Technological Research and Innovation 2024

MINISTRY OF DEFENCE

SECRETARIAT GENERAL OF DEFENCE
AND NATIONAL ARMAMENTS DIRECTORATE

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PRESENTATION

BY THE SECRETARY GENERAL OF DEFENCE AND NATIONAL ARMAMENTS DIRECTOR

With the **"Report on Technological Research and Innovation"**, the Secretariat General of Defence/NAD presents the main results obtained in 2023 by the technical-scientific research projects supported by the Defence. These are the fundamental activities that, by involving and encouraging the best national entities in the academic, scientific, and manufacturing fields, contribute to the objective of maintaining and increasing the **national technological advantage**. A **strategic objective** that, in light of the current **geopolitical dynamics** and the **trajectories of technological development**, has become even more crucial.

In fact, the nature of modern conflicts, when compared to the last century, has highlighted how technology plays a more complex and stratified role so much so as to represent the **frontier of competition**. At the same time, this is all happening as we move towards a **new industrial revolution** driven by Artificial Intelligence. This current context reinforces the **Defence's great attention to scientific research**, recognized as an essential vector for contributing to technological development, not only for our Armed Forces, but for the entire country.

Technology generates growth and produces **transversal effects in all sectors**, regardless of the scope of application. Just think how, historically, research and technological developments in the military field have positively influenced the progress of our society (from the Internet, to GPS, to drones), and have increased the understanding that technology represents a **sector of high strategic value for the entire country**. It is capable of influencing the progress and well-being of society in times of peace and of dominating the battlefield in times of war. In essence, achieving a high degree of **technological sovereignty** simultaneously represents an opportunity for economic and social growth in the civil field and, in the military field, an essential precondition for ensuring the operability and strategic autonomy of our Armed Forces, which allows them to carry out their missions and safeguard national interests.

There is, therefore, an intrinsic relationship that links the **protection of national interests**, the **operability of the military, technological sovereignty**, and the ability to move proactively in the field of innovation.

For this reason, the Ministry of Defence, through the Secretariat General of Defence/NAD, makes every possible effort to operate synergistically with all public and private national entities interested in technological innovation and, at the same time, promotes and actively participates in key international research initiatives, both within strategic alliances and with like-minded countries.

In a parallel effort in line with the programmatic guidelines of the Minister of Defence, a critical analysis of the current organizational model of innovation and technological research within the

Ministry has been conducted over the last year to identify the most suitable solutions to:

- "strengthen synergies with the academic world, research centers, and the industrial sector, without neglecting SMEs, start-ups, and informal groups of experts";
- reduce the innovation cycle time within the National Military Research Plan (PNRM), ensuring greater organizational and operational flexibility of the organizations responsible for managing technological innovation processes;
- ensure greater convergence between the objectives of technological innovation and strengthening the country's industrial base to meet the capacity needs of the military instrument.

The challenges faced in this field are not simple, because they are part of a highly dynamic and competitive geopolitical and technological situation. For this reason, it will be necessary to continue on the path undertaken, systematizing all the excellences of the country, and aspiring to ever better performances, which give Italy, and its Defence System, the recognition it rightfully deserves in the international landscape, for the standing of its academics, its industry, and its Armed Forces.

The Secretary General of Defence/NAD
Lieutenant General
Luciano PORTOLANO

FOREWORD

BY THE DIRECTOR OF THE V DEPARTMENT - TECHNOLOGICAL INNOVATION

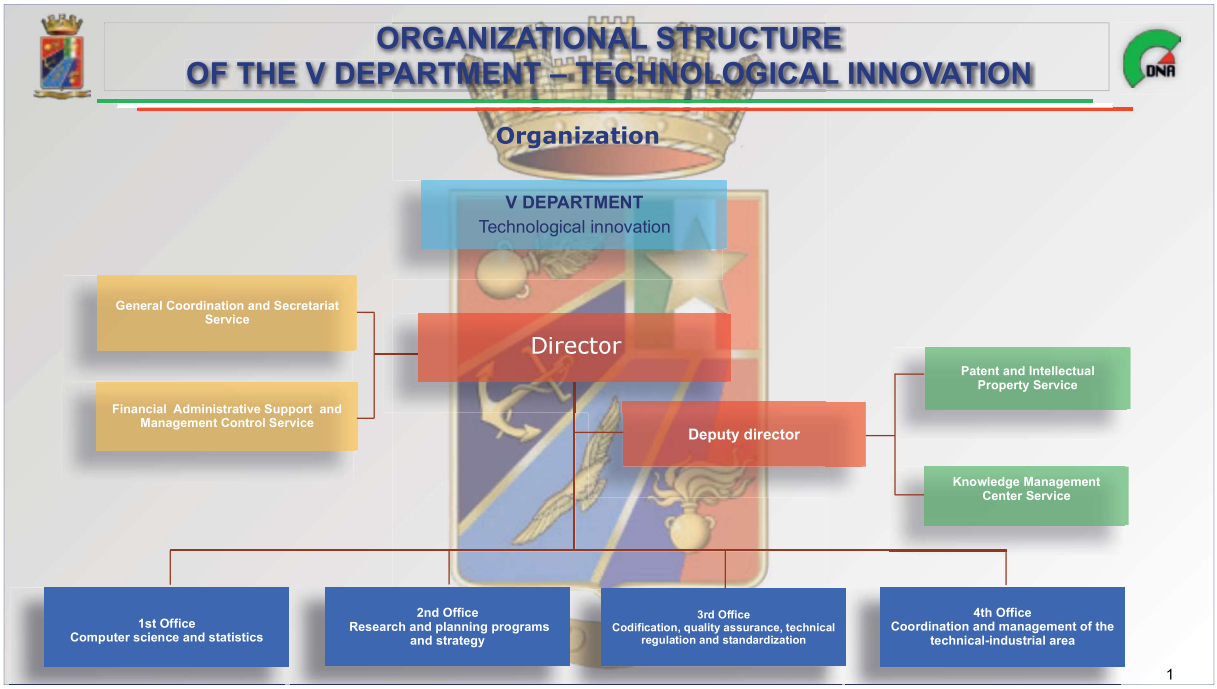
We now live in a world of constant and rapid change, with fewer and fewer certainties. In the defence sector, where technology is a fundamental factor of efficiency and competitiveness, the need to look to the future to identify new paths and anticipate changes is even more essential than anywhere else, indeed it is vital for the interests of the country. Hence the importance of military research, which traditionally acts as a driving force for the entire industrial sector in terms of innovative ideas and programmatic input.

In full awareness of this reality and of the need for continuous and virtuous interaction and co-operation between the defence and the civilian sectors, beginning with universities, the activities of the Department illustrated in this document will be developed with conviction, and with particular attention to young people and their natural enthusiasm, because innovation and enthusiasm are two indispensable sides of the same coin.

The Director
Dr. Giovanna ROMEO

A LOOK AT THE ORGANIZATION

ORGANIZATIONAL STRUCTURE



Through the action of the V Department "Technological Innovation", the Secretariat General of Defence/NAD identifies, promotes and initiates technological research projects and programs (R/T) for Defence, the so-called "military research", within the national and international cooperation sphere. This occurs thanks to the activities and skills of the organizational units of the aforementioned Department, represented in the figure below, including, particularly, the 2nd Office which deals with research, experimentation and testing, and related planning strategies.

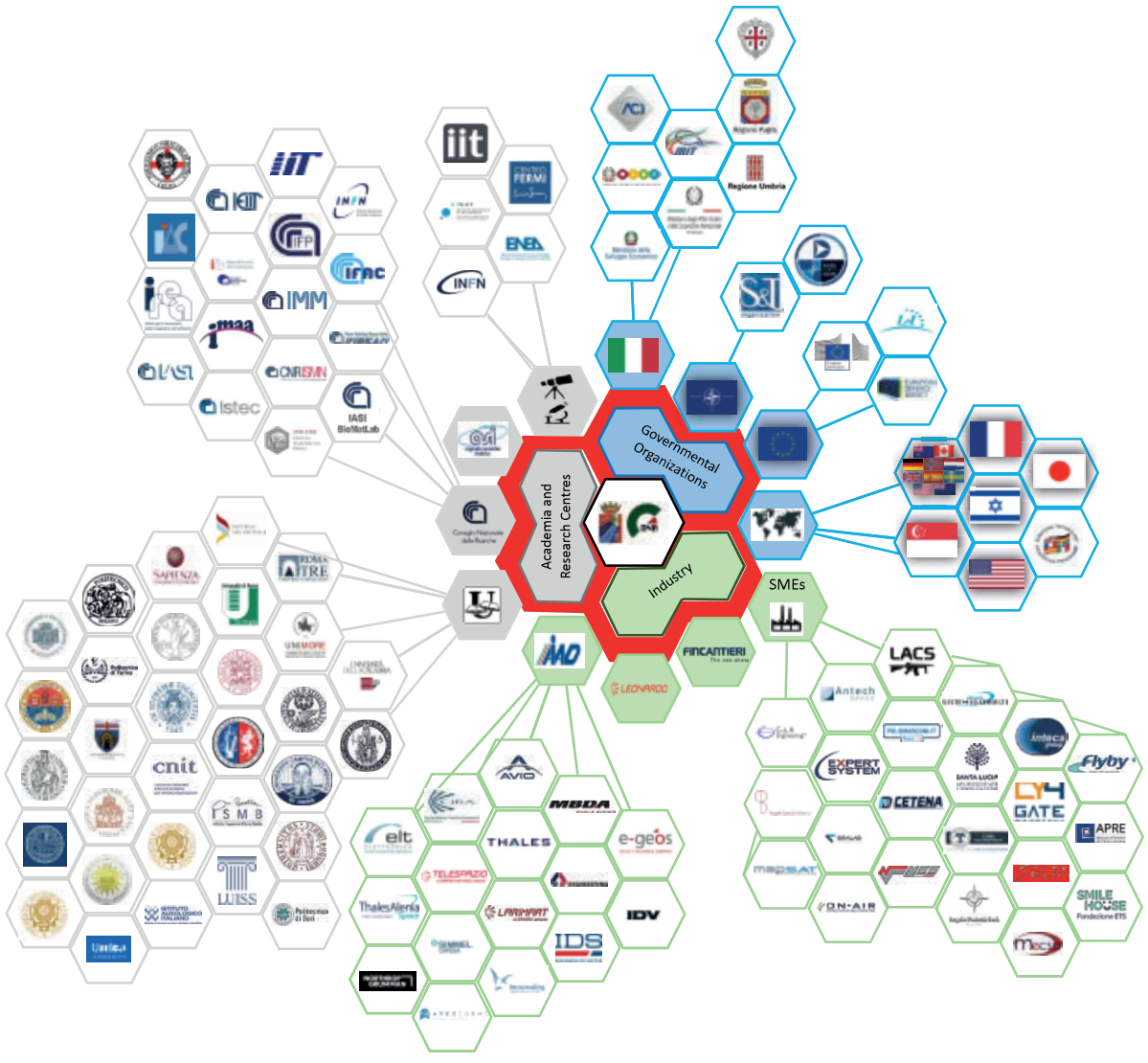
This research activity includes a series of initiatives, primarily aligned with the criteria and indications of the Defence General Staff (SMD), which identifies the areas of primary technical-capability interest (the so-called clusters) towards which it should be oriented. Among these initiatives we find:

- the National Military Research Plan (PNRM), aimed at industries, small and medium-sized enterprises, startups, universities, and national, public and private research bodies, with the aim of maintaining and enhancing national levels of excellence in specific technological sectors of interest to Defence.
- the technological research projects carried out at the Defence Test Centers, which aim to orient and strengthen Defence capabilities in the Test and Evaluation (T&E) sector.
- the Framework Agreements with Universities and research bodies, aimed at increasing the wealth of scientific and technological knowledge of Defence.
- international programs, developed mainly within the EU (EDA - European Defence Agency and EDF - European Defence Fund), NATO (STO - Science & Technology Organization, DIANA - Defence Innovation Accelerator for The North Atlantic, NIF - NATO Innovation Fund) and bi/-multilateral agreements.

THE NETWORK FOR TECHNOLOGICAL RESEARCH

THE EXTERNAL ORGANIZATION

The effectiveness of the innovation and technological research strategy implemented by the Secretariat General of Defence/NAD is based on the creation and constant updating of a network of external relations with highly specialized, heterogeneous elements/organizations with diversified objectives, which compete in a synergistic manner to achieve Defence guidelines in the field of innovation and research. This network of relations maintained by the Secretariat General of Defence/NAD is divided into three cornerstones, namely governmental, scientific organizations (universities/academic and research bodies), and the industrial sector.



THE INTERNAL ORGANIZATION

An equally essential tool for identifying objectives and managing and exploiting knowledge is the internal organization of Defence relating to technological research, which can also be schematized according to three organizational cornerstones:

- the Defence General Staff and those of the Armed Forces (FF.AA.), oriented towards identifying the objectives of technological research and exploiting the results, with a view to the prospects of capacitive development;
- the Technical and General Directorates (DD. TT. and DD.GG.) of the Secretariat General of Defence/NAD, indispensable for technical competence and project management;
- the Test Centers of the Armed Forces, an ideal test bed for the experimental validation and valorization of the final results of the research activity, often consisting of technological demonstrators.

STRATEGIC OBJECTIVES

According to the Minister of Defence's Guideline Act, the modernization of the military instrument requires the support and harmonization of technological research that should be oriented towards achieving the capacity development objectives of the Armed Forces. This involves, in a synergic way, all the Defence Entities that deal with research, experimentation, and testing, in both the developmental and operational fields.

The subsequent strategic objectives of the scientific and technological research programs for Defence are focused on different areas of intervention, aimed at identifying and protecting technologies considered to be of "strategic value" in order to guarantee national technological sovereignty and ensure support for national projects or projects of national interest within the cooperation programs of the European Union. This is achieved in collaboration with the defence industrial sector, in order to maintain and develop the sector's specific technological "know-how" and involves collaboration with national and international partners in the industrial sector and the search for synergies with research centers and universities.

To achieve these objectives, the strategy of the Secretariat General of Defence and National Armaments Directorate, through the V Department "Technological Innovation", is based on capability-pull and technology-push approaches. In addition, it provides for coordination and collaboration actions between different organizations, such as Ministries, research centers, industry, and scientific bodies, and aims to create a network of synergic relationships for technological research, in collaboration with governmental, scientific, and industrial organizations.

The resulting technological research activities for Defence include various areas, such as the National Military Research Plan (PNRM), technological research and development projects conducted at Defence Test Centers, Framework Agreements with universities and research bodies, as well as international programs developed within the EU, NATO, and bilateral frameworks.

The priority areas of interest for military technological research, in full coherence with the capability needs of Defence, pursue the objective of adapting the military instrument to future challenges by trying to intercept the extremely high evolutionary dynamism of the main emerging technologies of interest.

In particular, three macro objectives are defined from which derive directions and priorities:

(1) Have efficient and effective Armed Forces that are truly integrated and multi-domain:

C2 e Multi-Domain Situational Awareness: solutions capable of receiving, combining, and representing integrated data from military and civil sensors and systems belonging to the five operational domains (terrestrial, maritime, air, cyber, and space), including the information and electromagnetic environments and ensuring the ability to plan and conduct multi-domain operations[1]. The identified solutions must ensure: full interoperability of the Command and Control systems, functions, and elements (Advanced Interoperability); technological flexibility, defined as the ability to rapidly integrate new technologies into systems already in use (Continuous Technology Integration); the centricity of information (Data centricity); and agility, portability, and scalability in terms of ranking and size according to the MOSA (Modular Open Systems Approach) model.

1 Military activities conducted in multiple domains to perceive, understand and subsequently orchestrate convergent effects to generate multiple dilemmas at such a speed as to overcome the adversary's decision-making capacity. The conduct of these activities occurs through the synchronization of military actions with other instruments of national power and/or with allies and partners, under a synchronized command and control structure.

(2) Strengthen the ability to operate in the Space and Cyber domains, in urban and underwater environments, and to generate effects in the cognitive dimension:
- **Space technology**: development of sensors/assets for: Detection, Mitigation, and Protection from new threats in specific domains (Hypersonic, Anti-Satellite Systems - ASAT, Space based Early Missile Warning); Military Satellite Communications – MILSATCOM (including the development of innovative narrowband communication waveforms for operations in complex EM scenarios); Earth Observation; Access to Space; Responsive Space Capabilities; Space Domain Awareness (SDA); In-Orbit Servicing; Electromagnetic Spectrum Surveillance; stratospheric platforms;
- **Cyber**: solutions for achieving situational awareness in cyberspace, for monitoring and defending Information Technology (IT) and Operational Technology (OT) systems on the battlefield / critical infrastructures on national territory, as well as attacks in the cyber domain. Technological solutions to combat influence and disinformation campaigns in cyberspace. Technological solutions that generate effects in cyberspace through the exploitation of the electromagnetic spectrum (Cyber Electro-Magnetic Activities - CEMA),
- **Underwater**: technology to control the underwater domain, to survey and to protect critical infrastructures (energy and communication sectors), and to ensure the operational effectiveness of the vehicles and the devices that operate there;
- **Urban warfare**: technology to map, control, and exploit the characteristics of the urban territory and its subsoil and for the operational effectiveness of the military vehicles and devices that operate there (including unmanned systems);
- **Cognitive warfare**: technology and methodology for the mitigation and the exploitation of the tools relating to the influence, interference, or alteration aimed at increasing or decreasing the capabilities of the human mind.

(3) Continue to study, research, apply, and evaluate Emerging and Disruptive Technologies (EDTs):
- **Artificial Intelligence**: solutions supported by the use of Artificial Intelligence models in all of its forms (statistical, logical, and semantic), including multi-agent models, to streamline typical military use cases (both operational and managerial), in at least one development phase (simplification and standardization, digitalization, automation, advances analytics, and implementation of cognitive technologies) and in areas such as:
  a. Command and Control;
  b. ISTAR;
  c. Security;
  d. Combat Support;
  e. Autonomous Systems;
  f. Automation of staff processes;
  g. Data Management (including Data Centric Security);
  h. Logistics;
  i. Adaptive Training;
  j. Administration;
  k. Training;
  l. Health Care;
  m. Image and Video Analytics;
  n. Predictive asset maintenance;
  o. Weapon and alarm systems improvement;
  p. Energy security;

  focusing on core technologies, technological application areas, and performance characteristics;
- **Quantum technologies**: solutions based on Quantum Sensing (including Quantum Position, Navigation, and Timing - PNT),

Quantum Communication and Quantum Computing (Information Science);

- **Autonomous Systems**: technology for the development and contrast of Robotic Autonomous Systems (RAS) and Unmanned Systems (UxV) in all operational domains, enabling technologies for multi-domain interoperability and for the implementation of:
  a. Swarming;
  b. Hardening techniques and skills[2];
  c. Tecnologie di *Manned-Unmanned Teaming* (MUMT).
- **Development of next generation complex systems**: development of directed energy weapons (laser and electromagnetic pulse – EMP) and their defence systems; development of capabilities to penetrate adversary air defence systems[3] and of solutions to increase the effectiveness of our own; development of armed drones, loitering munitions, and their defence systems;
- **Strengthening a soldier's operational capabilities**: increase in defensive and offensive capacity (individual armament characterized by greater lethality and engagement capacity, exoskeletons, innovative and high-performance protective equipment); increase in energy autonomy for powering C2 equipment and supplies, human enhancement, advanced awareness, prevention, detection, and for combating the CBRN threat; development of biosensors and bioelectronics applications for monitoring the vitals and stress levels of fighters, reducing the negative effects of illnesses;
- **Nano technology, Novel materials, and manufacturing**: development of high-performance materials resistant to very high temperatures and high stress, with peculiar mechanical – structural and/or electrical/electronic/electro-optical properties and characteristics; development of stealth, protection for electronic circuits from high-power electromagnetic pulses (EMPs), superconductors, and adaptive camouflage, and the use of 3D printing technology;
- **Hypersonic Technology**: development of solutions relating to materials, propulsion systems, guidance systems, warheads, flight profile simulations of threats (in order to identify their limits), sensors (space/aerospace, land, and naval) and innovative actuators (or the implementation of innovative solutions aimed at increasing the performance of existing actuators);
- **Adaptation to the effects of Climate Change – Environmental sustainability, energy safety and resilience, efficiency of infrastructure, and adaptation of vehicles, systems, and equipment**: solutions for reducing the military's logistical and environmental footprint, for increasing the safety and efficiency of military infrastructure and vehicles (smart buildings, near zero energy buildings, field structures, biofuels and hybrid propulsion/fuel cells, renewable energy sources, energy management systems, and diversification of supply systems), technology for adapting/maintaining optimal performance standards for platforms, weapon systems, and personnel equipment against the effects generated by climate change;
- **Next generation communication networks**: solutions supported by the use of 5G (including their integration with the Non Terrestrial Network – NTN) and 6G technologies. Research on the architecture

2 "Hardening"/shielding process that protects electronic circuits from the harmful effects of high-power electromagnetic pulses (EMPs).

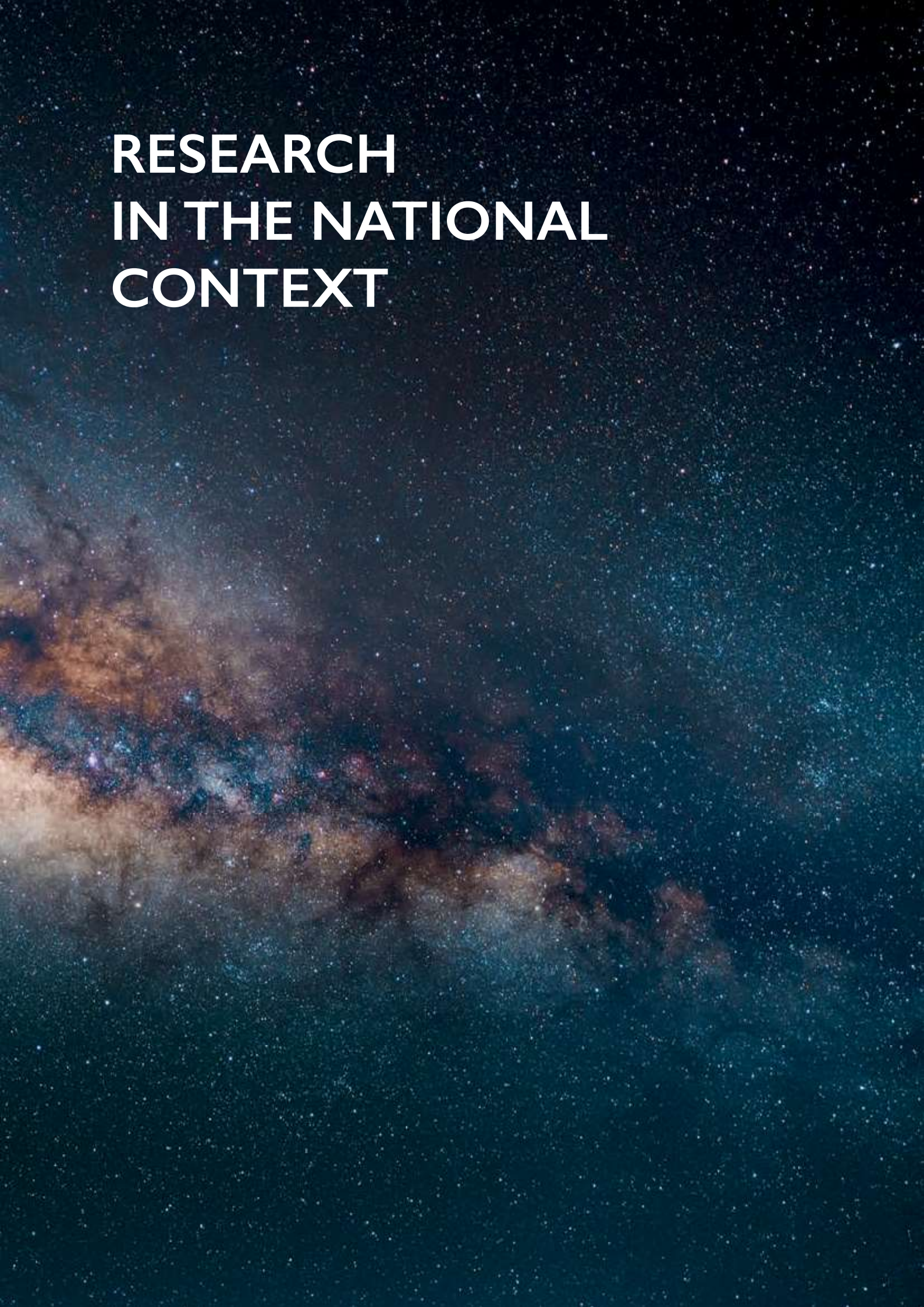
3 Anti-Access/Area Denial (A2/AD) bubbles included.

and the identification of the parameters of next generation networks. Development of communication equipment characterized by greater resilience to electronic warfare and with reduced requirements in terms of size, weight, power, and bandwidth.

These macro objectives, with the related directions and priorities, which represent the areas of strategic interest for military technological research and the modernization of defence capabilities, align with the priority capacitive-technological aggregates identified annually by the Defence General Staff. The identification of these directions and priorities allow for more effective and efficient planning and management of financial resources, reducing the fragmentation of technological research activities and the dispersion of resources across multiple and diverse initiatives.

This approach, which represents a strategic and organizational direction for the Secretariat General of Defence/NAD to constantly pursue, will help build a new shared mindset of the Defence Administration for Innovation, aimed at the continuous promotion of an integrated military and civil organization, an efficient incubator of new ideas and technical concepts for Defence.

RESEARCH IN THE NATIONAL CONTEXT



INTRODUCTION

The results of some of the projects within the research programs conducted by the Secretariat General of Defence and National Armaments Directorate during 2023 are presented below. These are considered exemplary technical-scientific activities, currently underway or completed, of relevant technology for the Defence and security sector:

- Advanced Sonar Signal Processing System **(ASSPS)**
- Underwater quantum communication prototype **(QuSUB)**
- Study of the SATCOM communication system Bi-Band X-ka antenna with multipurpose radomes **(SABB-XKa)**
- Low-cost X-band Multi-mission AESA seeker **(SAMBA.X)**
- Cryptographic security in automation systems **(CRYPTOBOX)**
- Upgraded V6 combustion engine for medium armored vehicle **(V6-HPOWER)**
- Creation of predictive methods for the design and optimization of ballistic helmets **(CRANOS)**
- *Miniaturized* Redundant FOG-INS **(MRFOGINS)**
- Proactive anti-UAV system to protect army tanks and patrols in urban areas **(PROACTIVE)**
- Innovative 4-2 seater all-terrain vehicle, full hybrid **(FHYW44)**
- Innovative system for navigation and safe position in the absence GNSS signal **(SINAPSIS)**
- Hypersonic suborbital space-plane capable of supporting the payload during orbit insertion **(HYPERION)**
- Interoperable unmanned ground control station **(MAGICS)**
- Application of HUMS and Vulnerability/Survivability methodologies to RPAS platforms **(ZENIT)**
- Electronic Warfare Quantum **(EWQ)**
- Technologies developed in the fiber optic telecommunications sector **(GIRL)**
- Development of a 5G modem for UAVs for LOS and BLOS communication **(M5G)**
- Spatial super-resolution for hyperspectral satellite images **(SR4IS)**
- Study of the system and the space segment with Antenna Adaptivity, on broadband **(ADAPTIVE)**
- Prototype of insectarium in class 3 biosafety facilities **(C3Lab)**
- A package consisting of skis, bindings and dedicated sensors **(SKIING WITH DISABILITIES)**

The project aims to apply sonar signal processing algorithms coupled with the use of specifically trained neural networks that enable passive discovery and estimation of target DoA (Direction of Arrival) in deep and shallow water environments. In addition, the project aims to create a system that can be fully integrated into command and control systems. In phase 1 of the project, together with the experts from the different fields provided by the defence administration, we were able to freeze the necessary requirements to implement the innovation in the system, both for the classical sonar signal analysis and for the introduction of neural networks. The result was to move towards a hybrid solution that aims to reap the benefits of both technologies. In phase 2, the realisation of the software modules and the synthetic dataset for training and testing will be conducted. The final phase aims to test and validate the project output. The HMI proved to be of excellent use during the testing phases and the additional elements, the integration of which has been planned, promise to increase performance and provide a level of support to the operator which far exceeds the norm.

INTRODUCTION

The Project aims to explore the state of the art in sonar signal processing algorithms with the best ratio of performance in terms of detection versus computational power employed and sensitivity to background noise and multipath, typical of shallow water environments. The chosen set of algorithms, in addition to being compared in terms of key performance indexes, will be optimised with the application of specifically trained neural networks that will enable the system to perform passive discovery and target DoA estimation. The objective of the project, in addition to the real time analysis and detection part, is also to create a system that is more prepared for integration with the command and control system than traditional systems by implementing a two-way exchange between the command and control system and the sonar system of target information. The advantage of using neural networks is that the network can be retrained at a later date, either on the same type of target, improving performance by using a larger dataset, or on different types of targets. This can be achieved by a simple retraining of the classifier, without the need for a substantial change in the structure of the neural network.

TECHNICAL BACKGROUND AND SOLUTIONS

Nowadays, the signal processing landscape of sonar data streams focuses on classical statistical algorithms and stand-alone systems, which are not integrated into command and control systems, with which they merely exchange data. The acoustic characteristics of shallow-water environments are variable in both space and time with a high level of background noise. The conventional algorithms used are threshold algorithms and are often subject to a high number of false alarms. A stand-alone sonar system is also limited to minimal data exchange with the control system (reception of ship data and transmission of sonar tracks). Target information is in fact exchanged between the sonar system and the command and control system in a unidirectional

manner in favour of the latter. The raw sonar data is not made available to systems outside the platform that embarks the sonar itself. The project reflects the indications contained in the 'Defence Multiannual Planning Document (DPP) for the three-year period 2021-2023', with a particular focus on the Interforce Component, Consultation, Command and Control (C3) and the interoperability and integration in a multi-domain direction of the national military instrument.
In addition to the obvious national connotation, the project is aimed at the development of capabilities and systems that are interconnected and able to inter-operate with each other and in an environment with an increasingly digital connotation, where surveillance, intelligence gathering and command and control capabilities are crucial, even in advanced positions for better decision-making and rapid response to changing situations. Its objective is the development of productive capacities to reduce or eliminate Italy's dependence on strategic international suppliers.

METHODOLOGY

The need to look to the future and to seek better performance has led us to pursue the integration of artificial intelligence techniques in detection and classification techniques. The identified solution consists of a hybrid of classical processing [1][2][3] alongside the use of neural networks [4] to combine discovery and DoA (Direction of Arrival) estimation of broadband acoustic noise sources in situations of varying SNR (signal-to-noise ratio). The dataset creation phase consists of the collection of a synthetic dataset, but with features extrapolated from real signals, generated in an adequate number to accomplish both good network training and network validation. As with current sonars, the acquired data is first processed by a conventional beamformer, so as to obtain an output signal for each DoA with a predetermined angle resolution that depends on the size of the array and the number of sensors. In the training phase, a subset of this data is used to build a classifier, which uses recent advances in neural networks to distinguish background noise and objects of interest and predicts the DoA of the target. The system will also be able to use information from other on-board systems to improve its performance in discovering and estimating the DoA of targets. 2D time-frequency representations of the signals are used as input

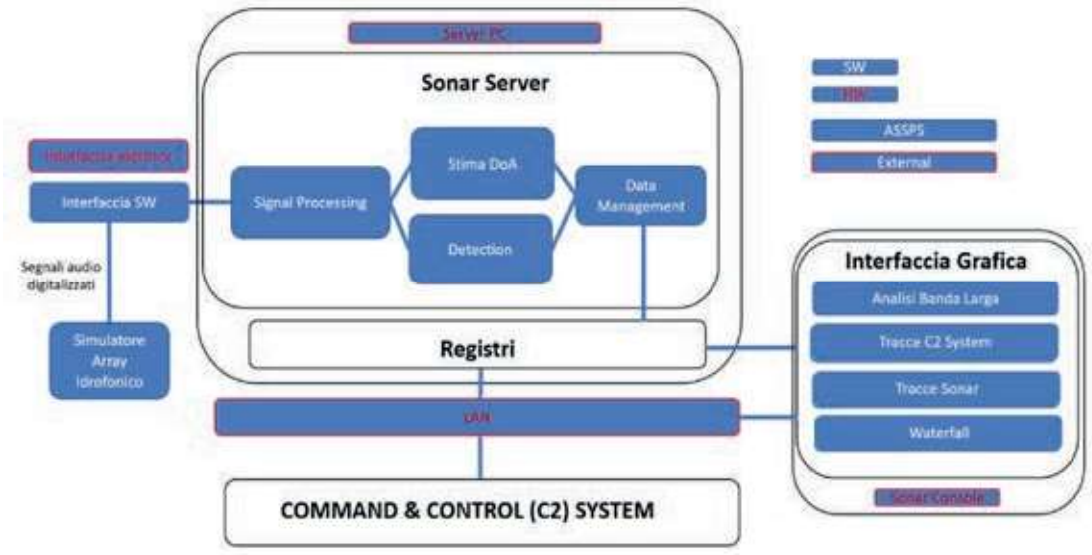


Figure 1 - System architecture scheme.

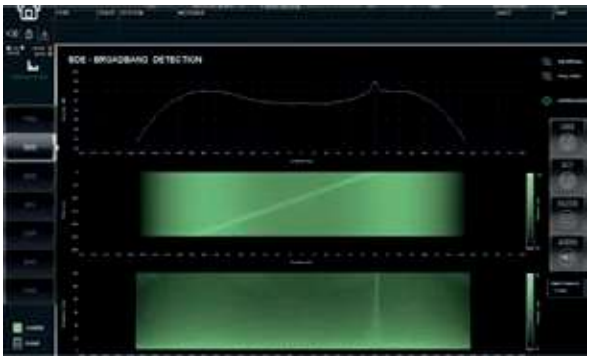


Figure 2 - Example of a user interface for passive sonar signal analysis.

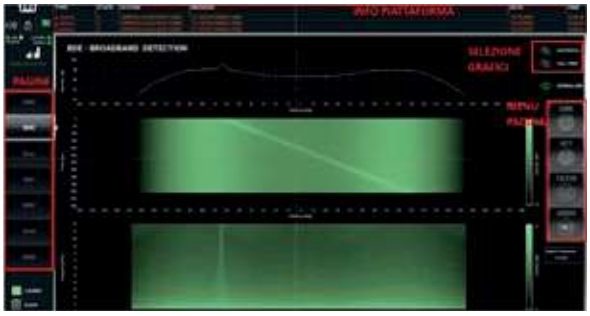


Figure 3 - User interface with meaningful sidebars and status bars.

