FLARE: AN OPA FOR TECHNOLOGY VALIDATION USED AT THE ITALIAN AEROSPACE RESEARCH CENTER

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1. ABSTRACT

Validating aircraft technologies at high Technology Readiness Level (TRL) is usually a very high cost and risky activity. In order to satisfy its flight validation needs for RPAS enabling technologies, CIRA set up a multipurpose flying platform named Flight Laboratory for Aeronautical REsearch (FLARE), exploiting the possibilities offered by the Optionally Piloted Aircraft (OPA) paradigm. FLARE is based on the certified version of the P92 Echo Super aircraft produced by TECNAM and modified to integrate proprietary experimental set-ups. The flight experiments are performed in Optionally Piloted flight mode with the attendance of the pilot in command (PIC) which can always take back the control of the aircraft simply overriding the flight commands. FLARE has already been used successfully in the National Program for Aerospace Research (PRORA) framework and it is expected to be used in the framework of European projects for RPAS technology validation. Due to its characteristics of flexibility and low operational cost, the FLARE OPA offers a broad spectrum of uses for technology validation in aeronautics such as avionics, aero-structural, propulsion and sensors technology. The paper will provide a technical description of the FLARE vehicle configuration and its performance, the modification applied to the baseline vehicle, the description of the payloads   carried on board and the description of the process to get the Permit to Fly from the Italian Airworthiness Authority (ENAC) including the relevant test plan. The paper will also describe the configuration and performance of the dedicated Ground Control Station (GCS) hosting an innovative data-link system which ensures communication tasks between the Ground Control Station and the on board payload (digital data exchange, on board video transmission and vocal communications). The GCS allows test engineers both to monitor the flight experiments and to interact with the on-board payloads. In conclusion, the paper will provide technical information on how an OPA may represent a valid flight platform for technology validation.

2. ACRONYMS, ABBREVIATIONS, SYMBOLS

- ADSB: Automatic Dependent Surveillance - Broadcast
- AFB: Air Force Base
- AFM: Aircraft Flight Manual
- AGL: Above Ground Level
- AMM: Aircraft Maintenance Manual
- ASI: Italian Space Agency
- ATM: Air Traffic Management
- ATCO: Air traffic Controller
- CA: Continuous Airworthiness
- CAMO: Continuous Airworthiness Maintenance Organization
- CAPEX: CAPital EXpenditure
- CC: Configuration Control
- CIRA: Centro Italiano Ricerche Aerospaziali
- CS: Communication System

- DOC: Direct Operating Cost
- EASA: European Aviation Safety Agency
- ENAC: Ente Nazionale Aviazione Civile
- EPCU: Electric Power Control Unit
- EPMS: Electrical Power Management System
- FD: Flight Director
- FLARE: Flying Laboratory for Aerospace Research
- FCC: Flight Control Computer
- FTI: Flight test Instrumentation
- FTP: Flight Test Plan
- GCS: Ground Control Station
- GNC: Guidance, Navigation and Control
- GPS: Global Positioning System
- MTOW: Maximum take-off weight
- NOTAM: Notice-to Airmen
- OPA: Optionally Piloted Aircraft
- PIC: Pilot in Command
- PRORA: PROgramma nazionale di Ricerca Aerospaziale
- PTF: Permit to Fly
- RFO: Remote Flight Operator
- SOF: Safety of Flight
- VLA: Very Light Aircraft
- VMC: Visual Meteorological Conditions
- VTS: Vehicle Tracking System

3. INTRODUCTION

While the term "low cost" is easily associated to commercial air transportation in the common view of providing cheap flights to passengers, it may not be the case for flying experimental payloads. Indeed, flight tests are still very "high cost", lengthy and risky activity and may easily turn into the worst nightmare for aerospace program managers. However, without going into real flight conditions, no aerospace technology can get the label "flight qualified" which opens the door to deploying technologies into real products. Being more and more involved in R&TD projects requiring flight test demonstration, the Italian Aerospace Research Center (CIRA) has developed a different approach in order to get rid of the cost and the logistic burdens typically associated to flight experiments without losing significance in the research outcome.

