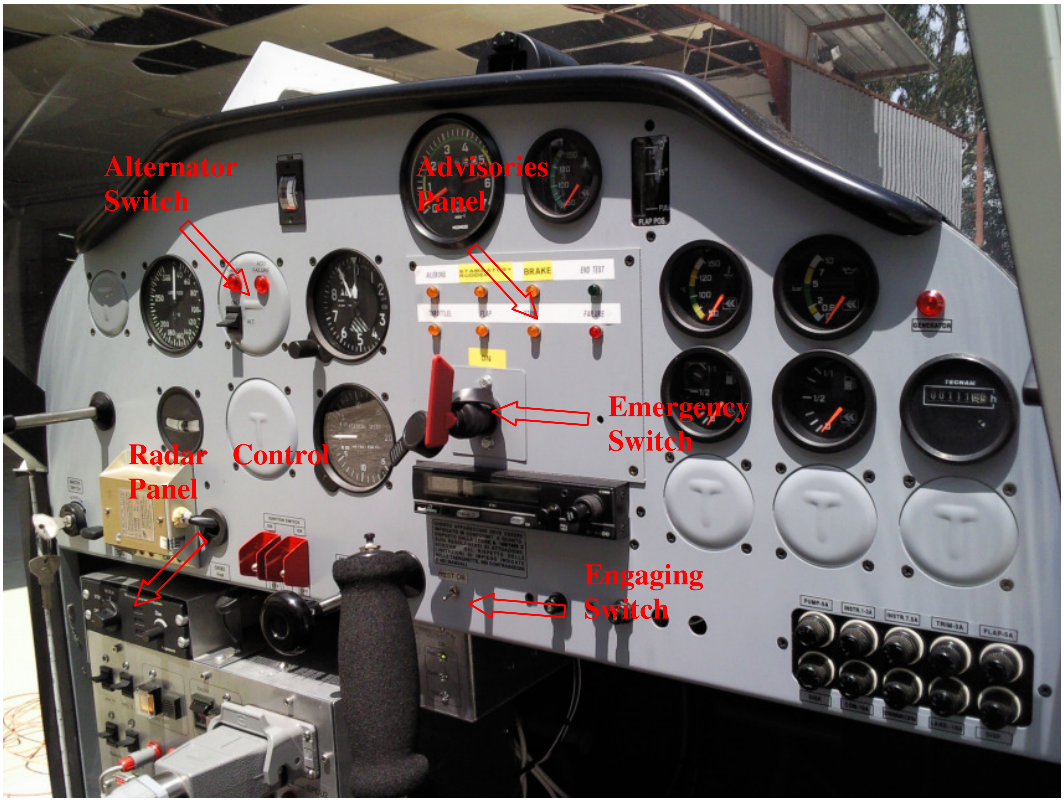

Figure 16: FLARE modified cockpit

7.0 GROUND SEGMENT

The ground segment is composed by a Ground Control Station and a GPS base station. The GPS base station is used for position accuracy improvement based on the differential position correction. The GCS devices, distributed in five Engineering Work Stations (EWS), are located inside a (5.2 m x 2.25 m x 2.35 m) shelter. The FLARE guidance, navigation and control is supervised through a dedicated EWS (GNC & VCK), whereas another station is used for the mission and route planning (MOP). The collision avoidance system is supervised through two different EWS, a station allows the control of the ODID subsystem, and another one guarantees the management of the collision avoidance functions (ACA). The RPV EWS receives the on board video stream, through the WBDL datalink, and the aircraft data needed for the piloting, through the NBDL datalink. These data are available on the Ethernet bus shared among all the EWS, and on a separate RS232 point to point link through the communication controller. The piloting telecommands are sent to FLARE via NBDL datalink using a RS232 data bus. In Figure 17 is showed the described architecture.

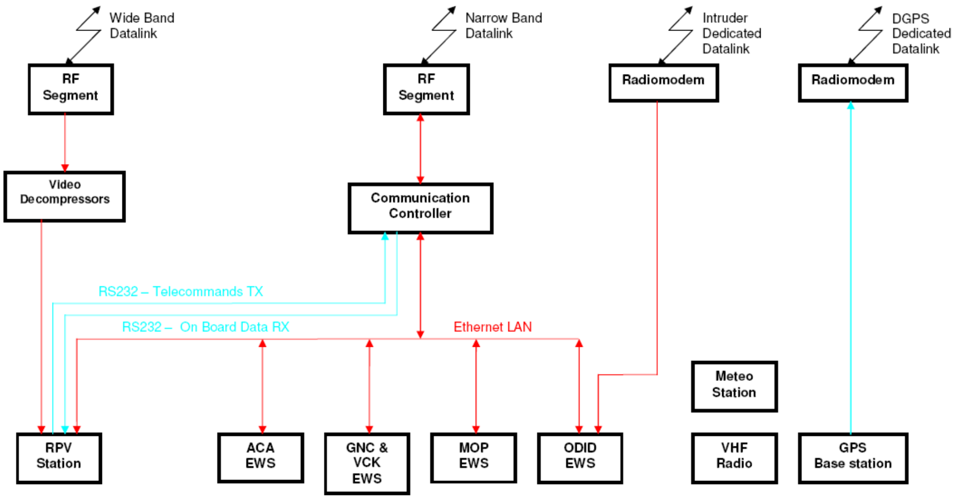

Figure 17: GCS architecture

8.0 CONCLUSIONS

This paper described the configuration of FLARE OPV inside TECVOL project. The wide use of general aviation commercial off-the-shelf components, integrated on existing VLA category aircraft, has made possible the realization of a very flexible and modular flying test bed. The use of a VLA has allowed low costs modifications with reduced integration time and small impact on the aircraft and on its estimated performances. The excellent VLA flying characteristics and the possibility to be operated on very short semiprepared/grass airstrip, with its low operations and maintenance costs, represent additional remarkable advantages for an experimental flying test bed.

9.0 REFERENCES

[1] Harvey M. Gates, John C. Knudsen, *"A Case for Optionally Piloted Vehicle Research and Development"*, Rohnert Park, CA, 2007, AIAA Paper 2007-2760.

[2] J. Walker, R. Kenagy, *"Guidance Material and Consideration for Unmanned Aircraft Systems"*, Radio Technical Commission for Aeronautics (RTCA) Inc., DO-304, Washington DC, March 2007.

[3] J. Utt, J. McCalmont, M. Deschenes, *Test and Integration of a Detect and Avoid System"*, Chicago, IL, 2004, AIAA Paper 2004-6329.

[4] P. S. Anderson, *"Development of a UAV Ground Control Station"*, MSc. Thesis, Linkoping University, 2002.

[5] *"Development and Operation of UAVs for Military and Civil Applications"*, RTO-EN-9, April 2000.

[6] TECNAM *"P92-Echo S Flight Manual"* Capua, 2004.

[7] TECNAM P92-Echo S www.tecnam.it