Figure 4 - Signal user interface for passive sonar signal analysis on DRASS console.

to the neural network. These are first obtained from the original data and then given as input to the neural network. The output solutions to the neural network and the respective raw data will be collected and made available to the command and control system (Figures 1, 2, 3 and 4).

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The main innovation proposed in the project is the introduction, in passive sonar systems, of the breakthroughs brought about by the use of neural networks in the discovery of targets and estimation of their broadband DoA. The advantages in terms of performance in using such networks have been amply demonstrated in scientific literature. In fact, ranging DoA discovery and estimation algorithms based on neural networks have been shown to be less sensitive to background noise, interference and multipath effects than conventional techniques. Technological growth in supporting hardware for computing provides the possibility to increase the processing power to be applied without affecting the size and power necessary, perhaps even optimising it. It is therefore possible to perform a complete integration of the sonar processing system with that of the host platform's combat system, making the data coexist on a single on-board network for easy consultation and tactical evaluation. The use of neural networks for this type of system can be adapted in other fields of military value that use both passive and active monitoring of acoustic signals such as surveillance, mine detection and in all applications where acoustic signal classification is advantageous.

CONCLUSIONS

Considering the trajectory of underwater technology, one of the main objectives is that of restoring the nation's ability to autonomously manufacture submarines, including manufacture of the main on board equipment. Prominent

among these systems is the sonar system. From a technological point of view, sonar is the most complex component, as it requires both a high level of signal processing capability and dedicated technology for the production of piezoelectric elements and their installation in arrays. The modernization of classical techniques used in signal processing and the application of neural networks as a supporting tool pave the way for the realisation of new state-of-the-art sonar systems. Experienced operators will be able to apply their knowledge to the interpretation of the results provided by the software but assisted by artificial intelligence in decision support. Integrating the information available to command and control within the software suite will standardize the solutions provided and increase their accuracy.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

ASSPS	*Advanced Sonar Signal Processing System*
C2	*Command and Control*
DoA	*Direction of Arrival*
HMI	*Human Machine Interface*
HW	*hardware*
LAN	*Local Area Network*
SNR	*signal-to-noise ratio*
SW	*software*
PNRM	*Piano Nazionale di Ricerca Militare*

KEYWORDS

Command and Control, Intelligence, Surveillance, Reconnaissance (ISR), Artificial Intelligence, sonar systems, passive sonar, sonar signal analysis.

PROJECT INFORMATION

PNRM number:	a2021.191
Organization:	Directorate of Naval Armaments
Responsible entity:	Directorate of Naval Armaments – 1st Dpt – Submarine Programme Office
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QuSUB

The need for communication between submerged vehicles is of paramount importance. With the advent of quantum computers (QC), classical methods of communication will no longer be sufficient to guarantee the secrecy and integrity of communication. To respond to this danger, this project investigates the use of quantum key distribution (QKD) technologies in the underwater environment.
To study the feasibility of QKD, theoretical models has been developed on classical and quantum optical communication between two submerged vehicles under various environmental conditions. These models have been verified in the laboratory and a device capable of demonstrating QKD technologies in a subsea environment has been engineered.
At this stage of the project, it was found that, under optimal conditions, it is possible to establish a classic optical communication of more than 400 m and perform key exchange via QKD up to 300 m. A QKD system compatible with pressure resistant containers has also been designed, capable of being mounted on an unmanned underwater vehicle (UUV) and an underwater platform (mothership).
The feasibility analysis shows that a QKD system for the exchange of cryptographic keys between submerged vehicles is possible and represents the most secure method of communication, immune to the advent of CQ.

INTRODUCTION

In the context of military communications, two fundamental requirements are highlighted: speed and security. The transmission capacity required to communicate data between fixed or mobile workstations is becoming an increasingly stringent requirement, while the importance of such information often requires very high standards of availability, confidentiality, and integrity of the data.
QKD allows the creation of symmetric cryptographic keys, ensuring, according to the fundamental laws of quantum physics, the discovery of any interceptor. Currently, some prototypes have demonstrated the use of QKD in a subsea environment, reaching the maximum distance of 50 m [1].
In this project we will realize a pair of devices capable of exchanging quantum cryptographic keys between a UUV and a mothership. These devices will be able to automatically align and remain aligned during the relative movement of the two devices (Point and Tracking).
The technologies developed in this project will not only be able to protect the transmission of data between military vehicles, but also protect the necessary communications between the operations centre and the sensors and actuators of underwater infrastructures.

TECHNICAL BACKGROUND AND SOLUTIONS

To date, three different technologies are used for underwater communications: acoustic, radio frequency, and optical. Among these, the subject of the QuSUB project are optical communications, which have been very successful in recent years. Optical waves have a high transmission rate (several Gbps) and have high directionality. This technology makes it possible to transmit data up to hundreds of km in optical fiber, but they are lim-

ited to a few kilometres in free space in the air and a few hundred meters in the water. Moreover, the possibility of interception is not negligible; for this reason, in recent years, the exploration of submarine quantum communication technologies has been intensifying to implement QKD systems that distribute secure keys between two or more users. The security of QKD can also be guaranteed in cases where an eavesdropper uses unlimited computing power and storage memory and any conceivable device (as long as the laws of physics allow it). Thus, the transmission of cryptographic keys through an open channel, entirely under the control of an eavesdropper, can be considered perfectly secure (figure 1).

The basic elements of a QKD (figure 2) system are a transmitter (Alice) and a receiver (Bob). Keys are shared over the QKD link, which usually consists of a quantum channel and an authenticated classical channel. The first is reserved for transmitting quantum signals, such as dimmed light states at the single-photon level, to transmit strings of random bits. The second is reserved for synchronization and data exchange between QKD modules.

To date, several demonstrations have been presented of the use of QKD in water [2-4], but they are limited to laboratory tests between stationary devices. In the project, we aim not only to mount these devices on mobile vehicles, but also to realize a complete underwater optical communication system.

METHODOLOGY

The project was divided into 3 phases:

1. Preliminary study
2. Design and prototype production
3. Prototype installation and field testing

Of these, the first phase has just been successfully completed. Specifically, in the first phase of is:

1) Developed a software simulator to estimate the efficiency performance of a QKD system in an underwater environment.
2) Validate the simulator with laboratory tests and production of a design for the transmitter and receiver of the QKD system including the point & tracking system.
3) Definition of the mechanical layout of the optical and electronic components that make up the QKD system, and design of watertight and pressure-resistant containers.

In the simulator, the underwater environmental factors that affect the performance of the communication system (classical and quantum) in different geographical areas and different at times of the year were analysed.

During the validation, the channel was characterized based on the theoretical model, through laboratory tests. The deterministic attenuation and the effect of turbulence induced by temperature variations, movement of water masses and the presence of air bubbles in the medium were studied.

Finally, single-photon transmission tests were performed for various water conditions and, with the results collected, the relative bit error rate (classical and quantum) was analysed.

In the validation of the layout, a joint analysis was first performed between CABI CATTANEO and QTI for:

1) determine the ideal subdivision of the functional blocks constituting the “Alice” and “Bob” systems.
2) optimize the arrangement of the components inside the pressure containers.

As a result of this analysis, it was decided to design a single container for the summarization of the Alice module.

As far as the Bob module, only the telescope section will be submerged, while electronics and optics will be installed on the surface.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The technologies developed in this project will make possible to detect any attempt to inter-

cept the exchange of cryptographic keys between submerged vehicles. This will make it possible to establish secure communication between these vehicles. In addition, in this project, techniques for the transmission of data in a submarine environment using visible light will also be developed, increasing the speed of data transmission by several orders of magnitude compared to the speeds possible with acoustic communications even if with a range of only a few hundred meters.

These technologies can be used, for example, for data transmission between submarines, submarines and UUVs, or with surface vehicles. This project also paves the way for the use of underwater QKD and optical transmission for the recovery of data from submerged sensors through the use of UUVs.

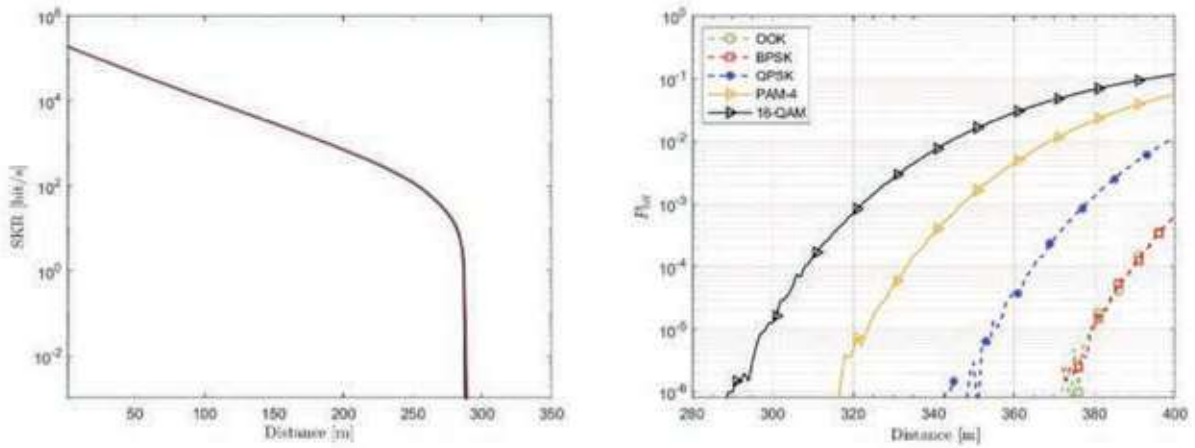

Figure 1 - Results obtained from the software simulator. On the left, you can see the Secret Key Rate (SKR) as a function of the distance between Alice and Bob of a QKD system in an underwater environment. On the right, the Bit Error Rate (BER) in the simulated classical communication system as a function of transmission distance.

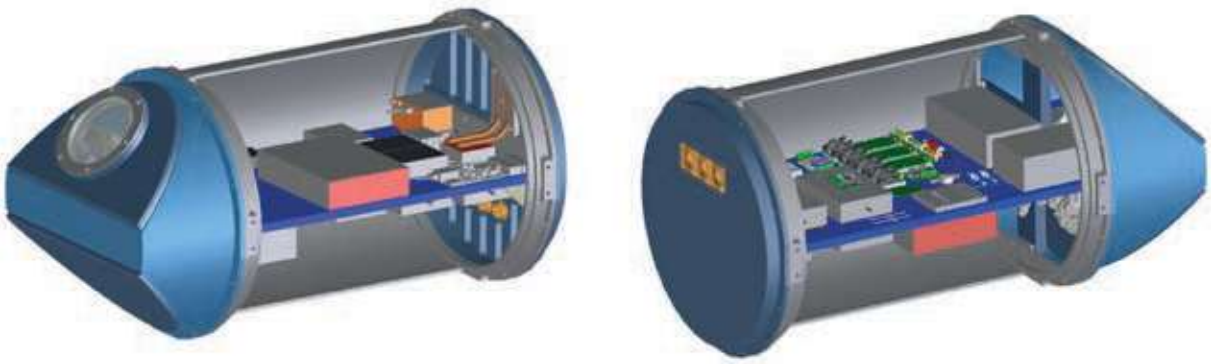

Figure 2 - Rendering del trasmettitore del sistema QKD progettato durante questa fase del progetto / Rendering of the QKD system transmitter designed during this phase of the project.

CONCLUSIONS

In conclusion, this project will create a prototype of underwater quantum communication immune to any present and future interception attempts. In this first phase it has been calculated that an optical communication system can transmit data up to a range of 400 m and cryptographic keys can be exchanged up to 300 m under ideal water

conditions. The model used in these calculations was also validated with laboratory tests and the components needed to build the device have been identified. In addition, the initial design of the system and the containers that will host it has been completed.

So far, all the objectives have been achieved, giving confidence to the success of the project as a whole.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

CQ	*Quantum Computer*
QKD	*Quantum Key Distribution*
UUV	*Unmanned Underwater Vehicle*

KEYWORDS

Cryptography, Underwater, QKD, Quantum, Optical Communication.

PROJECT INFORMATION

PNRM Number:	a2020.214
Organization:	Direzione Armamenti Navali (NAVARM)
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SABB-XKa

The continuous evolution of the use of satellite communication systems in the military field increasingly involves the need to rapidly exchange high data flows and at the same time reducing overall dimensions of on-board military assets. The project "SABB-XKa - *Study of the X-Ka Dual Band Antenna Satcom System with different radomes designed for specific environments or platforms*" aims to design and build a complete SATCOM prototype, compact in size, versatile and capable of operating simultaneously in the K-Ka and C-X frequency bands. During phase 1 of the project, all the necessary requirements of the system were identified, various solutions were simulated until excellent results were obtained in terms of the entire system performance. The implementation and optimization of the system prototype will be carried out during phase 2 of the project, with the aim of verifying its real performance. Due to its small size and versatility, the system can be used for multiple applications, as for example, for the flow of data with submarine, ground, naval and aerial vehicles or for the remote control of UAVs (Unmanned Aerial Vehicles).

INTRODUCTION

New operational scenarios are causing a rapid change in the needs of using satellite communication systems installed on board of military assets, particularly on submarines and drones. Indeed, these means are increasingly used in Intelligence Survey Recognition (ISR) operations to provide documentation and video footage to be transmitted covertly and in real time. Therefore, it is needed to develop systems capable of guaranteeing high data flows to and from the satellite carriers installed on board of military assets, an operational need also implemented in the Italian defence sector with the launch, in collaboration with France, of the new system Athena-Fidus satellite. The use of new frequencies for data transmission and reception, together with a strong demand for space minimization, has made it necessary to develop a compact system, consisting of a single transmitting/receiving antenna, capable of operating simultaneously at different frequency bands, adding to the C-X band channels the new K-Ka band channels. The new system will make it possible to exploit the full potential of each band, especially greater data transmission speed in the K-Ka band and lower losses arising from meteorological conditions in the C-X band.

TECHNICAL BACKGROUND AND SOLUTIONS

The technological solution identified by the ATS (Temporary Scope Association), whose participants are Dallara Compositi, Navisystem Marine Electronics and the Department of Information Engineering of the University of Pisa, consists of the design of a compact high-performance (e.g. high radiation efficiency) multi-band SATCOM system operating in 4 distinct frequency bands: C (7. 25-7.75 GHz) and K (20.2-21.2 GHz) bands for the downlink and X (7.9-8.4 GHz) and Ka (30-31 GHz) bands for the uplink. To achieve a reliable link with geostationary satellites, the antenna is designed to transmit and receive signals with circular polarization, in particular Left-Hand Circular Polarization (LHCP) for the downlink and Right-Hand Circular Polarization (RHCP) for the uplink. The antenna has been designed to satisfy the following system require-

ments within the operating bands: Aperture efficiency (ε_{ap}) greater than 50%; Voltage Standing Wave Ratio (VSWR) less than 2; Compliance with the reference standards for Sidelobe Level of the radiation patterns.

The design of the entire system made it possible to find the proper location of all the equipment necessary for operation (feeder, OMT, filters, LNB, BUC, cables, mechanics, etc.) inside a radome with a maximum diameter of 600 mm. Furthermore, to ensure adequate protection of the new antenna, it was necessary to design different types of composite material radomes, having the same transparency characteristics in an extremely wide frequency range, made with physical and structural characteristics to be able to perform in very different operating environments:

- Submarine radome: resistant to high external pressures present during the submersion phases;
- Light radome: to be used on drones and aircraft in which the payload is favored over mechanical and/or environmental performance;
- Ballistic radome: resistant to high kinetic stresses in naval and ground applications.

METHODOLOGY

To make the antenna as compact as possible, a self-supported configuration has been chosen [1], so that both the receiver and transmitter can be placed behind the main reflector (Fig. 1). The dual reflector antenna has a Ring Focus configuration [2] to limit the blockage effect of the sub-reflector while maximizing the antenna efficiency (Fig. 2-3) (Tab. 1). A coaxial waveguide is used as a feeding structure to allow for satisfactory system performance at all the system frequency bands [3]. Specifically, the internal circular waveguide is dedicated to the K-Ka band while the external coaxial waveguide allows for the propagation of the C-X band signals. To connect the feeding structure to the receiver and transmitters, ad-hoc polarizer filter and OMT (Ortho-Mode Transducer) have been designed for the C-X band. This represents one of the most innovative aspects of the SABB-Xka project, since both the components are not commercially available for coaxial structures. Contrarily, commercial devices are used for the K-Ka band.

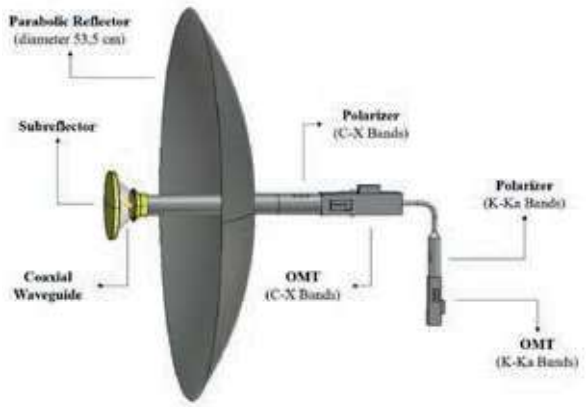

Figure 1 - Radiant system architecture for the SABB-XKa project.

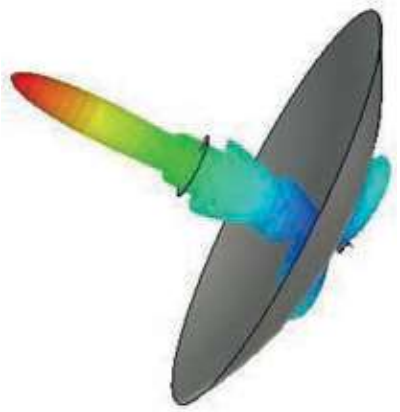

Figure 2 - Gain pattern at X band.

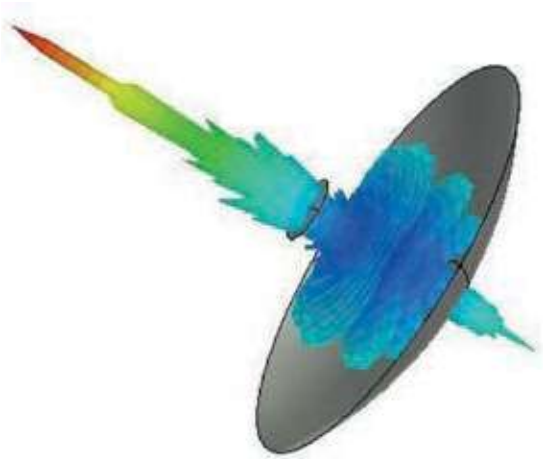

Figure 3 - Gain pattern at Ka band.

Band	Frequency Range [GHz]	Polarization	I earn [dBi]	Opening efficiency (ε_{ap})	VSWR in band
C	7.25 – 7.75	LHCP	30,2	59%	< 1,4
X	7.9 – 8.4	RHCP	31	60%	< 1,4
K	20.2 – 21.2	LHCP	37,4	44%	< 2
Ka	30 – 31	RHCP	42	56%	< 1,3

Table 1 - Performances of the SABB-XKa antenna obtained by numerical simulation.

During the design of each type of radome, an extensive and meticulous campaign of material characterization tests (electromagnetic and mechanical) was carried out, with the aim of identifying the most suitable materials to use. Through IL (Insertion Loss) calculation simulations, the composite material stratifications for each radome were defined, in order to limit losses in the bands of interest. In the case of the submarine radome (Fig. 4) it was necessary to carry out numerous iterations between FEM (Finite Element Method) structural analyzes [4][5] (Fig. 5-6) and IL analyses, in order to find the right tradeoff between radio transpar-

Figure 4 - Submarine radome.

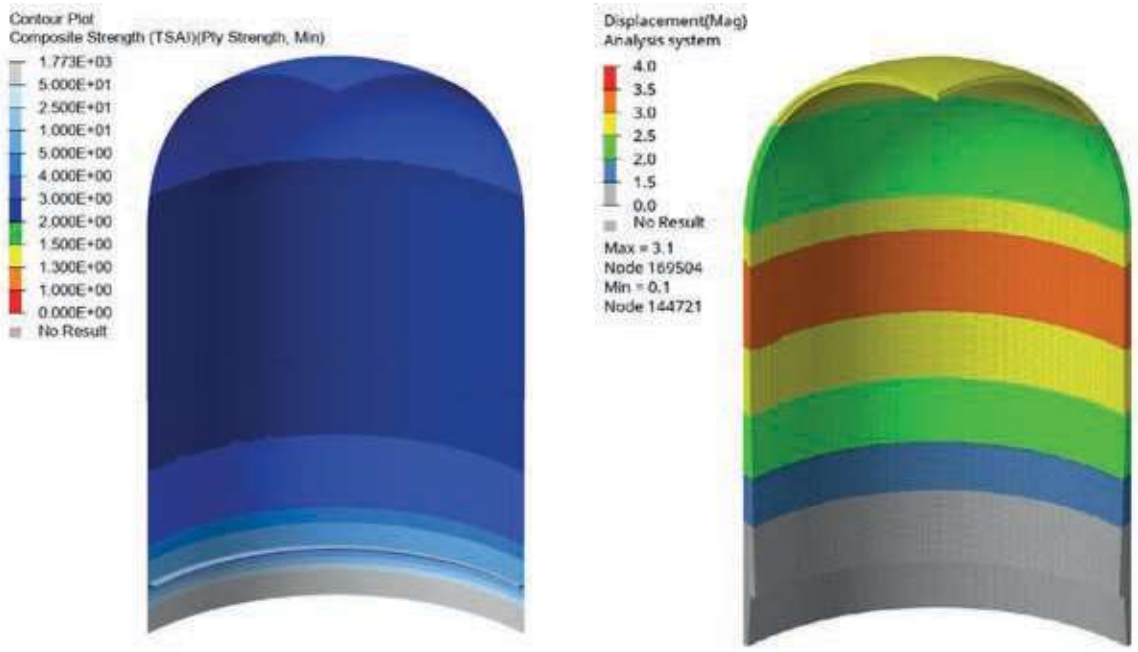

Figure 5 - Submarine radome: FEM results on composite part.

ency and structural resistance. The structural analysis was validated through fatigue tests on samples and will be further verified through a pressure resistance test on the first prototype. Furthermore, all IL simulations have been validated through tests on samples carried out in an anechoic chamber (Tab. 2) and will be verified again on prototypes.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The objectives achieved in the first phase of the project were such as to allow the activation of the next phase aimed at continuing the study and designing a prototype system in order to verify its real performances. The development of the system was mainly focused on underwater applications where the increase in data transmission speed, together with the reduction of overall dimensions, will allow high advantages to be obtained in terms of *Indiscretion Coefficient (1)* due to the exposure of the antenna. Thanks to the small size and versatility of the system as well as the presence of the study of radomes for alternative uses, with the appropriate adaptations, the system can also be used for other purposes, as for example the remote control of UAVs (Unmanned Aerial Vehicle) or for the data flow with ground, naval and aerial vehicles.

CONCLUSIONS

The SABB-Xka system design has given excellent results in terms of performance obtained in the simulation phase. The subsequent develop-

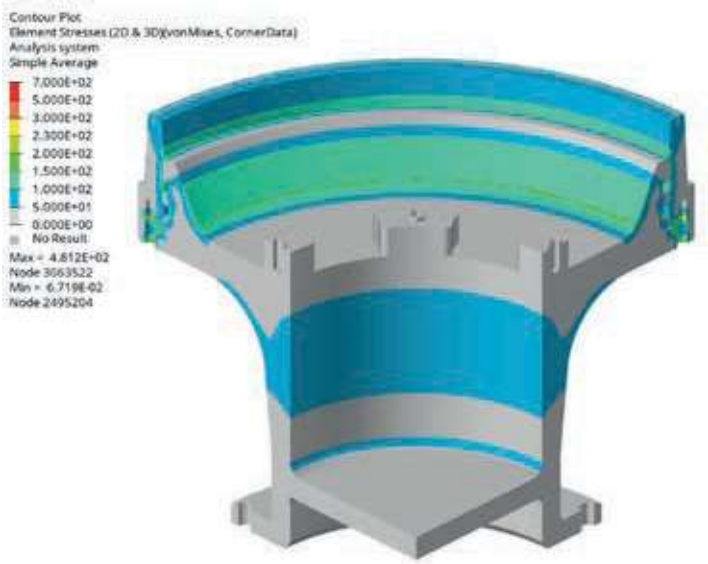

Figure 6 - Submarine Radome: FEM results on metal flanges.

Radome	IL band C [dB]	IL band X [dB]	IL banda K [dB]	IL banda Ka [dB]
Submarine	-0,7	-1,2	-1,27	-1,8
Light	-0,35	-0,37	-0,54	-0,3
Ballistic	-0,59	-0,44	-0,47	-0,77

Table 2 - "Insertion Loss" results of the 3 types of radomes obtained in tests carried out on samples in an anechoic chamber.

ment that is leading to the creation of the first working prototype has already highlighted a high level of technological maturation of the project. In the near future, the use of SATCOM systems will increasingly play a strategic role at a global level for the transmission of sensitive intelligence data and the remote piloting of UAVs. Having a broadband system with a high data flow will allow to operate more effectively in different areas and weather conditions. If a satellite operating in the same bands is released, the system would be able to exchange data on both channels simultaneously. These features make the system innovative, versatile and unique in its kind.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

SATCOM	*Satellite Communications*
ISR	*Intelligence Survey Recognition*
ATS	*Temporary Scope Association*
LHCP	*Left-Hand Circular Polarization*
RHCP	*Right-Hand Circular Polarization*
OMT	*Ortho-Mode Transducer*
LNB	*Low Noise Block converter*
BUC	*Block Up Converter*
IL	*Insertion Loss*
FEM	*Finite Element Method*
UAV	*Unmanned Aerial Vehicle*

KEYWORDS

SATCOM, Dual-band, Antenna, Radome, Submarine, Aircraft, Naval, Ground vehicle, Ballistic, Drones, UAVs.

PROJECT INFORMATION

PNRM number:	a2019.211
Organization:	Naval Armaments Directorate - NAVARM
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NOTES

(1) The term “Indiscretion Coefficient” means the percentage of time during which the submarine must expose an external appendage (in this case the antenna), thus being detected by radar or electro/optical devices.

SAMBa.X

The SAMBa.X project, funded by the Naval Armaments Directorate within the National Military Research Plan, has led to the development of an innovative architecture for missile seekers based on high-performance and highly reliable AESA (Active Electronically Scanned Array) technology. Moreover, the adopted architectural choices have significantly reduced recurring costs, ensuring economic sustainability even for mass production. Innovations have also extended to the signal processing component, introducing algorithms capable of outperforming legacy solutions, coupled with increased robustness against intentional interferences (ECM) and improved aim point selection capabilities, thanks to SAR/ISAR algorithms.
The project has been divided into three well-defined phases, including system design, critical component realization, and finally, the construction and integration of the technological demonstrator. The ongoing final phase aims to demonstrate the full maturity of the implemented technologies and the effectiveness of the proposed solutions.
In summary, SAMBa.X will highlight the possibility of developing, on a national scale, the entire technology and know-how necessary for creating a compact and scalable AESA antenna suitable for missile applications, within relatively short timeframes and at reasonable costs.

INTRODUCTION

This project aims to achieve several critical objectives. Firstly, it seeks to demonstrate the feasibility of developing highly performant and reliable anti-ship seekers, significantly reducing production costs. Secondly, it focuses on the development of critical microelectronic technologies, specifically highlighting chips and electronic modules designed entirely in Italy and ITAR-free. Finally, it aspires to strengthen the national industrial base, with a focus on SMEs and research centres, enabling them to successfully operate in the missile sector and thereby supporting the growth and competitiveness of national expertise in the strategic field of missile technology.
Additionally, numerous technological challenges have been addressed and resolved, including the effective implementation of digital beamforming synthesis with innovative DBF techniques, the use of SAR/ISAR algorithms to optimize the impact point, the enhancement of EP capabilities through advanced array processing techniques and modern multi-channel receivers, and the increase of MTBF through architectural choices based on the best semiconductor materials (GaN-on-SiC).
In summary, the ultimate goal has been to enhance the performance of anti-ship seekers by adopting an innovative approach to AESA technologies, addressing current challenges and proposing solutions better suited to modern operational scenarios.

TECHNICAL BACKGROUND AND SOLUTIONS

In today's operational context [1], multichannel AESA architectures emerge as the only technological solution capable of overcoming the limitations of legacy solutions. However, the use of AESA technologies poses significant challenges, including the need to implement an efficient and compact cooling system, as well as the adoption of methodologies aimed at drastically reducing

overall costs. A more in-depth analysis, however, leads us to identify a common reason for these problems, which lies in the architectural choices made by major manufacturers who employ plank solutions. This technological choice, combined with the high number of chips required to configure an antenna with adequate performance, results in a considerable increase in weight, dimensions, and heat production during operation, making them challenging to cool.

On the contrary, the SAMBA.X project proposes an AESA antenna with TRM on tiles parallel to the radiating plane that employs specifically designed multichannel chips. This solution dramatically reduces the number of components needed to set up an effective front-end, thereby bringing about various benefits, including a reduction in overall costs and footprint, as well as improved thermal balance, contributing to greater reliability and operational availability.

In addition to architectural innovations, the project also addresses limitations from a signal processing perspective and introduces several innovations. Specifically, to enhance target detection and discrimination in both blue water and littoral environments, combined SAR and ISAR techniques are employed, along with advanced monopulse angular estimation techniques specific to the architecture under consideration [2]. Modern techniques such as MUSIC are also incorporated, while EP performance is enhanced through the use of multi-channel receivers and spatial filtering techniques to counter jamming from multiple sources simultaneously.

METHODOLOGY

The SAMBa.X project is structured in three distinct phases, each dedicated to a specific objective:

1. feasibility study for a low-cost AESA anti-ship seeker and definition of innovative processing solutions to adapt its performance to modern operational scenarios.
2. design and realization of the AESA antenna and its related electronic critical components, particularly the TRMs and its chipset.
3. implementation of a technological demonstrator for the seeker to prove the effectiveness of the proposed antenna architecture and new processing algorithms.

In the “Phase 1” of the project, target discrimination algorithms based on SAR/ISAR Radar Imaging techniques were proposed (results in Figure 1), along with DBF algorithms to implement SAP (Spatial Array Processing) filtering to enhance EP capabilities. At the system level, requirements and architecture of the seeker were defined, and requirements were cascaded down to the AESA antenna unit.

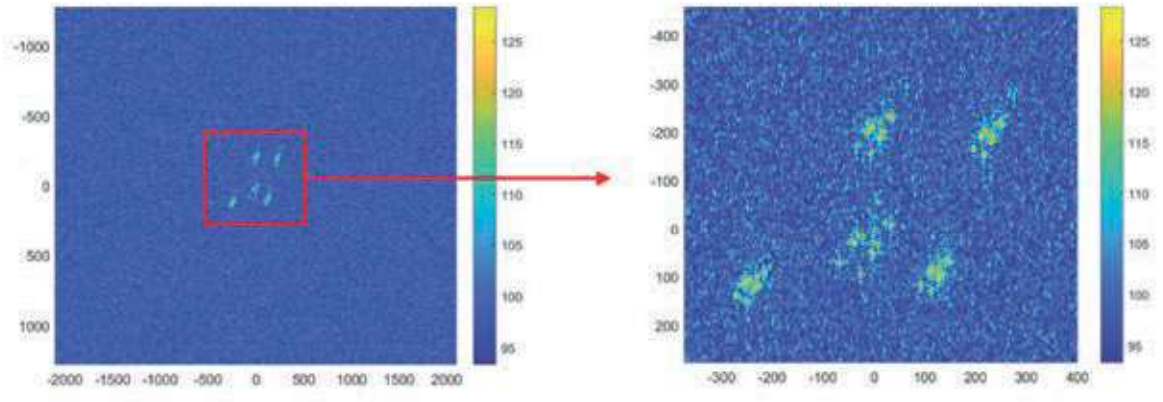

Figure 1 - Example of achievable results in terms of discrimination by applying a SAR technique to a tight naval formation composed of 5 units (the reference system is centered on the formation).

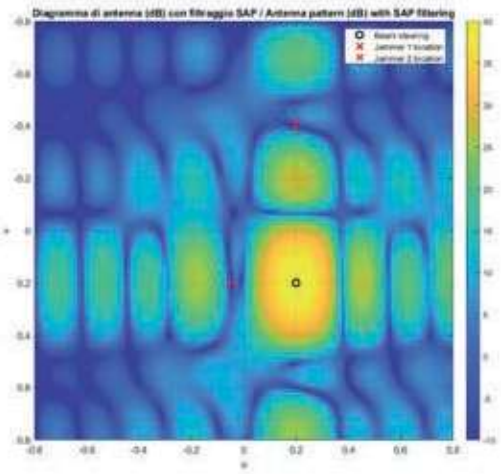

Figure 2 - Example of results achievable in terms of interference cancellation with SAP filtering in the presence of two jammers.

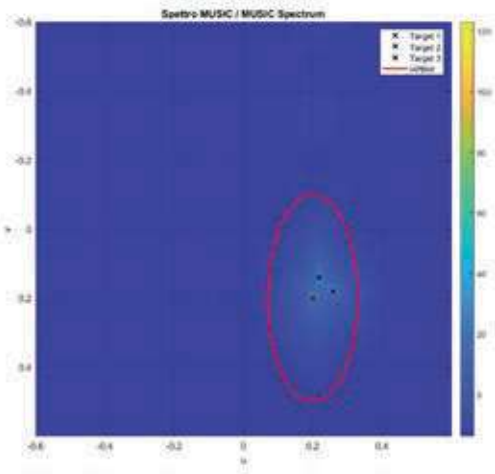

Figure 3 - Example of results achievable with MUSIC algorithms with three targets located in the main beam at the same range gate.

During "Phase 2" of the project, a digital twin of the AESA antenna was created to develop a model suitable for performance analysis and operational implementation (results in Figure 2 for SAP and Figure 3 for MUSIC). In this phase, prototypes of the planar 4x4 XTRM module (X-band TRM in Figure 4 with a breakdown of the module) were also developed. At the chipset level, the XTRM module employs a custom TR (Transmit-Receive) chip based on 15 μm GaN-SiC technology that integrates the entire front-end of the seeker (Figure 5 focuses on the chip development process).

The ongoing "Phase 3" of the project involves creating a technological demonstrator for the AESA seeker with a reduced-size antenna and offline processing to demonstrate the effectiveness and maturity of the proposed technologies (Figure 6 shows the current status of the antenna arrangement).

