DeSIRE 2: Satcom Modeling and Simulation a Powerful Tool to Enable Cost Effective and Safe Approach to RPAS Operational Deployment

Giancarlo Cosenza[1], Alessandro Mura[2], Alessandro Righetto[1], Fabio De Piccoli[1], Dario Rapisardi[1], and Laura Anselmi[1](✉)

[1] Telespazio, a Leonardo and Thales Company, Rome, Italy
{giancarlo.cosenza,alessandro.righetto, fabio.depiccoli,dario.rapisardi, laura.anselmi}@telespazio.com
[2] Leonardo SpA, Rome, Italy
alessandro.mura@leonardocompany.com

Abstract. Drones are a breakthrough systemic solution for a number of applications, from institutional and governmental purposes to a wide range of possible commercial applications. Autonomous and remotely controlled machines, fully integrated with many devices all connected wherever they are, are going to be a major part of the Internet of Things (IoT), where satellite communication plays a pivotal role.

Modelling and Simulation (M&S) are very helpful tools in the design and risk reduction of sustainable integration of Autonomous Systems into cost effective operational activities. As matter of fact, the M&S approach is extensively used in the DeSIRE 2 (Demonstration of the use of Satellites complementing Remotely Piloted Aircraft Systems integrated in non-segregated airspace 2nd Element). The ongoing Project, recently launched by the European Space Agency and the European Defence Agency, aims to demonstrate a service based on a Remotely Piloted Aircraft (RPA) flying in Beyond Radio Line of Sight (BRLOS) using space assets (SatCom, SatNav). The project has been kicked off in April 2015, after a selective process among important European consortia, and is leaded by Telespazio.

Through Model and Simulation, within DeSIRE 2 it will be possible to:

- Decrease costs, considering the loop “designing, building, testing, redesigning, rebuilding, retesting”;
- Make easier the “what-if” definition and analysis allowing the definition and experimentation and test of CONOPS;
- De-risk the overall project.

To characterize adequately the Satcom link of DeSIRE 2 against the stringent performance requirements of the aeronautical context, an intensive measurement campaign is required. Concerning flight, the testing hours for a large RPAS are very costly. Therefore, it has been decided to add to the experimental flight campaign a combination of simulated and emulated environments, which replicate, as much as possible, the real operational conditions.

J. Hodicky (Ed.): MESAS 2016, LNCS 9991, pp. 309–336, 2016.
DOI: 10.1007/978-3-319-47605-6_26

The models used in the simulation will be refined during the iterations, increasing the robustness and reliability, thus, making available results otherwise difficult, costly and even dangerous to be experiment directly in the real world.

An overview of the main expected results and how they should support the European standardisation and regulatory activities in the framework of the Air Traffic Insertion (ATI), especially for the definition of future satellite-based command & control datalinks, will be given as well. The paper will explain how the project intends to characterise the Satcom command and control datalinks for both Ka and L frequency bands.

It will be described how the threefold simulation/emulation/flight campaign approach will be followed to demonstrate that the system meets or exceeds the design requirement by combining:

– Mission Simulation, including satcom, airborne, mission applications and combination of the above segments;
– (Satcom) Emulation with real satellite full communication and RPA/RPS simulators.
– Mixed simulation and emulation will also be considered and real hardware will be introduced in the simulation loop (e.g. real satellite transponders and on board satcom terminals);
– Flight Campaign.

At any stage of this iteration, the results will be fed-back into the simulation/emulation chain. For example, the measured jitter and error rates will be introduced to update the parameters for the simulators for more trustworthy results.

1 The DeSIRE 2 Project - Quick Introduction

The project started about one year ago, with a budget of 2.6 M€. The winning consortium is composed by e-GEOS, Leonardo, Piaggio Aerospace, ViaSat, Skyguide and Ædel Aerospace (Fig. 1).

After an initial design phase now concluded with its Critical Design Review held on last January, the ongoing Phase 2 of the project will pass through its manifold demonstration phases.

DeSIRE 2 will field a complex mix of national and European technologies including, as key innovation, the Piaggio Aerospace's RPAS P1.HammerHead (P1. HH), with the central collaboration of Leonardo most of the on-board avionics and of the Remote Pilot Station (RPS or Ground Control Station - GCS).

Telespazio plays the role of system integrator and, together with its subsidiary eGeos, will be the service provider for all the End Users involved.

The project can count on a User Advisory Board composed by key leading Institutions in the selected application areas such as the Italian Coast Guard (ICG), Guardia di Finanza (GdF), Department of Civil Protection (DPC), the European Fish Control Agency (EFCA) and Armasuisse.

Fig. 1. DeSIRE 2 industrial team and advisory boards

It is worthwhile to note also the important contribution from the national competent Air Traffic Insertion (ATI) Stakeholders. ENAC (Ente Nazionale per l'Aviazione Civile) and ENAV (Ente Nazionale di Assistenza al Volo) that will participate along the entire project life to consolidate the operational and regulatory requirements to operate RPAS in response to institutional needs, in close coordination with the European and International ATI Stakeholders European Aviation Safety Agency (EASA), Eurocontrol; Single European Sky Air Traffic Management Research (SESAR), Joint Authorities for Rulemaking on Unmanned Systems (JARUS).

During the flight test campaign, the P.1HH will be fully integrated with the Telespazio and e-Geos satellite infrastructures and through them to the involved End User Operating Centres, to provide real time and near real time value added services.

Among the most important planned activities, Telespazio is in charge of the development of the air/ground communication system integrating a twin SatCom systems (in both L- and Ka-bands - in partnership with Viasat) for both Control and Non Payload Communication (CNPC) and Payload data links transmission. Furthermore, the Prime, is in charge of the development of innovative satellite navigation services, based on Global Navigation Satellite System (GNSS)/European Geostationary Navigation Overlay System (EGNOS) receivers, On the side of End User service provision, e-Geos will take care of the integration of the real time surveillance data acquired by RPAS with that derived from Earth Observation satellites, providing high benefit services. Leonardo will also provide the overall Mission Simulation environment for which Telespazio, in turn, is in charge of the SatCom simulator components. Telespazio is also in charge of the Emulation Platform.

The Italian Space Agency (ASI) will make available the Ka band SatCom resource from the Athena Fidus satellite.

2 Background and Related Works

The European RPAS Steering Group (ERSG), a group of stakeholders gathering the main organisations and experts of the European aviation, including EASA, EUROCONTROL, EUROCAE, SESAR JU, JARUS, was founded with the purpose of establishing a roadmap for the safe integration of civil RPAS into the European aviation system [1].

DeSIRE2 is part of the RPAS related ESA IAP (Integrated Applications Promotion) activities focused on maritime surveillance, inside the ERSG Regulatory WG Roadmap [2].

DeSIRE2 represents the Second Element of the joint ESA - EDA RPAS demonstration roadmap aimed at supporting the development of governmental/institutional & commercial services based on Remotely Piloted Aircraft Systems (RPAS) supported by satellites and integrated into non-segregated airspace.

Objectives are to develop and demonstrate a service based on a Remotely Piloted Aircraft (RPA) flying in Beyond Radio Line of Sight (BRLOS) using space assets (SatCom, SatNav) for satellite communications, extending the work performed in Desire – First Element [3].

The project addresses the following perspectives:

- Regulatory perspective: contributing to some of the regulatory improvements in the European Regulatory Roadmap, and disseminating the results to relevant regulatory and standardisation bodies. Main contribution will be represented by the definition and validation of certification requirements (e.g. RCP - Required Communication performance - in terms of transaction time, Continuity, Availability and Integrity [6]) for RPAS C2 link satellite communication according to the approach proposed by JARUS [4, 5].
- User perspective: developing the applications and demonstrating the operational service provision shortly after the completion of the project.
- Technology perspective: demonstrating the technology required for supporting the regulatory improvements defined by the European RPAS Steering Group and satisfying user needs.