The FLARE aircraft

Thanks to the support of the National aerospace research program PRORA, CIRA has developed an Optionally Piloted Aircraft (OPA) derived by a commercial, off-the-shelf, ultra-light aircraft, a TECNAM P92-Echo S. The aircraft, which was named FLARE (which stands for Flying Laboratory for Aeronautical Research), has been modified to perform as a flying test bed capable to provide flight validation of autonomous flight technologies, to test

traffic separation scenario based on ADS-B technology and improve weather-forecast satellite based systems. CIRA also plans to use FLARE, in future, for the development of aero-structural innovative technologies such morphing wing and propulsion, as part of the Italian Aerospace Research program (PRORA).

In order to get the authorization to fly the modified aircraft under the current Italian airworthiness regulation, CIRA has coordinated a complex technical effort which included design, modifications as well as continuous airworthiness of the basic aircraft and its systems, producing the necessary documentation to ensure the compliance to the CS-VLA (Very Light aircraft) certification regulation, adopted as a reference. This technical process involved the contributions of nearby airframe manufacturers such as TECNAM and OMASUD, the local Flying Club and external consultants for the development of the necessary documentation contributing to the Safety of Flight assessment issued under CIRA responsibility.

Thanks to a fruitful technical cooperation with the Italian Civil Aviation Authority (ENAC), CIRA has finally achieved the relevant Permit to Fly (PTF) on April 14, 2016. The permit, valid for one year, has been issued on the basis of the system and safety documentation produced by CIRA in accordance with the recent ENAC NAV32E regulation relevant in-flight testing activities.

As soon as the PTF was available, CIRA started an intensive test campaign, which included a maximum of 38 experimental flights, operating the aircraft from the local Capua airport (ICAO LIAU).

4. THE OPA PARADIGM

A clear definition of OPA does not exist yet within European airworthiness rules. However, since 2010, this category has been subject of the FAA order 8130.34 which defined the rules for "Airworthiness Certification of Unmanned Aircraft Systems and Optionally Piloted Aircraft". This order establishes procedures for issuing special airworthiness certificates in the experimental category or special flight permits to unmanned aircraft systems (UAS), optionally piloted aircraft (OPA), and aircraft intended to be flown as either a UAS or an OPA, under the designation OPA/UAS. According to FAA an OPA is "an aircraft flown with a safety pilot onboard where remote control of the aircraft may be engaged or disengaged by the safety pilot. Once the system controls are engaged, the aircraft is controlled by a pilot operating the ground control station. Whether the system control is engaged or not, the pilot in command (PIC) will always be the pilot sitting in the aircraft." The paradigm is based on an on-board safety pilot (i.e. PIC, pilot in command) for the purpose of overriding the system in the case of malfunction or any other hazardous situation.

According to FAA order 8130.34, all traditional manned aircraft are in principle eligible for modification. CIRA choose to modify a TECNAM P92 Echo Super for its low CAPEX, low DOC, easiness of airworthiness support since the factory is nearby CIRA premises and for the availability of an EASA certified version. Although this FAA order was not applicable in Italy, it represented a sound reference for the purpose of obtaining a Permit-to-Fly and many of the decisions taken along the process to get the Italian permit-to-fly were quite similar to those suggested or requested by FAA.

The validity of the OPA paradigm is being demonstrated in several projects worldwide as it is becoming more and more accepted for its cost and operation benefits. Recent European projects include:

- AT2TECH RV-OPV-EV a two-place, single-engine LSA aircraft based on the Evektor Eurostar SLW
- Diamond DA42 Centaur Optionally Piloted Aircraft (OPA) developed together with AURORA SCIENCES
- Q01 MALE optionally-piloted aircraft developed by Reiner Stemme Utility Air Systems (RS-UAS), primarily for the Qatar Armed Forces.