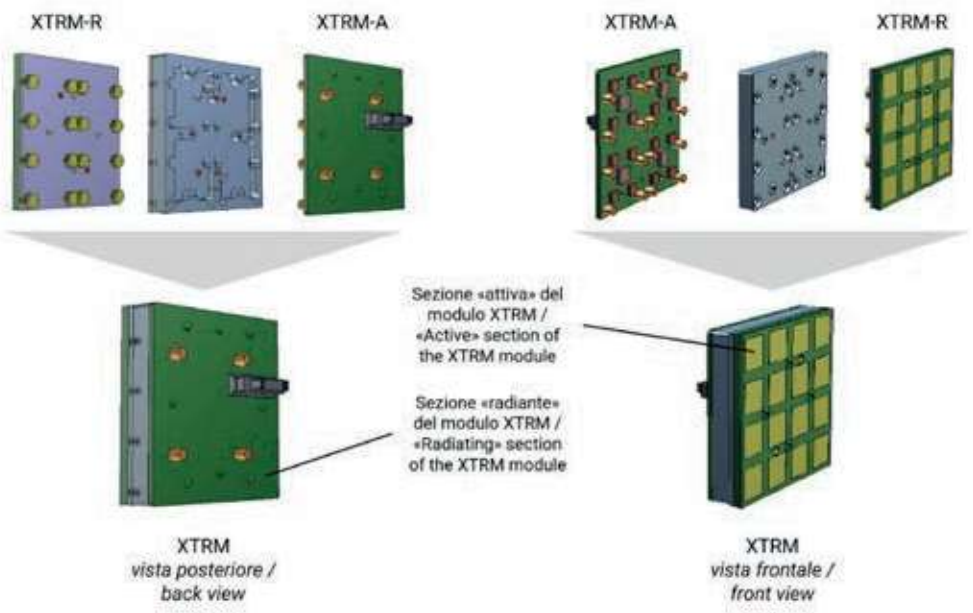

Figure 4 - Breakdown of the XTRM tile architecture with indication of the main components: XTRM-A (XTRM Active Section, i.e., the beamforming board) and XTRM-R (XTRM Radiating Section, i.e., the board with the radiating elements).

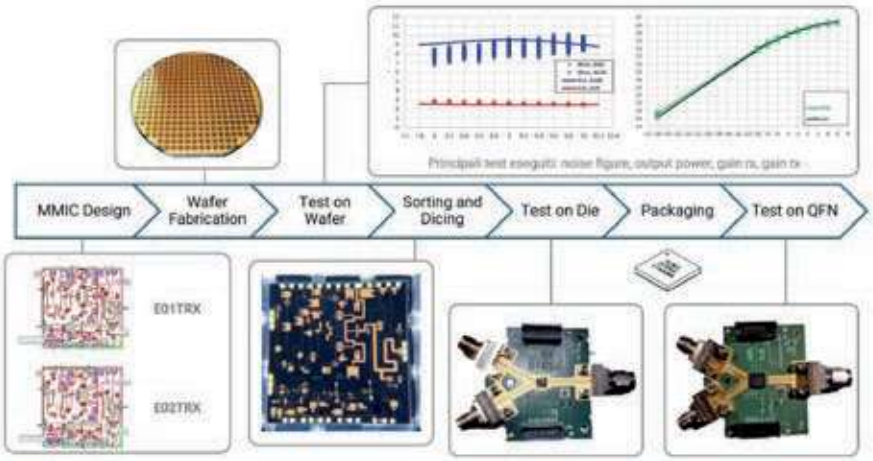

Figure 5 - Main phases of the evelopment and qualification process of the TR chip.

Figure 6 - Assembling the antenna for the technological demonstrator of the AESA seeker with three XTRM modules arranged on a single row.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The technology developed within the SAMBa.X project can be employed not only in the missile context for which it was designed but also in other operational scenarios. A specific case is that of tactical radars used to support close protection (against UXV threats, including loitering munitions) for naval and land assets, with particular reference to small-tonnage naval units equipped with small calibres, up to 40 mm, and on-the-move combat vehicles (e.g., AICS).

Furthermore, considering the opportunity to use this technology in civilian contexts, it has been decided to develop the XTRM module in two different versions. The first version, called XTRM High Power, is tailored for Defence applications and uses a custom ELDES-designed chip with high performance. The second version, called XTRM Low Power, instead utilizes COTS chips with reduced performance but lower costs. This latter version is more suitable for the civilian market (e.g., DAA for high-end commercial drones). In both cases, there are no export constraints since the technology used is entirely designed in Italy, manufactured with a wholly European supply chain, ITAR-free, and boycott-free.

CONCLUSIONS

The SAMBA.X project, currently in its third phase, is demonstrating that it is possible to develop, at a national level, rapidly and at low costs, the entire technology, components, and enabling algorithms for missile applications. Specifically, planar modules of the AESA antenna and the corresponding TR chips (entirely designed by ELDES) based on GaN-SiC technology have been developed and tested, significantly improving operational availability due to a notable increase in logistical performance (MTBF). Additionally, thanks to the fruitful collaboration between industry and university, a new signal processing scheme has been defined, utilizing state-of-the-art array processing techniques, greatly enhancing overall radar performance. Furthermore, cutting-edge monopulse techniques have been developed and optimized for multi-mission radar systems [2].

In terms of potential short-term impacts of the project, there are prospects for both deployment as a seeker in the export version of missiles and the development of retrofit kits for tracking radars. Moreover, through internal self-financing, ELDES has initiated projects to both modernize the Poseidon product line with AESA technology and create an innovative tactical radar for Land & Naval applications..

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AESA	*Active Electronically Scanned Array*
AICS	*Armored Infantry Combat System*
COTS	*Commercial Off-The Shelf*
DAA	*Detect and Avoid*
DBF	*Digital BeamForming*
EA	*Electronic Attack (ex ECM)*
EP	*Electronic Protection Measure (ex ECCM)*
GaN	*Gallium Nitride*
ISAR	*Inverse Synthetic Aperture Radar*
JSR	*Jammer to Signal Ratio*
MMI	*Marina Militare Italiana (Italian Navy)*
MTBF	*Mean Time Between Failures*
MUSIC	*MUltiple SIgnal Classification*
SAP	*Spatial Array Processing*
SAR	*Synthetic Aperture Radar*
SNR	*Signal to Noise Ratio*
SiC	*Silicon Carbide*
TR	*Transmit-Receive*
TRM	*Transmit-Receive Module*
TWT	*Travelling Wave Tube*
UXV	*Unmanned X Vehicle*
VSHORAD	*Very SHOrt-Range Air Defence*
XTRM	*X-band Transmit-Receive Module*

KEYWORDS

AESA, Digital Beamforming, Digital Twin, GaN, ISAR, Phased Array, Radar, SAR, Seeker, TRM.

PROJECT INFORMATION

PNRM number:	A2018.029
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NOTES

(1) The SAMBa.X project is conducted by ELDES srl in collaboration with the National Laboratory of Radar and Surveillance Systems (RaSS), which is part of the National Interuniversity Consortium for Telecommunications (CNIT).

(2) The X-band is traditionally employed by the legacy seekers [1] of the Italian Navy (MMI). Thus, remaining in this band allows the MMI to utilize the same assets for maintenance and leverage the wealth of experience gained in this band by its experimental units.

(3) A high peak power is considered one of the most effective and straightforward EPM techniques. This technique relies on maximizing the Signal to Noise Ratio (SNR) to achieve a negative Jammer to Signal Ratio (JSR), rendering any Electronic Attack (EA) technique substantially ineffective.

CRYPTOBOX

Phase 1 of the project saw the development of a prototype micro-cryptographic device capable of establishing a cryptographic security perimeter for OT or IIoT control devices (e.g. PLCs), guaranteeing maximum latency on the control network compatible with the most common communication protocols, both for application on new installations and for application within legacy solutions to be modernized (retrofit).
The CRYPTOBOX project, in addition to guaranteeing data integrity, aims to provide a solution to ensure the authenticity of information exchanged between PLCs and other devices that constitute DCS and SCADA networks, respecting performance constraints in terms of latency and throughput.

INTRODUCTION

CryptoBox project aims to develop a cryptographic solution to secure communications between Industrial Internet of Things (IIoT) devices by introducing a security layer on top of the current network infrastructures used in industrial automation systems.
The role of micro-cryptors in industrial environments is to ensure an adequate level of security for the controlled systems and overcome the technical difficulties associated with the use of security protocols on devices used in difficult environmental conditions, guaranteeing real-time performance.
The context of Operational Technology (OT) and Industrial Internet of Things (IIoT) applications often sees the use of clear-text communication protocols and the use of low-power/low-heat dissipation devices (low performance) that are not fitted for the implementation of robust cryptographic security schemes already implemented in the Information Technology (IT) context. This choice is due to the environmental working conditions of the devices and the specific dynamics of automation plants. In these environments, systems' availability, that is the ability to operate continuously and immediately, is the top priority over the aspects related to data confidentiality or communication authentication.

TECHNICAL BACKGROUND AND SOLUTIONS

In automation networks, and in particular for Distributed Control Systems (DCS) and Supervisory Control And Data Acquisition (SCADA) systems, the main threat generally consists of a direct attack on the control systems (e.g. Programmable Logic Control or PLC and Remote Terminal Unit or RTU) or the remote units directly connected to measuring instruments and actuators. The attack can be carried out by creating or manipulating information packets built by exploiting the intrinsic weaknesses/vulnerabilities of the industrial communication protocols. In fact, some of the most common protocols, designed to guarantee a specific performance in terms of data transfer speed, do not allow authentication or formal correctness (semantics) check of the transmitted information and have not been developed to natively resist direct sabotage actions to the connected plant.
The simplicity with which it is possible to conduct a potentially disastrous attack against these systems, if not adequately protected, makes control networks particularly attractive to potential attackers. In addition, the high strategic value of systems within critical infrastructure, constitutes an element of strong interest for state actors and Advanced Persistent Threats (A.P.T.), capable of developing deadly targeted attacks on these infrastructures.

METHODOLOGY

The Phase 1 of the project led to the realization of a prototype of cryptographic solution composed of micro-cryptors (namely the CryptoBoxes) based on the Field Programmable Gate Array (FPGA) technology, with the objective of meeting the requirement of low latency on the communications exchanged by the connected IIoT devices.

CryptoBox ciphers, in fact, allow for the implementation of a high-security cryptographic layer to ensure that, once out of the automation cabinets, all traffic to and from PLCs and RTUs is secured from any attacks carried over the control network. The security of the cryptographic layer (figure 1) is guaranteed by the hardware implementation of the TelsyGuard protocol (figure 2) , based on the VPN (1) WireGuard, a standard already implemented on various platforms, including the Linux kernel. WireGuard is a secure network tunnel operating at layer 3 of the ISO/OSI stack.

The cryptographic protocol development and its implementation on the selected hardware were designed to ensure the flexibility and ease the installation of the solution on the plants providing, from the early design phases, an adequate countermeasures to direct attacks on the ciphers themselves, in line with the best secure design standards (secure by design approach).

The prototype developed has allowed to verify the validity of the project, guaranteeing in its experimental implementation the minimum performance set for the project, or maximum admissible latency of less than 4 ms in all test conditions (Ethernet 10/100/1000 Mbit/s), and in the case of modern Gigabit Ethernet, measured latencies of less than 1 ms (achieved ~0.3 ms).

Figure 1 - Cryptographic layer and compatibility with industrial protocols..

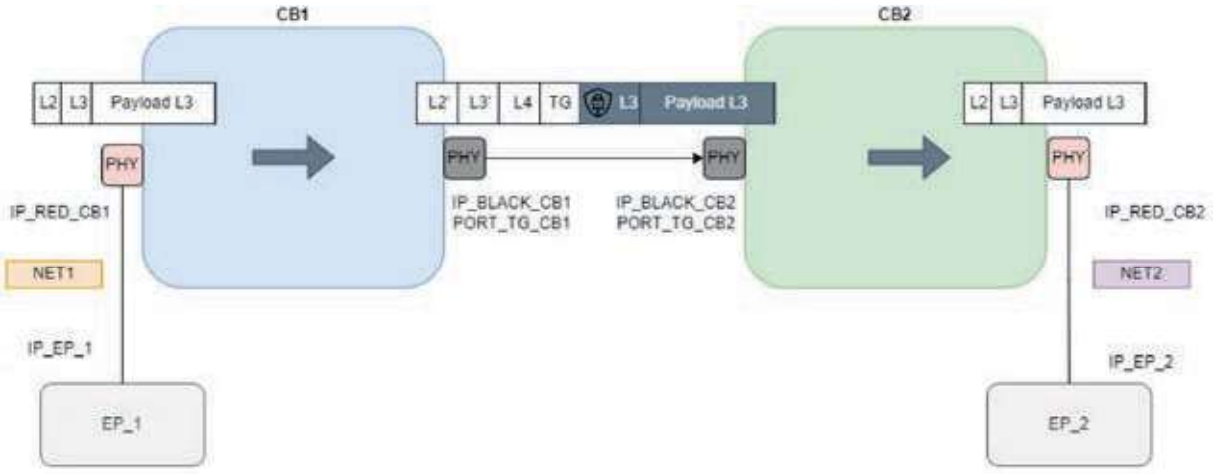

Figure 2 - VPN - TELSYGUARD - Implementation on Layer 3.

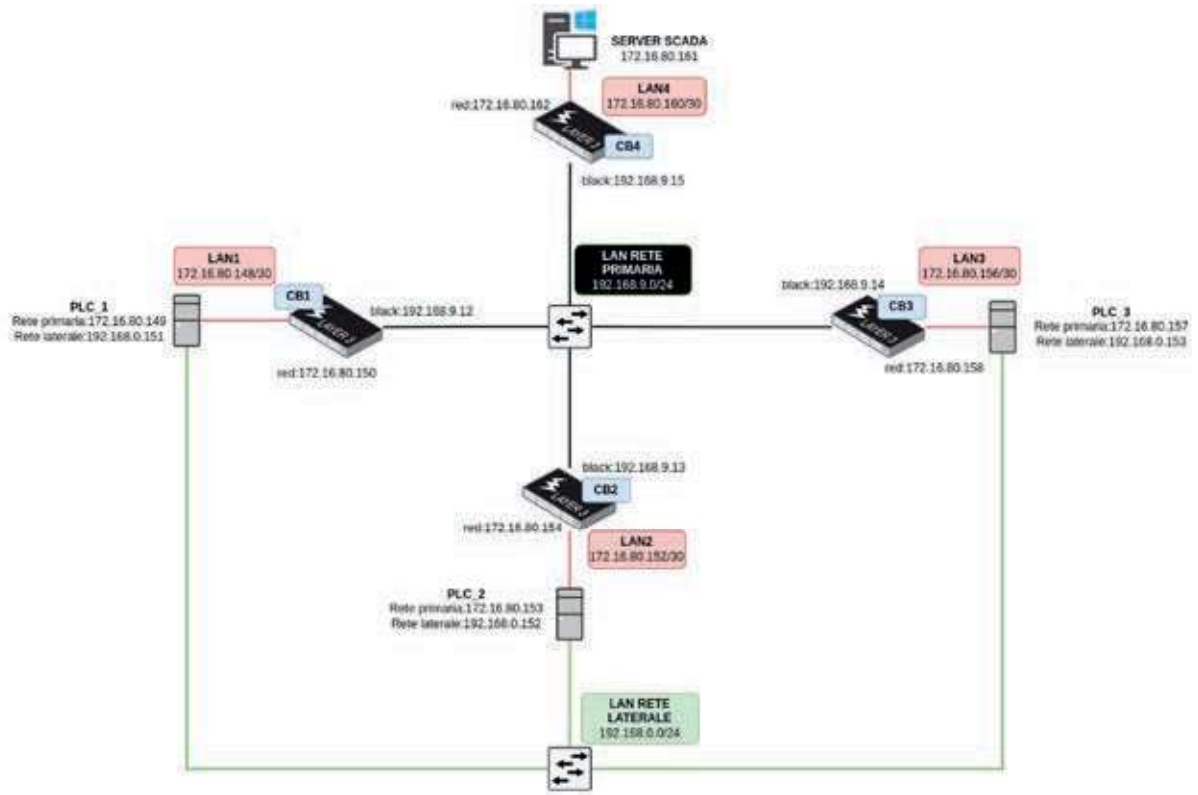

Figure 3 - Laboratory test environment (TRL 4).

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The tests were carried out at the Telsy laboratories, simulating the communication between PLC cabinets and a SCADA server, effectively simulating a possible configuration on board the Naval Units of the Italian Navy. This type of application scenario differs little from many other maritime and terrestrial application scenarios. In fact, the target of this technological solution is strongly dual-use, being intended for industrial automation plants based on COTS (commercial off the shelf) devices. The use could reasonably be extended within the critical infrastructure control systems and the systems available to public and private organizations within the Cyber Security perimeter.

CONCLUSIONS

Prototype devices developed for the project are fully functional and have demonstrated that they can guarantee performance well beyond expectations.

During the Phase 2, new internal features will be developed, making them directly usable in the high-availability architectures typical of naval units and critical industrial infrastructures. An optimization of the hardware with respect to the cost/performance ratio will also be sought, making the implementation of this type of devices sustainable across a wide spectrum (retrofit on in-service units, installation in existing industrial plants, etc.).

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

IoT	*Internet of Things*
IT	*Information Technologies*
OT	*Operational Technologies*
DCS	*Distributed Control System*
SCADA	*Supervisory Control and Data Acquisition*
COTS	*Commercial off-the-shelf*
VPN	*Virtual private network*

KEYWORDS

Cyber Security, IOT, OT, Ciphers, SCADA, Supply chain, critical infrastructure, FPGA, encryption, authentication.

PROJECT INFORMATION

PNRM number:	a2019.168
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NOTES

(1) VPN – Virtual Private Network

6V-HPOWER

The goal of 6V-HPower PNRM project is to upgrade the engine of the VBM Legacy platform, which has a traditional injection-based system by means of an in-line pump, making it suitable for hybridization in order to create a future power-pack for hybrid AIFV vehicles. The general guideline pursued to achieve the objective of updating the engine of the Legacy VBM was to maximize the use of "carry-over" components already used in other applications in use by the Italian Armed Forces and/or present in development programs in place with Italian Armed Forces. The main results obtained with the update of the engine are: increase in engine displacement, adoption of a Common Rail fuel system, adoption of a turbocharger suitable for the self-assigned performance and predisposition of the same for hybridization. These modernizations, if the premises are confirmed during phase 3 of the project (the one that provides for the performance of bench tests on the prototype-demonstrator built in phase 2), will allow a significant increase in the power/weight ratio of the VBM Legacy bringing it to a value close to 23hp/t, in line with an average requirement of good mobility for platforms of the same class.

INTRODUCTION

The VBM Legacy currently in use by Italian Armed Forces has a power/weight ratio of about 19hp/t, not in line with the values found on competing vehicles belonging to the same class. To increase the mobility of the armored vehicle in question, one possible way, the one considered technically more viable, is represented by increasing peak power by upgrading the V6 Legacy propulsion unit.

TECHNICAL BACKGROUND AND SOLUTIONS

The problem identified on the VBM Legacy currently in place at the Italian Armed Forces is that of a limited peak power of the thermal unit compared to the weight of the vehicle. As a consequence, this leads to vehicular mobility that is not in line with those of competing platforms. The technological solution identified to overcome this gap was to enhance the propulsion unit by increasing its peak power and, through the study of the changes to be made to the layout, also prepare it for future hybridization intervention.

Hybridization is going to become a fundamental asset in the military field due to its innovative push, since the hybridization technique is mostly widespread only in the civilian field, and tactical nature, since it guarantees the intrinsic lengthening of the vehicular mission while also making available the use of greater electrical power. In this project however, hybridization is dealt with purely at the level of study aimed at identifying the most convenient way of predisposing the heat engine to be hybridized, up to the definition and study of specific electric machine for a parallel hybrid architecture able to respect the constraints of the overall dimensions of the rear part of the internal combustion engine.

Since the activity involving the whole design of an hybrid power unit is extremely expensive from a technical point of view, the application of the study to a specific vehicular platform can only be pursued in the context of future dedicated technological research projects.

METHODOLOGY

The study aimed at updating the propulsion unit was articulated starting from the analysis of the "carry-over" components in place on various engine applications, consequently studying their functionality and compatibility and, if any, limitations. Following this selection, an EBOM was drawn up for the choice of which components to develop starting from the existing ones or to design ad hoc for the application at issue, also with the support of DMU-based methodologies, which was updated in progress as the project moved forward. As a result, the construction drawings of the bill of materials were issued.

The so-called components characterized by a long "lead time" were immediately identified and selected and for them priority was given to the design so as to be able to order them from different selected suppliers with a chronologically sequenced timing with the aim of making them available on the date scheduled for the physical realization of the DTA.

At the same time, a series of activities, usually carried out in the design of a powertrain, were as well carried; among them: FEA of the most stressed engine components (crankcase and crankshaft), CFD study of the combustion process with related efficiency evaluation and simulation of engine performance together with a verification of the opening/closing profile of the intake and exhaust valves with relative calculation of Hertzian pressures that act on their profiles and finally check the dynamic behavior of the valve control in engine over-revving mode.

In parallel with the activity carried out on the thermal unit, an evaluation of the pros and cons of different hybrid architectures was carried out for an armored vehicle of the same VBM Legacy category, with the consequent preliminary sizing of an electric machine to be included in the hybrid architecture considered most suitable for meeting the objectives (parallel hybrid architecture).

Subsequently, the final overall DMU of the thermal unit was carried out (Figure 1) and the final study was carried out to evaluate the integration of the electric motor into the hybrid structure, inserting it into the DMU.

Phase 2 activity ended on 14/11/2023 with the construction of the DTA prototype (Figure 2) suitable for testing.

Figure 1 - DMU of preliminary electrical machine directly connected with the combustion engine.

Figure 2 - Assembled engine (DTA).

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The study of the enhancement of the V6 internal combustion engine used on the VBM Legacy vehicle and its predisposition to be hybridized is considered strategic in the military field both for its intrinsically innovative nature and for the creation of the conditions, in a tactical operational context, to expand the possibilities in terms of mobility and to operate in contexts that require high levels of stealthiness. In particular, this predisposition guarantees the vehicle to pursue a longer vehicular mission and a use of greater electrical power or the same amount for much more time.

The above-mentioned operational needs, technically, are declined as a decrease in consumption (with reference to the increase in mission duration) and the availability of an electric APU, much quieter and with minimal maintenance than traditional ones. Both capabilities have a beneficial impact on logistics support with the ultimate aim of decreasing TCO.

CONCLUSIONS

The upgrade resulting in the physical realization of the Legacy VBM V6 engine has made it possible to build a prototype that should ensure the vehicle to achieve a power-to-weight ratio in line with those of other OEMs active on the market. In fact, these considerations are planned to be confirmed in phase n°3 of the 6V-HPower project, i.e. the phase that provides for bench-testing of the thermal unit, called DTA, for performances assessment.

It is therefore necessary to verify on a test bench whether the studies carried out to upgrade the propulsion unit are actually able to guarantee the target power-to-weight ratio. Otherwise, the test results will provide IDV with tangible detail of the limitations of the prototype engine and ideas or cues for further updates and modifications.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AD	*Amministrazione Difesa*
APU	*Auxiliary Power Unit*
AIFV	*Armoured Infantry Fighting Vehicle*
CFD	*Computational Fluid Dynamics*
DMU	*Digital Mock Up*
DTA	*Dimostratore Tecnico Avanzato*
EBOM	*Engineering Bill Of Materials*
FEA	*Finite Elements Analysis*
IDV	*Iveco Defence Vehicles*
OEM	*Original Equipment Manufacturer*
PNRM	*Piano Nazionale della Ricerca Militare*
TCO	*Total Cost of Ownership*
VBM	*Veicolo Blindato Medio*

KEYWORDS

Engine, Upgrade, Assembly, Hybridization, Mobility.

PROJECT INFORMATION

PNRM number:	a2018.174
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CRANOS

The CRANOS project focuses on protecting soldiers' heads from injuries and traumas. Specifically, the research has concentrated on defining predictive methods based on advanced modeling approaches, which can be used for future applications aimed at designing and optimizing ballistic helmets. Once validated with experimental data, these methods represent reliable and effective high-fidelity models that allow for a comparison between different design solutions based on various threats even before producing the device itself. The project has developed a modeling approach for military protective helmets, enabling the construction of a virtual prototype capable of replicating experimental qualification tests and, more generally, impact events in the form of "virtual tests". This approach, built on state-of-the-art knowledge and the previous experience of the working group in advanced modeling, has been applied to a real case, demonstrating excellent capability in replicating the phenomena in question. The objectives have indeed been achieved and validated through the usage of numerical methods to construct a virtual model of a helmet currently in service by the Italian Armed Forces.

INTRODUCTION

Traditionally, combat helmets have been designed to protect against impact-related threats. Over the past few decades, several generations of helmets have been developed in search of optimal solutions. These solutions aim to find a balance between various requirements, such as addressing new threats and finding a compromise between the helmet's lightweight and protective capabilities. Recent studies have shown the potential for further optimizing helmets through technological and design aspects, including the use of innovative high-performance composite materials and enhanced understanding of the impact of events on the head. Additionally, there are increasing non-ballistic requirements that are gaining importance to ensure protection in a broader context. Achieving an optimal solution is, therefore, a complex process that necessitates the definition of advanced predictive design methods, which rely not only on experience and experimental tests but also on virtual models. CRANOS has been involved in defining such methods.

TECHNICAL BACKGROUND AND SOLUTIONS

The CRANOS project has led to the development of a modeling approach for military protective helmets. In the preliminary design of such devices, numerous tests are often required to validate the proposed solution, resulting in increased production times and associated costs. The availability of a virtual helmet prototype, which can be used to verify the performance of current and innovative solutions against a wide range of threats and operational conditions, represents a cutting-edge technological solution to improve the development of these devices. Among the various scenarios are those resulting from non-ballistic requirements such as "blunt" cases like impacts or falls. The proposed technological solution provides a virtual platform that can facilitate the design and development of new solutions, reducing time and uncertainties while increasing operational responsiveness. Therefore, the proposed solution provides a rational and effective tool to address trauma issues concerning the upper body (head),

which is becoming increasingly important in recent conflicts. The objectives have been achieved and validated through the use of the method to construct a virtual model of a helmet currently in service by the Italian Armed Forces. This model is built based on a significant contribution from the helmet manufacturer, VM Safety, which provided geometric models, material descriptions, and the helmets themselves used for experimental validation activities. These helmets underwent ballistic tests under current requirements and standards; additional tests were conducted in non-standard situations. All tests were replicated by the model, which demonstrated excellent capability in reproducing the helmet's behavior under all experimental conditions.

METHODOLOGY

The project was structured into several steps, which allowed for the development of an updated and validated methodology. An extensive literature review activity helped define a specific state-of-the-art, providing updated and multidisciplinary information on issues concerning military helmets, design and verification criteria, and more specifically, modeling methods related to the materials used. Furthermore, traumatic brain injury phenomena were thoroughly investigated. Modeling methods for ballistic helmets were then defined through increasingly complex approaches. These methods were applied to various cases related to two modern-designed helmets, the PASGT and the ACH, using data from scientific literature (both for construction and validation). This methodology was then applied to a helmet used by the Italian Armed Forces. This helmet, provided by VM Safety, was reconstructed in a Finite Element Model (FEM) (Figure 1) virtual environment. Impact experimental tests were conducted in a real environment and replicated in a virtual environment. The experimental tests were performed using current standards, specifically NATO STANAG 2920 and NIJ 0106.01; these tests were conducted in both standard form and through unconventional variations to verify the model's behavior even in more challenging and "extreme" cases compared to typical usage scenarios. The tests were conducted at the ballistic laboratory of the National Test Bench (BNP). The obtained results (experimental and virtual) were compared (Figure 2), showing excellent agreement across a wide range of scenarios. Additionally, the validated model was used for virtual investigations into non-ballistic impact tests such as blunt impacts. Finally, the methodology was consolidated to provide guidelines for future designs.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The development of helmets and protective headgear is currently an important focus, even in civilian settings, as evidenced by recent updates to standards such as ECE 22-06. The studies conducted in this project hold significant value in the direction of designing increasingly protective helmets and headgear in all contexts. The results achieved by the project have also demonstrated the robustness of the modeling approach across a diverse range of cases: namely, the establishment of a single baseline model capable of conducting various tests without the need for specific ad-

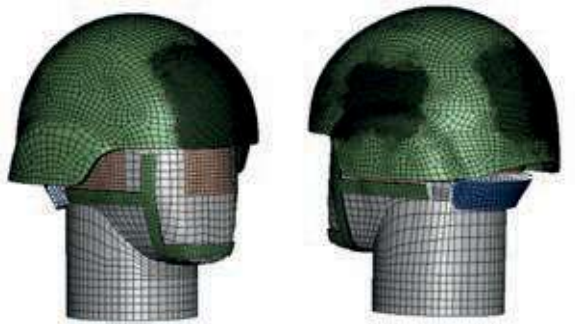

Figure 1 - Complete model for FEM simulations of ballistic impact penetration. The model also includes the "dummy head" with clay for trauma measurement.

Figure 2 - Numerical-experimental comparison of an occipital impact, Cal 9x19 FMJ (7.45g) - 390 m/s; the experimental (16 mm) and numerical (15 mm) trauma measurements show excellent agreement.

justments. The model has indeed proven capable of replicating a variety of scenarios ranging from complete penetration to energy absorption through extensive deformation, with different impactors and impact energies. The method has thus allowed for the construction of a robust numerical model capable of investigating a multitude of requirements. In this context, the ability to utilize virtual models can be employed for an optimization process of helmets towards various, including innovative, requirements (thus different from what has been done so far), aiming to achieve increasingly high-performing products that meet new challenges.

CONCLUSIONS

The project has fully achieved its purpose, demonstrating the capability to define and create a valuable predictive tool capable of conducting virtual tests with an excellent replicative capacity of the main physical parameters involved. Specifically, it has allowed for the identification of an effective modeling approach (capable of reproducing the phenomena in question) and efficient (capable of producing results with limited analysis duration). This approach has been applied to a real-world case study, namely a composite material helmet currently in use by the Italian Armed Forces, through the replication of experimental tests according to existing standards and beyond. These tests were simulated by the model, and the comparison allowed for the validation of the modeling approach even under more severe conditions than those required. This has extended the validity of the modeling approach so that it can be applied to new and previously unconsidered cases in the future. Finally, the validated approach was applied to simulate cases of non-ballistic impact (blunt impacts), demonstrating the model's capabilities in this context as well. The excellent results open up broad possibilities for future utilization of this approach for further evolution phases of ballistic helmets.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

FEM	*Finite Element Model*
BNP	*Banco Nazionale di Prova*

KEYWORDS

Ballistic helmets, virtual models, FEM (Finite Element Method), ballistic impact, blunt impact, engineering design.

PROJECT INFORMATION

Contract number:	n. 133 signed in data 23.12.2022
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MRFOGINS

In the field of defence system applications, there is an increasing problem of having navigation tools that are reliable, performing, space-saving, that are adaptable and therefore usable transversally on multiple platforms in order to reduce integration costs also with respect to the peculiarities of use and that, moreover, are based on a completely *ITAR FREE* technology that guarantees immediate availability and complete national independence. The project "MRFOGINS: Miniaturized Redundant FOGINS" is focused on the study and development of a navigation and inertial measurement system, autonomous on board the missile or at the level of the weapon system, based on advances and appropriate configurations, also in intrinsic redundancy, of the fiber optical gyroscopic inertial technology in optical fiber and on the optimal integration of quartz and MEMS sensors that meets the needs described above. In addition, such systems must be easily adaptable with Weapon Control Units (WCUs) of different platforms (Anti-Ship/Deep strike, Air Defence...).

INTRODUCTION

Inertial sensors for position, geographic north and attitude determination used in avionics, land and naval platforms are based on mechanical or micromechanical gyroscopes, fiber optic gyroscopes or laser ring gyroscopes or even on Hemispherical Resonator Gyroscopes. These technologies, extremely mature, can provide very accurate solutions with good reliability, but with high dimensions, weights, and power consumption. In addition, these systems do not have an IHM (Integrated Health Management) and an intrinsic redundancy, in fact, in most applications, the redundancy is implemented with the replication of the stabilization and/or navigation equipment. The development of optical miniaturization techniques and a sensor fusion algorithm allows to improve the reliability of the navigation and stabilization system by reducing the system redundancy, currently implemented through inertial replication. The miniaturization also allows a drastic reduction in the footprint, making the system compact, while maintaining high performance, accuracy and reliability, fundamental elements for all avionics, land, and naval platforms for the purpose of orientation, positioning in the absence of GNSS and stabilization.

TECHNICAL BACKGROUND AND SOLUTIONS

In inertial sensors for position, geographic north, and attitude use in avionics, land, and naval platforms, IHM management would provide the ability to detect and diagnose faults and take appropriate action in response to a failure or early warning. Hence the need to develop a technology that allows to reduce the system redundancy made by inertial apparatus replication, providing an intrinsic redundancy within the apparatus. An important contribution is made by optical integration, (Figure 2) which, contrary to the state of the art, does not use discrete fiber optical components, making the system more compact. The final prototype was built by integrating four fiber optic gyroscopic angular velocity sensors and four quartz accelerometer sensors, hybridized with four 6-DoF IMUs (3 accelerometers and 3 gyroscopes) based on MEMS technology, all in skewed configuration and tetrahedron geometry. The in-house FOG sensors have made further improvements in terms of performance but

without compromising the size and weight of the system, demonstrating the high scalability of the FOG technology. Specifically for missile applications, inertial platforms represent one of the main subsystems of missile systems. The requirements allocated to the IMU are functional to the performance and mission of the missile. Once the requirements of the inertial platform have been established, it is possible to commission the construction of ad hoc inertial platforms with often high costs or to search the market for an inertial platform already marketed. In both cases, the inertial platforms represent a "black box" system that cannot be piloted by the missile's WCU and cannot be adapted/scaled according to needs. The "white box" configuration developed allows the IMU to be customized at a functional level. Compared to current systems, the MRFOGINS system is able to overcome the limitations in terms of size, consumption, reliability, adaptability and ITAR components.