3 DeSIRE 2 Mission Simulation

3.1 Distributed Simulation Environment Implementation Using an Iterative Approach

The development of technologies and standards is the key for the full integration of Remotely Piloted Aircraft System (RPAS) in the worldwide airspace.

These types of aircraft have to be operated taking into consideration the risk of each specific task, by applying proportionate rules suitable for each different environment.

The evolution of the RPAS technology and rules cannot be carried out without a significant testing period, CONOPS studies, "what-if" scenarios, and training phases for all the involved operators. All of the above must have a large agreement among all the stakeholders, from the RPAS industry to the National and International Authorities.

Just to give an idea of the complexity of the topic, one of the most important challenges in the Instrument Flight Rule (IFR)/RPAS insertion is to demonstrate the validity and limits of:

- Ad-hoc operational procedures to operate RPAS in non-segregated airspace;
- Airworthiness rules that normally are used to "certify" an RPAS for experimental scope;
- Existing technologies and systems compared to the requirements and capabilities of the current and future ATM systems (e.g. SESAR project).

Keeping these in mind, the typical problems span from allowing the assessment of the feasibility to introduce RPAS in non-segregated airspace for each traffic density to the use of satellite communication to cope with the Beyond Radio Line of Sight (BRLOS) situation as well as from the definition and test of emergency procedures to the development of Detect and Avoid (DAA) technology. Without mentioning the paramount issues of possible cyber-attack to the whole system.

Considering the extreme practical difficulties and very high costs in setting up test and trials in a real environment, the operational simulation approach seems to be the right if not the only solution.

Furthermore, the multiple technologies involved together with a number of stakeholders, points out that the Distributed Simulation is a suitable solution to cope with a myriad of technical and user's requirements.

To face this complex situation, in the DeSIRE 2 project there are three main guidelines:

- Iterative approach;
- Extensive use of distributed simulation;
- Final user direct involvement with requirements elicitation and near-simultaneous testing.

3.2 Iterative Approach

As shown in Fig. 2 the project is evolving from a pure simulated environment to a live system where the real aircraft will fly in a real scenario. The simulated scenario was chosen taking into consideration the feasibility in terms of cost, time and permit to fly as required in a real setting.

Wherever possible, the simulated system will be completed with real components. In this way, it will be possible to "superimpose" the two environments creating a mixed exercise (real + virtual) where real actors will be able to operate together with simulated parts. Eventually, when all the constraints will be overcome, this approach will be ready for the migration from the mixed situation to the all-real one.

3.3 Extensive Use of Distributed Simulation

The simulation architecture will be the cradle for all the exercises foreseen in the DeSIRE 2 project and it is intended to:

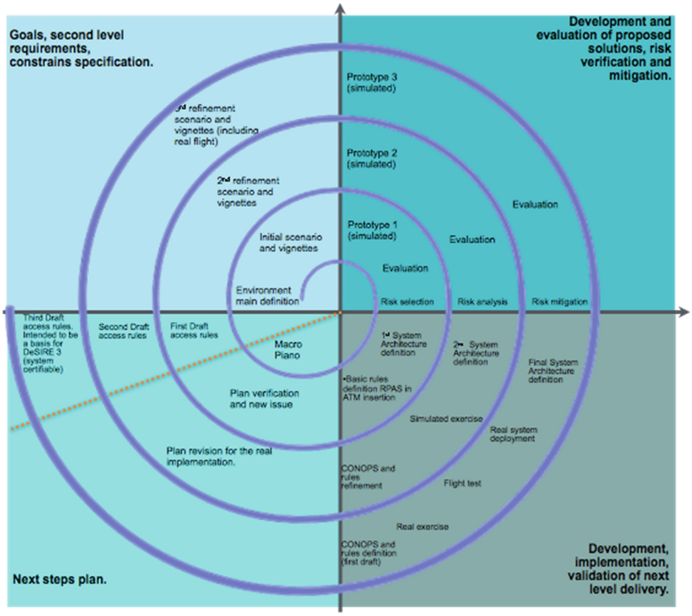

Fig. 2. Iterative approach

- Decrease costs, in particular considering the loop "designing, building, testing, redesigning, rebuilding, retesting, etc.". All the phases that can be simulated are taken off the loop of real tests by using the models created in the initial design. The iterative approach allows for the refining of the models used in the simulation, increasing their robustness and reliability as the project proceeds collecting data coming from the emulation and real flight.
- Obtain results that would be costly, difficult or even dangerous to experiment in the real world (e.g. system complexity and the number of the actors make too expensive and/or physically impossible the real exercise). By using simulation, also critical situations can be investigated without risk. In these cases, simulation will allow the project to run at any level of detail for as many times as needed, being constrained only by the intrinsic hardware limitation. Moreover, a fine tune of time control can be available speeding up or slowing down the experiment according to specific needs.
- Facilitate the "what-if" definition and analysis. In the DeSIRE 2 project, this is particularly important for all the preparatory phases including the definition, experimentation and tests of CONOPS, and the state of related rules. Specific tools to measure the most significant exercises' parameters are in place to facilitate the data gathering and their analysis.
- Investigate the effects of several changes by simply changing the parameters and/or the environmental conditions.
- De-risk the overall project. The simulation will take a key part in all the de-risking steps including the preparation, design and implementation of the real experiments.

In the current implementation each mission's goal is fulfilled by using a simulated aircraft, operating in an ATM sky generated by an IFR traffic simulator integrated with other simulated and real objects while the evolution of the mission simulation is carried out. Examples of these objects are: RPAS ground station; vessel traffic controlled and displayed by a VTS real system, ATM Control Working Positions, other cooperative actors, test targets.

Afterwards, the chain of events recorded will be used to:

- Guide the experiment in the real environment;
- Suggest maneuvers to challenge the real system;
- Compare the results coming from the real field with the previous one.

The latter bullet will have consequently the possibility of fine-tuning the simulation system that will be available for further, more trustworthy, exercises.

3.4 The Distributed Approach

The simulation approach will include the use of single equipment as well as whole systems, depending on the level of needed analysis.

Because of the extreme heterogeneity of the technology and equipment involved, a distributed approach has been adopted. A dedicated network is used, allowing constructive, virtual and, wherever possible, live simulations. Each participating working group, specialised in a specific operation, contributes delivering its portion of virtual simulation.

3.5 The Simulation Network: SimLabs

The Leonardo's Simulation Network (SimLabs in the following) is a scalable and reconfigurable on-demand operating network among simulation laboratories, which establishes a synthetic environment that allows constructive and virtual simulation systems.

The test bed, instead of having a single monolithic simulator able to represent all the characteristics of the overall system, is composed of a network-based federation of simulators. Each involved lab manages and maintains the complete control of its simulator.

The simulation network has been implemented as configurable and scalable environment in which it is possible to:

- Design a synthetic environment where scenarios, objects and related relationships can be defined;
- Design and test equipment, systems behaviour, rules, doctrines, strategies and tactics;
- Allow people to operate on any object, the object's action or rules put in place for the defined scenario;
- Integrate and validate systems.

Each lab is able to participate, in real-time, to the evolution of a specific shared operational scenario, making available simulators, together with people and related expertise without increasing the costs by avoiding equipment duplication. Moreover, each institution is able to maintain all the IPR on the specific piece of software and/or the simulated or real component.

SimLabs could be also seen as a technological asset through which various expertise, skills and tools, available across several Labs can be shared.

Since the co-development and testing with partners have become increasingly common, the technology has been designed to make available the shared environment not only internally but also to industrial, academic or institutional partners in a "hosting service mode".

The subsystems are implemented as federates exchanging data via HLA (High Level Architecture protocol).

The network may also provide the connected sites with a specific support to their system development and performance evaluation activities in a "System of Systems" fashion.