5. OVERVIEW OF THE FLARE FLYING PLATFORM

3 kW auxiliary alternator

FLARE is based on a P92 ECHO S, serial number 869, an ultra-light aircraft manufactured by TECNAM Aeronautical Construction with a MTOW of 450 kg and 100 Hp ROTAX engine 912 LS. The Echo S has an EASA certified version, which is the P92 JS, with higher MTOW (550 kg) and same engine power. In order to support the Permit-to-Fly process, TECNAM issued a compliance declaration, stating the similarity of the P92 Echo S to P92JS and identifying the minor structural modifications necessary to ensure similarity such as the installation of the stronger wing struts foreseen in the JS certified version.

With respect to the P92 JS, CIRA implemented other aircraft modifications in order to transform a conventional ultra-light aircraft in a flying laboratory. These modifications included:

- an auxiliary 3 kW alternator with a larger engine nacelle;
- an air data boom near the left wing tip;
- the removal of the left (pilot) seat in order to make room for the scientific payload;
- the installation of equipment supporting plates in the baggage compartment;
- inspection openings and small fixtures on the fuselage and wing panels to allow installation of antennas and instrumentation.

In addition to the above modifications, the aircraft also hosts electronic hardware to provide electrical power to the different subsystems and command and control functions to enable automatic flight conditions. The experimental set-up power supply is guaranteed through a distribution system named as EPMS (Electrical Power Management System). The EPMS is a very complex set-up that includes the necessary functions dedicated to power supply generation, filtering, distribution, monitoring and test such as: alternators, buffer battery, Ground Power Supply Unit, DC/DC converters, Electric Power Control Unit (EPCU), Micro Controller and Conditioner and the Battery Test Unit.


EPCU

The EPCU has the task to receive the voltage coming from the different sources (e.g. Alternators, batteries, DC/DC and GPSU) providing filtering and distribution functions to the on-board equipments.

In case of failure of the 3kW auxiliary alternator, the power supply is ensured for a limited amount of time by two lead batteries mounted in the fuselage. In this

event, the system will feed some of the loads of the experimental set-up for about twenty seconds. The system is also designed to ensure protection for all the loads supplied directly through fuses placed upstream of the power cables. Two circuit breakers are installed. The first protects the general line feed may be used by the on-board pilot to shut-off the whole experimental set-up. The second breaker is located to protect the power line from the alternator voltage regulator (ACU). Both are located at the bottom of the cockpit in a position clearly visible to the pilot.
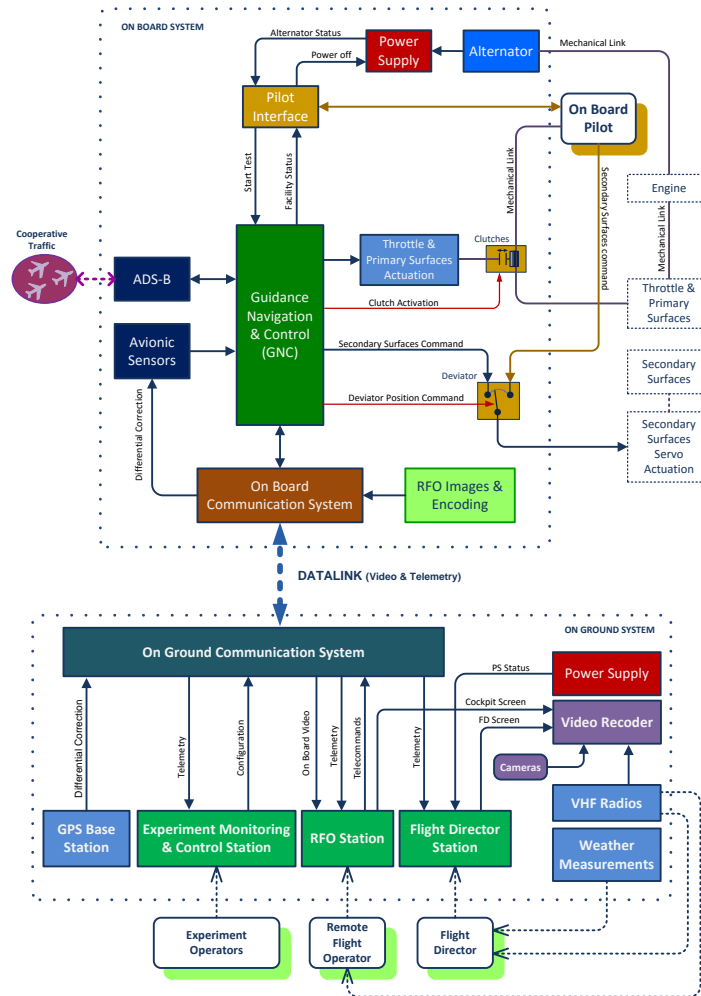