METHODOLOGY

The MRFOGINS prototype is in HSRIMU (Hybrid Skewed Redundant IMU) configuration comprising a redundant skewed inertial measurement unit (SRIMU) and a hybrid redundant inertial measurement unit (HRIMU). Four gyroscopes and four "navigation grade" accelerometers have been integrated, and the "sensor fusion" has been created with four "lower-tactical grade" IMUMEMS 6-DOF (in orthogonal triad of three accelerometers and three gyroscopes). In order to achieve the intrinsic redundancy of the system, optical miniaturization techniques have been developed using an innovative platform: Lithium Niobate on Insulator (LNOI). The realization of Multi-Functional-Integrated-Optical-Circuit and optical structures for coupling chips and Polarization Maintaining Fiber (PMF), have made it possible to reduce the bending effects in integration, to achieve intrinsic redundancy, and at the same time to achieve a reduction in the system footprint. The development of an IHM (Integrated Health Management) algorithm has provided the ability to detect and diagnose faults and take appropriate corrective actions in response to a failure or an ''early warning''. This has made it possible to increase the overall reliability of the MRFOGINS ''system'', enriching its ''fail-safe'' and ''fault-tolerant'' capacity, i.e. fault detection, identification and exclusion (FD/FDI/FDE) and, therefore, to obtain a condition of operational

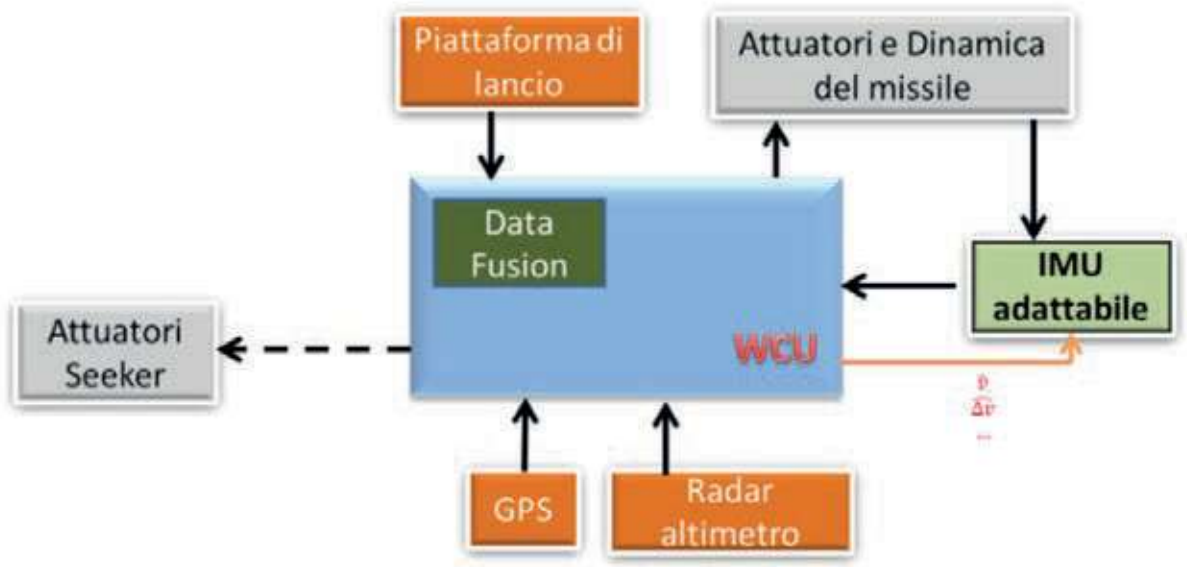

Figure 1 - Diagram of the "white box" navigation architecture.

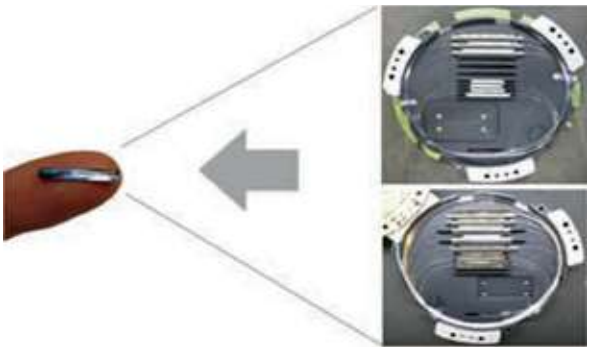

Figure 2 - Miniaturization: integration and hybridization of optoelectronic components into photonic chips.

continuity even in the event of a failure, at the cost of a reduced degradation of the performance of the MRFOGINS system. The system has been integrated and tested on the WCU demonstrating the effectiveness of the navigation and communication architecture between WCU and missile

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

In the military field, the MRFOGINS inertial device is compact, (Figure 3)with high performance and accuracy, (Tabella 1 e Tabella 2) reliable, redundant, a fundamental element for all avionics, land, and naval platforms for the purpose of orientation, positioning in the absence of GNSS and stabilization. For avionics (especially UAVs), underwater (especially AUVs) and special forces (raiders and RRAOs) applications for portable targeting/designation, the requirements for weight, volume, consumption, reliability, and redundancy of inertial navigation systems are increasingly stringent. The redundant sensor cluster also finds next-generation avionics applications for fighters in which the

Figure 3 - Model 3D-CAD and real prototype MRFOGINS.

subsystems, with a "white box"(Figure 1) IMU approach, customizing the IMU at a functional level through the configurability of the coefficients of the Coning and Sculling filter, of the IIR filter, of the frequency of the output data, moreover the estimation of bias is redirected in feedback to the IMU, improving the calibration and increasing the overall performance of the Navigation algorithm, all with the same control interfaces (ICDs).

sensors are distributed, and the navigation capability can be entrusted to a central computer, in order to reduce the total number of ISAs (Inertial Sensor Assemblies), while maintaining performance and reliability. The feature of piloting via WCU (i.e. "white box") allows to optimize the performance of the IMU and therefore of the entire missile system. In addition, being ITAR free means immediate availability, lower costs and complete national independence on a fun-

Parameters	MRFOGINS (IMU)
Bias stability accuracy (1 sigma)	<0,007°/√hr
Noise accuracy (1 sigma)	<0,006°/√hr
Scale factor accuracy (1 sigma)	<50ppm
Maximum dynamic range	<2000°/sec
Electrical power consumption	<14W
Dimensions	External diamater 117mm (base 133mm), height 200mm
Redundancy class	II
Active Sensors (Gyroscopes)	4

Table 1 - Performance achieved with MRFOGINS (IMU).

Parameters	MRFOGINS (INS)
Heading Accuracy (RMS)	0,393°secante latitudine
Accuratezza di assetto Roll/Pitch (RMS)	0,006°/0,005°
Accuratezza di posizione (CEP 50)	4.13Nm/hr
Tempo di allineamento (dato disponibile)	<2min
Tempo di allineamento	<15min
Consumo di potenza elettrica	<14W
Temperatura operativa	-40°C< T<+70°C

Table 2 - Performance achieved with MRFOGINS (INS).

damental technology not only specifically at the missile level or at the level of the weapon system but also more generally at the level of any other defence system.

CONCLUSIONS

Once the development and construction of the prototype was completed, the integration and functional connection of the various hardware and software components was made: IMU, GNSS and WCU in order to verify the integrated components. The field validation in limited operating conditions of the prototype was carried out by ATP tests on a rotary table in extended thermal range, and at uncontrolled ambient temperature under dynamic conditions of the MRFOGINS prototype integrated with GNSS, in order to assess the performance obtained by comparing it with the performance required for the different applications of use (Long Range, Anti-Ship, Surface attack, Anti Air) previously evaluated. Tests have shown an increase in both system continuity and performance. The FOG technology is also highly scalable, so it is possible to further improve its IMU and navigation performance. Thanks to the further development of miniaturization techniques, it would also be possible to increase the continuity of the system compared to the 4-axis solution by creating an n-axis HSRIMU that would allow the Fail Op/Fail Safe functions without too many impacts on the final system footprint.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

ATP	*Acceptance Test Procedure*
AUV	*Autonomous Underwater Vehicle*
DOF	*Degree of Freedom*
FDIR	*Fault Detection, Isolation, and Recovery*
FDI	*Fault Detection and Isolation*
FDE	*Fault Detection Exclusion*
FD	*Fault Detection*
GNSS	*Global Navigation Satellite Systems*
HRIMU	*Hybrid Redundant IMU*
HSRIMU	*Hybrid Skewed Redundant IMU*
IHM	*Integrated Health Management*
IMU	*Inertial Measurement Unit*
INS	*Inertial Navigation System*
ISA	*Inertial Sensor Assembly*
ITAR	*International Traffic in Arms Regulations*
LNOI	*Lithium Niobate on Insulator*
MEMS	*Micro Electromechanical Systems*
MRFOGINS	*Miniaturized Redundant FOGINS*
PMF	*Polarization Maintaining Fiber*
SRIMU	*skew-redundant inertial measurement unit*
WCU	*Weapon Control Unit*
UAV	*Unmanned Aerial Vehicle*

KEYWORDS

IMU, INS, fail safe, FOG, IHM, Intrinsic Redundancy, ITAR FREE, WCU.

PROJECT INFORMATION

PNRM number:	a2017.041
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PROACTIVE

The PROACTIVE counter-UAV project has developed a system for the protection of military assets from air attacks carried out by means of Remotely Piloted Air System (RPAS) or Unmanned Aerial VehicleS (UAV) when they are moving in unprotected urban areas. The real-time monitoring system of the area of interest and possible counter-measures is based on the use of UAVs equipped with optical-acoustic sensors, cooperating with each other through an intelligent control and dynamic reconfiguration system with continuous exchange of information addressed to the real-time detection, tracking and identification of hostile UAVs in Armed Forces possible intervention areas. The main scientific results achieved by the PROACTIVE project concern the study and development of algorithms for (a) localization and tracking of hostile UAVs with audio/video sensors installed on cooperating UAVs, (2) the control and reconfiguration of a cluster of UAVs and (c) the implementation of enforcement strategies. Furthermore, the PROACTIVE project has developed and implemented a new acoustic sensor with circular and spherical geometry that can be installed on UAVs and is capable of locating hostile UAVs flying in the area of interest.

INTRODUCTION

The work program and objectives of Phase 2 of the PROACTIVE project were expected to face aspects of management of the network of optical-acoustic sensors positioned on the various UAVs of the cluster, real-time processing of the audio and video data transmitted by the sensors and of the flight control of the cluster's UAVs, according to specific research lines: (a) distributed analysis, recognition and audio/video re-identification of hostile UAVs in flight; (b) localization and tracking of classified hostile UAVs; (c) counter strategies with jammers or by obstructing the movement of hostile UAVs. The research activity concerned in particular the further developments in terms of algorithms for the localization and classification of possible threats and for the implementation of intervention strategies through the coordination of multiple units following the identification of a threat. Therefore, the experiments on localization and tracking of the movement of hostile drones were considered, as well as the development of algorithms for the joint analysis of audio and video flows coming from the sensors on board the aerial devices and the study of techniques for the control of mobile devices, including the study phases of algorithms for approaching the hostile drone and the coordination of the intervention cluster for the implementation of countermeasures.

TECHNICAL BACKGROUND AND SOLUTIONS

The development of the HW and SW platform of the PROACTIVE project took into consideration the implementation and creation of an integrated system that can implement the functions required by the technical proposal. The first objective achieved was to define the hardware (HW) architecture of the system including the mobile units (quadcopters classifiable as UAV or MAV) with the control and communication devices, the sensors for audio and video data collection (microphone arrays linear, circular and spherical, and small video cameras), the ground station and the audio and video (A/V) stream transmission and control data communication system for a central-

ized multistream of A/V streams from mobile. The second objective achieved was the definition of the software architecture (SW) of the sub-system for the coordination of the various physical devices and the development of the algorithmic components of data analysis and functional control. Particular attention was given to the development and creation of the interactive user interface through which the various SW functions (including control of individual drones and the cluster, control of data flows and related visualization) can be activated and used in real time on the ground station. For movement control, the MAVLink protocol was used which defines a series of messages and commands for communication with the autopilot. The Pixhawk-6c was chosen as the UAV control device due to its reliability characteristics. The multi-drone architecture to protect the area from hostile UAVs is illustrated in Figure 1. This architecture is based on A/V data acquisition and Wi-Fi communications between flying UAVs and between UAVs and the station of land (GCS). The scenario involves a flying UAV responsible for monitoring the protected area and two ground-based UAVs ready to take off as soon as a hostile drone is detected in the monitored area. The facility is centralized with a ground station (GCS) as the main node.

The audio sensors made with arrays with circular, spherical and tetrahedral geometry are those that contain the main aspects of scientific innovation of the PROACTIVE project compared to the state of the art (Figure 2). In particular, in addition to using sensors commercial off-the-shelf with different configurations, dimensions and weight, new models and configurations of more effective microphones for the purposes of the project were designed and created. Both the circular array carried by the Matrice 100 (left part of Figure 2) and the Ambisonic (right part of Figure 2) were designed and built in the laboratory. In particular, the Ambisonic sensor is the most recent and is so compact that it can be mounted without problems on F450 type UAVs. The Zylia sensor was instead used on the local node of the ground station (central part of Figure 2).

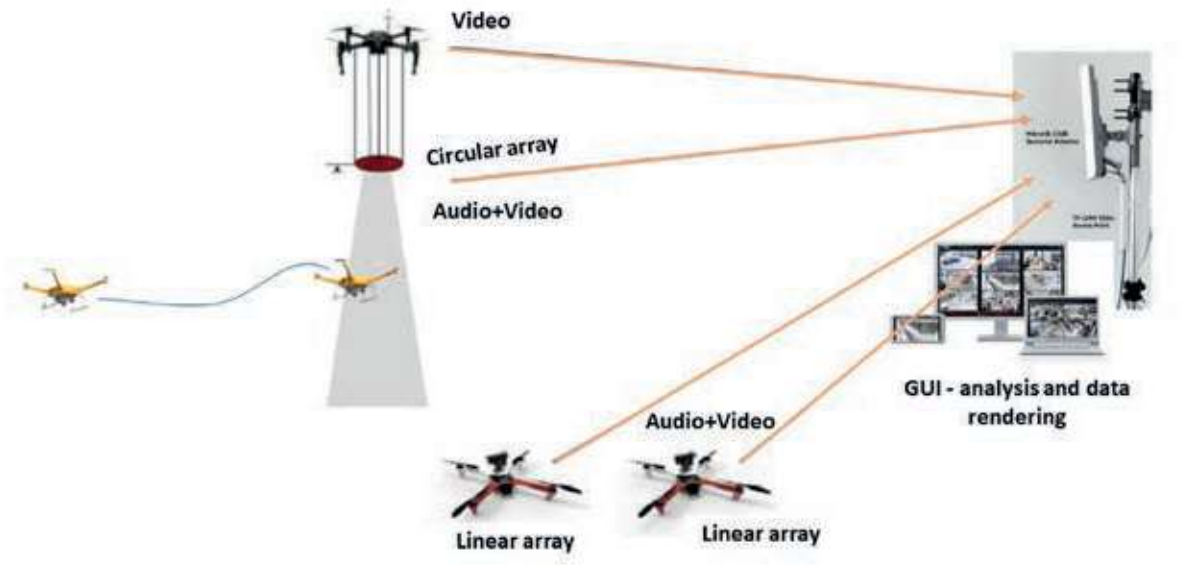

Figure 1 - Scheme of the PROACTIVE system's logical architecture, to monitor and protect military assets from hostile UAVs.

Figure 2 - Audio sensors: circular array (left), Zylia spherical array (center), Ambisonic tetrahedral array (right).

METHODOLOGY

The HW and SW architecture of the PROACTIVE system was subjected in the initial phase of the project to specific data acquisition and recording sessions (audio/video flows from all sensors and telemetry data from each single UAV) for the creation of specific datasets to be used both for research purposes and to test the functionality of the system. Subsequently, numerous test and field experimentation sessions have been carried out. In order to illustrate the architecture of the PROACTIVE system and its functions, the various demonstrators developed are described below. For each individual demonstrator, specific videos were recorded by combining the recordings made via an external camera (capable of filming the entire experimental area) with the recordings made with screen capture software which allowed the video streams to be acquired from the ground station screen (GCS). These video flows concerned the outputs of the different SW components of the system which manage both the movement control and coordination unit of the interceptor UAVs and the communications with the on-board autopilot and the audio and video flows.

Here are briefly illustrated 4 sub demonstrators created.

1) An Aurelia drone (target) flies under the circular array acoustic sensor, kept in flight by a guard UAV (DJI Matrice 100 drone), entering an area within the field of view of its raspi-cam where it is detected (Figures 3 and 4). The approach direction of the Aurelia drone is opposite to the frontal direction of the F450 interceptor drone. After the video detection phase, the ground station sends the detection signal and the direction of origin of the hostile Aurelia drone to the F450 interceptor drone that takes off and aligns its main axis in the direction of the target.

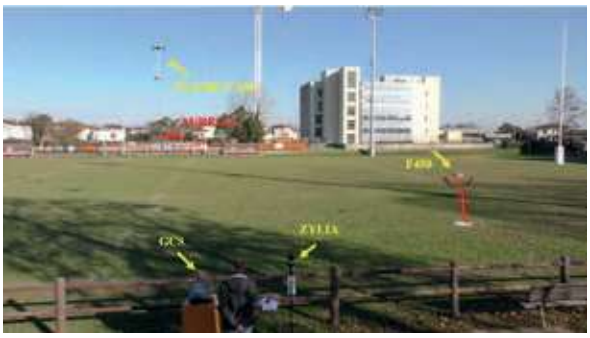

Figure 3 - Video detection from raspi-cam flow mounted on Matrice 100 drone.

Figure 4 - View of video streams and control on the ground station screen after video detection.

2) An Aurelia drone (target) moves in an area outside the field of view of the local detection node and in the opposite direction to that of the main axis of the F450 interceptor drone (Figures 5 and 6). After the audio detection phase, the ground station sends the detection signal and the direction of origin of the Aurelia target drone to the F450 interceptor drone that takes off and aligns itself in the direction of origin of the target.

Figure 5 - Audio detection (with Zylia sensor) with acoustic energy threshold and angle measurement.

Figure 6 - Visualization of A/V streams and control on the ground station screen after audio detection.

3) An Aurelia target drone enters the field of view of the local camera in a frontal direction with respect to the F450 interceptor drone (Figures 7 and 8). After the video detection phase, the ground station sends the detection signal and the direction of origin of the Aurelia target drone to the F450 interceptor drone that takes off and moves quickly towards the target position. It is important to note that in this demonstrator the F450 interceptor drone is not tethered to the tether and can make an untethered move in the direction of the target drone (the pilot of the target drone had to move it quickly to avoid collision).

Figure 7 - Video detection from local camera using Yolo neural network.

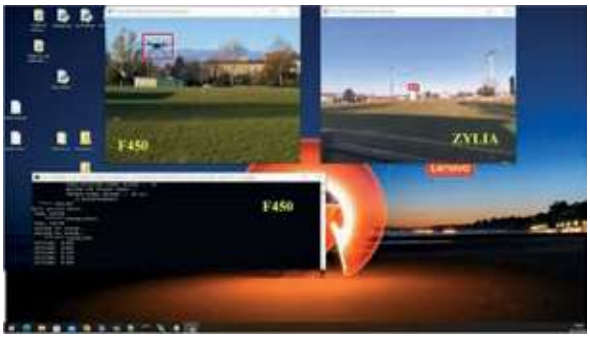

Figure 8 - View of video streams and control on the ground station screen after video detection.

4) A target drone (Aurelia) moves within the field of view of the local camera and in the opposite direction to that of the two F450 interceptor drones (Figures 9 and 10). After the video detection phase, the ground station sends the detection signal and the direction of origin of the Aurelia target drone to the F450 interceptor drones which rise and align their main axis in the direction of the target.

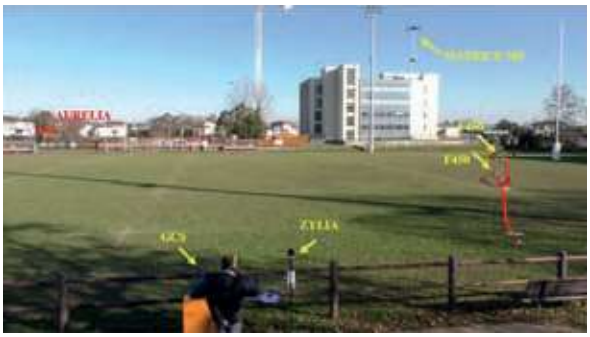

Figure 9 - Video detection from local camera via Yolo neural network.

Figure 10 - View of video streams and control on the ground station screen after video detection.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

One possible application of the multi-drone system is Intelligence, Surveillance and Reconnaissance (ISR). A multi-drone ISR system consists of a number of UAVs equipped with A/V sensors to monitor a particular area of interest and protect it from hostile UAVs. In these systems, the control and coordination of the drones are made possible by wireless communications between the various units. Communication between the UAVs and a ground control station, where the multimedia streams are received, is necessary for a centralized and potentially autonomous decision-making system. Automatic control and communication can lead to an architecture that does not require the intervention of a ground operator, in which UAVs are completely autonomous. When the multimedia acquisition system detects an approaching hostile UAV, the ISR system is able to detect it in real time and autonomously counteract it to eliminate the threat. However, more generally, multi-UAV-based systems can be employed for military monitoring, interception, espionage, patrolling and countering approaching unauthorized entities in operational scenarios. Only recently is the new paradigm emerging called the Internet of Military Things (IoMT), a class of Internet of Things for combat and warfare operations. However, these systems can also find application in civil environments.

CONCLUSIONS

The activity carried out during the project concerned the following main aspects:

- Software development of a technological demonstrator for the deployment of a cluster of UAVs, the identification of potential threats using innovative audio/video sensors positioned on the UAVs and the implementation of appropriate countermeasures;
- Implementation, integration and use of the different sensors and defence SW components studied and designed during the research work;
- Experimental tests of the logical architecture with validation of the individual software modules implemented;
- Implementation and improvement (refinement) of intervention strategies through the coordination of multiple units of interceptor drones upon identification of a threat. In particular, the localization and tracking algorithms for the movement of hostile drones have been developed starting from the analysis of acoustic data and video data with sensors positioned on the in-flight and ground units;
- Implementation and refinement of the algorithms for the joint analysis of the audio and video flows coming from the sensors on board the UAV devices;
- Study and implementation of techniques for controlling a cluster of UAVs moving in the area of interest.

The research carried out within the “proactive counter-UAV” project showed the study and subsequent creation of a complex system with sensorised, multiple, distributed and coordinated aerial robotic units. Analyzes were also conducted on both the synchronization of the nodes and on cyber-security aspects, two fundamental components for this type of system, especially if operating in a military scenario.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

A/V	*Audio e Video*
GCS	*Ground Control Station*
HW	*Hardware*
IoMT	*Internet of Military Things*
ISR	*Intelligence, Surveillance and Reconnaissance*
MAV	*Micro Air Vehicle*
SAPR	*Sistema Aeromobile a Pilotaggio Remoto*
SW	*Software*
UAV	*Unmanned Aerial Vehicle*

KEYWORDS

Proactive counter-UAV, multi-drone, audio and video acquisition, anti-drone monitoring, microphone sensors, MAVLink, distributed nodes system, Internet of Military Things.

PROJECT INFORMATION

PNRM number:	a2018.145
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FHYW44

The military tactical light and heavy vehicle scenery is undergoing deep changes, due to the necessity of reducing the thermal and acoustic trace of the vehicles and, not less important, the pollutant emissions reduction. The vehicle that has been developed, during this National Military Research Plan is a Full Hybrid vehicle: an "Utility Terrain Vehicle" with purely electric traction.
The purpose that led the design of this vehicle has been that of using an innovative technology used by the most advanced electric vehicles, selecting the better components to satisfy all the operational requirements.
The need for extended autonomy and reduced vehicle stop time for recharging the battery suggested the installation of an on-board range extender. The different vehicle control logics allow to optimize the fuel consumption in the hybrid mode, while in the "full electric" mode they make the vehicle silent and with low thermal trace in the required sceneries.
During the tests the Advanced technological Demonstrators achieved excellent results, showing in some occasions performances that went beyond the initial targets. These vehicles will allow to experiment even more future optimizations, either in the energetic point of view and in the operating one, according to the different operating requisites.

INTRODUCTION

The actual land reconnaissance vehicles, used by Italian army, special forces included, are moved by IC engines. The solution presented in this NMRP is to realize a light-weight vehicle, two or four seats, with a back load plane, full hybrid and four-wheel drive, that can offer to the armed forces an high operational capacity based on a silent mobility, low thermal trace and ready to use.
The vehicle is designed with rigidity and functionality that can satisfy military use in extreme conditions, but thanks to its modularity will allow a large use even in civil field, like firefighters, rangers, urban police, ecc.
The lighting system is designed to be ready for future road homologation and has also a stealth mode.
The tubular aluminum chassis has an opening in the upper part of the roof, so it allows an operator to exercise his activities overlooking from the upper part of the vehicle. The chassis is arranged to equip the vehicle with pantograph gun support on both sides and fixing points for guns over the upper part of the roof.
Vehicle's structure and dimensions allow its aero transport on C13 and heli trasnsport on CH47, and the aero-drop of the vehicle.

TECHNICAL BACKGROUND AND SOLUTIONS

Land vehicles used by armed forces for reconnaissance activities are powered by internal combus-

tion engines. This kind of engines allow to gain high specific power, but have also a drawback linked to high thermal and acoustic trace.

The solution proposed in this NMRP consists in the development of an UTV vehicle with a "full hybrid" powertrain and range-extender layout, i.e. serial hybrid with electric propulsion and a range-extender to recharge the battery.

On military ground, that solution gives an effective answer to the problem, ensuring maximum silence during the full electric mobility and a great use flexibility, thanks to the range extender coupled to the control logics for motors and battery that can maximize performance, autonomy or global efficiency depending on the need.

To minimize vehicle's weight and so make it fit for aero transport it has been used an aluminum alloy with excellent mechanical properties, developing the production process and the heat treatment.

To reduce even more the vehicle's traceability, the lightning system allows to use, if needed, IR war lights to realize a stealth mode. With the adoption of specific control logics, is also possible to use the range extender to keep an high battery state of charge approaching the target, ensuring a sufficient autonomy in the full electric mode near the mission target.

A specific design has been carried out for the gears in the transmission, such as the choice for the teeth profile and the repartition of the ratios, to ensure the most silent running typical of electric motors.

METHODOLOGY

The methodology that led to the final definition of the different functional groups of the UTV vehicle is composed of several phases, that are listed below:

1) Analysis of operational needs and requirements definition
2) Analysis of the technologies, the processes, and the materials; selection of the most appropriate solutions
3) Calculations necessary to the final layout definition
4) Design of components and systems
5) Machining and assembling of the components
6) Test on bench, road, off-road
7) Possible design review, optimization

In this case, the inputs for the powertrain design were the requirements of the NMRP in terms of autonomy and performance in electric mode. The need for having a silent, lightweight but at the same time capable to ensure a sufficient autonomy to complete a mission led the choice to a hybrid powertrain with serial layout.

From the requisites of the NMRP, with a predictive calculation, necessary power and battery capacity to reach the target of performance and autonomy have been estimated, addressing the choice of motors and battery.

The calculations have then been optimized with a specific 1-D software developed by Oral Engineering.

Then, they have been defined the torque and current maps of the electric motors, the motor control maps to be implemented inside the inverters and the battery capacity; battery that has been designed and assembled by Oral Engineering.

The electric motors have been custom built, the same for the gearboxes and all the parts of the powertrain.

The first characterization of the powertrain has been made at the test bench, once validated the right working of all the parts the system has been installed onto the vehicle and the on/off road test phase started.

During the tests, the ATD proved to be reliable, silent, with low thermal trace. Performance and autonomy proved to be aligned with calculations.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The 4 WD mode allows to overcome low grip surfaces, with slopes up to 60% ensuring maximum performance on every ground: on road and off-road.
The range extender, while the vehicle is stationary, will be able to work as electric generator (APU), to give up to 10 kW of electricity to a base camp.
The vehicle, with a lightning system designed to reach civil homologation, is equipped with a military light system that can switch to war lights in stealth mode.
The chassis shows an opening in the upper part, to make possible for the operator to exercise his activities from the upper part of the vehicle. The chassis can be equipped with pantograph gun support on both sides and gun supports on the roof.
The dimensions of the vehicle allow to place two UTV in tandem on the helicopter CH47, to be aero-transported on the C-130 and to be aero-dropped, fixing it to the platform with hooks. In addition, the vehicle can be lifted by an helicopter thanks to apposite hooks on the upper part of the chassis.

CONCLUSIONS

The results of the activities completed during the NMRP showed the high maturity level of the project, giving the ATD a TRL 7.
The complete definition of the parts that build up the vehicle and the assembling of the DTA made possible to complete functional and performance tests to evaluate its characteristics.
During those tests the ATD achieved excellent performance results, showing in some cases better performances than the initial targets.
These vehicles will allow to test further future optimizations, either on the performance side and in the functional point of view, according to different operating requirements.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

APU	*Auxiliary Power Unit*
CI	*Internal Combustion*
DTA	*Advanced Technological Demonstrator*
kW	*kiloWatt*
PNRM	*National Military Research Plan*
TRL	*Technology Readyness Level*
UTV	*Utility Terrain Vehicle*
WD	*Wheel Drive*

KEYWORDS

Full, Hybrid, Vehicle, range estender, APU.

PROJECT INFORMATION

PNRM number:	a2018.152
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SINAPSIS

In modern operational scenarios, having continuous, accurate, and reliable Position, Navigation, and Timing (PNT) information is crucial. Currently, PNT data is provided by satellite navigation systems (GNSS), which are increasingly vulnerable to attacks and alterations aimed at disrupting or manipulating the satellite signal in contested environments.
The SINAPSIS program, Repertoire No. 8734 dated 09/12/2020, aims to ensure the success of a mission in Navigation Warfare (NAVWAR) scenarios by ensuring position, navigation, and timing data in the absence or malicious alteration of the GNSS signal, adhering to the principles of Accuracy, Integrity, Security, Continuity, and Resilience.
The activities are organized into three phases, each lasting one year. During the first year, the state of the art, specifications, and design of the innovative gyroscope were studied and defined. Research on Data Fusion algorithms and sensor technologies allowed for design planning. The second phase, in the second year, focused on SINAPSIS component development, data fusion, and prototype realization. The third and final phase of the project involves developing a testbed to verify the technological demonstrator.

INTRODUCTION

In various operational contexts and across manned and unmanned aerial, terrestrial, and naval platforms, mission success can depend on the accuracy and integrity of Position, Navigation, and Timing (PNT) data, currently based on GNSS data. This research project defines a system to ensure mission success even in the absence or manipulation of the GNSS signal, leveraging technological innovation to address tactical scenarios from conventional warfare to current peacekeeping, peacebuilding, and cyberwar missions.
The core of SINAPSIS is a software-defined platform that integrates data from independent, complementary, and heterogeneous devices by studying, implementing, and integrating three fundamental technologies: inertial sensors, GNSS receivers, and precision oscillators. This system is also crucial in numerous civilian applications as technological advancements have made it simple and cost-effective to create GNSS signal disruptors, drastically increasing the risks of malicious attacks, even in homeland security.

TECHNICAL BACKGROUND AND SOLUTIONS

Currently, platforms rely on PNT systems using data provided by GNSS systems. However, they are susceptible to satellite signal attacks (Jamming) or alterations (spoofing). In this Navigation Warfare scenario, the accuracy and integrity level of PNT data becomes insufficient for mission continuation and success.
A spoofing attack can provide erroneous information to ISR platforms, such as drones, diverting them from areas of interest, or prevent attacks using precision-guided weapons that rely on GNSS signals. In general, an attack on vital PNT information can lead to the paralysis of a mission, whether aerial, terrestrial, or maritime.
SINAPSIS is an ITAR-FREE hardware and software system based on innovative technol-

ogy that ensures navigation, position determination, and time in operational scenarios in the absence, shortage, or manipulation of the GNSS signal. SINAPSIS will guarantee accuracy, a fundamental requirement for completing missions such as ISTAR and Strike. The system will be highly flexible due to its SW-defined structure and will ensure the integration of future PNT signals. Thanks to its high capability to maintain a stable and accurate time reference, it can serve as a synchronization reference for military networks and devices.

Inertial sensors, gyroscopes, and accelerometers represent the main support for navigation, and the high-frequency data they provide allows for dead-reckoning navigation, ensuring continuous data availability. However, the data provided by these sensors are subject to drift over time, which is normally corrected by the GNSS signal. The project is developing an innovative demonstrator based on Hemispheric Resonator Gyro technology, which will provide an inertial-class sensor with dimensions and consumption lower than Ring Laser Gyro and Fiber Optic Gyro technologies.

METHODOLOGY

The SINAPSIS program is allowing the development of an INS/GNSS navigation system (Figure 1) based on the integration of three fundamental technologies:

- an HRG (Hemispherical Resonator Gyro) inertial sensor (Figure 2);
- an SDR (Software Defined Radio) GNSS receiver;
- precision CSAC (Chip Scale Atomic Clock) oscillators.

The development of an innovative sensor based on HRG technology is the cornerstone of the SINAPSIS program. This sensor will provide inertial class accuracies with smaller dimensions and lower consumption compared to the more established Ring Laser Gyro and Fiber Optic Gyro technologies (Figure 3).

The GNSS receiver based on an SDR architecture will provide advanced functionalities in satellite geolocation, ensuring anti-jamming, anti-spoofing capabilities, and the flexibility to integrate new information sources.

The use of precision oscillators will ensure an independent, stable, and secure time reference, crucial for many applications such as device synchronization (Figure 4).

In addition to these three elements of significant technological innovation, the implementation of a modular and scalable data fusion algorithm guarantees the use of alternative sensors to GNSS, making it easy to integrate attitude, position, and velocity information.

Figure 1 - SINAPSIS system overview.

Figure 2 - HRG gyro.

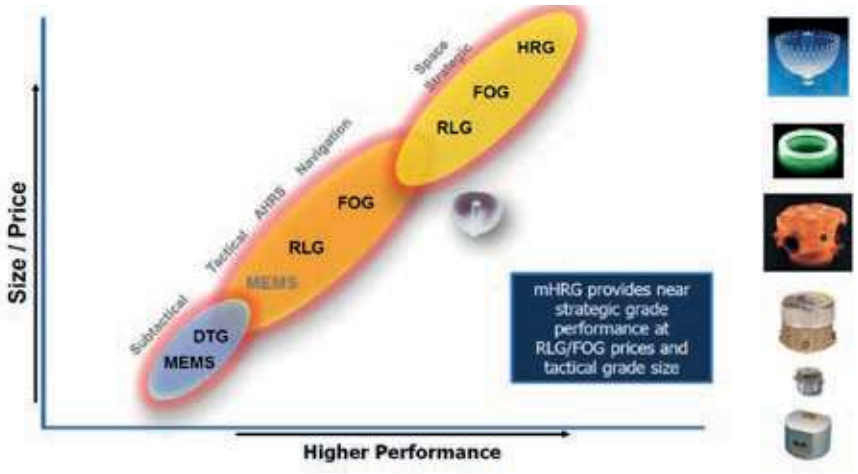

Figure 3 - Gyro Technology comparison.