During the last decade, multiple joint events have highlighted the flexibility and the effectiveness of the implementation of a real-time Virtual-Constructive-Live simulation, involving various systems and laboratories.

The network has been connected with several institutions: not only other Leonardo's Divisions but also partners and customers facilities (e.g. the Rome NATO Center of Excellence of M&S, the Italian Navy facilities in Taranto, the Italian Army in different sites).

In its implementation, SimLabs is also used to provide a Proof of Concepts tool offering an environment in which Concepts of Operation can be designed and experimented. Furthermore, it is possible to train and verify the ability of operators, to exercise operational procedures and to interact with command and control systems. Finally, it can be used as a reconfigurable demonstration tool for customers' prospect.

To facilitate the integration, the architecture concept is scalable, starting from the single site is then extended in a step-by-step approach to reach a geographical distributed configuration.

In this way, each group can start working independently on its own portion of project just having in common the local SE.

The capability to grant connection and interoperability is one of the main characteristics of these laboratories. Their high-configurable and scalable architecture allow them to be very adaptable to a wide spread of tests and trials from systems design/analysis to activities including portion of real scenarios.

It is noteworthy that this approach is well known by most of the participating groups and already used in other distributed simulations in previous programmes.

A portion of this network is already available for DeSIRE 2 and a specific set-up and integration among Leonardo's labs is under construction considering the possible extension to other participants in the future projects.

3.6 The Scenario and the Simulated Actors

Following the spiral structure depicted in the Fig. 2 the first step will be to define and implement the simulated scenario.

The zone has been chosen according to the following considerations:

- Significant exercises consistent with real current emergency situations can be carried out;
- A number of possible flight corridors for RPAS are already defined;
- It is relatively easy to define a non-segregated zone for the final exercise.

In the Fig. 3 the zone is shown in the official map of Italian Air Forces.

Among all these possible corridors, a specific subset will be cut out in order to focus only on the itinerary needed for the exercise.

The corridors, currently used in the DeSIRE 2 mission simulation exercise, are shown in Fig. 4.

They include portions of the "Decimo corridor", "Victor corridor", "Trapani corridor", (including "GHOST Areas" (1 and 2), "TC2" and "TC3"), "HESPO corridor", "TANGO corridor".

A new possible corridor starting from the Grottaglie Airport and finishing in the Taranto southern littoral will be also considered.

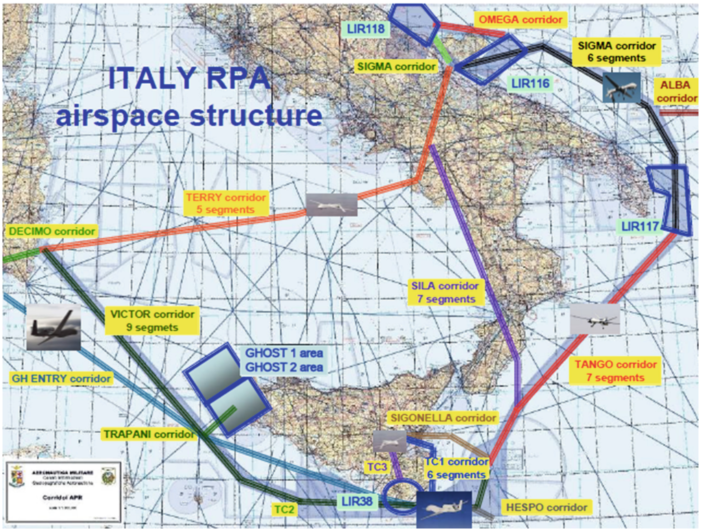

Fig. 3. Zones and Italian air fore map

3.7 The IRIS Environment

To cope with all the previous requirements, for the implementation of the DeSIRE 2 scenario in the distributed synthetic environment, has been chosen a product currently under development in the Leonardo Company.

The IRIS (IFR/RPAS Integration Simulator) is a Simulation Environment that aims at replicating substantial aspects of real RPAS operations in an ATM sky under realistic operating conditions and in a fully interactive fashion.

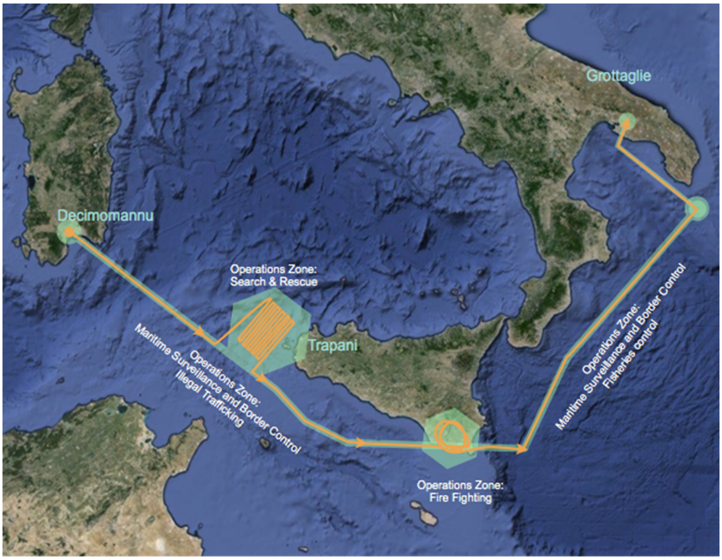

Fig. 4. Simulated scenario

It is based on SimLabs technology and is intended, in this specific implementation, as a tool for Experimentation and Test, Evaluation and Training for the RPAS insertion in a IFR space, including CONOPS studies, Mission preparation and rehearsal, brief and debrief sessions, basic, intermediate and advanced training.

The environment is agnostic and could be used in a number of different domains where IRF/RPAS insertion will be required.

An example is the recently configured Blue Border Surveillance and Security scenarios where the most relevant components are:

- ATC Simulator (which has an interface with the real equipment);
- MDA Simulator (which has an interface with the real equipment);
- RPAS Simulator (which may have both an interface with the real equipment (RPS) or being completely simulated);
- Communication Simulator, which includes a satellite segment).

The SimLabs represents the glue among the IRIS different subsystems listed above.

In Fig. 5 an example is given of the test cases that will be performed before starting the real Mission exercises.

3.8 The ATC Simulator

This is an essential part of the IRIS infrastructure and represents one of these subsystems.

The ATC Simulator system provides a support for the ATC environment, including workload evaluation, flow control, optimum airspace configuration and new control procedure for RPAS.

Test	Description
Test 1	Entire flight plan Switch from RLOS to BRLOS BRLOS communication monitoring Change of flight level to verify ATC Voice and CPDLC (UC1+UC2+UC3)
Test 2	Flight until the first waypoint. meteorological condition will be degraded. Record the performances of ATC (Voice e CPDLC) communications and satellite channels (Ka-band and L-band) (UC1+UC2+UC4)
Test 3	Flight until the first waypoint and clear sky RPIL changes the position and the asset of RPA, sending C2 command through BRLOS: modify immediately the pitch angle and climb's speed to the P1HH dynamic limit values (UC1+UC2+UC3)
Test 4	Flight until the first waypoint and clear sky RPIL commands the same acrobatic maneuvers of test 3, repeating them with all the degraded meteo conditions (UC1+UC2+UC4)
Test 5	Flight until the first waypoint and clear sky Ka-band o L-band are alternately disabled and the emergency procedures are monitored (UC5)

Fig. 5. Simulation tests description (example)

Its primary function is the realistic simulation of an ATC environment where a predefined group of aircrafts are automatically flown by the System. This is followed by controlled Pseudo-Pilots and the insertion of a RPA controlled by RPS according to the ATC rules and Controllers instructions.

It is a flexible and powerful system having the capability of running a wide range of ATC Simulation Scenarios for advanced training of Controllers. This allows investigations in which RPAS may be able to use a technical capability or procedural means to comply with ATC instructions, including current and new concepts to be conceived and tested in the simulation.