ELECTRONIC ARCHITECTURE

A proprietary FCC is capable to provide control, in closed loop, of the movable surfaces and the engine throttle using the data coming from the Navigation sensors (AHRS, GPS, INS, ADS, Magnetometer, etc.). Servo actuators were installed on the command line of the primary control surfaces and on the engine throttle. In the engaged mode, each electro-magnetic clutch links the actuator to the relevant command line.

The mechanical connection of actuator-surface / throttle is performed via a clutch. Even when the actuator is engaged, the pilot can resume the mechanical control overriding the actuators, with the consequent slipping of the clutch on the flywheel. The clutch rest position disconnects the actuator.
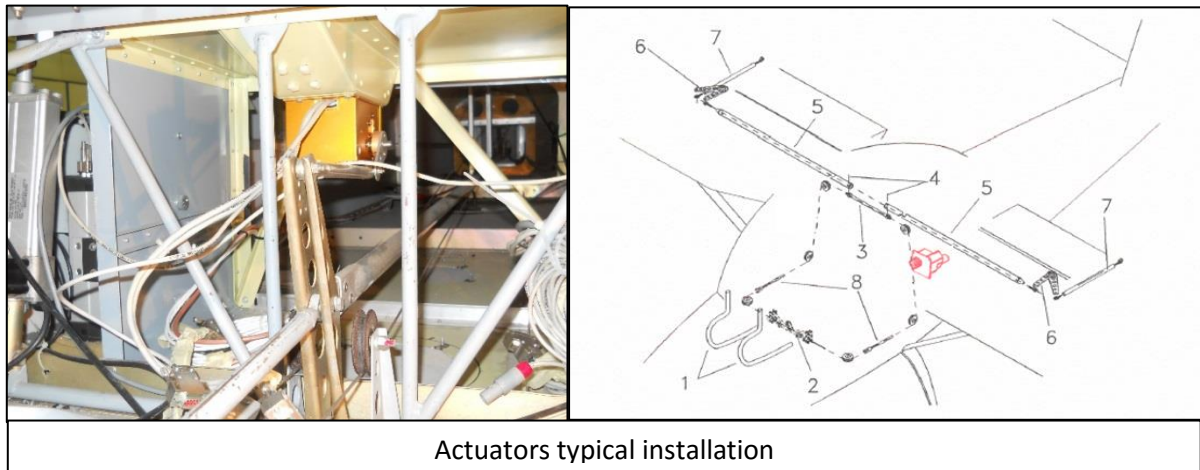
Actuators typical installation
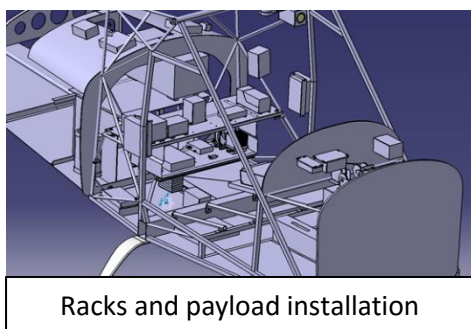
Racks and payload installation

To accommodate all experimental avionics on board, the left seat was removed and the baggage bay space was used as well. By doing so, the major portion of the equipments were installed inside the cabin for easier operation and maintenance. For a more rational installation of the embarked systems, three mounting trays were designed to fit the different equipment. Their design was part of the structural verification process in order to ensure the capability to withstand the expected load conditions.