The modularity of the data fusion algorithm also aims to be easily updatable and extendable to the use of innovative sensors and technologies, such as image-based or radar-based localization (Figure 5). Through phase one of the SINAPSIS project, research activities have been conducted on the state of the art, on Positioning Navigation and Timing techniques in a NAVWAR scenario, examining data fusion techniques and the types of sensors capable of responding to identified scenarios. The specifications of the SINAPSIS system and the HRG sensor have been defined as a result. Phase two, currently underway, has seen the completion of the system design to date.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The strategy of Northrop Grumman Italia for the next three years involves developing entirely national and ITAR-FREE technologies not currently present in Italy, creating value in Italy ("Made in Italy" from development to service).

The future system will be one of the new products at the core of Northrop Grumman Italia's business, which has been providing localization and navigation systems to Italian and international armed forces since 1961. SINAPSIS is being developed in accordance with the accuracy and robustness requirements typical of military appli-

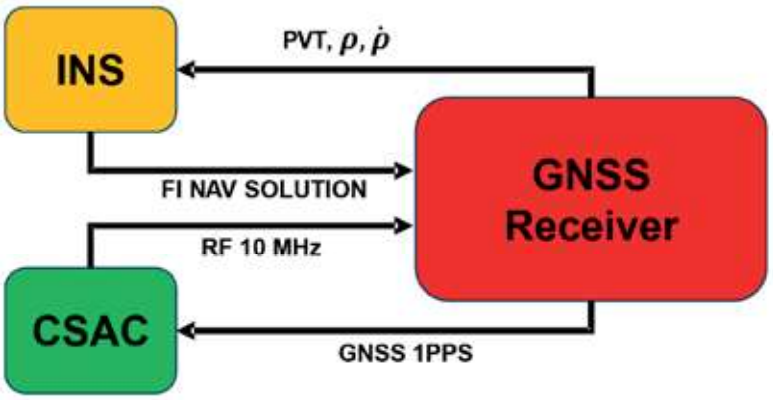

Figure 4 - GNSS Interaction overview.

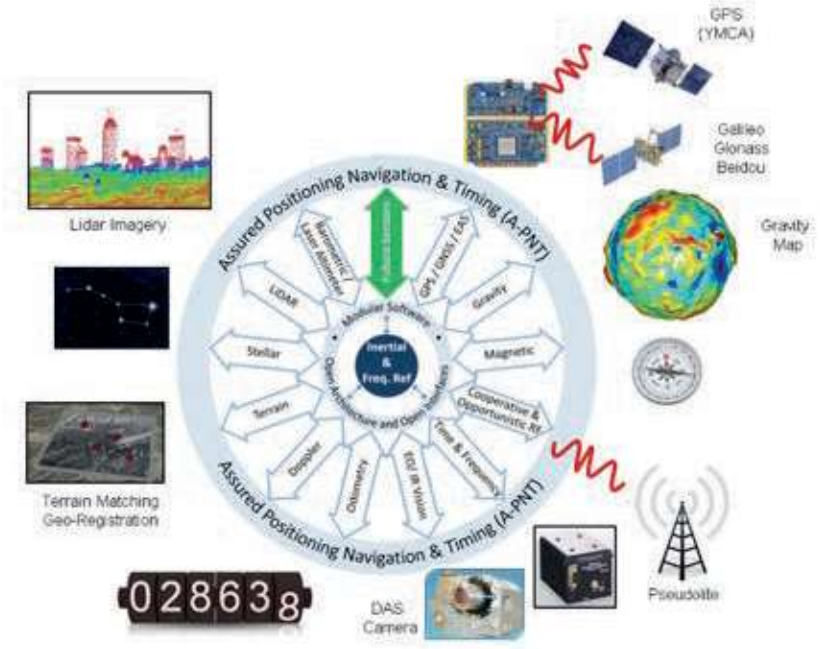

Figure 5 - APNT global view.

cations. Thanks to its wide range of civilian and military applications, the system can be marketed in both national and international markets. A GNSS jamming and spoofing immune PNT system is of high importance in numerous military and civilian applications.

These technological advancements will enable effective countermeasures against a type of attack that is becoming frequent and easy to carry out, and can lead to dangerous situations for critical infrastructure such as airports, communication networks, energy grids, and infrastructure control and monitoring systems. GPS timing is also widely used in numerous civilian systems, from communication networks (NTP servers) to banking systems.

CONCLUSIONS

During the first phase of the SINAPSIS research project, the critical issues in navigation in contexts where the GNSS signal is absent or subject to disturbances were identified. In these scenarios, particularly in missile contexts where the ability to be quickly operational is crucial, one of the problems related to the absence of the GNSS signal is the lengthening of the system initialization times, which becomes dependent on an external operator for initial position information.

After the prototypes of the HRG sensors, called Q-HRG (Quartz-Hemispherical Resonator Gyroscope), were developed, environmental tests validated their electro-mechanical design in an avionic environment. In the ongoing second phase, the System and GPS design has been completed, and parts procurement for two prototypes has been carried out. In the future third phase, the prototypes will undergo intensive hardware and software integration and performance verification in static and dynamic environments, including simulated GPS signal attack situations. The success of the entire program will enable Italy to have innovative ITAR-FREE technologies capable of meeting the current WARFARE scenarios that our Armed Forces are called upon to face.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

CSAC	*Chip Scale Atomic Clock*
FF.AA	*Forze Armate*
GNSS	*Global Navigation Satellite System*
GPS	*Global Positioning System*
NAVWAR	*Navigation Warfare*
NTP	*Network Type Protocol*
PNT	*Position Navigation Timing*
Q-HRG	*Quartz-Hemispherical Resonator Gyroscope*
SDR	*Software Defined Receiver*
SGD	*Secretariat General of Defence*

KEYWORDS

Gyroscopio, CSAC, sailing, GPS, GNSS, spoofing, jamming.

PROJECT INFORMATION

PNRM number:	a2019.216
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HYPERION

HYPERION is a Mach 4.5 hypersonic suborbital spaceplane for: (i) surveillance and interception (so-called scramble) in national airspace extended up to 100km altitude, against threats from hypersonic weapon systems; (ii) 50-60km air-launch of a 100kg payload into low orbit.
Based on the heritage of years of conceptual studies of the Campania Aerospace District ecosystem on the HYPLANE civil application, the project is dedicated to the consolidation of feasibility and preliminary design, including 5 technological demonstrators related to the aircraft configuration and some critical components. The aircraft demonstrator#1 was built in Phase 1 and subjected to 1000 wind tunnel test conditions at CIRA and INCAS (Romania).
There are four reference missions for which feasibility has been confirmed. An experimental Flight Demonstrator (manned/unmanned) based on available propulsion systems (two Eurofighter EJ200 engines and a VEGA Zefiro 9 rocket) was also studied, for a suborbital mission with a maximum speed of M 4 and an apogee of 80km, operable in the Tyrrhenian area, between the airports of Grazzanise and Decimomannu, long proposed as the Suborbital Test Polygon.

INTRODUCTION

The defence of national airspace is currently limited to a maximum altitude of approximately 20km. The development of hyper-fast weapon systems that fly at higher altitudes and their diffusion which is expected to be exponential, require the identification and implementation of adequate countermeasures. Thus, the need arises to develop systems capable of reaching every point of the extended airspace, i.e. up to 100km altitude, reducing the threat response time from reporting the threat to 6 minutes from the current 20.
The availability of a spaceplane capable of reaching high speeds and altitudes, taking off and landing horizontally from short runways without launch platforms or mother aircraft, meets the need. This aircraft is also capable of air-launching - via expendable rocket - payloads towards LEO starting from altitudes higher than those reachable with current fighter aircraft. It will be possible to put 100kg into orbit, starting from any point in the national airspace.
HYPERION integrates the best aeronautical and space technologies, with already high TRLs that guarantee a short time-to-market.
Given the close similarity with the HYPLANE civil aircraft from which it derives, HYPERION is intrinsically dual for a wide market of applications: defence, space tourism, low gravity experimentation, pilot/astronaut training, flight for urgent intercontinental missions.

TECHNICAL BACKGROUND AND SOLUTIONS

The military scenarios of the imminent future see a massive use of hypersonic weapon systems: gliding aircraft and cruise missiles. The new defence systems must be characterized by:

- high speed,
- maneuverability,
- response rapidity,
- load,
- penetration,
- destructive power,
- low human risk.

The proposed solution is HYPERION: hypersonic reconnaissance/interceptor, with hybrid turbo-ramjet/rocket propulsion (Figure 1), capable of carrying out repeated suborbital flights during a single mission, without limitations on the launch site.

Figure 1 - HYPERION configuration. The aerodynamic configuration is characterized by aerodynamic efficiency L/D>4.5 with an angle of attack of 6-8 degrees and a low wing loading factor (between 85 and 130 kg/m2) to guarantee loading conditions around 1.2g along stratospheric flight paths. The same vehicle will experience maximum accelerations of approximately 4.2g in pull-up maneuvers during suborbital flight.

Key features include:

- small-sized "single-stage" aircraft;
- horizontal take-off/landing from "short" runways <1,000m with engines in turbojet mode;
- subsonic climb up to an altitude of 10km (speed of 240m/s);
- acceleration through the transonic and up to M<5 with climb along a constant dynamic pressure trajectory and propulsion in ramjet mode;
- suborbital jumps towards the Karman line (100km altitude), through ignition of a booster rocket;
- possibility of air-launch a second stage from altitudes of 50-60km for the insertion of payloads (<100kg) in LEO;
- gliding descent and horizontal landing powered by turbojet.

The studies carried out in previous years on the HYPLANE spaceplane (Figure 2) were based on general requirements focused on civil (business aviation) and space applications: speed corresponding to M 4.5 in stratospheric flight at an altitude of 30km over distances of 7,000km, or in suborbital flight at a maximum altitude of 100km. Topics investigated were:

- configuration studies;
- mission analysis and flight profiles;
- aerodynamic characteristics;
- surface temperature distribution;
- structural assessments of the fuselage;
- identification and trade-off of propulsion systems;
- evaluation of masses;
- runway length.

Faster or bigger systems still require today important technological developments, more massive investments and do not present a positive business case.

Figure 2 - HYPLANE HYpersonic SpacePLANE. The large wing surface has the advantage of allowing take-offs and landings at low speed (60 m/s) and therefore the spaceplane can take off and land horizontally (HTHL) on short-medium length runways (<1,000 m).

METHODOLOGY

Phase 1 feasibility refers to four missions:

- Planned Suborbital Reconnaisance Mission (PRSM, Figure 3)
- Quick response Interception Suborbital Mission (QISM, Figure 4)
- Long Range Stratospheric Mission (LRSM, Figure 5)
- High-altitude Air-Launch Mission (HALM, Figure 6)

It includes a series of Technological Demonstrators. The computational aerodynamics

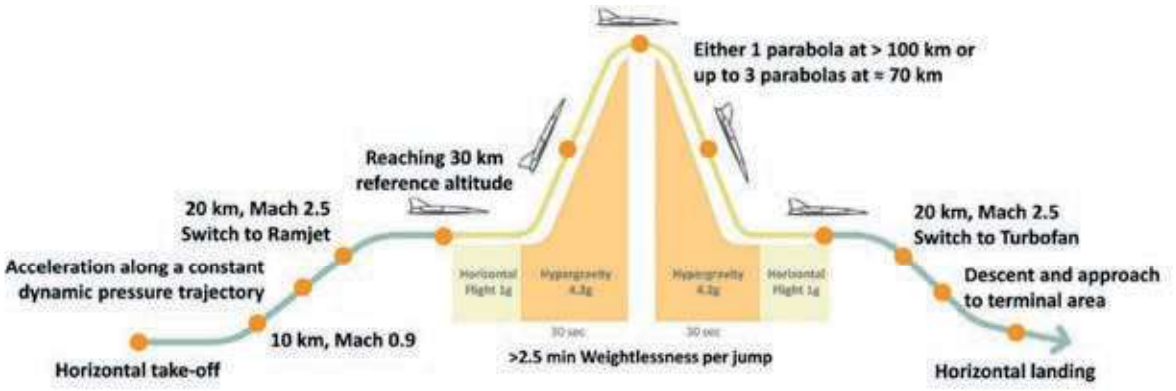

Figure 3 - Planned Reconnaissance Suborbital Mission (PRSM). Routine suborbital flight reconnaissance mission. The primary characteristic is total compatibility with civil air traffic both in flight and during take-off/landing.

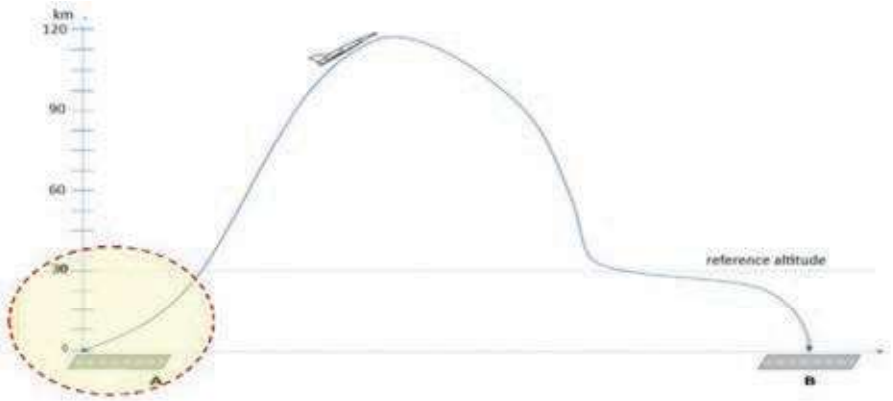

Figure 4 - Quick-response Interception Suborbital Mission (QISM). Mission entirely similar to the PRSM but framed in an emergency situation and therefore based on total priority over air traffic both in flight and in airport area.

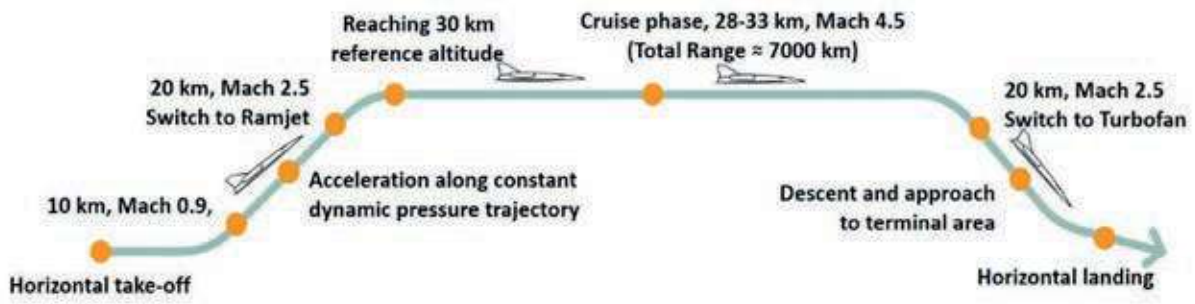

Figure 5 - Long Range Stratospheric Mission (LRSM). Long-range mission to reach theatres of participation in peacekeeping operations, with the objective of reconnaissance, operational support and transport of special units or materials.

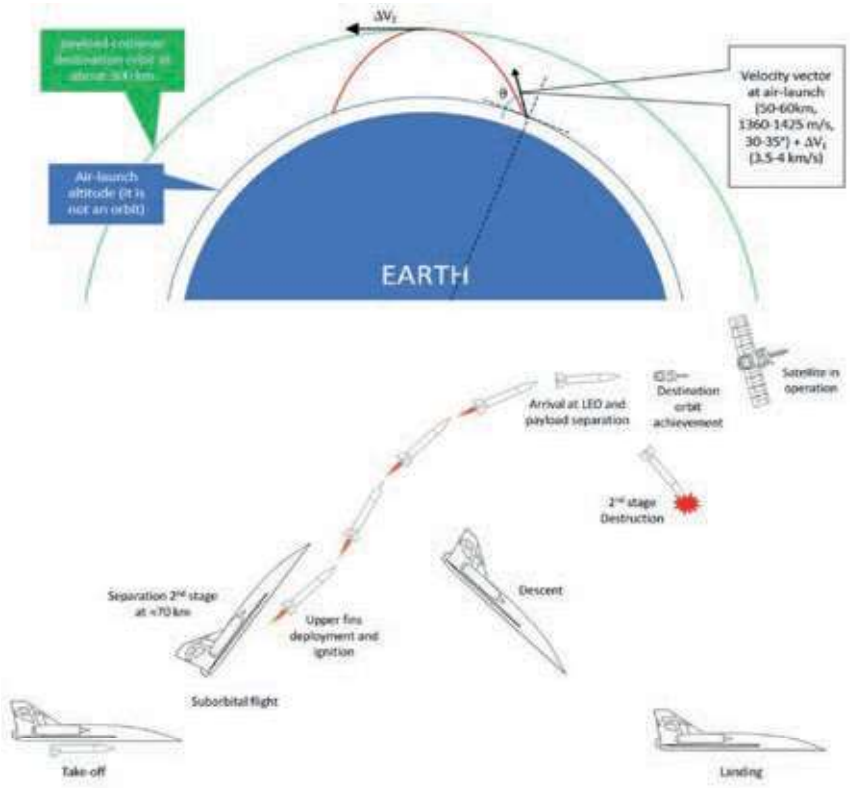

Figure 6 - High altitude Air-Launch Mission (HALM). Mission to put significant payloads into orbit by air-launch from high altitudes.

(CFD) at M∈(0.18÷6) and various settings was confirmed by wind tunnel tests carried out with the Demonstrator #1 (Figures 7, 8, 9), obtaining the results of Figure 10. The aerothermodynamics led to the surface temperature distribution, highlighting intense gradients on the stagnation points of the radome and leading edges (Figure 11).

Figure 7 - Demonstrator #1 of the HYPERION configuration. 1:72 scale model for wind tunnel tests in subsonic, transonic and supersonic regimes.

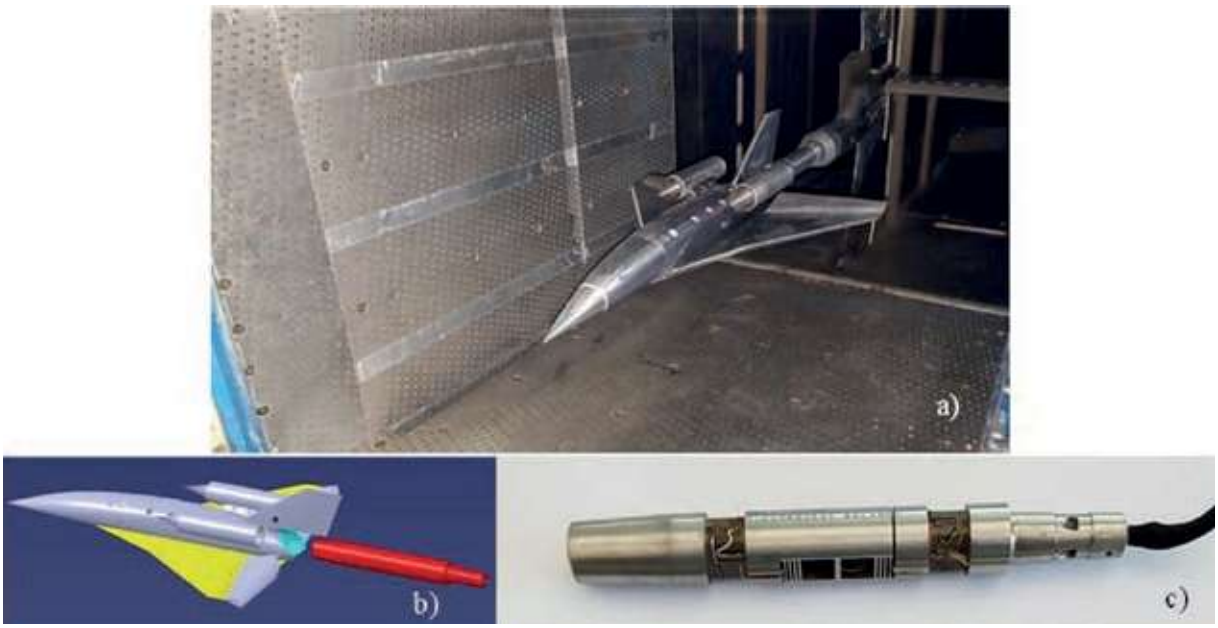

Figure 8 - Demonstrator #1 in the CIRA PT-1 wind tunnel; a) model in the test chamber, b) CAD representation of the installation of the model on the sting, c) balance for measuring the resulting aerodynamic forces acting on the model. Test campaign in the range M=0.18÷1.3 at various settings.

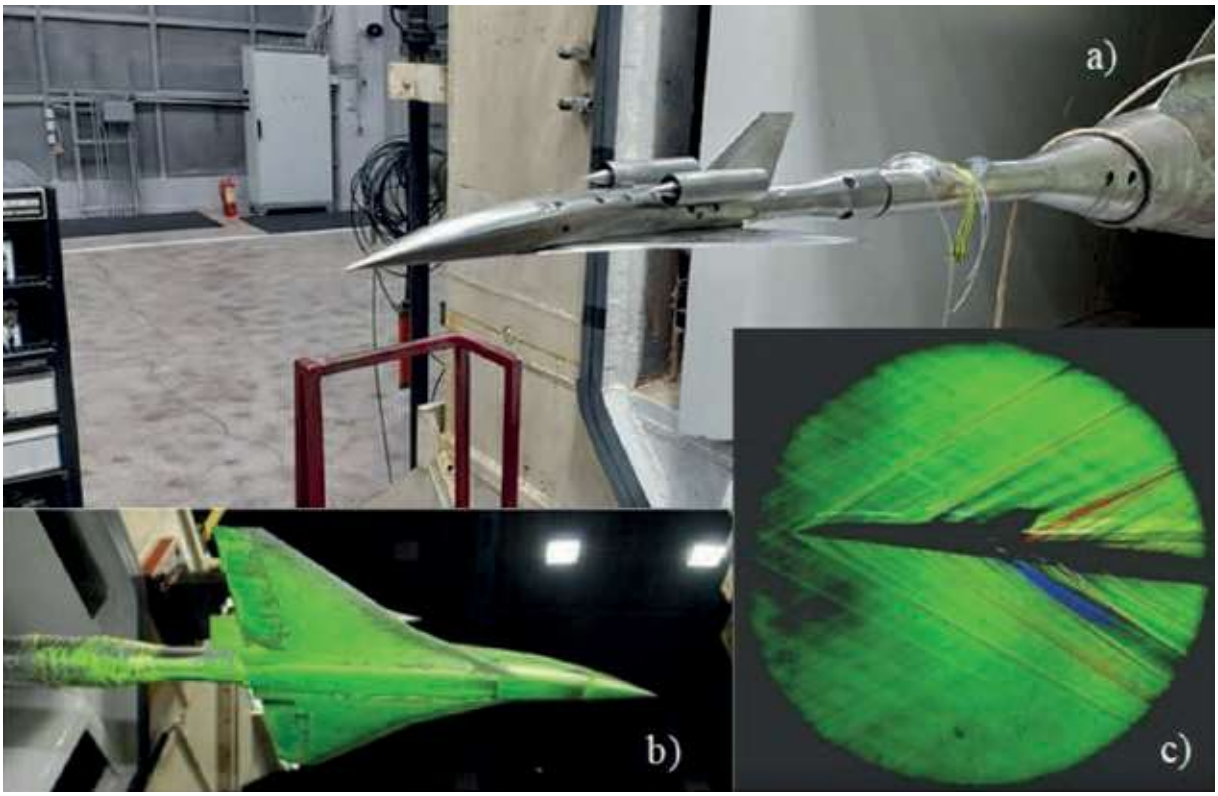

Figure 9 - Demonstrator #1 in the TWT wind tunnel of INCAS (Romania); (a) model set up in test chamber, (b) Oil paint flow visualization at M=1.1, α=2 deg, δ_{elevon}=-20 deg, (c) Color Schlieren visualization at M=2.0, α-sweep. Test campaign in the range M=1.1÷3.5 at various settings.

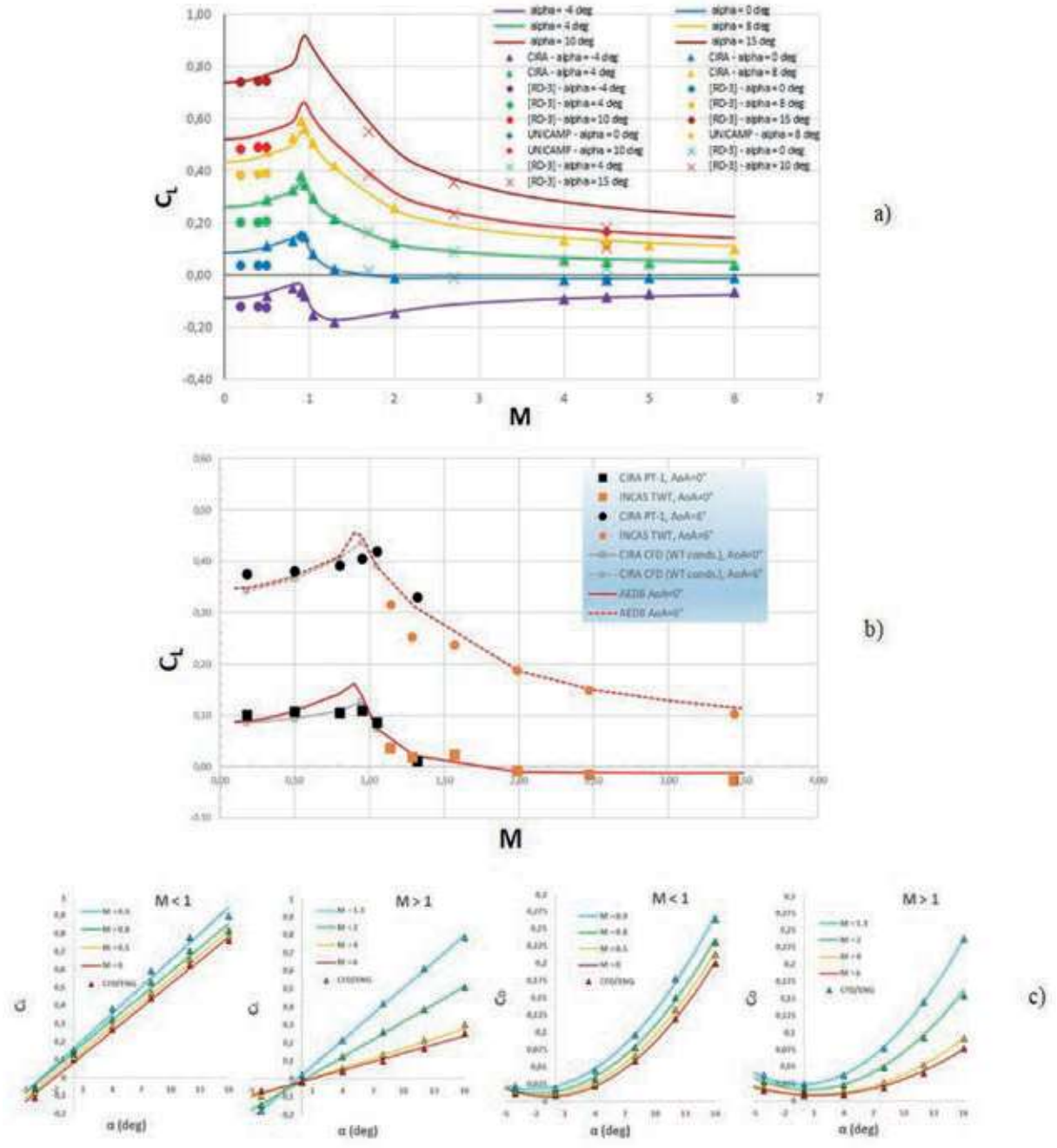

Figure 10 - Aerodynamics. (a) Lift coefficient C_L as a function of M and α, obtained with CFD; (b) wind tunnel tests at CIRA (M=0.18-1.3) and INCAS Romania (M=1.1-3.5); (c) aerodynamic data base has been obtained starting from previous HYPLANE data, including aerodynamic and moment coefficients, stability and control derivatives, as a function of flight parameters (α, M, altitude, control surface deflections) for subsonic, transonic, supersonic and hypersonic regimes.

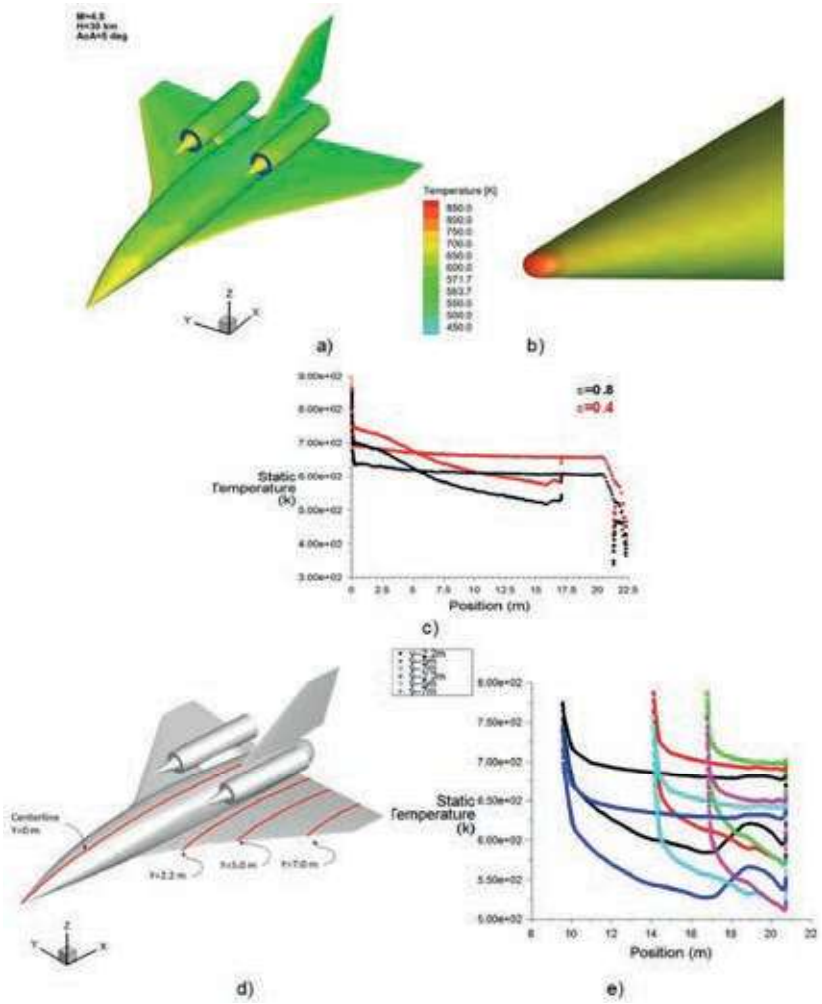

Figure 11 - Equilibrium radiative temperature for flight at M∞=4.5 altitude H=30km and for α=5 deg: (a) surface distribution over the entire vehicle with emissivity coefficient ε=0.8; (b) surface distribution for ε=0.8 over the first 10 cm of the radome; (c) comparison of the temperature on the symmetry plane of the entire fuselage for ε=0.8 (black) and ε=0.4 (red); (d) reference sections along the wingspan; (e) comparison of the temperature on the three reference sections.

For the structural design (Figures 12, 13, 14) the use of titanium alloys and 360 load conditions were assumed. The propulsion system consists of two multi-cycle Supercharged Ejector RamJet engines (SERJ, Figure 15), and a hybrid paraffin-liquid oxygen booster (Figure 16).

The analysis of trimmability, controllability and stability allowed the definition of the nominal trajectory for the missions. The dynamic instability found concerns the phugoid motion with slow characteristic times, easily manageable with specific control algorithms (SAS/CAS). Ultimately, with reference to the PRSM mission, HYPERION can reach an apogee of 92km with a maximum speed of approximately M 5 and downrange of 2800km (Figure 17).

The following technological demonstrators will be realised in Phase 2:

- Nose-radome (Figures 18, 19)
- Wing leading edges (Figures 20, 21)
  - Variable thickness stainless steel, with passive cooling
  - Titanium alloy with semi-passive cooling using heat pipes
- Supersonic air inlet (Figures 22, 23)
- Ramjet fluid dynamic duct (Figures 22, 23)

As intermediate development step, the Flight Demonstrator based on COTS subsystems, as the EJ200 of the Eurofighter and the Zefiro 9 of the Vega launcher, allows reaching M 4,2 and 78km of altitude with a range of 380-400km (Figure 24).

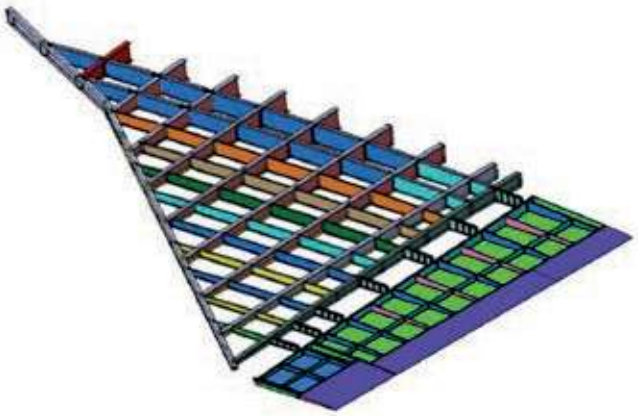

Figure 12 - Structural configuration of the wing.

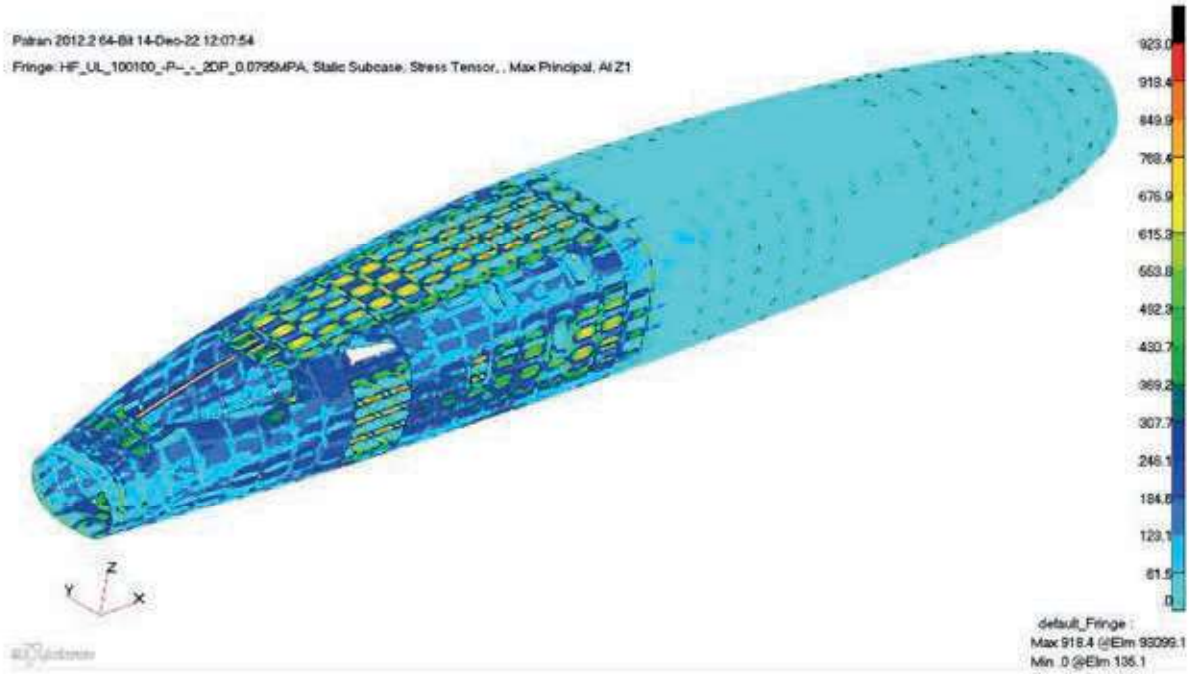

Figure 13 - FEM analysis of the fuselage structure.