As an example: ATC Simulator shall be used to determine the impact of integration of RPAS on ATM in some areas assuming RPAS may be unable to comply with all existing manned operations rules, particularly in case of C2 (Command & Control) data-link loss between RPAS and the remote pilot, and other emergency cases.

The simulation scenarios shall be used also for assessment of whether RPAS might, in the early phases of ATM integration, not behave exactly in the same way as manned aircraft. The latency and a different flight awareness of the crew, will impact on separation provision. Moreover, by means of ATC simulation scenarios, shall be possible to better evaluate the sensitivity of RPAS in different weather conditions and the capacity to react to these by simulating a specific coordination between ATC and the Remote Pilot especially for immediate maneuver, level changes and rerouting.

3.9 The Maritime Domain Awareness (MDA) Simulator

This is the second main subsystem of IRIS representing the specialisation of this application for the Blue Border Surveillance.

In its completed implementation, it includes simulators of:

- Distributed sensors: radar, electro-optical sensors, transponders (AIS) and radio equipment (voice, communication intelligence-COMINT), airborne sensors (UAV, Airplane, helicopter), buoys sensors;
- Satellite surveillance providing radar images relevant to the whole extended EEZ including the continental shelf;
- Protection systems for coastal infrastructures (e.g. ports, oil terminals) and offshore platforms;
- Local C4I canters performing sensor data collection and processing, sensor management, compilation and broadcasting of Common Operational Picture (COP);
- Regional C4I canters that receive and merge data from local C4I, protection systems as well as other legacy systems and satellite imagery, compile the high level COP and manage operations.

3.10 The RPAS Simulator

It is composed by a synthetic environment and several objects, including a number of RPAS models, represented in a 2D/3D scenario.

SYENA (Synthetic Environment Animator) is a Leonardo Simulation Environment Suite designed to create, run and manage complex tactical scenario with a high level of realism.

Syena is also meant to provide the user with the maximum level of flexibility in the creation of elaborated scenario and mission planning. Scenarios with thousands of entities can be generated rapidly and their run-time evolution can be monitored and easily modified by the user.

Syena is here used to implement the RPAS operational environment “inserted” in the ATC Simulation.

3.11 Integrated Communication

Simulated by the SVC (namely “Simulatore e Valutatore delle Comunicazioni”). Developed by the Leonardo Company, it is a simulation environment dedicated to the communication network analysis and validation.

The application fields of SVC range from the evaluation of new architectures and solution to Acquisition Support and Training.

Specifically, its advantages are to model and simulate new communication techniques and technologies before their introduction “in the field. Verify their applicability and operational benefits can be obtained in complex scenarios.

4 The RPAS Satcom Challenge: Complementary Approach

To allow a Remotely Piloted Aircrafts System (RPAS) to be safely integrated into non-segregated airspace, from the perspective of the Air Traffic Management (ATM) system, entails RPAS to behave as any other manned aircrafts. This principle implies that, the performance required for the communication capabilities, expressed as RCP/RCTP (Required Communication Performance/Required Communication Technical Performance") meet challenging requirements in particular for the C2/ATC links between the RPS (Remote Pilot Station) and the RPA (remoted Piloted Aircraft) [4, 7].

Due to limits on RPA availability, risk mitigation requirements and budget constraints the time for flight trials are limited to 30 flight hours. This limited duration is not sufficient to exercise and demonstrate the performance requirements under all the nominal and contingency situations. Even to prove that error rate does not exceed the expected value would require thousands of hours of flight campaign.

M&S are very helpful tool also in this context for characterizing the RPAS communication links. DeSIRE 2, in particular, will address the Beyond Radio Line of Sight (BRLOS) case where satcom is mandatory. As matter of fact a twin satcom link solution is foreseen, combining an L band channel for C2/ATC purposes with a wider Ka band channel for both C2/ATC and Payload data transmission.

In the first phase a pure simulation of both Satcom components, integrated with the other mission elements (airborne, ATC and mission applications already described) will be provided. Considering the iterative approach, this phase will be followed by a mixed simulation and emulation, where real hardware is introduced into the satcom simulation loop (e.g. real satellite terminals and transponders) using a full flight emulation platform with a motion test bench, reducing the need of a flying RPA.

At any stage of this communication iteration, the results will be fed-back into the simulation/emulation chain. As an example, the measured jitter and error rates will be introduced as updated parameters for the simulators for more realistic results (Fig. 6).

The advantages of this approach are:

- Higher confidence on simulation results;
- Higher confidence on overall design;
- Much richer set of test conditions and performance statistics than would be attainable with sole flight campaigns.

A series of field tests, through flight trials, will close the demonstration campaign.

Satcom Simulation, emulation and flights measurement campaign will allow to measure some specific parameters (e.g. BER/PER, latency, etc.) that will have to be related with the RCP/RTCP parameters (availability, integrity, continuity, transaction time).

In particular, for the Satcom link, the following parameters will be measured:

- BER Bit Error Rate or PER Packet Error Rate
- Satellite link Quality (Eb/No or C/N)
- Latency

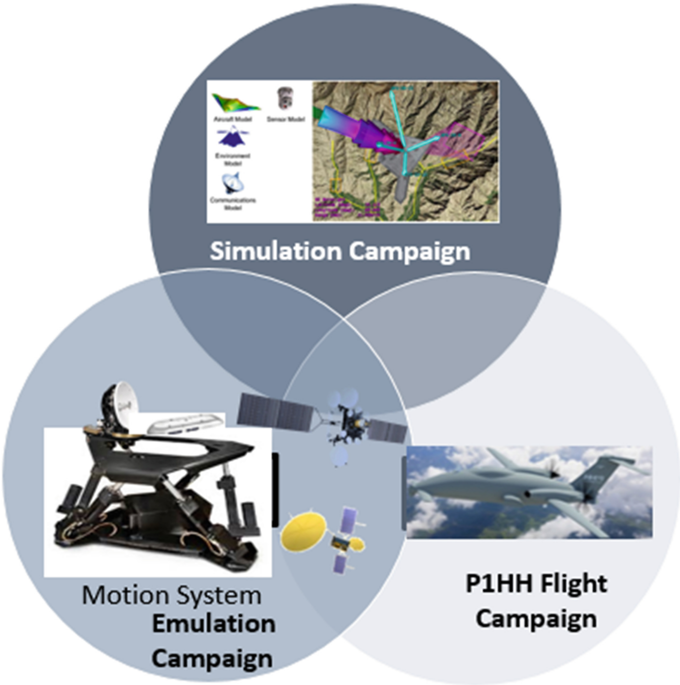

Fig. 6. DeSIRE 2 threefold complementary approach

4.1 Satcom Simulation

The Satcom module simulates the Satcom communication channels among RPA, RPS and Teleport. It is used to propagate satellite over the time scenario, simulate the on-board antenna pointing dynamics, subject to the aircraft attitude changes, and compute the geometries of the scenario, e.g. distance to satellite, azimuth and elevation angles (Fig. 7).

The geometric engine computes the geometric parameters for the link budget, among which distances (e.g. RPA Sat, Sat gateway, RPS-RPA,), visibilities (e.g. RPS-RPA), visibilities interference (e.g. RPA Sat during operations), azimuth and elevation of satellites as seen by SATCOM antennas (e.g. on-board RPA, on the Teleport-gateway, RPS).

Satcom module computes information on propagation channel characteristics, related to propagation delay, C/N, data rate, BER/PER, mainly derived from geometric and link budget calculations, and sent to the simulation environment so that the degradation of the propagation channel can be applied to the sensor data flows.

All the information is used to estimate the propagation channel characteristics of Ka band and L band frequencies (e.g. free space loss, total loss, propagation delay, C/N, data rate, BER/PER, Doppler effect), and consequently the link budget. The total latency also takes into account the ground network latency, estimated from the characteristics of the different trunks of the satellite networks.