The communication, positioning and datalink tasks were allowed by a number of different antennas for the execution of the flight experiments, which were not part of the JS version. In total, 2 VHF antenna, 3 GPS antennas, 2 LOS Data-link antennas, 1 ADSB receiver antenna and 1 ADSB transponder-out antenna plus a satellite link antenna were installed on the upper wing and on top/bottom fuselage.

Finally, the original cockpit was modified to install additional visual alarms, instruments and markings to be managed by the safety pilot during the remote and automatic flight piloting phases.

FLARE cockpit

The experimental sections of the cockpit containing FTI displays were delimited by the typical orange strips.

6.   THE AIRWORTHINESS FRAMEWORK

The fundamental paradigm, upon which the entire airworthiness process was based, is the similarity between the P92 Echo S and the EASA certified version P92 JS   acknowledged by ENAC. Therefore, only the differences with respect to the JS version were subject to ENAC verification in a supplemental logic. From the flight safety standpoint, the presence of a pilot in command on board, typically a production test pilot acting as safety pilot capable to take over the control of the aircraft at any time and under any operating condition of the experimental set-up, was also an important pillar of the PtF process.

The compliance to each requirement was achieved by providing the necessary documental evidence to ENAC, which approved its content thru a formal review process, by using a

Compliance Check List. Taking into account the aircraft category, its ability to perform flight operations in safe conditions was demonstrated with reference to the following basic rules:

- NAV 32E for identifying the process to get the permit-to-fly;
- CS-VLA for general and specific Airworthiness Requirements;
- ICAO Annex 16 chap. 10, Volume I for the noise requirements;
- NAV 4F for electronic equipments;
- National Technical Regulations III/30/C for "equipment and operational requirements for aircraft".

27 documents were delivered to ENAC along the process, but the most relevant documents referred into the PtF were:

- the Aircraft Flight Manual, including a special part with all the limitations related to the experimental flights;
- the Aircraft Maintenance Manual, including a special part related to the experimental set-up;
- the Flight Test Plan, describing the flight tests to be carried out in the campaign and all the relevant information to the operational team;
- the Safety of Flight, addressing any issue critical for Safety and the Hazard Analysis;
- the Configuration Control document containing the updated information about the FLARE aircraft and the Ground Control Station configurations.

Relevant tests requested by ENAC for delivering the permit to fly were:

- EMC/EMI with the entire the set-up switched on;
- Operating temperatures of the equipment;
- Actuators override capability.

ENAC and CIRA also agreed a set of flight limitations to be applied, in case the experimental set-up is operating: flight allowed only in VMC, the minimum altitude at 750 feet agl, the max altitude at 3000 feet agl, the maximum angle of bank in maneuver 30 ° and the use of the set-up was strictly forbidden during take-off and landing.

7. COMMUNICATION SYSTEM (CS)

The FLARE aircraft and the Ground Control Station aircraft are equipped with a two-way data-links, called Communication System (CS), used for transferring telemetry, platform housekeeping data, data generated by experiments, on-board video, remote controls and configuration data and service.

The CS is composed of a flight segment and ground segment. Having to allow an exchange of bidirectional data between the aircraft and the ground, the CS has two separate channels of the S-band unidirectional simplex communication. The first, operating in down-link called WBDL (Wide Band date link) is able to transfer from the aircraft to the GCS up to 12Mbps, while the second, operating in up-link called NBDL (Narrow Band Data-link) is able to transfer from the GCS up to 1 Mbps (and beyond, depending on the range to cover). The nominal range is about 20km that may be increased by decreasing the amount of information to be exchanged.

Communications, both in down-link that up-link, are asynchronous, i.e. there are no restrictions on timing and / or synchronization between the systems, units and components operating in reception and transmission in the same segment.