Figure 14 - Structural configuration of the tail.

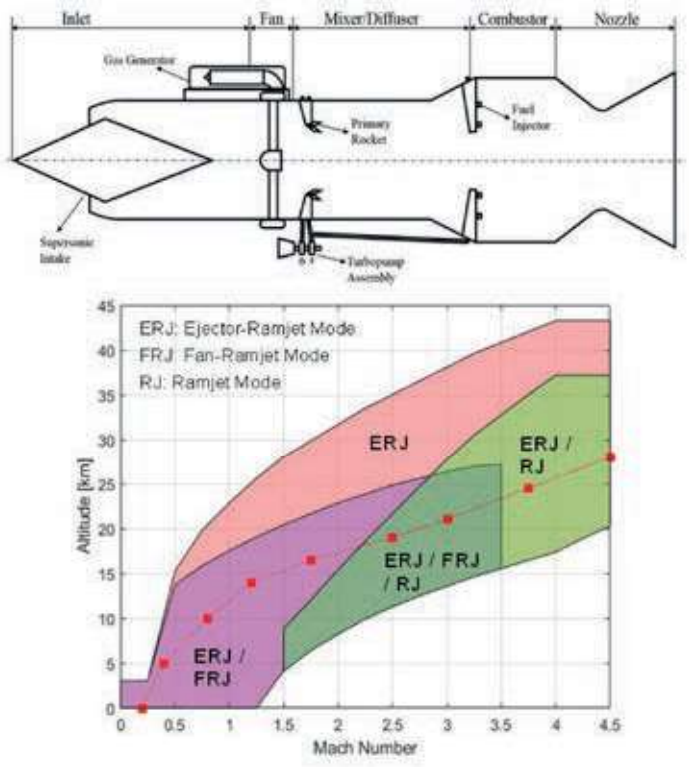

Figure 15 - The Supercharged Ejector RamJet (SERJ), designed in the sixties of the last century, is a multi-cycle engine that can operate in the following modes: turbofan, ramjet, fan-ramjet, supercharged ejector ramjet, ejector-ramjet. Conceptual diagram (top) and operational map with typical climb trajectory up to cruise speed of Mach 4.5 (bottom).

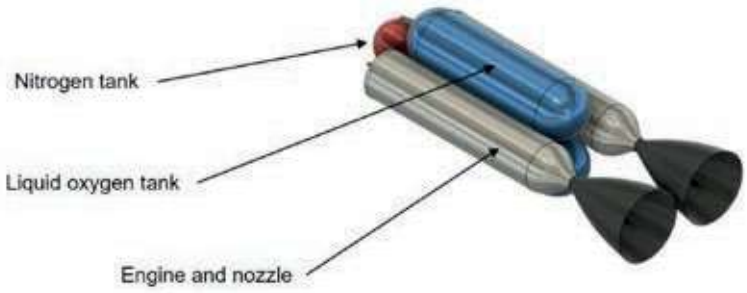

Figure 16 - Layout of the paraffin-LOx hybrid rocket.

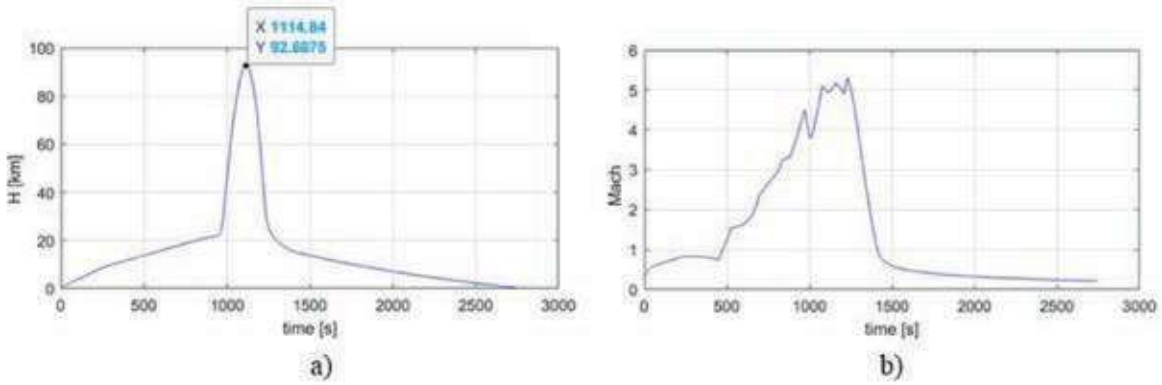

Figure 17 - Altitude (a) and Mach (b) evolution during the nominal PRSM-type optimal trajectory.

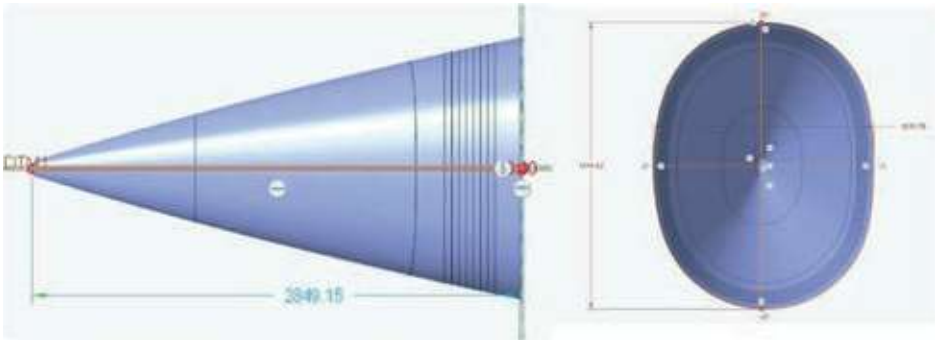

Figure 18 - Configuration of the Demonstrator#2 Nose-Radome.

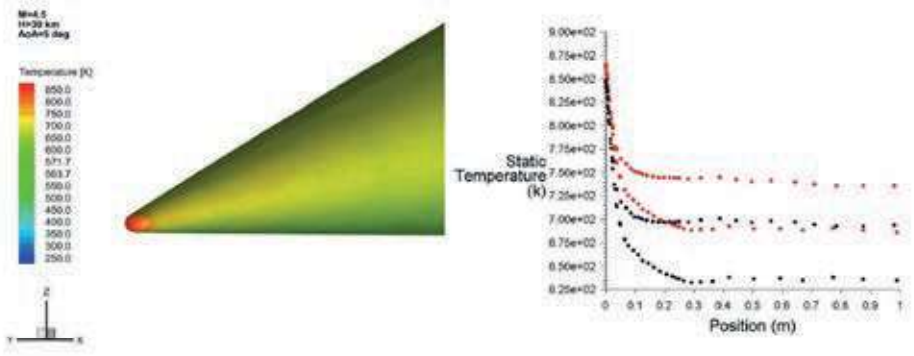

Figure 19 - Radiative equilibrium temperature on the radome.

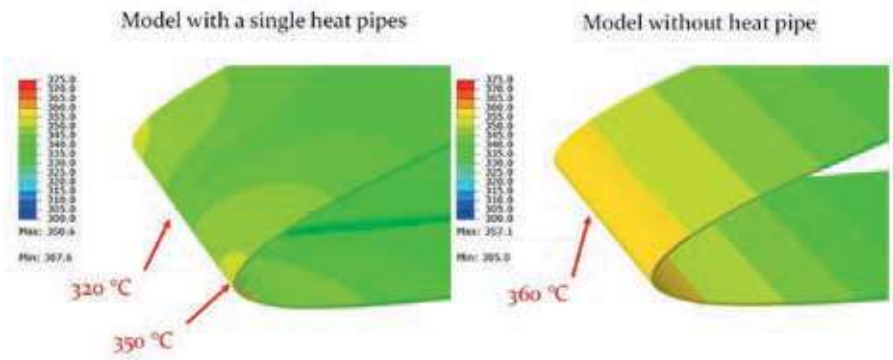

Figure 20 - Simulation of a wing leading edge segment with and without a heat pipe.

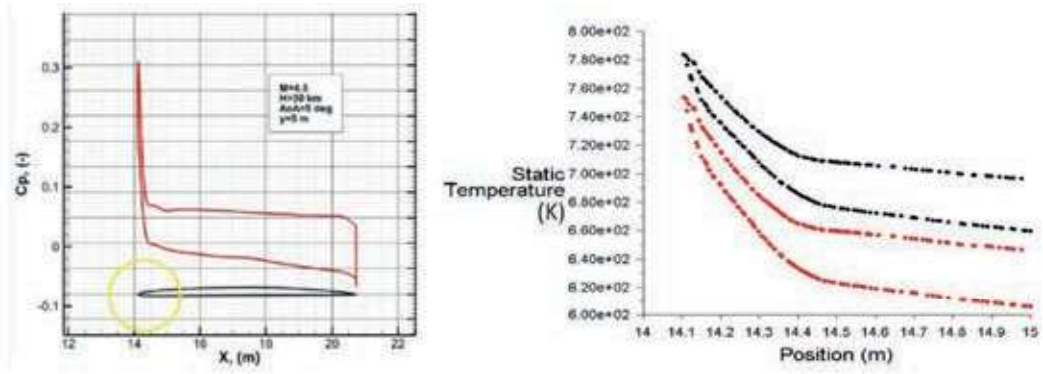

Figure 21 - Mechanical (C_P) and thermal (temperature in radiative equilibrium conditions) loading conditions on the wing leading edge.

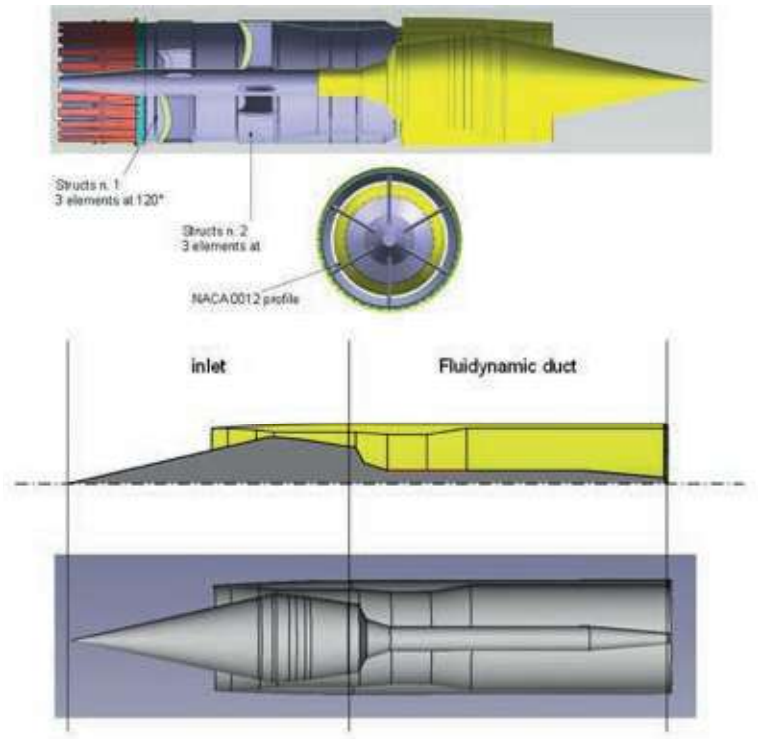

Figure 22 - SERJ engine, Supercharged Ejector Ramjet. Ramjet mode configuration (top); interface between the inlet and the duct (bottom).

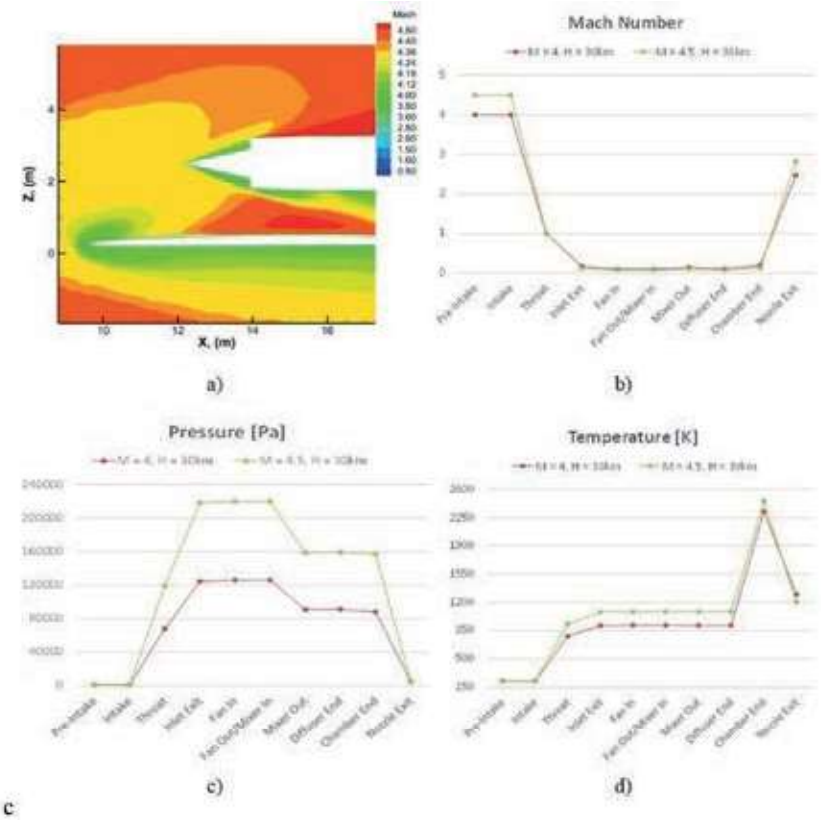

Figure 23 - SERJ Engine. Reference operating conditions of the air intake and duct in ramjet mode: Mach isocurves (a), evolution of M (b), pressure (c) and temperature (d) downwards the engine axis.

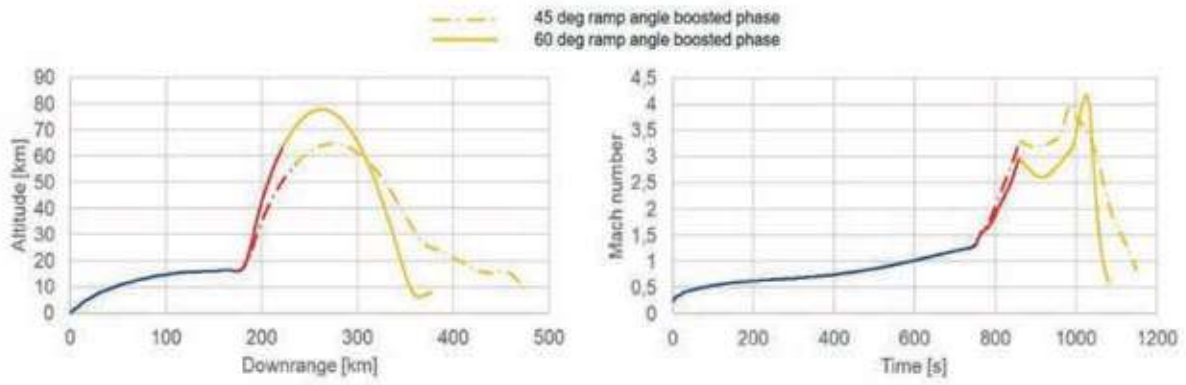

Figure 24 - Flight Demonstrator – flight trajectory. (a) altitude as a function of downrange; (b) velocity profile in terms of M over time.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

HYPERION can operate in ordinary planning conditions to carry out reconnaissance missions, urgent transport of special units or particular loads, training of pilots-astronauts; but also in emergency conditions for scramble interception operations. The system can be used for dual and civil uses such as intercontinental, urgent and fast transport of people and goods using many of the world's medium-small airports. The HYPLANE civil version also expands applications to the space tourism market with the prospect of a much better ticket price than what is currently available on the market, contributing to a faster innovative evolution of aviation.

Rather than the various ongoing studies relating to tens-hundreds-seat supersonic and hypersonic civil transport aircraft, it is more worth to use smaller low-hypersonic aircraft for market segments such as suborbital space tourism and testing, urgent business trips, air taxis, rapid transportation over long distances of human organs for transplants and medicines. These aircraft are technologically and economically more convenient and will be able to stimulate the development of larger and heavier systems, complementing them.

The Campania aerospace ecosystem is ready to play an important role in the development of HYPERION or its associated technologies.

CONCLUSIONS

Phase 1 of the project confirmed the validity-feasibility of a **suborbital hypersonic spaceplane**, with multicycle turbo-ramjet propulsion, for **surveillance/interception in the national airspace extended to 100km** altitude against threats from hypersonic systems, and for air launch from 50-60km of 100kg payload in low earth orbit. We are now aiming to build the demonstrators in Phase 2.

Like HYPLANE from which it derives, **HYPERION is the only design of an aircraft for suborbital and stratospheric cruise hypersonic flights**. A comparison with other aircrafts is given in Figure 25. The project is helping to direct developments towards aircraft of similar size and will encourage the development of even higher performing systems.

Furthermore, a Flight **Demonstrator equipped with an available propulsion system** (EJ200 of Eurofighter and Zefiro 9 of VEGA) was studied to carry out **experimental suborbital flights at M 4 and apogee of 80km**, in the Tyrrhenian area between the airports of Grazzanise and Decimomannu, proposed as the **Suborbital TEst Polygon (STEP)**.

HYPERION demonstrates the competence of the Campania industrial/academic system, capable of developing cutting-edge technologies and systems that allow Italy to participate as a protagonist in upcoming international programs. The project has contributed to the "HYPLNE Family" (Figure 26).

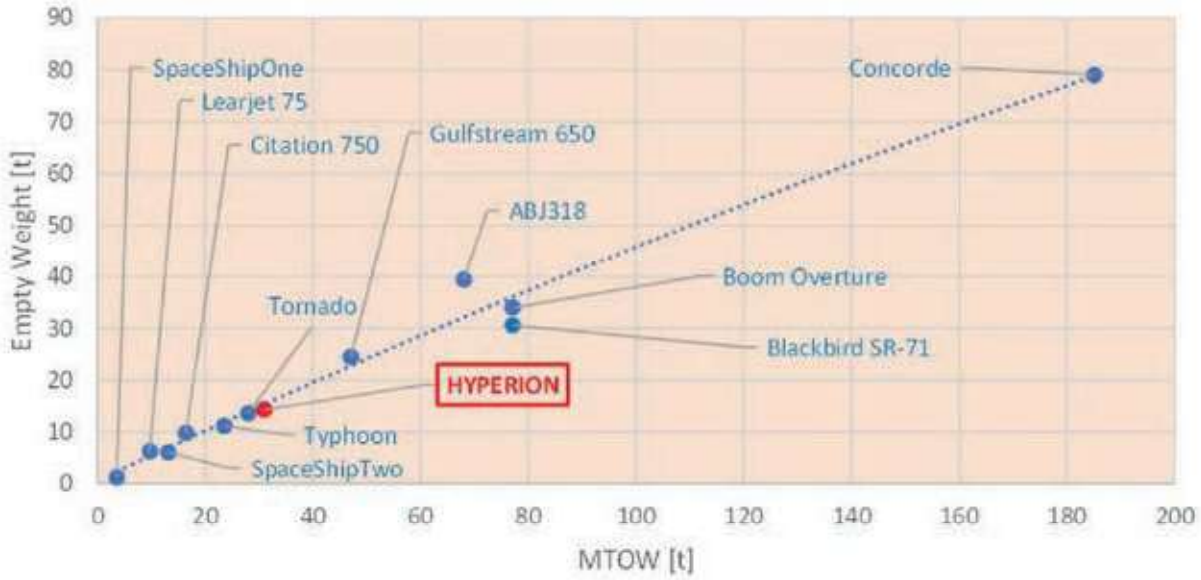

Figure 25 - Comparison in terms of Empty Weight as a function of the Maximum Take-Off Weight (MTOW) of HYPERION with other aircrafts (business jet, fighter, space tourism, Concorde).

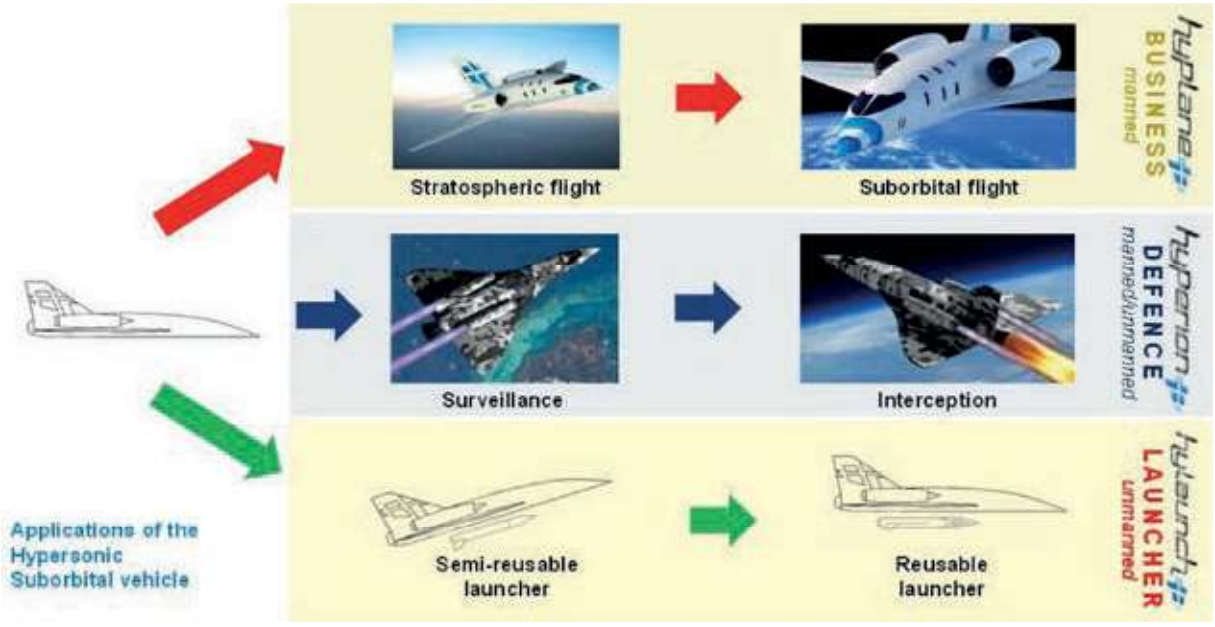

Figure 26 - The HYPLANE family. Thanks to the great versatility of the basic concept, the same spaceplane satisfies a family of applications ranging from suborbital and stratospheric cruise flights of civil interest (HYPLANE), to military surveillance and interception missions (HYPERION), and to space launch capacity from 50-60 km altitude (HYLAUNCH).

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

α, AoA	*Attack Angle*
δ	*Flaperon deflection angle*
ε	*Thermal emissivity coefficient*
g	*Earth gravity*
C_L	*Lift coefficient*
C_P	*Pressure coefficient*
CAD	*Computer Aided Design*
CAS	*Control Augmentation System*
CFD	*Computational Fluid Dynamics*
COTS	*Commercial Off The Shelf*
ERJ	*Ejector-Ramjet*
EW	*Empty Weight*
FEM	*Finite Elements Model*
FRJ	*Fan-Ramjet*
GTOW	*Gross Take Off Weight*
HALM	*High altitude Air-Launch Mission*
HTHL	*Horizontal Take-off Horizontal Landing*
HYLAUNCH	*HYpersonic airLAUNCH*
L/D	*Lift-over-drag ratio*
LEO	*Low Earth Orbit*
LOx	*Liquid Oxygen*
LRSM	*Long Range Stratospheric Mission*
M	*Mach number*
MTOW	*Maximum Take Off Weight*
PRSM	*Planned Reconnaissance Suborbital Mission*
PT-1	*Pilot Tunnel-1*
QISM	*Quick-response Interception Suborbital Mission (scramble)*
RJ	*Ramjet*
SAS	*Stability Augmentation System*
SERJ	*Supercharged Ejector Ram-Jet*
STEP	*Suborbital TEst Polygon*
TRL	*Technology Readiness Level*
TWT	*Trisonic Wind Tunnel*

KEYWORDS

Hypersonic, suborbital flight, spaceplane, demonstrator, reconnaissance, interception.

PROJECT INFORMATION

PNRM number:	a2019.224
Organization:	Direzione degli Armamenti Aeronautici e per l'Aeronavigabilità (ARMAEREO)
Responsible entity:	Temporary Enterprise Group "Hyperion" composed by Distretto Tecnologico Aerospaziale della Campania Scarl (DAC, mandatario), Consorzio CALTEC, Centro Italiano Ricerche Aerospaziali (CIRA), MBDA. Other contributors are the DAC actuators Aerosoft, Atm, Lead Tech, Tecnosistem, Trans-Tech, Università della Campania Luigi Vanvitelli, Università di Napoli Federico II.
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MAGICS

The "Manned unmAnned Ground Interoperable Control Station" – MAGICS project aims to fill the operational gap between 4th/5th with 6th generation military aircraft. The objective is the development of a capability to enable the pilot of the "Manned" aircraft to execute a mission by means of an intelligent cooperation with one or more autonomous unmanned wingman. For this scope, an "On-board" system composed by an advanced graphical user interface (HMI) supported by artificial intelligence (AI) algorithms has been developed, enabling the automatic interaction with the wingman Unmanned Aerial Vehicles (UAV).
This demonstrated the potential extension of legacy aircraft operational capabilities with the Manned-Unmanned Teaming (MUMT) functionality. Moreover, the exploitation of AI power inducing a high degree of automatic control of the wingmen in flight had not significant impact on the pilot's workload.

INTRODUCTION

In order to fill the gap with 6th generation swing-role aircrafts embedding native mechanisms for cooperation with a drones swarm, it is necessary to elevate the intelligence of the 4°/5° generation aircrafts by means of external capabilities able to manage and control automatically the unmanned wingmen and the related payloads/armament. So the pilot would be provided with an extremely powerful decision-support tool (*"Decision Superiority"*) able to combine information incoming from command center with those acquired autonomously by UAVs. This would increase the strategic view of the scenario ("Strategic awareness"), realizing a sort of on-board *Aerial Operation Center* - AOC.
The proposed solution mainly consists of an advanced AI based on Deep Reinforcement Learning algorithms, deployed and distributed onto the piloted vehicles and Unmanned wingmen, controllable through a simple and intuitive HMI. It allows UAVs to perform complex sequences of actions (tasks) autonomously without requiring continuous control inputs from the pilot. High-level commands are sent representing the required EFFECTS to be applied on the tactical scenario. So a significant step over existing operational architectures is performed, where UAVs are usually manged by dedicated control station only.

TECHNICAL BACKGROUND AND SOLUTIONS

In order to integrate the MUMT capability on legacy platforms (4th/5th generation) equipped with display not designed for this purpose, with reduced dimensions and resolution (e.g. MFD 4" x 4" - 600x600 pixel), it has been essential to optimise and simplify the operational commands to manage the wingman UAS minimising the pilot's workload as well.
This was achieved through the use of Artificial Intelligence algorithms (Deep Reinforcement Learning), capable of giving to the wingman UAS a high level of autonomy, so enabling them to perform a mission with a really small number of commands to be issued by the pilot.
To implement this capability, a technology demonstrator has been developed whose architecture is based on Software components described below and shown in Figure 1:

- C1 - Human Machine Interface (HMI): graphic interface simulator based on the digital MFD (Multi Function Display) concept.
- C2 - Effect Manager: component responsible for the decomposition and automatic assign-

ment of tasks to the unmanned wingman aircraft, in order to achieve the required EFFECT.

- C3 - Task Manager: component responsible for carrying out the specific task, which makes intelligent use of the elementary commands made available by the wingman UAS.
- C4 - Command Manager: component responsible for managing the commands made available by the UAS platform : flight control, navigation and on-board sensor management.
- C5 - Wingman Simulator: component executing the dynamic simulation of "CLASS I SMALL" unmanned aircraft within the operational scenarios selected for the demonstration phases.
- C6 - Tactical Scenario Simulator: COTS Software package responsible for the graphic generation of the operational tactical scenario.

METHODOLOGY

The implementation of the components of the demonstrator is shown in Figure 2. Component C1 is the MFD simulator, developed to allow the pilot to interact with the legacy cockpit through Avionics Formats accessed by "SoftKey" It allows to enter commands, monitor and control the assignment of EFFECTS to the wingman UAVs. This component has been built using a Model-Based approach, automatically generating C++ code, to be integrated with the other components of the system.

The UAS simulators has been also developed with a Model-Based approach , by using MATLAB/Simulink™ tool suite environment, taking advantage of the automatic C++ code generation feature, as well.

The wingman UAS has been simulated by a 6-DOF model of a NATO CLASS I SMALL UAS, with configurable performance and geometric characteristics, containing on-board sensor functionalities to detect entity in the tactical scenario.

The main software component is the MAGICS Core, which includes the AI algorithms (C2-C3-C4) and the UAS simulator (C5).

The AI integrated in the C2 and C3 components, allowing the wingman aircraft to perform the EFFECTS, has been trained by means of the Deep Reinforcement Learning technique.

The *Ray RLlib Machine Learning framework* and the *Gym library* have been used to build-up the training environment. The neural network architecture used is a *Multi-Layer Perceptron (MLP)*

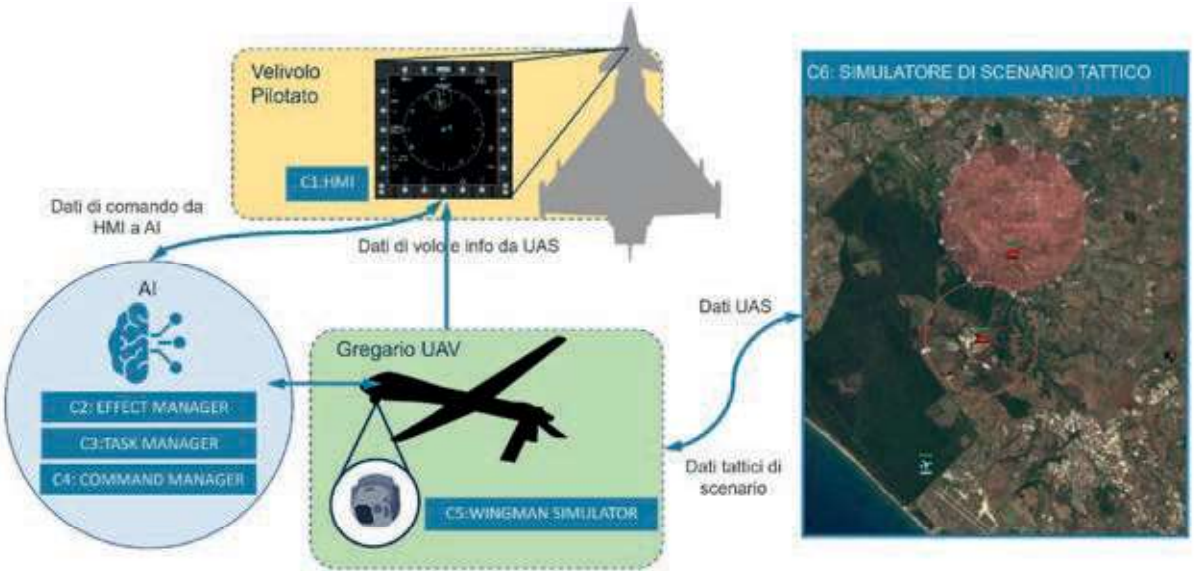

Figure 1 - Architectural diagram of the MAGICS demonstrator.

receiving in input information related to the UAV's attitude, mission and tactical scenario organised in Framestacking, in order to consider the time evolution of the incoming data. The training algorithm has been *Proximal Policy Optimization (PPO)*, chosen for its intrinsic stability and capability to handle continuous data. To optimize inferential performance and minimize its "footprint," the neural network has been implemented in C++.

The tactical scenario simulator has been built using Command™ PE COTS software integrated with the MAGICS Core SW application.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The MAGICS project demonstrated the MUMT capability and the real feasibility to be used by 4th/5th generation airborne platforms.

For this purpose, some representative EFFECTS of a tactical military context has been developed and tested:

- "TARGET ACQUISITION" which enables UAVs to operate in hostile terrain. They autonomously detect and designate targets navigating through anti-aircraft defence zones. This capability has potential uses in advanced surveillance missions and tactical support.
- "FOLLOW ME" which expands the possibilities of deployment in tactical operations, by allowing wingman UAVs to follow a human aerial leader in formation. This functionality has practical applications in coordinated reconnaissance missions, dynamic monitoring of critical areas and real-time tactical support.

The achieved results open new perspectives in the execution of complex aerial missions, characterised by swarms of wingman UAS operating in critical tactical scenarios.

MAGICS application concepts extend beyond the military context, so they can be adopted in civil security operations, emergency management, environmental monitoring and search and rescue operations. The intuitive graphic interface and the advanced AI make the system accessible even by non-specialist operators, expanding its usage possibilities.