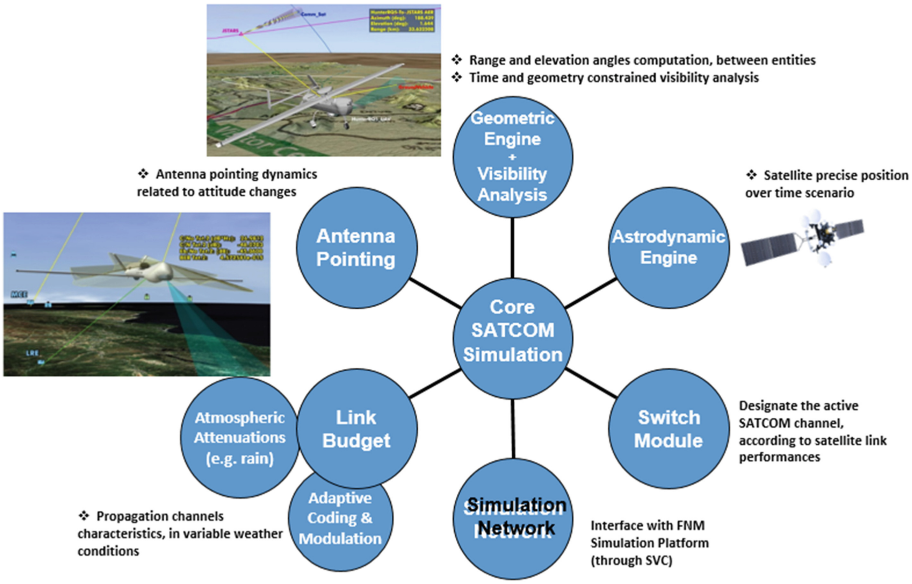

Fig. 7. DeSIRE 2 satcom simulation concept

The main differences between Ka and L band SATCOM simulator components is in the following areas:

- Link budget calculation, L-band is much more resilient to rain/snow/ice/cloud/ scintillation events.
- Antenna pointing characteristics, the L-band antenna is a phased array type, therefore mechanical inertia is negligible.

The integration module automates the management of the other modules of the platform and handles the information flow of simulation parameters from and to the UDP server. This module needs to be adapted/extended to suit the specific needs of the simulation.

Satcom module communicates exclusively with SVC, through a dedicated UDP socket. From SVC, Satcom module receives all pertinent scenario information, in particular simulation time, aircraft data (position, velocity, acceleration, and attitude), simulated sensors data characteristics, weather conditions on aircraft and on HUB/gateway generated by the synthetic environment.

Satcom module sends to SVC information on propagation channel characteristics, among which propagation delay, C/N, data rate, BER/PER, mainly derived from geometric and link budget calculations, so that SVC can apply the degradation of the propagation channel, if present, to the sensor data flows.

The Ka – L band Switch Module, using the link budget information and an internal algorithm for Ka-L band switching, is responsible to designate the active SATCOM channel to be used for CNPC data transmission. This information is timely transmitted to the SVC every time the simulation scenario is updated.

Most of these simulation exercises stress the communications between the various actors. On the other hand, communications, the Satcom ones in particular, are the focus of the research addressed within the project and the simulation platform is aligned with this general objective.

SVC, already described, is in charge of orchestrating the overall simulation of communications. It is SVC that:

- Simulates the data flow between the RPA and RPS by putting the RLOS and BRLOS channels behaviours in the CNPC and Payload communications;
- Changes the behaviour of all channels in function of the RPA state;
- Integrates the environmental information from the Synthetic Environment (SE) with the Telespazio Satcom Ka/L simulator in order to receive and use the parameters performances passed by the latter for the BRLOS communications.

4.2 Satcom Emulation

The emulation campaign will focus mainly on the Satcom link and as such, will allow to perform extensive measurements of Satcom specific performance parameters.

The emulation will use the same Satcom terminals planned to be mounted on board the RPA, fastened to a motion platform, a hexapod equipped with six electric actuators that give it six degrees of freedom, and the ability to mimic the attitude changes of the RPA (Fig. 8).

The motion system will allow to replicate the same conditions that on-board antennas encounter during a typical flight phase, e.g. misalignment of Ka band antenna after an emergency maneuver.

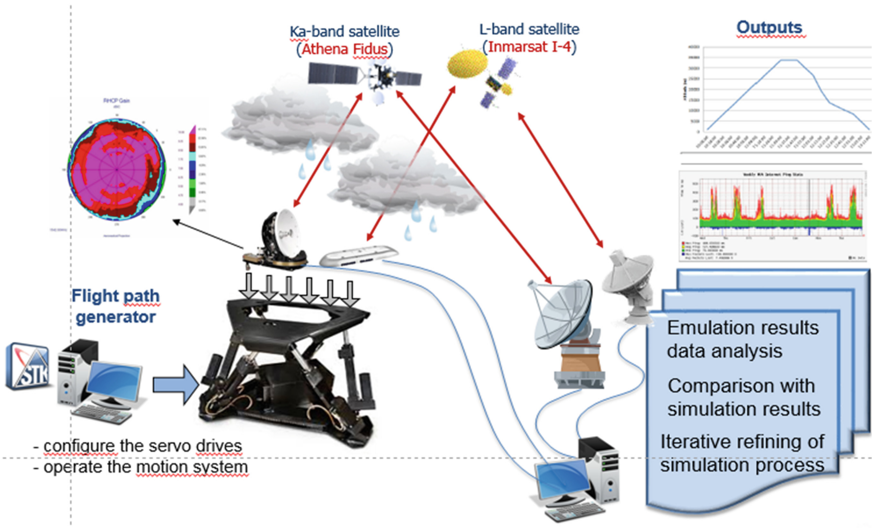

Fig. 8. Satcom emulation

The emulation test phase gives the project the significant opportunity to test the antennas extensively without limitations imposed by a real flight test, especially due to time and cost limits.

The emulation testbed guarantees many hours of data that can be analyzed for statistical purposes and so for RCTP derivation.

In addition, tests on switch between the L band and Ka-band will be performed. Several degraded performance will be induced on Ka band link to force the system to switch to L-band link, more resilient to rain outages. Also the reverse switch will be tested.

The switch tests will help to evaluate the dual link switch process, in order to refine the switch logic algorithm.

In this case the motion platform will not be required. Both terminals will be positioned on ground to ensure the complete visibility to the satellites.

The emulation phase will allow bypassing some limitations imposed by the flight campaign.

In fact, the emulation testbed will allow testing a second L-band antenna that will not be possible to mount and test, for reason of costs and design complexity, on board.

The performances of two L band antennas will be compared to determine if differences exist and so the best solution to offer to the end-users.

Besides the emulation test phase will allow testing the antennas in variable weather conditions, therefore also in rainy conditions, contrarily to the flight campaign, during which the RPA will flown only when the weather conditions permit, so-called clear sky conditions, especially for safety issues.

The emulation platform will remain in operation for a long period, during which the antenna/s mounted on it will be subjected to the normal variations of weather conditions.

The measurement of satellite link performances will be mainly based on the collection and statistical analysis of the following type of data:

- Satellite Link Quality & Performances of both the Ka-band and L-band links, with measurements derived directly from Satcom modem through the SNMP Protocol (Simple Network Management Protocol), aimed at "physical" characterization of the satellite link;
- IP Data flows transmission performances for both UDP and TCP Protocols, with measurements derived from Network Monitoring tools, aimed at evaluating end-to-end performances of a specific data flow over the satellite link path (i.e. measuring the speed of the network, the elapsed time for a particular network transaction, the IP packet loss rate/percentage) in both directions (forward link and return link – see note below).