The WBDL ground segment is characterized by two separate receiver chains, respectively associated to a directive antenna and an hemispherical coverage antenna. The use of a combiner allows the simultaneous use of the above two antennas so to increase the robustness of the system: the hemi-omni antenna, in fact, operates mainly when the airplane is near the ground station, namely in the situation where it is more difficult to aim properly the directional antenna in the direction of the aircraft. Both receivers lines are equipped with a damping system controlled by a suited software, which avoids that the power transmitted by the onboard segment may saturate or damage the equipment used for reception.

The same software allows, also, to decouple, manually or automatically, the directive antenna from the respective receiving chain, when the distance between the aircraft and the directive antenna and such as to not make sufficient the intervention of the mitigation system. The power dimming system and the antenna decoupling are controlled on the basis of the received RF power monitoring and GPS location of the aircraft received telemetry data sent to the ground.

The NBDL ground segment is characterized by two separate transmission lines, respectively associated with the directive antenna used for the WBDL (both WBDL channels and NBDL may use the same antenna via a diplexer) and to a different hemi-omni antenna, connected

GCS and telemetry antenna

through an RF switching system to the ground transmitter. The two lines, of course, are not simultaneously active, but are alternately connected to ground transmitter by means of the above mentioned software.

The directive antenna for both the WBDL and the NBDL is a satellite dish of about 1.2m in diameter. For pointing purposes, this antenna has been equipped with a tracking system called Vehicle Tracking System (VTS). The evaluation of the aiming angles is made on the basis of the position data received from the aircraft. The real-time software has been equipped, in addition, with prediction algorithms about the position of the aircraft, based on the latest received positions, to make it more robust to the interruption of the data stream as a result of signal loss. In a recent flight test campaign, the CS showed the proper functioning in the above configuration for aircraft distances up to 20km.

8. GROUND CONTROL STATION (GCS)

The Ground Control Station (GCS) architecture is made of the following operating sections:

– On Ground Communication Station: ensure communications between the Ground Control Station and the onboard systems for sending data remote control / configuration data and for the reception of telemetry data. it also allows reception of video generated by the system "RFO Images & Encoding" board over that sending the differential correction generated by the GPS base ground station and sent to the onboard GPS.

FD display in GCS

- Monitoring & Control Experiment Station: Station equipped with a suitable workstation with the task to monitor, in real time, the performance of the experiments on the functions to be validated in flight.
- RFO Station: Station equipped with End Effector, and with displays and interfaces control compliant to avionic standards to enable remotely the execution of the control function tests of the flying platform.
- Flight Test Director Station: Station equipped with display and interfaces to allow the management of the mission, the supervision of the planned experiments and communication with the FLARE pilot, and that of any traffic simulating aircraft cooperating, via voice connection. Furthermore, a VHF radio is installed to allow communications between on-board pilot and the Flight Test Director.
- GPS Base Station: GPS Base Station generates differential correction intended to GPS RTK board.
- VHF radio: There are two VHF Radio installed respectively in the position of Flight Test Director and the Remote Pilot station.
- Weather Measurement: Weather Station that provides information on the conditions weather on the ground near the runway.
- Audio-video recording system: System used to record what happens in shelter during the in-flight testing. This can be helpful during the phases of debriefing or in general the analysis of the results of the experimental phase.

FD and RFO stations

9. THE FLIGHT TEST PLAN

After receiving the permit-to-fly, FLARE is currently involved in a flight test campaign whose objectives are:

- control the basic performance and basic flying qualities of the vehicle after the changes made to the basic configuration of the aircraft for the installation of the experimental set-up;
- check the data-link performance, defining the actual operational envelope;
- verify the performance of the navigation and control software;
- verify the performance of remote piloting control station;
- verify the performance of the separation capability provided by the ADS-B based system;

The scheduled tests have been grouped into test phases, so as to ensure an incremental approach to the achievement of the different objectives.