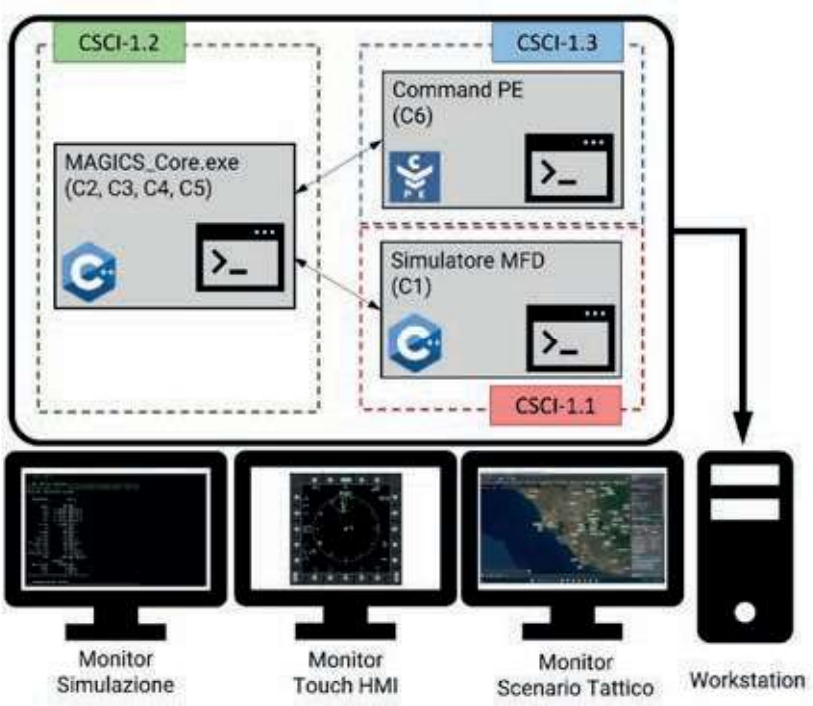

Figure 2 - Software and hardware components of the MAGICS demonstrator.

CONCLUSIONS

Phase1 of the project demonstrated the applicability of AI in the cooperative management of hybrid air squadrons composed by aircrafts with/without a pilot on board.

Wingman UAVs have been made able to execute complex sequences of actions without the direct and continuous intervention of the pilot, marking a significant step over existing technologies. The experimental use of the Deep Reinforcement Learning technique in the implementation of TARGET ACQUISITION and FOLLOW ME EFFECTS demonstrated the validity of the approach both from functional and algorithm performance point of view.

The avionics formats developed and tested using the MFD simulator, enabled automatic and simplified interaction among pilot and wingmen, demonstrating the possibility of smooth and easy integration of MUMT capability into the avionic mission systems of $4^{th}/5^{th}$ generation aircraft.

The minimal increase in pilot workload allowing to focus tasks such as decision-making and supervision has been proved. The developed system has been considered promising of improvements in air mission execution, enhancing tactical and strategic operational capabilities.

Finally, the MAGICS project has demonstrated the capabilities of the MUMT functionality, proving its potential use as “derisk” or operational activity, by integrating this subsystem as retrofit kit on $4^{th}/5^{th}$ generation platforms waiting for 6^{th} generation.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AI	*Artificial Intelligence*
AOC	*Aerial Operation Center*
COTS	*Commercial Of the Shelf*
DOF	*Degree of Freedom*
HMI	*Human Machine Interface*
MAGICS	*Manned unmAnned Ground Interoperable Control Station*
MFD	*Multi Function Display*
MLP	*Multi Layer Perceptron*
MUMT	*Manned-Unmanned Teaming*
PPO	*Proximal Policy Optimization*
SW	*Software*
UAS	*Unmanned Aircraft System*
UAV	*Unmanned Air Vehicle*

KEYWORDS

UAV, UAS, Artificial Intelligence, Deep Reinforcement Learning, HMI, MUMT, Neural Network.

PROJECT INFORMATION

PNRM number:	A2020.208
Organization:	Direzione degli Armamenti Aeronautici e per l'Aeronavigabilità (ARMAEREO)
Responsible entity:	UTAER
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The ZENIT project delivered application methodologies for HUMS (Health and Usage Monitoring System) and V/S (Vulnerability/Survivability) applied to RPAS (Remotely Piloted Aircraft Systems) platforms, with the goal of optimizing the maintenance strategy for individual machines and fleets, as well as increasing operational safety and mission suitability. The ZENIT project is divided into two parts; Part 1 focuses on identifying requirements and defining methods, while Part 2 is directed towards creating an application environment that allows the implementation of activities developed throughout the entire project. The main activities developed in Part 1, which has already been concluded, are described hereafter. The project utilized modeling methods within the two major areas of HUMS and V/S. The primary achieved results are methodological in nature and have led to the development of methods for defining a Digital Twin for Health and Usage Monitoring, as well as an advanced analytical and statistical tool for assessing the vulnerability/survivability of the platform of interest (V/S part).

INTRODUCTION

The ZENIT project falls within the definition of innovative strategies for the optimization of maintenance activities for individual machines and fleets, aiming to increase operational safety and mission suitability. The real-time management of an autonomous flight system, designed for long-distance travel in often unfavorable environmental conditions (high altitudes, wide temperature variations, etc.), requires the development of intelligent systems. These systems, based on the current health status of the most critical subsystems and the prediction of structural degradation, should support operators in making timely and reliable critical decisions. Additionally, these systems could autonomously formulate decision-making strategies. In the same context, the analysis of survivability is conducted with the primary purpose of highlighting any critical issue that could make the system vulnerable to external threats, whether they are man-made or generic. In particular, such analyses would be of strong interest both if integrated from the early design phases of the machine and if conducted to serve as a tool supporting the design of protective surfaces, with the common goal of reducing the machine's vulnerability level.

TECHNICAL BACKGROUND AND SOLUTIONS

First-generation HUMSs (Health and Usage Monitoring System) are implemented on some aircrafts, enabling the acquisition, recording, and processing of data to support aircraft maintenance. However, despite their fundamental role, these assessments are not sufficient for an accurate and precise identification of anomalies necessary for optimal management and control of the autonomous aircraft subsystems, as well as for a reliable prediction of their remaining life. Although there are various applications of structural and system monitoring in the literature, the implementation of such approaches for on-demand diagnosis and prognosis at an industrial level is currently very limited.

This project has therefore allowed the development and use of a Digital Twin of the aircraft system, based on numerical and analytical models. This enables the implementation of effective

and economically advantageous HUMS that do not extensively and systematically rely on very expensive experimental tests, carried out only in specific particularly critical circumstances and in the final verification phase of the system.

Throughout its operational life, an RPAS (Remotely Piloted Aircraft System) is constantly exposed to external threats, potentially capable of degrading its operational capabilities or causing complete inoperability. In particular, the possible explosion of missiles near the remote piloted system represents a significant threat characterized by two damage mechanisms: i) the shockwave created by the detonation of the explosive material; ii) the fragmentation of the missile case, generating fragments with high penetration power. Therefore, vulnerability analysis of the machine is of fundamental importance to minimize risks associated with conducting operations in hostile environments. The project has thus allowed the development of an integrated and advanced computing environment capable of conducting vulnerability analyses of a system of interest through the modeling of threats and their effects.

METHODOLOGY

The HUMS activity focuses on the development of methodologies for defining a Digital Twin of the aircraft system. This is based on numerical and analytical models, enabling the implementation of HUMS that do not extensively rely on experimental tests. These tests are carried out only in the final verification phase of the system. The proposed technological solution integrates the combined use of virtual sensors and model (Digital Twin) of the main subsystems, also considering the presence of damages. This allows for a evaluation of the behavior of the intact aircraft, compared in real-time with what is observed by the sensors, to identify any possible anomalies. Specifically, HUMS includes:

(i) The multi-physical Digital Twin of a drone (Figure 1), developed in the Matlab environment, comprising algorithms based on artificial intelligence correlating flight parameters

(a)

(b)

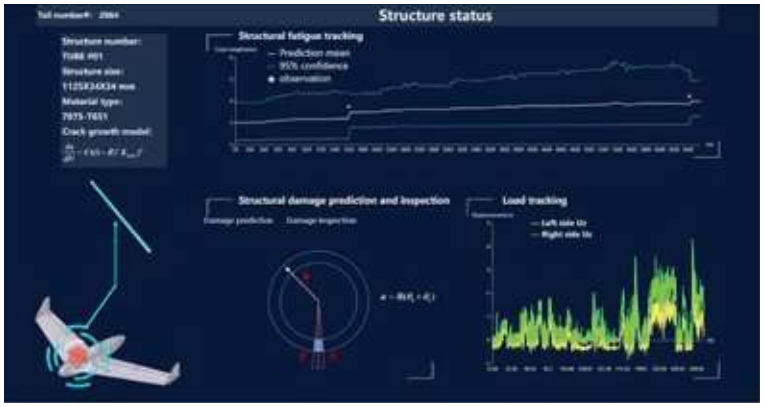

Figure 1 - (a) main interface of the Digital-Twin, (b) diagnostic and prognostic sub-interface.

with local deformation measurements, using finite element simulations and computational fluid dynamics (CFD).

(ii) Algorithms for load monitoring, based on the inverse Finite Element Method (FEM), to reconstruct in real-time the displacement (shape sensing) and deformation field of the entire structure from a set of local deformation measurements (Figure 2) and to identify anomalies.

(iii) Diagnostic and prognostic algorithms based on Monte Carlo techniques and artificial intelligence.

The V/S activity focuses on the development of an advanced computing environment consisting of:

(i) Analytical methods to describe the threat, the system, and their mutual interaction. In particular, analytical models of fragmentation missile threats with proximity fuzes are developed.

(ii) A probabilistic environment for calculating the survival probabilities of each individual component, each system, and the machine itself. The vulnerability analysis determines the most critical components of an analyzed RPAS considering desired threat directions and different missile detonation distances (Figure 3). This value could potentially be correlated (posteriorly) with the performance of any disturbance systems installed on the platform.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The use of remotely piloted aircraft systems will see a constant increase in the coming years, both in civil and military domains. In this context, aspects related to the reliability of many aircraft subsystems play a fundamental role. Even minor malfunctions or damage issues could quickly turn into catastrophic events in the extreme conditions in which the drone must operate. This project has allowed verifying the feasibility and effectiveness of implementing HUMS (Health and Usage Monitoring System) through the use of simplified Digital Twins. It also estimates the robustness of these systems in presence of variable operational and

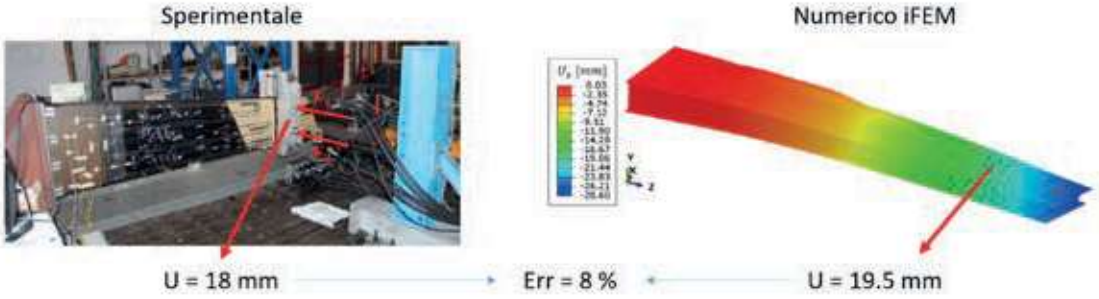

Figure 2 - Technical application of the inverse FEM to a section of a wing made of composite material. A set of local deformation measurements is used to reconstruct the entire displacement field of the structure, without the need to know the applied loads, with an acceptable error.

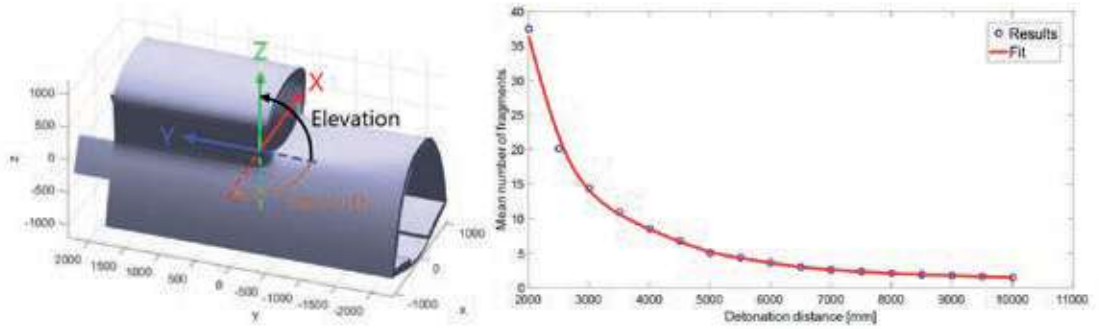

Figure 3 - Application of a V/S module to a plausible case: a) representative piece of a fuselage(skin) RPAS, b) relationship between the average number of fragments hitting the Skin and the distance to the detonation point of the missile.

environmental conditions, providing a cost-benefit analysis of the potential of HUMS systems.
Furthermore, the absence of a human crew is a crucial aspect in the policy of reducing the vulnerability of the machine. This characteristic promotes the use of such remotely piloted systems in diverse ranges of potentially critical conditions, exposing the RPAS to potentially hostile environments. These aspects, related to HUMS and V/S issues, highlight how the design of an RPAS requires advanced tools to improve its effectiveness in missions and enhance its survival capabilities against possible external threats.

CONCLUSIONS

The project has allowed for an in-depth exploration of HUMS and V/S applied methodologies to RPAS platforms. Effective and economically advantageous HUMS methods have been defined. The proposed technological solution will integrate the combined use of virtual sensors and a virtual model (Digital Twin) of the main subsystems and their possible interconnections, both in normal conditions and in the presence of damage. This allows for a constant evaluation of the expected behavior of the intact aircraft and a real-time comparison with what is observed by the sensors to identify any possible anomalies.
An analytical and statistical tool for evaluating the V/S of the platform of interest has also been defined. In particular, it is possible to represent various threats that the platform could face during its use in a computing environment, obtaining quantitative assessments of both individual systems and the overall platform. From these analyses, improvements can be made, such as the implementation of redundancies, protected zones, etc. The proposed method can be applied during various phases of the design process and even later if substantial modifications are allowed.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

CFD	*Computational Fluid Dynamics*
FEM	*Finite Element Model*
RPAS	*Remotely Piloted Air System*

KEYWORDS

HUMS, Machine Learning, inverse FEM, Digital Twin, Vulnerability, Survivability, RPAS.

PROJECT INFORMATION

PNRM number:	a2020.302
Organization:	Direzione degli Armamenti Aeronautici e per l'Aeronavigabilità (ARMAEREO)
Responsible entity:	Politecnico di Milano
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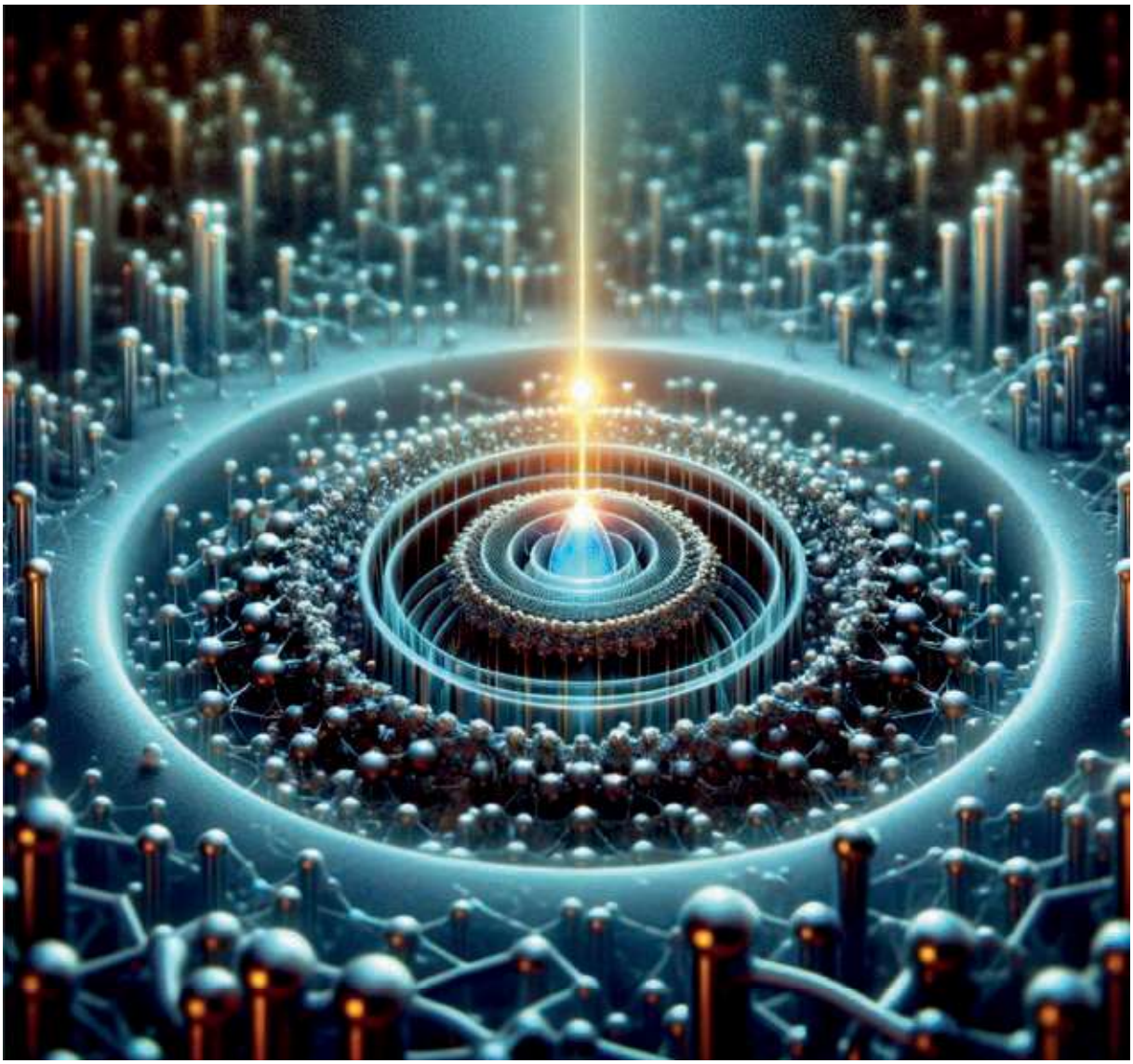
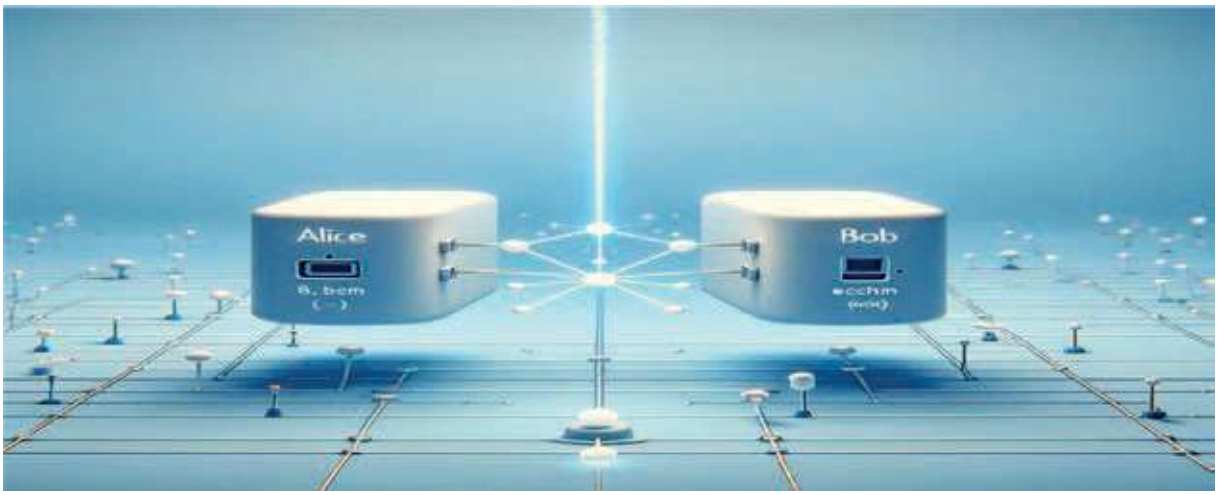
The PNRM a2019.004 “EWQ – Electronic Warfare Quantum” research program focuses on developing quantum technologies for cryptographic applications, particularly on generating and manipulating single photons for Quantum Key Distribution (QKD). This research, a collaboration between the Smart Manufacturing Lab and the Politecnico di Torino, aims to surpass the limitations of existing technologies using nanotechnology and metamaterials to operate in non-cryogenic environments. It includes the development and evaluation of a Single Photon Source (SPS) device and explores the BB84 protocol for secure cryptographic key distribution. Phase 1 concentrates on analyzing, studying, and simulating the SPS system and its use in quantum cryptography, proposing a physical experimental model to be further developed in Phase 2.



SPS Representation



QKD Implementation

INTRODUCTION

The project delves into the forefront of quantum technologies, aiming to overcome existing technical barriers through innovation in advanced cryptography. It focuses on using nanotechnology and metamaterials to facilitate non-cryogenic applications, highlighting the importance of creating and optimizing Single Photon Sources (SPS) for Quantum Key Distribution (QKD). By implementing the BB84 protocol for secure cryptographic key transmission, the project seeks to significantly extend the capacity and efficiency of quantum cryptography, promising a revolutionary evolution in digital communication security. The initiative stands out for its innovative approach in exploring the potential of single photons and metamaterials, laying the groundwork for future technological developments that could redefine security standards in the vast landscape of quantum computing.

TECHNICAL BACKGROUND AND SOLUTIONS

Phase 1 addressed the crucial issue of secure cryptographic key management, a pivotal node in digital communication security. Traditionally, key distribution poses challenges related to their secure storage and the risk of interception. The proposed solution leverages the Einstein-Podolsky-Rosen (EPR) effect to generate photon pairs with opposite polarizations, one of which is transmitted to the recipient. This approach, combined with the BB84 protocol, allows for secure key distribution by measuring a subset of photons to verify the absence of interceptions, and using the remaining photons to retrieve the private key.

The core technological problem involves creating an SPS (Single Photon Source) device that operates at room temperature, overcoming the need for cryogenic conditions. The adopted technological solution includes the use of nanotechnology and metamaterials, particularly an optically active nanostructured surface that optimizes photon emission and directionality. This approach aims to minimize positioning errors and integrate the SPS directly onto the surface during manufacturing, increasing the efficiency of the device.

METHODOLOGY

The project utilizes cutting-edge methodologies in the field of quantum cryptography, with a particular focus on Quantum Key Distribution (QKD) through the use of single photon sources (SPS). The research focuses on analyzing and developing SPS devices that operate at room

temperature, thus overcoming the limitations of existing technologies requiring cryogenic conditions. The methodological approach includes simulating photonic emission and physically creating an experimental optical bench to test the efficacy of the BB84 protocol, a cornerstone in quantum cryptography for the secure distribution of cryptographic keys.

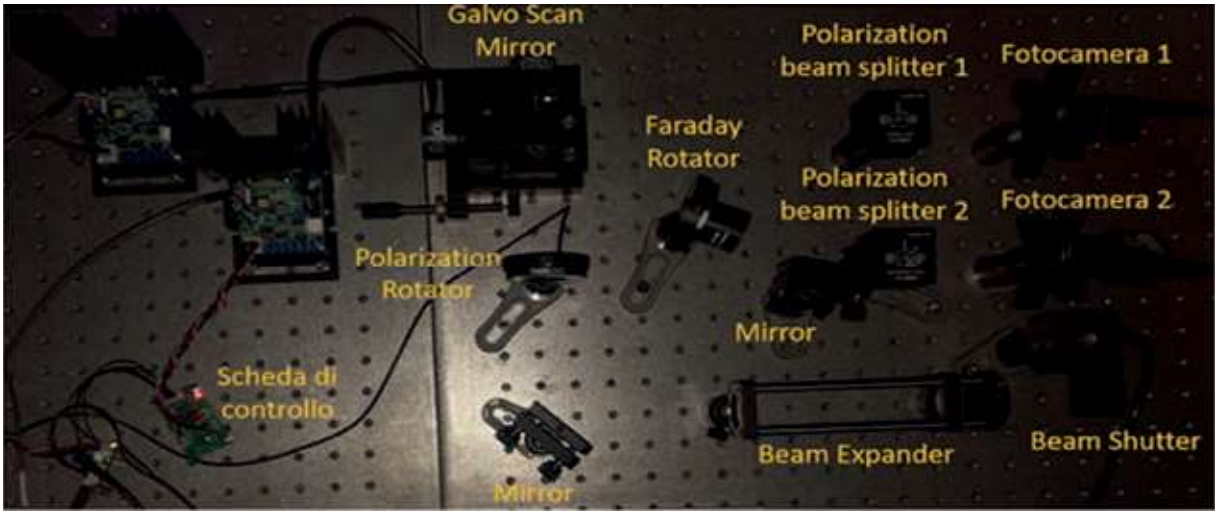
The experimental phase involved the use of an optical bench driven by a laser to emulate the SPS, providing a means to preliminarily evaluate the interaction between polarized photons necessary for the BB84 protocol. Furthermore, the design and simulation of an innovative photonic environment based on nanostructured surfaces (hyperbolic metamaterials) were carried out to optimize the emission and directionality of photons, a key aspect to minimize errors and inefficiencies typical of conventional SPS devices.

The experimental implementation also included the setup of standardized optoelectronic modules for Alice and Bob, automating the measurement and management of components, demonstrating full functionality in the cryptographic key exchange process through the BB84 protocol. This methodology allowed not only to test the effectiveness of the proposed communication system but also to lay the groundwork for future implementations that surpass the current technical and practical limitations of quantum cryptography systems.

From an imagery perspective, there are several visual representations such as the implementation of the BB84 protocol between Alice, Bob, and Eve (Figure 1), the diagram of a two-level system for the generation of single photons (Figure 2), and SEM images of metamaterials (Figure 3), which comprehensively illustrate the technical advancements and innovations proposed by the research.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The project has highlighted potential uses and significant practical implications in the field of digital communication security. By implementing advanced technologies for Quantum Key Distribution (QKD), based on the BB84 protocol and the use of Single Photon Sources (SPS) operating at room temperature, it paves the way for innovations in quantum cryptography. The practical applications of this technology are manifold and include cybersecurity for critical infrastructures, banking systems, military and government communications, as well as telecommunications networks.



Test Bench

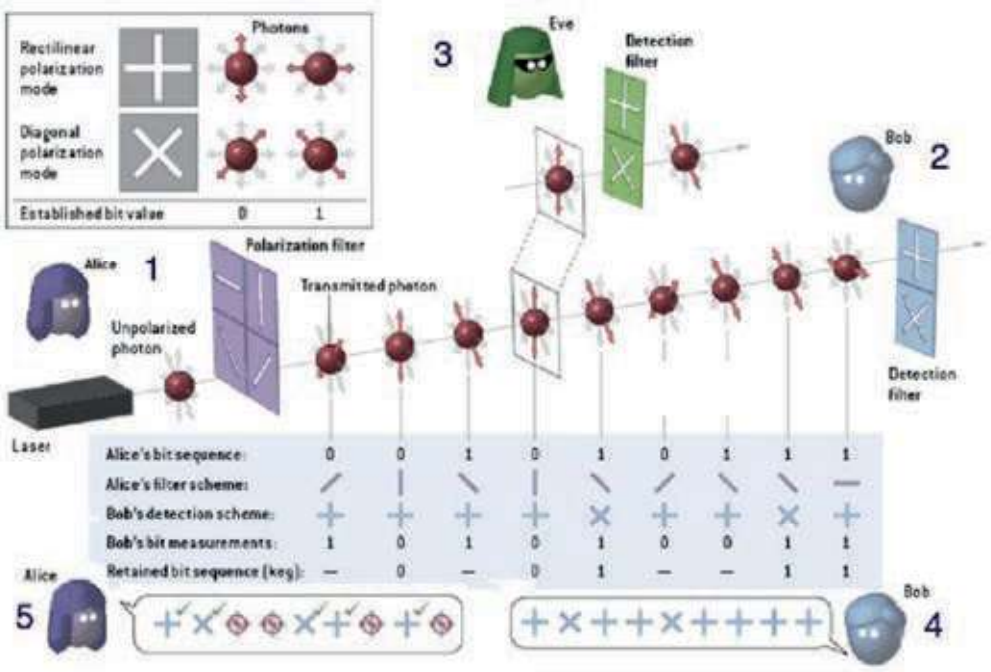


Figure 1 - BB84 implementation between Alice - Bob and Eva.

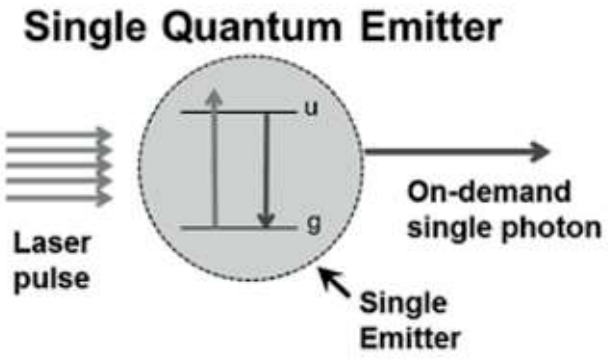


Figure 2 - Schematic of a two-level system for the generation of single photons.

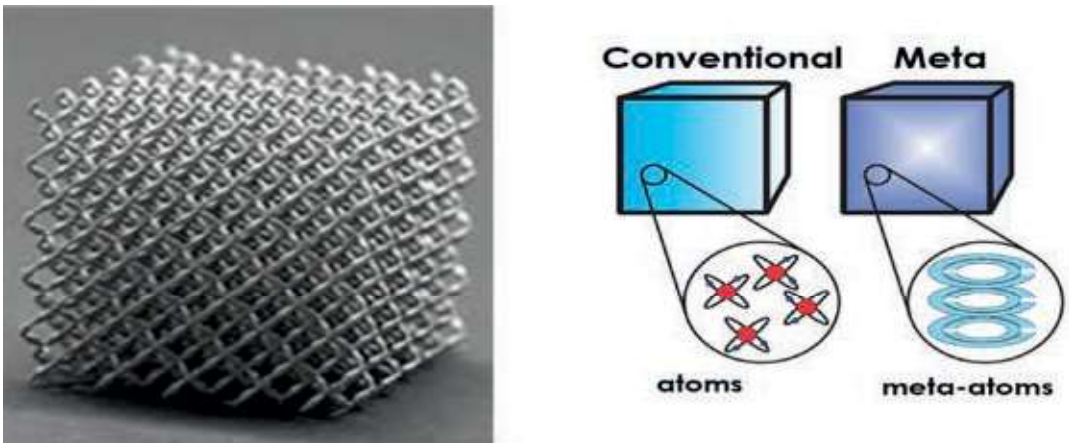


Figure 3 - SEM image of a metamaterial and schematic representation of the difference between a material and a metamaterial.

The practical implications also extend to enhancing security in online transactions and the protection of sensitive data, making QKD technology an ideal solution against potential threats posed by quantum computers to classical cryptography. Furthermore, the adoption of SPS devices operating at room temperature could mean greater ease of integration and reduced operational costs, making quantum cryptography more accessible and feasible for a wide variety of applications.

The research has also laid the groundwork for future development, aiming to overcome current technical limitations and explore new frontiers in quantum security. As Phase 2 of the project progresses, the integration and full testing of the SPS device are anticipated, with the goal of further validating the effectiveness and efficiency of the proposed quantum communication system. This represents a fundamental step towards the realization of a communication network exclusively dedicated to the secure exchange of cryptographic keys, marking a significant advance in the field of cybersecurity and quantum cryptography.

CONCLUSIONS

The conclusions of Phase 1 of the project highlight the success in implementing the planned activities, with promising results that enable progression towards Phase 2. The research delved into issues related to the management of cryptographic keys through Quantum Key Distribution (QKD), tackling the challenge of continuously updating key security. The experimentation focused on developing and evaluating devices for the emission of single photons (SPS), with the creation of an experimental test bench to test the BB84 protocol, essential for the secure exchange of keys.

This phase led to the conception, design, and simulation of an innovative SPS device, optimizing photonic emission through nanostructured surfaces. This approach aims to overcome current limitations, such as the need for cryogenic conditions, towards practical room-temperature solutions. Moreover, the validation of the BB84 protocol has confirmed its effectiveness in key exchange, while also highlighting the need for further developments to address challenges posed by existing communication technologies.

In summary, Phase 1 has laid solid scientific and technological foundations for advancing in quantum cryptography, promising significant progress in communication security. The next phase will see the complete development and testing of the SPS device, with the goal of achieving effective and secure quantum communication.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

EPR	*Einstein-Podolsky-Rosen*
QKD	*Quantum Key Distribution*
SPS	*Single Photon Source*

KEYWORDS

Quantum Key Distribution (QKD), Quantum cryptography, Single Photon Source (SPS), BB84 Protocol, Communication security, Nanotechnology, Metamaterials, Single photon generation, Quantum computing, Non-cryogenic environments.

PROJECT INFORMATION

PNRM Number:	a2019.004
Contracting Authority:	Direzione Informatica, Telematica e Tecnologie Avanzate (TELEDIFE)
Project Responsible Entity:	ATS (Temporary Purpose Association) – Politecnico di Torino, Smart Manufacturing Lab
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GIRL

The exponential increase in the volume of data collected by observation satellites implies an increased demand for bandwidth, power and size of terrestrial communications antennas, raising economic and security issues. An innovative solution is the adoption of infrared laser communication. The GIRL project realizes an on-the-ground optical communication system with extremely low ground illumination, very high speed and extremely small sized ground and on-board equipment. The development required the design of infrared telescopes and the use of equipment designed for fiber optic transmissions suitably modified for use on board the satellite.

The project has made it possible to create an on-board apparatus with a very low mass (1 kg), power (30 W) and volume (1 dm3) and an equally efficient telescope and ground equipment (45 kg, 250 W). In particular, the on-board telescope has a diameter of 2 cm while the ground telescope has a diameter of 20 cm.

The GIRL system will be installed on a micro-satellite and therefore, would not present any implementation difficulty on satellites of a higher class.

INTRODUCTION

GIRL is an innovation that allows the use of technologies developed in the field of telecommunications on optical fiber. The main technological innovation is to make Gbit/s technology accessible to satellites with a mass of only 25kg. A laser link allows for a single communication session per orbit, compared to multiple microwave links, allowing maximum images collection.

The ground station consists of a 20 cm telescope, with an adjoining pointing system and a simple receiver. The small size of the ground station (less than 25 kg) and its low cost can allow for the deployment of multiple ground stations in relation to operational needs. Due to its small size, the ground station can also be carried “on the shoulder”.

Satellite laser communications have been the subject of research in the last 20 years, with maximum interest by the Defence, for its intrinsic anti-jam and anti-interception capabilities: the short connection time and the restricted reception area guarantee maximum security.

The system is inherently dual: the attractiveness of satellite communication systems is linked to the fact that they operate in global coverage without intermediate “landings” on terrestrial networks. In addition, laser communications do not require any coordination with the ITU.