Note:

- "RX link" is intended as downlink channel from Satcom terminal viewpoint, that corresponds to the "Forward Link" transmitted from the Gateway to the Satcom terminal (GW to RPA);
- "TX link" is intended as uplink channel from Satcom terminal viewpoint, that corresponds to the "Return Link" transmitted from the Satcom terminal to the Gateway (RPA to GW).

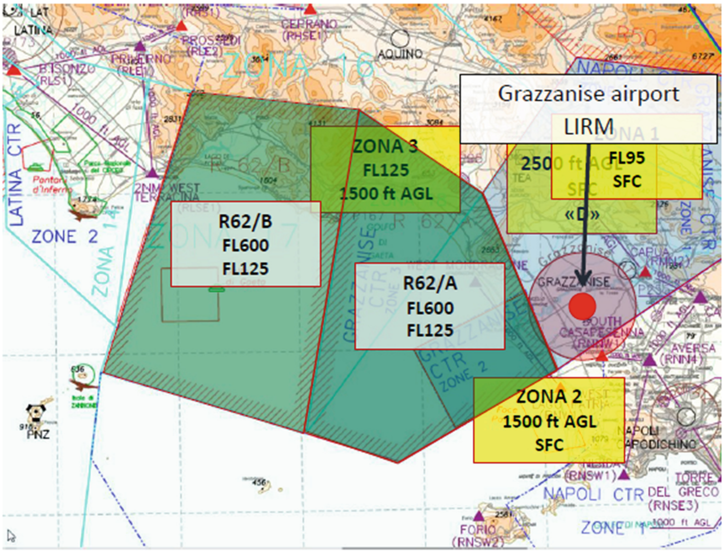

Fig. 9. Grazzanise airspace

Performance Measurement analysis will be also correlated, when applicable, with motion platform "maneuvers" and meteorological conditions.

5 The DeSIRE 2 Flight Demonstration

5.1 The Airspaces

The airspace involved in the demonstration are shown in Fig. 9:

- Grazzanise ATZ
- Grazzanise CTR
- LI-R62A
- LI-R62B

R-62 is a restricted area and during flight tests, it will not be accessible to other civil airspace users for safety reasons. Nevertheless, during demonstration the RPA will be under control of civil ATC (ENAV) and will follow real ATM procedures, including:

- Preparation of an actual IFR flight plan (FPL) and submission through the Aeronautical Information System;
- Operation under military control for airport operations (Grazzanise TWR) and handoff to civil ATC (ENAV) for departure, climb, en-route and arrival phases;
- Use of SIDs and STARs procedures specifically designed by ENAV for the flight campaign;

- Continuous radio contact with ATC during OAT phase for mandatory reports of normal operations.
- The typical flight demonstration mission will be divided in four phases:
- Planning and preparation: mission is planned by pilots, ground crew and involved end-users. The RPA is prepared and checked for flight.
- Departure and deployment: the RPA will depart from base, climb and reach the target area for use-case demonstration. During this phase the RPA operates as a GAT (General Air Traffic, following ICAO civil aviation rules). After departure RPA control is typically switched from RLOS to Satcom BRLOS.
- Operation: the RPA performs the operational task (e.g. S&R, law-enforcement, etc.) acquiring the status of OAT (Operational Air Traffic) if necessary. The RPA is controlled through Satcom BRLOS datalinks.
- Return to base: the RPA returns to the base and lands. This phase of flight is again conducted as GAT and before landing RLOS, links are re-activated.

The base for the flight campaign is Grazzanise airport (ICAO code LIRM) and neighbouring “R-62” (ROMEO-62) areas, from sea level up to around 20.000 ft (Fig. 10). The operational theatre is representative of a real scenario and covers both land and sea areas.

Fig. 10. Grazzanise airbase

Flight missions will mainly be conducted over the sea, but sorties along the coast or with the coast in-sight could also be possible if required by the use-case scenario.

The mission will be conducted between FL200 and a minimum altitude varying between 2500 and 4500 ft. The difference in minimum altitude is caused by mountains obstructing RLOS datalinks at low altitude in some areas. A survey campaign is currently being conducted (at the time of writing) to characterize such obstruction area.

The typical duration of a flight will be between 1.5 and 3 h.

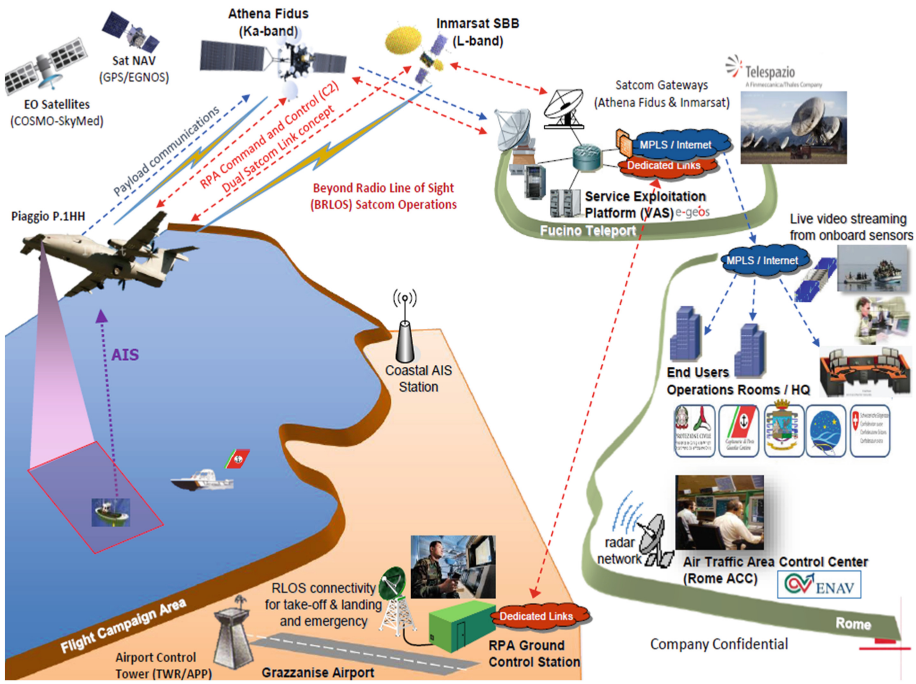

Fig. 11. DeSIRE 2 system demonstration architecture

5.2 The DeSIRE 2 System Demonstration Architecture

The Demonstration System Architecture (DSA) that will be set up during the project is presented in Fig. 11. From a logical point of view, this architecture can be structured in three major segments:

- **Space Segment** composed by the SatCom Satellites Athena Fidus (made available by ASI), operating in Ka Band and Inmarsat I-4, operating in L band: Ka will support both aero safety services and real time payload data dissemination; L band will be used only for CNPC to increase its overall availability. The EO Satellites based on COSMO-SkyMed constellation and ESA Sentinel satellites are included, providing both Synthetic Aperture Radar (X and C bands) and Optical data.
- **Ground Segment** composed by elements needed to control the operation of the mission, the integration of the RPA in the airspace and the mission data exploitation:
  - **The Fucino Teleport** where both Athena Fidus and Inmarsat L band Gateways are located. For Ka band data link, a dedicated Viasat Mini-Hub is integrated with the ASI Athena Fidus Gateway.
  - **The RPS** located at the airport and connected to the Fucino Teleport through a dedicated, secure and redundant terrestrial link.
  - **The Value Added Services (VAS) Processing centre**, in Rome (e-GEOS and Telespazio headquarter), connected to the Fucino Teleport, The VAS processing

center will take advantage of Matera Ground Station, to acquire EO satellite data and operate information extraction and integration with available ancillary data (maritime Automatic Information System - AIS, Vessel monitoring system - VMS, Long-Range Identification and Tracking - LRIT and met-ocean data).
  - **The SatNav centre** based in Telespazio headquarter of Rome will be able to process data coming from on board GNSS/EGNOS receiver.
  - **The End User Interface Networks** to transfer real time RPA payload and value added data to the End User system at their operational premises.
- RPA segment. The Piaggio P.1HH prototype will be incorporating all the equipment necessary to perform the DeSIRE 2 mission tasks:
  - satellite terminals (both Viasat Ka and Inmarsat L band)
  - EO/IR video camera, AIS and EGNOS receivers integrated with the Payload Management subsystem,
  - The Voice comm, ATC connection and other safety critical items (Air Data, Traffic Collision Avoidance System -TCAS 1 and the transponder Mode S), or Nose Cams and Datalinks.