Therefore, the flight test campaign is articulated in three phases in order to accommodate several instances. After the modifications on the basic aircraft, which also included the replacement of the propeller, the vehicle performance calls for verification. Before conducting experiments on autonomous flights, comprising aircraft separation assurance, the full capability of key elements devoted to this task, such as data-link, GNC software and ADS-B system, must be proven. The flight tests focusing on the above mentioned aspects constitutes the first part of the experimental campaign (shake down): the aircraft is piloted by the PIC and data are acquired, collected and deeply analyzed. Once the aircraft and the experimental set-up is ready for autonomous flight proof, the RAID experiments take place (2nd phase). The RAID (RPAS-ATM Integration Demonstration) project is shaped to demonstrate the effectiveness of procedures and technologies applied to RPAS in view of

their integration in the civil aviation system. Such an integration stems from the perspective of the future ATM (Air Traffic Management) system proposed and developed by SESAR (the Single European Sky ATM Research initiative). For this purpose, the cooperating traffic is represented by two aircrafts, one of them is a manned aircraft of the same class of FLARE and the other is a small RPAS whose weight does not exceed 5Kg. The procedures define the kind of interactions among the involved test operators, mainly the remote flight operator (RFO) and the simulated air traffic control officer (ATCO2) which intervenes for all of the operation within the flight test area while the real air traffic control officer (ATCO1) manages interactions between the aircraft concerned in the tests and the general aviation traffic. The technologies that constitutes the core of the experimental set-up are based on sensors, on actuation devices and on a flight control computer (FCC) which is equipped with proven software to allow autonomous way-points navigation and separation assurance. As far as autonomous navigation is concerned, the outcome of the RAID tests allows for a useful evaluation of the operators performance (RFO and ATCO2), with particular reference to the workload and situational awareness. With respect to the separation assurance, the automatic management system of separation based on ADS-B aboard a RPAS is opposed to the separation provided by ATCO. Flight demonstration intends to show that the proposed algorithms are able to assure aircraft separation in real-time, so as to avoid situations of potential conflict, even without the assistance of a human operator. As such, it can be considered as a fundamental step for promoting the integration of unmanned aircraft into non-segregated airspaces. Two of the flight tests of the RAID campaign are planned aiming to verify the workload of RFO and ATCO2 in managing situations of loss of separation, due to simulated conditions respectively of GPS spoofing and jamming (GPS signals are faked to alter the aircraft real location and steer the aircraft to an unwanted location).

Finally, the 3rd phase of the flight test campaign concentrates on the AIRONE project (sAtellite lInk for personal aiRcraft weather informatioN sErvice) which is a research initiative jointly funded by ASI (Italian Space Agency) under the 3rd EMS Frame Program on TLC and Integrated Applications. In this project, an avionic payload, consisting of a set of digital sensors and devices for processing and storing data, is embarked on board for the verification of systems to support navigation even in bad weather conditions.Basically, the AIRONE system is a navigational aid in adverse weather conditions, capable of detecting any hazard weather along the planned route and suggesting the pilot an alternative route by which circumvent the hazard. The planned route, as well as the suggested alternate route, are displayed by means of a tablet device portraying meteorological graphics and geographic elements on the actual digital aeronautical map.

Taking into account all of the requirements coming from the three different phases of the test campaign, the flight test area was identified bearing in mind the following considerations:

– to avoid towns and densely populated areas;
– to give priority to areas nearby CIRA premises and Capua airport to facilitate logistics and ground operations;
– to remain within Data-Link coverage limits;
– to make sure the flight trajectory fall within the test area;
– to minimize interferences with the airports of Capua and Grazzanise (and their air spaces).

The flight test plan, which is one of the required document for achieving the PtF, has resulted in a very detailed report where procedures are formalized, flight test scopes are described, flight test cards are duly prepared and roles of each flight test team member are clearly defined. Since the flight test area falls within the CTR of the Grazzanise Air Force

Base, a specific NOTAM was released by ENAC under the endorsement of the Grazzanise AFB. The area was about 18.5 km long and 6.5 km wide. Since the flight trials were restricted to an altitude below 3000 ft, commercial traffic was allowed to cross the FTA at higher flight levels without interfering with CIRA flight operations, even in the case of incoming and outgoing traffic from Naples International Airport.
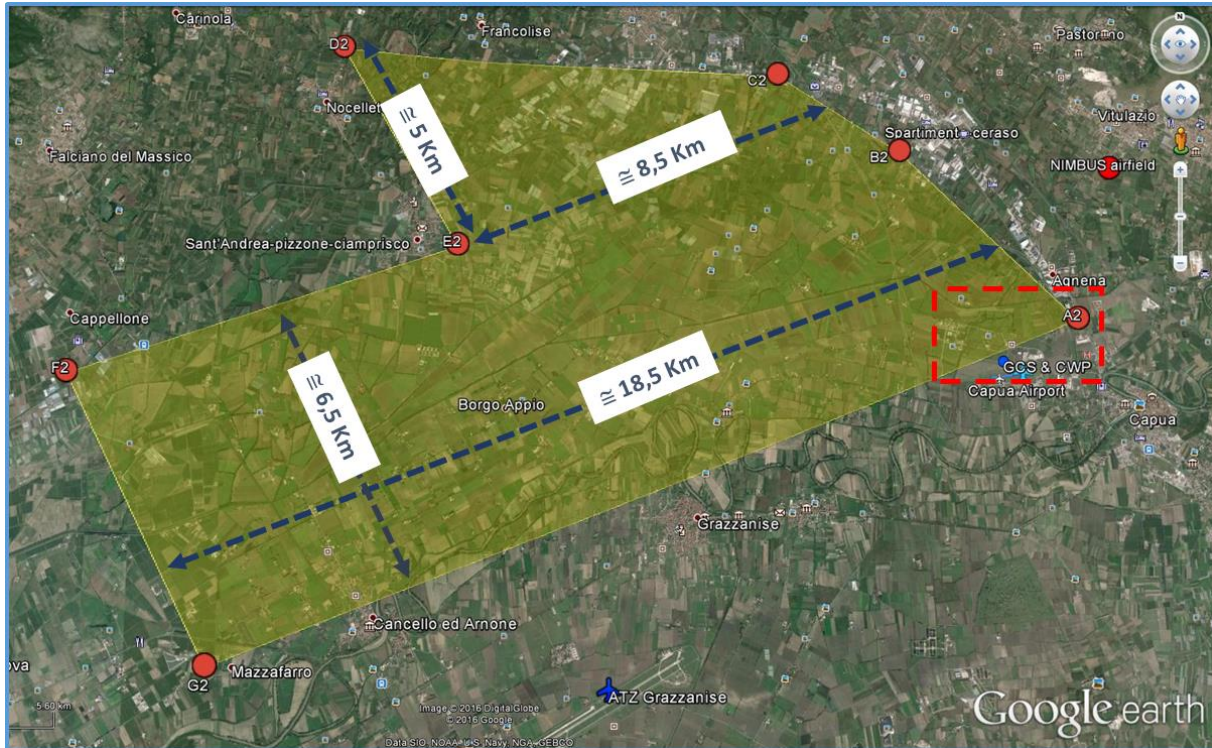
Flight test area – green shaded

10. LESSONS LEARNED

The choice to use an OPA for RPAS technology validation at CIRA provided several advantages over a fully RPAS platform including: take-off and landing from a normal airport, flight trials performed into a non-segregated area covered by NOTAM, reduced logistics footprint, high operation efficiency up to 3 flights per day and limited downtime for maintenance operation. Also, the process to ensure the permit-to-fly was simplified if compared to an equivalent process for an RPAS platform. In the end, the cost saving with respect to a test campaign performed with an RPAS was significantly lower. The process would probably have been more straightforward starting directly from a certified version of the aircraft instead than its ultralight version. Last, the most important key point was the timely and open involvement of ENAC (Italian Aviation Authority) which provided a sound guidance thru the rule "forest" and the Italian Air Force for their endorsement to operate in the Grazzanise CTR.

11. ACKNOWLEDGEMENTS

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