5.3 M&S as Support to Plan the Most Effective Demonstration Phase Vs. the ATI and User Mission Requirement

The project will provide an important step forward for the «safety critical» RPAS CNPC Services, by defining a first set of RCPs applicable to both the RPAS C2 and ATC links following the JARUS C2 link RCP Concept [R2] to define a certification path for the RPAS category above the threshold of 150 kg:

M&S, as far as ATI Requirements are concerned, will support DeSIRE 2 to demonstrate the following major requirement by allowing to create **the storyboard** of the fights dedicated to this particular requirement section that includes:

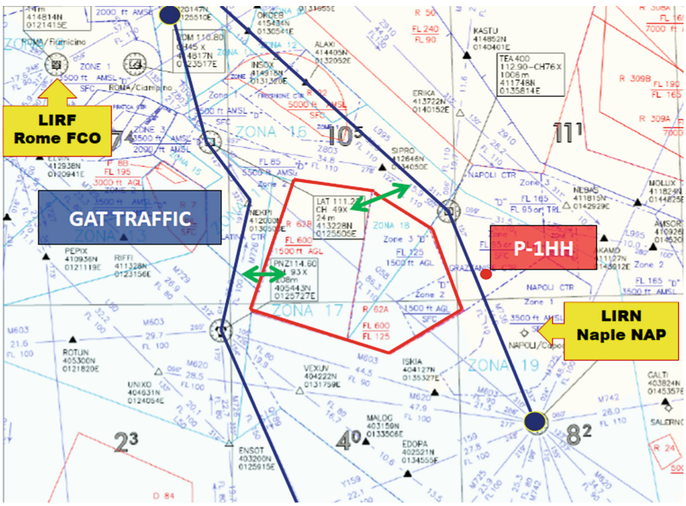

Fig. 12. Virtual intruder exercise

- Dual satcom link concept (L-band and Ka-band links) for •increased availability
- Cost-efficiency
- BRLOS satcom link performance measurements for CNPC and Payload data transmission
- End-to-End Voice Communication latency and QoS evaluation (RPIL -ATC)
- ATC procedures execution:
- RPIL-ATC interaction with ATC Relay over Satcom link and
- Implementation of C2 commands to RPA following ATC instructions
- Situation Awareness based on TrAw Data
- Virtual intruder exercise (Fig. 12)

As far as the User Mission Requirements, are concerned, DeSIRE 2 is going to provide interoperable, state-of-the-art real time services, to major institutional End Users operating in one of more of the following operational sectors:

- Search and Rescue
- Law Enforcement
- Fishery Control
- Fire Crisis Management

Modelling and Simulation will support to define **the storyboards** of the flights dedicated to demonstrate the major requirements identified in the following Use Cases.

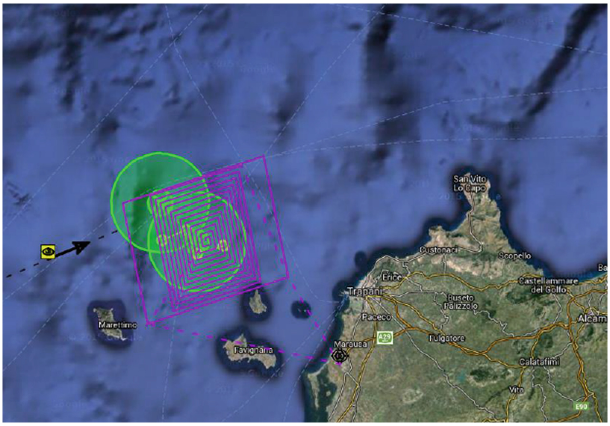

Fig. 13. Search and rescue use case

Search And Rescue Use Case Objectives - Operational support needs expressed by the ICG:

- Routine monitoring of maritime areas to detect anomalies (e.g. not-cooperative vessels) with Earth Observation Satellite Data
- Response to an Emergency call of the ICG to activate the monitoring service of a vessel in distress in a known position

- Detection of vessels not transmitting their position in a given area of operation, this includes the integration of vessels identification data (AIS as a minimum)
- The target vessel type to be detected by the service shall have the following characteristics:
- Metallic and non-metallic materials, such as wooden or rubber boats
- Length of 5 to 80 m (Fig. 13)

Law Enforcement Use Case Objectives - Operational support needs expressed by the Guardia di Finanza (GdF):

- Monitoring of commercial lanes to support anomalies detection (not-cooperative vessels, rendezvous, etc.)
- Service activation by the GdF to monitor a vessel in a given area of operation, based on GdF intelligence information
- Detection of vessels not transmitting their position in a given area of operation with integration of vessels identification data (AIS as a minimum)
- Target vessel type to be detected by the service shall have the following characteristics:
- Metallic and non-metallic materials, such as wooden or rubber boats
- Length of 5 to 30 m
- Certified localization reference to provide legal evidence in case of infringements detection (Fig. 14)

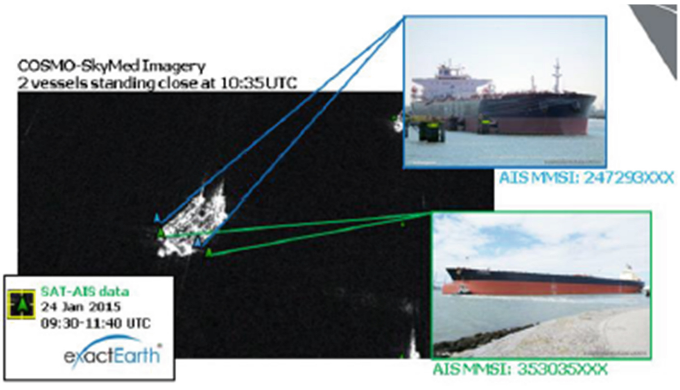

Fig. 14. Law enforcement use case

Fisheries Use Case Objectives - Operational support needs expressed by the ICG and EFCA:

- Routine monitoring of maritime areas subjected to illegal fishing activities to support anomalies detection (not-cooperative vessels, rendezvous, etc.).
- Detection of vessels not transmitting their position in a given area of operation (AIS as a minimum)

- The target vessel type to be detected by the service shall have the following characteristics:
- Fishing vessels
- Length of 5 to 80 m
- Identification of the used fishing methods
- Certified localization reference to provide legal evidence in case of infringements detection (Fig. 15)

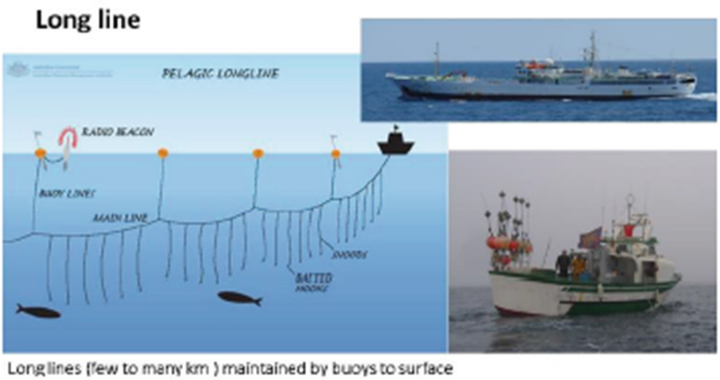

Fig. 15. Fisheries use case

<u>Crisis Management - Fires Use Case Objectives</u> - Operational support needs expressed by the Italian Civil Protection Department (ICPD) and CEREN:

- Routine surveillance of very risk areas, under weather condition (dry air, worm, windy) strongly favourable to ignition, in order to detect thermal anomalies to be identified as new active fires.
- Monitoring, after an emergency call, of active fires to verify the effectiveness of operations and firefighting coordination support.
- Provision, soon after the emergency fire events, of burn scar delineation and damage assessment (Fig. 16).

In the following Fig. 17 an example is given of the resulting ATI Use Case analysis that will be performed in detail with the full support of the DeSIRE 2 User Community, according to what has been agreed in the DeSIRE 2 User Consultation Meeting (UCM) of Rome of last May 24th 2016.

Each User presented relevant Entity's assets and workflows, confirmed high interest on the RPAS and proposed service model and willingness to take part in the Flights campaign making available Personnel to assist and validate the results, on field support and real time data gathered from other sources. (e.g. VTS, AIS,..).

The Users confirmed their availability to build precise storyboards for the flights in cooperation with the Project team.

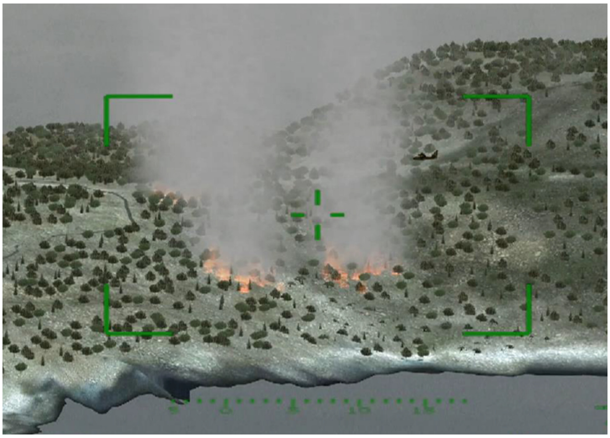

Fig. 16. Fires use case

ID	ATI Use Cases	Description
UC1	ATC Voice	Evaluate impact on ATCo-Remote Pilot voice communication of High Latency, introduced by Satcom
UC2	CPDLC	Evaluate ATCo-Remote Pilot interaction via CPDLC in BRLOS
UC3	BRLOS Comms performance in clear sky conditions	Evaluate BRLOS System Performance operating in L-band/Ka-band in "clear sky" conditions
UC4	BRLOS Comms System performance in degraded meteo conditions	Evaluate BRLOS System Performance operating in L-band/Ka-band in "degraded meteo" conditions

Fig. 17. ATI use cases (example)

The generation of the storyboards of the entire 30 h DeSIRE 2 Flight Demonstration Campaign has, as its main objective, to allocate all elementary flight test building blocks (see an example in Fig. 18) derived from the use case detailed requirement analysis.

The DeSIRE 2 Industrial Consortium, fully assisted by the entire DeSIRE 2 User Community and with the powerful support of the Mission Simulation tools described in the above sections, will generate the storyboards of each of the planned flights by making meaningful each elementary component of the P1.HH flight (Fig. 19).

ID	ATI Flight Tests
FT-ATI-001	BRLOS performance on Ka-band Satcom link (CNPC data)
FT-ATI-002	BRLOS performance on L-band Satcom link (CNPC data)
FT-ATI-003	CNPC (C2 and ATC Voice) End-to-End Communication latency / QoS evaluation (incl. C2, ATC)
FT-ATI-004	Payload Data End-to-End Communication latency / QoS evaluation
FT-ATI-005	BRLOS dual satcom link operations (for CNPC)
FT-ATI-006	RLOS-BRLOS handover
FT-ATI-007	ATC procedures
FT-ATI-008	virtual intruder
FT-ATI-010	Situational awareness based on D&A data (i.e. traffic information).
FT-ATI-010	Situational awareness based on D&A data (i.e. traffic information).

ID	Mission Flight Tests
FT-UR-001	Vessel detection Capability
FT-UR-002	Vessel recognition Capability
FT-UR-003	Vessel identification Capability
FT-UR-004	Vessel Tracking Capability
FT-UR-005	Multiple vessels detection capability within the AOO
FT-UR-006	AIS data reception and transmission capability
FT-UR-007	Fire detection Capability
FT-UR-008	Fire recognition Capability
FT-UR-009	Fire identification Capability
FT-UR-010	Sensors detection capability in bad visibility conditions
FT-UR-011	Specific Maneuvers Request from the User
FT-UR-012	Onboard Sensors looking direction modification request from the User
FT-UR-013	Real Time Data service delivery
FT-UR-014	VA products Near Real Time service delivery

Fig. 18. Flight tests building blocks (example)

Fig. 19. ATI and mission flight storyboards

The Storyboard will include in details parameters like:

- Flight altitude,
- RPA manoeuvres,
- Sensor to be used and relevant operations,
- Intruders Aircraft maneuvers,
- Deployment of supporting assets, e.g. target to be identified, User Operational Vessels and so on.

These elements, necessary to demonstrate the requirements mentioned above, will be addressed in order to optimise the limited fight hours and to reach the demonstration target in the most effective and efficient way.

The storyboard will take care also of the different flight execution phases, including:

- **Departure and deployment**: the RPA will depart from base, climb and reach (Transit phase) the target area for use-case demonstration. During this phase the RPA operates as a GAT (General Air Traffic, following ICAO civil aviation rules). After departure RPA control is typically switched from RLOS to Satcom BRLOS;
- **Operation**: the RPA performs the operational task subdivided in Target identification and Recognition (to be identified for each type of mission, e.g. S&R, law-enforcement, etc.) acquiring the status of OAT (Operational Air Traffic) if necessary. The RPA is controlled through Satcom BRLOS datalinks.
- **Return to base**: the RPA returns to the base and lands. This phase of flight is again conducted as GAT and before landing RLOS, links are re-activated.

6 Conclusions

Results from simulation, emulation and flight campaign will be compared and analyzed, will help to consolidate the safety requirements and establish the CONOPS for a Satellite based Data Link service for RPAS.

The service delivery concept will be refined and consolidated thanks to the feedbacks from the involved users.

The main results of the project and recommendations will be disseminated to the relevant stakeholders, including European standardisation and regulatory organisations, especially for the definition of future satellite-based command & control datalinks, in order to contribute to the process of the integration of the RPAS into non-segregated airspace.

7 Future Work

The project represents a significant step into the European Roadmap for the integration of RPAS into the civil airspace.

Future activities will build on the work performed in the framework of the project simulation and emulation campaigns aiming to assess and compare the performances of different types of satellite connectivity, in order to support RPAS C2 datalink for BRLOS operations. More in detail, future activities may extend the assessment to:

- Other types of satellite connectivity and terminals.
- Different classes of RPAS platforms and associated CONOPS.

Future measurement campaign will allow also to increase the statistic relevance of the test results, to refine the measurement methodology and to provide further elements supporting the definition of the target RCP applicable to the satcom component of the C2 datalink chain.

Main target will be represented by the assessment and optimization of:

- Latency and availability values on the technical/performance side, and of
- Satellite connectivity costs on the operational/economical side.

References

1. EUROPEAN COMMISSION: Towards a European strategy for the development of civil applications of Remotely Piloted Aircraft Systems (RPAS)
2. ERSG: European RPAS Roadmap
3. DESIRE D13 Final Report
4. JARUS: RPAS C2 link Required Communication Performance (C2 link RCP) Concept
5. JARUS: Guidance on RPAS C2 link Required Communication Performance
6. ICAO: Doc 9869 AN/462, Manual on Required Communication Performance (RCP)
7. ICAO: Doc 10019 AN/507, Manual on Remotely Piloted Aircraft Systems (RPAS)