TECHNICAL BACKGROUND AND SOLUTIONS

The complexity and spatial resolution of remote sensing sensors on Earth Observation (EO) satellites is constantly increasing, as is the amount of data collected by such instruments. As a result, there is an increasing need for bandwidth to download such data during the limited contact time with ground stations. The problem is made more acute by the emergence of satellite constellations. The use of microwave transmission systems, as the transmission speed increases, requires high power values and large antennas both on board the satellites and on the ground. In addition to the technical problem, there is also the impact on the confidentiality of communications and the susceptibility to malicious interference.

The use of laser connections in free space is proposed as a solution to previously identified problems. A C-band laser (1550 nm), modulated at 2 Gbit/s, enables connection times in the order of a minute in a foot print of 100 meters in diameter. The use of frequencies in the infrared region makes it possible to establish the connection both during the day and at night. With the use of optical communications, it is also possible to exploit in the satellite field the enormous technological progress made in the field of optical fiber transmission, which shows the same transmission windows as the atmosphere. The GIRL project has made it possible to enable optical communications even for satellites with a mass of less than 20 kg.

The downside of optical communications through the atmosphere is attenuation and scattering due to fog and clouds. Of course, the position of the receiving station has a great influence and in the case of "fixed" stations it is suggested to locate them over 1000 m above sea level and in dry areas in order to improve availability, which is still maintained over 90% of the time for the Italian territory.

METHODOLOGY

The optical link requires extreme pointing accuracy (<0,001°) and therefore the ground station transmits a signal at 830 nm to which the onboard terminal will hook before transmitting its modulated signal (Figure 1).

The system will consist of (Figure 2):

- An electronic control for the management and interface of the GIRL system with the host satellite for telemetry, remote controls

Figure 1 - Functional description of the Pointing, Acquisition and Tracking sequence: the ground station follows the satellite, whose orbital data are known, with a programmed pointing logic and starts transmitting an unmodulated carrier. The satellite will point at the center of the received beam and begins transmitting its modulated signal. The terminals will take into account the Pointing Ahead Angle for proper tracking.

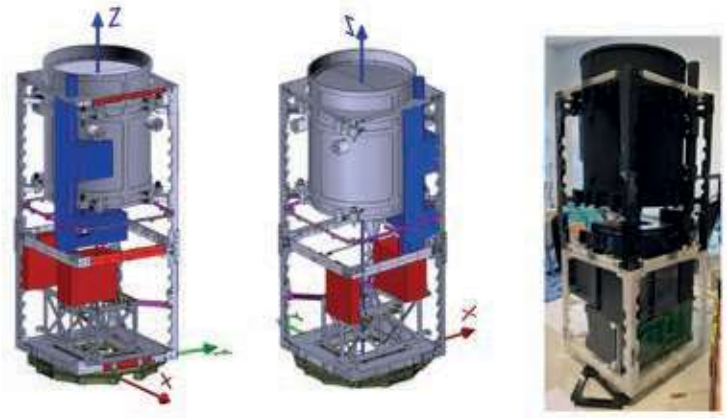

Figure 2 - Rendering of the GIRL system mounted on the EAGLET 2 satellite (dimensions 28x28x55 cm3). The room made available to the GIRL system are titled for the electronic components and the optical system (OPT) are duly titled. DHTE= Data Handling Electronic and Transmitter; EDFA= Optical Amplifier; OPT= Telescope, Fine Steering Mirror (FSM), and Ground Beacon Sensor.

and for the management of the data to be transmitted;
- A laser emitter with optical amplifier (EDFA) to reach the power of 1 W;
- A sensor to detect the beacon and cancel the pointing error via a Fine Steering Mirror (FSM).

Prior to GIRL integration on the satellite platform, exhaustive tests were performed (Figure 3).

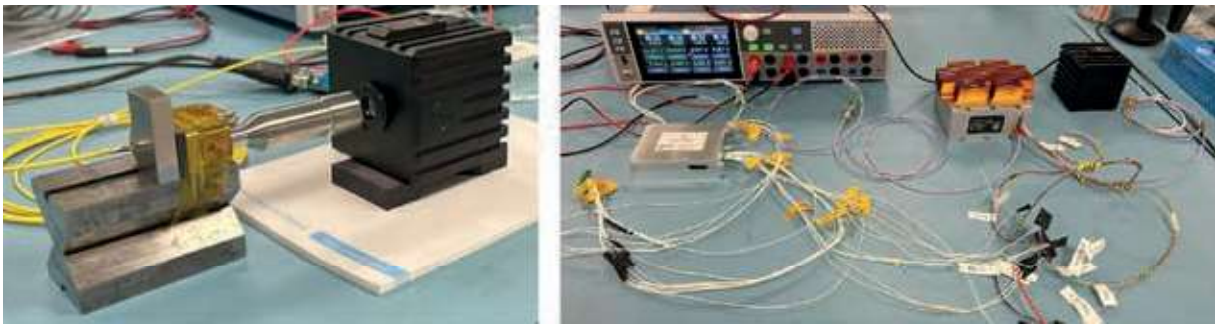

Figure 3 - The bench tests made it possible to characterize both the optical part (OPT) and the electronic subsystem.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The GIRL project is a product that can be installed on one of the two EAGLET 2 satellites of OHB-I, currently being acquired by the Ministry of Defence for in-orbit testing. The subsequent experimentation carried out by On-Air in collaboration with this Ministry will make it possible to verify the possibility of installing it on the satellites of the military and civilian EO constellations. FSO systems are also proposed for connections with stratospheric platforms and tropospheric aircraft. On-Air is also developing the concept of a bidirectional system that can be used in connections between satellites at very high data rates. Such a system would also allow a single satellite to transmit the data acquired by the satellite itself and to collect data from remote sites and deliver it to a remote recipient realizing a store and forward system.

On-Air wants to develop transmission systems and already has X-band transmitters and phased array antennas installed on OHB-I's EAGLET 2 satellites. On-Air believes it is appropriate to achieve capacity in a highly innovative sector where there are few players in the Small Medium Enterprise (SME) class. In the European field (EDF fund) the focus on SMEs is considered an important factor in the development of breakthrough innovations, with the consequent provision of resources to encourage the aggregation of European SMEs that wish to overcome the level of sub-suppliers by becoming suppliers of finished products.

CONCLUSIONS

The limitation of the available radio frequency bandwidth for the transmission of data from observation and communications satellites makes it increasingly urgent to use alternative means such as LASER communications that offer the possibility of communicating at Gbit/s speeds with very compact systems, fully compatible even with micro-satellites. Optical communications, in addition to not being subject to notification at the ITU, also offer secure and non-interceptable connections. The GIRL project has created a product of extremely low mass, volume and power and the first prototype is ready to be installed on a satellite of the Ministry of Defence for an intense experimental campaign. The technology is also suitable for use as an interconnection between satellites. Future activities should make it possible to cope with transmission speeds in the order of Terabit/s as well as make transmission from ground to board possible. The duality of the solution reached allows us to hypothesize a use in civil constellations such as those envisaged by the Italian PNRR plan.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

EO	*Earth Observation*
EDF	*European Defence Fund*
EDFA	*Erbium-Doped Fiber Amplifier*
FSM	*Fine Steering Mirror*
FSO	*Free Space Optics*
ITU	*International Telecommunication Union*
On-Air	*On-Air Consulting & Solutions SRL*
PNRR	*National Recovery and Resilience Plan*
SME	*Small Medium Enterprise*

KEYWORDS

FSO, LASER Communications, Infrared communications, Gbit/s.

PROJECT INFORMATION

PNRM number:	a2018.010
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Responsible entity:	On-Air Consulting & Solutions SRL
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The M5G Project aims to develop a Modem with 5G protocol to be installed on board a UAV which will allow “seamless” 5G connection with both a space segment of 5G Microsatellites and an Earth Station.
The Project is being carried out in three distinct Phases, with the First Phase being a preliminary project, the Second Phase focusing on the realization of a breadboard that will be tested on the bench, and the Third and final Phase focusing on the realization of the prototype device that will be tested in flight.
At the end of the First Phase, the HW and SW architecture was identified for the realization of the breadboard that will be realized in the Second Phase and the Flying Prototype that will be realized in the Third Phase.
At the moment the selected configuration is based on the Qualcomm Snapdragon X55 chipset integrated in the Telit module that implements the 3GPP 15 standard, which is currently the only one available to developers. However, the project does not exclude the possibility to analyze subsequent standards as soon as they become physically available.

INTRODUCTION

The market for unmanned vehicles (UAVs) is in strong and continuous growth, and the number of potential applications in both civilian and military fields for this type of vehicle continues to increase. To support this growth, the development of new and innovative wireless communication technologies has become an imperative requirement both to provide greater reliability to existing Command and Control (C2) systems for safe in-flight operations, and to improve mission data transmission by increasing data transfer rates for rate-demanding applications.

TECHNICAL BACKGROUND AND SOLUTIONS

Within the UAV sector, there is a strong demand for innovation in C2 and data-link systems for on-

board payload communications that overcomes the present limitations of communications, in particular by increasing data-rate, reliability, and data security, reducing vulnerability to interference, and overcoming the limitations caused by the exclusive utilization of Line-of-Sight (LoS) modes.
This technological push in the civil market turns out to be an opportunity for innovation in the military field as well, for which, in addition to benefiting from technological improvements for the issues mentioned above, there is a strong need to improve data security and resilience to unintentional and, especially, to intentional interference (Denial of Service / Jamming Attack).
The integration of UAVs within 5G communication networks with a satellite component is one of the most interesting technological responses to overcome the aforementioned issues.
Figure 1 shows a schematic of 5G TLC services based on the findings of the 3GPP working group.
In this context, the on-board communication systems of UAVs can connect to the cellular network as a special type of user (cellular-connected UAVs). Thanks to the now widespread accessibility of current (LTE) and near-future (5G) mobile networks, and the presence of increasingly advanced authentication mechanisms, C2 systems of cellular-connected UAVs can achieve significant improvements in communication performance over current ground-to-UAV systems in terms of both reliability and data security, as well as operational range and data exchange speed. Moreover, one of the key features of 5G is the increased resistance to interference, thanks to innovative technologies (digital beamforming, MIMO) that also extend their benefits to the case of intentional interference (jamming). Furthermore, the presence of a satellite component in the 5G ecosystem will facilitate Beyond Line of Sight (BLoS) communications for UAVs.
Figure 2 shows the interconnection diagram of the various System elements.
Figure 3 shows the Architecture of the Module with the integrated Qualcomm Chipset.

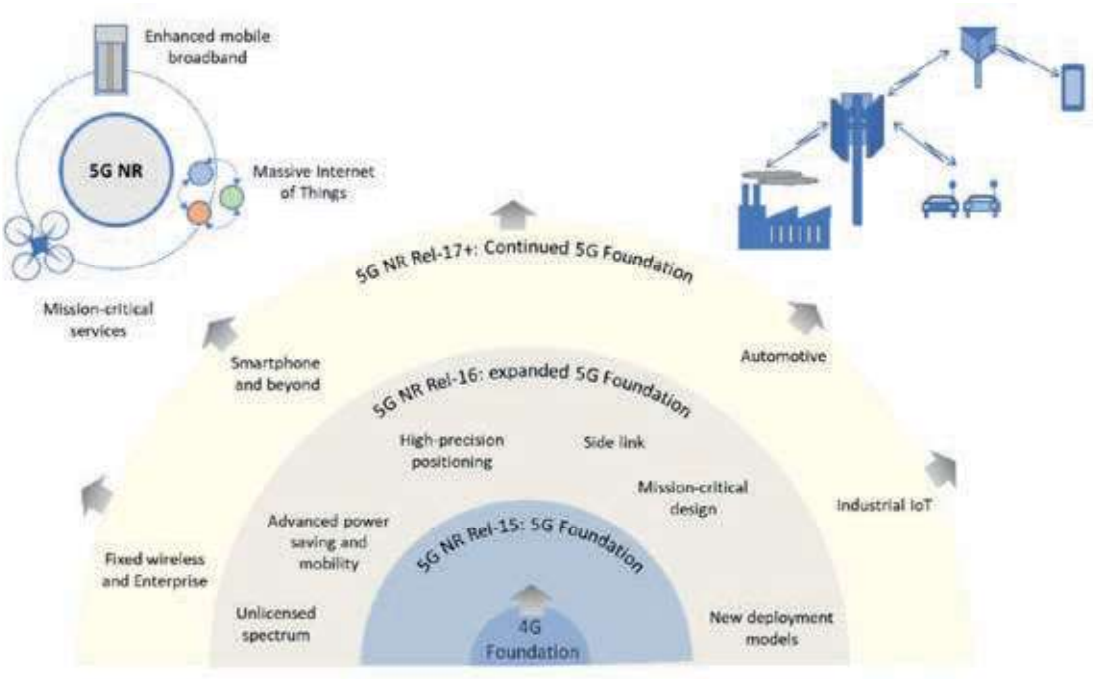

Figure 1 - Outline of 5G TLC services.

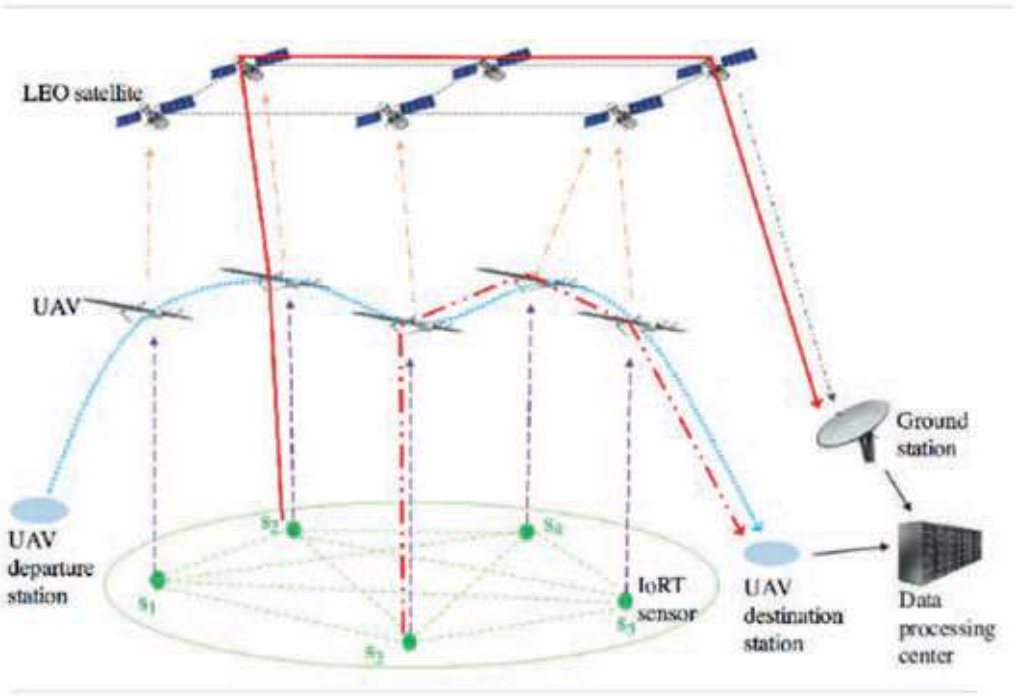

Figure 2 - Interconnection diagram.

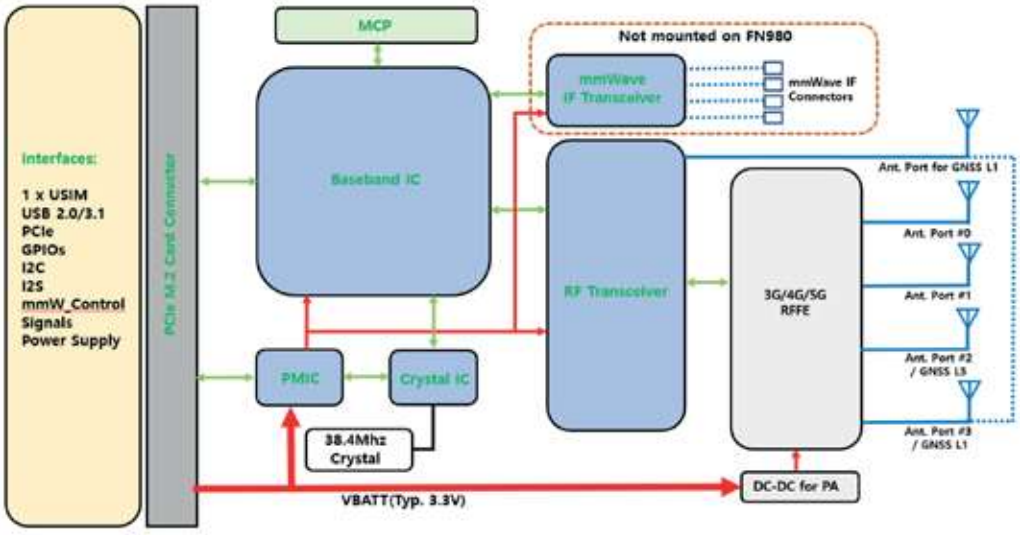

Figure 3 - Preliminary Architecture of the Module.

METHODOLOGY

The design and development foreseen in the project are divided into phases:

- Phase I: Preliminary Study
- Phase II: Detail Design and possible Realization of Critical Breadboards
- Phase III: Implementation of the 5G Modem and Experimentation.

Phase I involves the study, the design, and the implementation of the End-to-End simulation platform, a detailed definition of the requirements, and the development of the preliminary design based on the results obtained in the simulation environment. This will require an in-depth study of the 5G-NR radio interface and of the theoretical or semi-theoretical channel models between the transmitter and the UAV in both LoS and BLoS modes.

The Second Phase involves the finalization of the End-to-End model, the detailed system design, and the realization of a breadboard of system elements that will be deemed critical following the Phase 1 studies.

Lastly, the Third Phase involves the realization of the 5G Modem, which will be installed on a specially prepared ultralight aircraft in order to simulate the in-flight capabilities of the 5G Modem by reaching an overall research stage of TRL 6. Ground station deployment will then be set up in order to carry out a test campaign aimed at verifying the functionality of the system in an environment as close as possible to the operational environment for the LOS component.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The military value of the project is inherent in the description above. The main innovation is to allow UAVs to be equipped with state-of-the-art command and control systems that take advantage of the benefits derived from the 5G technology as outlined above. It can be expected that more and more Military Assets will find themselves operating in contexts where the difference in availability between military or civil products and technologies will become increasingly thin. These differences may only consist in some particular implementations of the technology, particularly with regard to cybersecurity issues.

The dual significance is inherent to the aspects described above, since the proposal considers to borrow the technology currently developed in the civil sphere for military applications. Conversely, the possibility of using this technology in the military sphere, given that the UAV issue is basically confined to Defence uses until the issue of non-segregated flight is resolved, will allow for early exploration of C2 issues applied to civil applications. In fact, if we were to move towards a massive deployment of UAVs for civil applications, new solutions would be required regarding the safety of people and properties from any failures that can be linked to any moving vehicle.

CONCLUSIONS

The First Phase of the activities has been completed, and Phase 2 will also be completed during 2024.

By virtue of the activities carried out in the Preliminary Study, Phase 2 involves:

- A detailed design of the data transmission and reception apparatus suitable for the scenario under consideration;
- Realization of prototypes of parts deemed critical, in order to verify design functions and features;
- Completion of the simulator based on the design choices defined in the preliminary study;
- Realization of a complete prototype of the modem according to the results of Phase 1. The prototypes made during the waveform and modem design, for verification of the most critical and specific parts, can be used for the final assembly of the modem;
- HW testing, aimed at verifying the proper functioning of what has been developed, such as the proper functioning of the electronic components mounted on board the prototype and the communication interfaces between the individual components or modules that make up the prototype itself.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

3GPP	*Third Generation Partnership Project*
5G	*Fifth generation technology standard for broadband cellular networks*
ATC	*Air Traffic Control*
Band C	*RF band from 4 to 8 GHz*
Band Ka	*RF band from 26 to 40 GHz*
BLoS	*Beyond Line of Sight*
CONOPS	*Operational Scenario and Concept of Operations*
CNR	*Carrier To Noise Ratio*
FSS	*Fixed Satellite Service*
GEO	*Geosynchronous Equatorial Orbit*
ICT	*Information and Communications Technology*
ITU-R	*International Telecommunications Union Radio*
LEO	*Low Earth orbit*
LoS	*Line-of-Sight*
MIMO	*Multiple Input Multiple Output*
NTN	*Non-Terrestrial Network*
UAV	*Unmanned Aerial Vehicle*

KEYWORDS

Modem, 5G, Command and Control, C2, UAV, Cyber, BLOS, LOS.

PROJECT INFORMATION

PNRM number:	a2019.125
Organization:	Direzione Informatica, Telematica e Tecnologie Avanzate (TELEDIFE)
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This document describes the project titled “Spatial Super-Resolution for Hyperspectral Satellite Images,” which addressed the issue of improving the spatial resolution of hyperspectral data from the Italian Space Agency’s satellite mission named PRISMA. In the project, the problem was tackled by leveraging algorithms for fusion between the 30m spatial resolution hyperspectral data and the higher spatial resolution data from the multispectral Sentinel-2 mission. Specifically, the ten Sentinel-2 bands with resolutions of 10m and 20m were considered. This article presents a new procedure, called PRISMA-SR, which, starting from Sentinel-2 data and the low spatial resolution image from PRISMA, provides a super-resolved image with a spatial resolution of 10m and the same spectral resolution as the PRISMA hyperspectral sensor. The first step of the PRISMA-SR procedure involves merging Sentinel-2 data at various spatial resolutions to obtain a synthetic multispectral image with 10 bands and a spatial resolution of 10m. Subsequently, an unsupervised procedure is applied to co-register the Sentinel-2 image and the PRISMA image. Finally, the two images at different spatial resolutions are appropriately combined to obtain the super-resolved hyperspectral image. The PRISMA-SR procedure includes innovative solutions for each step of the described processing chain.

INTRODUCTION

Hyperspectral (HS) sensors enable detailed analysis of the chemical and physical properties of observed scenes by measuring radiance across numerous spectral channels. The PRISMA mission by the Italian Space Agency, operational since March 2019, employs this technology for large-scale Earth monitoring. However, the limited spatial resolution of acquired data (30m) reduces potential applications. One possible way to overcome this limitation is by combining HS data with multispectral (MS) images of the same scene at higher spatial resolution. In this study, a HS-MS fusion scheme is proposed utilizing Sentinel-2 (S2) satellite data and PRISMA images. The procedure involves merging S2 data at various spatial resolutions to obtain synthetic S2 images at 10m resolution. Subsequently, a co-registration algorithm is applied between synthetic S2 and PRISMA images, followed by the application of a HS-MS fusion algorithm to obtain high-resolution PRISMA images. This procedure enhances the accuracy of adopted algorithms in military applications, ecosystem monitoring, mineral mapping, and urban surface analysis.

TECHNICAL BACKGROUND AND SOLUTIONS

A crucial issue of satellite hyperspectral (HS-SAT) technology is the low spatial resolution due to the need to maintain a high signal-to-noise ratio across all spectral bands. The spatial resolution of HS-SAT systems, including PRISMA, is approximately 30 meters, with each pixel covering an area of 900 square meters. This characteristic does not meet operational requirements in intelligence and security applications where phenomena of interest have dimensions of a few meters (medium-sized ships, tactical ve-

hicles). To leverage the capabilities of HS-SAT systems, processing strategies are needed to extract spectral information at a lower spatial scale by analyzing the hyperspectral image itself and integrating it with data from high-resolution spatial sensors (broadband or multispectral).

Analysis of the state of the art indicates that to improve the resolution of HS-SAT sensors, information present in the low spatial resolution HS image can be fused with that provided by a high spatial resolution MS image. This approach is known in the literature as hyperspectral super-resolution (HS-SR). The purpose of HS-SR techniques is to inject the spatial information from the MS sensor into the high spectral resolution data of the HS sensor.

The PRISMA payload does not include a high spatial resolution MS sensor. Therefore, to implement an HS-SR strategy, data from MS sensors of other satellite missions such as S2 are necessary. S2 is a program of the European Space Agency that provides regular coverage of the Earth with a median revisit time of 4 days.

S2 includes four bands in the VNIR with a resolution of 10m and 6 bands in the VNIR/SWIR with a spatial resolution of 20m. These bands overlap the spectral range of the PRISMA sensor, and they can be exploited to improve the spatial resolution of PRISMA data through the fusion algorithm proposed in the project.

METHODOLOGY

The proposed strategy, named PRISMA-SR [1], consists of a fusion algorithm between S2 data and PRISMA data capable of obtaining an HS image with a spatial resolution of 10m. The strategy is applied to spectral reflectance data to minimize radiometric differences between the HS image and the MS image.

PRISMA-SR is developed on three functional levels (Figure 1). It takes three input images: the two S2 images at 10m (X'_{10}) and 20m (X'_{20})

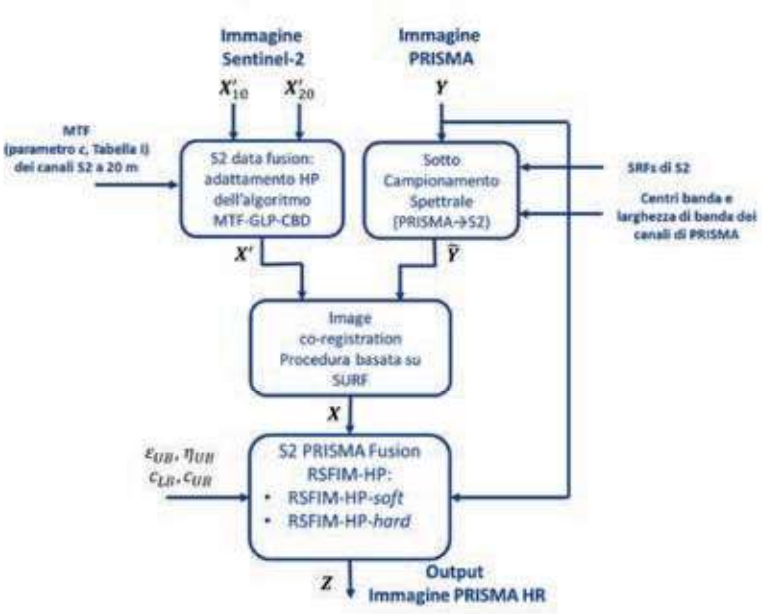

Figure 1 - Block diagram of the PRISMA-SR strategy. X_10^' and Y is the 230 band PRISMA image with a resolution of 30 m. X' is the super-resolved S2 image obtained by merging the two S2 data and contains 10 bands with a resolution of 10 m. X is the super-resolved S2 image after the co-registration process with the PRISMA image. Z is the high spatial resolution hyperspectral image containing 230 bands with 10 m resolution.

resolutions, and the PRISMA image (*Y*). In the first level *(S2 data fusion)*, the MTF-GLP-CBD fusion algorithm [2] is applied to the S2 data with the aim of bringing the spatial resolution of the X'_{20} image to 10m, obtaining the *X'* image with 10 bands and 10m spatial resolution. The second functional level *(Image co-registration)* deals with spatially co-registering the high-resolution *X'* image with the PRISMA image. To properly align the *X'* and *Y* images, it is essential to implement a co-registration strategy since the geolocation data of PRISMA, with errors up to 200 meters, require adequate compensation. The third functional level applies a fusion procedure to the PRISMA data (*Y*) and the super-resolved and co-registered S2 data (*X*) to obtain an image with a spatial resolution of 10m and 230 spectral bands (*Z*). This procedure is based on a modified version of the Smoothing Filtered-based Intensity Modulation algorithm [3] applied following the Hyper sharPening paradigm [4]. The modified version of the algorithm is resilient to residual registration errors and imperfect knowledge of PRISMA's optical system parameters.

In Figure 2, as an example, results obtained by applying the PRISMA-SR algorithm are shown. They concern three different scenarios. For each scenario, false-color representations in the visible and SWIR spectral ranges are provided for both the original PRISMA image (*Y*) and the image *Z* obtained by PRISMA-SR.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

In the military context, HS satellite super-resolution techniques, improve the ability to detect camouflaged targets in large-scale monitoring, enable accurate terrain mapping for operation planning, and enable the detection of crucial details such as military installations. Combining these techniques with other sources of information can enhance the effectiveness of military operations, enabling better collection of strategic information and increased awareness of the operational context. In the civilian realm,

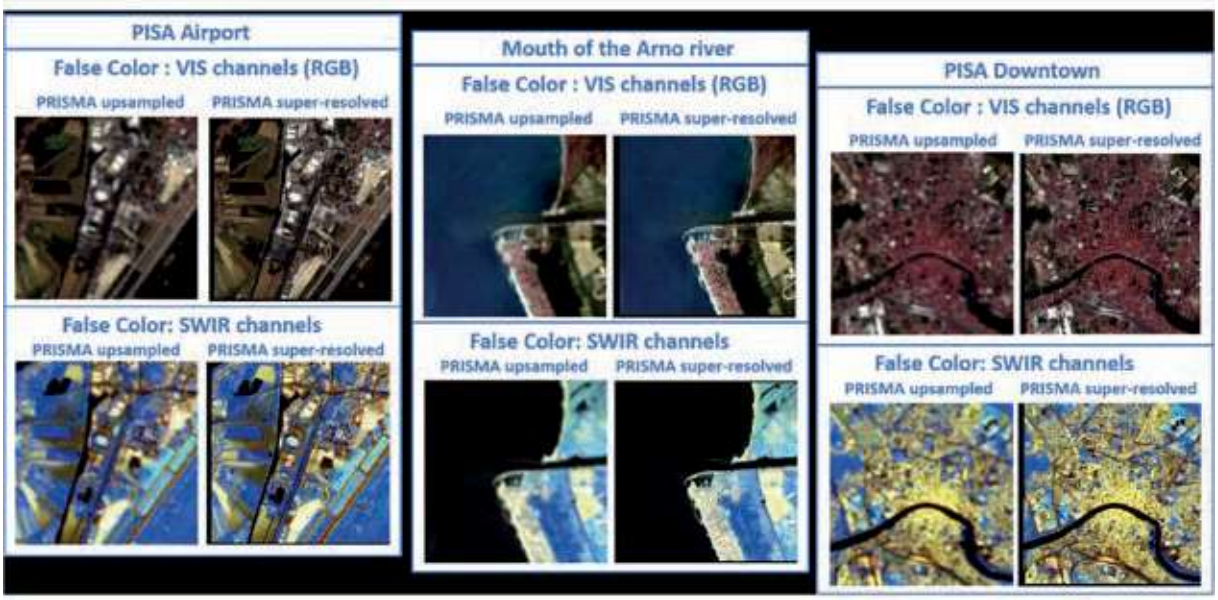

Figure 2 - Results of the PRISMA-SR algorithm obtained on three scenarios corresponding to the PISA airport, the mouth of the ARNO river and the city center of PISA. For each scenario, the false color representations in the visible (RGB) and SWIR of the original PRISMA image (left) and the corresponding image produced by PRISMA-SR (right) are reported.

super-resolution techniques refine the results of large-scale hyperspectral analysis by including more detailed spatial information, allowing examination of relationships between identifiable causes from spectral information and effects on the territory, infrastructure, and buildings associated with more detailed information. Some possible applications include: analysis of vegetation damage in areas affected by fires, detection of building abuses, identification of illegal dumps, classification of waste types, soil contamination maps, land use maps, and detection of illegal wastewater discharges. In particular, the methodologies under the project could be integrated into satellite data management software systems that would be of interest to various public and private stakeholders.

CONCLUSIONS

The PRISMA-SR procedure improves the spatial resolution of HS images from the PRISMA mission by fusing them with S2 images acquired over the same scene. The conducted study involved an analysis on simulated data, which demonstrated that using S2 images with 10 bands suitably processed to standardize the spatial resolution to 10m yields excellent results in terms of super-resolved HS image. In the experiments conducted, the performance achieved by exploiting the fusion of S2 images at different resolutions was better than that obtained by using only the 4 bands S2 image in the VNIR with a nominal resolution of 10m.

The main challenge encountered in the project is related to the fact that super-resolution is achieved by combining images from sensors onboard satellites that do not exactly follow the same orbit and do not acquire data simultaneously. The images used in the fusion process may not represent exactly the same scene. Consequently, at the points where changes occur between the two acquisitions, PRISMA-SR produces unreliable results on the super-resolved image. In future missions, it would be advisable to mount the HS sensor and the MS sensor on the same platform to avoid artifacts due to different acquisition conditions.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

HS	*Hyperspectral*
MS	*Multispectral*
S2	*Sentinel-2*
VNIR	*Visible and Near InfraRed*
SWIR	*Short Wave InfraRed*
HS-SAT	*Satellite Hyperspectral*
HS-SR	*Hyperspectral Super-Resolution*

KEYWORDS

Satellite Hyperspectral data, Spatial super-resolution, Multispectral/Hyperspectral fusion.

PROJECT INFORMATION

PNRM number:	a2019.043
Organization:	Direzione Informatica, Telematica e Tecnologie Avanzate (TELEDIFE)
Responsible entity:	Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT)
City, Region:	Parma, Emilia-Romagna
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4. M. Selva, B. Aiazzi, F. Butera, L. Chiarantini, and S. Baronti, "Hyper sharpening: A first approach on SIM-GA data," IEEE Journal of Selected Topics in Applied Earth Observation and Remote Sensing, Vol. 8, No. 6, pp. 3008–3024, Jun. 2015.

ADAPTIVE

The PNRM ADAPTIVE project, positioned on the Defence Administration military R&T roadmap, aims to respond to the operational needs of flexibility in configuring the TLC satellite mission of the It-MoD and of protection from disturbing signals. This project will study an adaptive antenna system with advanced features of beam-steering, beam-shaping and anti-interference capability, characterized by high-performance, compactness, and low complexity in comparison to existing solutions working on narrowband frequency ranges and having high consumption.
The adopted methodology involves the following activities in 2 phases: (i) identification of a reference architecture for the ADAPTIVE system; (ii) design and development of the ground SW component prototype for the estimation of the expected performance and the computing and management of the Beam Forming Network (BFN) configurations; (iii) design and development of a BFN HW demonstrator prototype based on TTDL and MEMS switch technology (with this latter technology being qualified for space use within the project).
Trade-off and demonstration in phase 1 provided promising results. Once completed, the ADAPTIVE project will provide solid technical know-how and HW/SW technological building blocks able support future satellite missions, such as SICRAL, thus strengthening the role of Italian Defence in the MILSATCOM sector.

INTRODUCTION

The Italian Defence SATCOM infrastructure is a key component for the Italian nation and for its recognized role in the context of International Defence and Coalition Interventions. Since 2001, the Italian Defence has equipped itself with a fleet of satellite assets operating in different frequency bands, currently including SICRAL-1, SICRAL-1B, SICRAL 2 and ATHENA-FIDUS.
The technological evolution implemented among these assets highlights a constant improvement of general performance and an ever increasing operative flexibility, in terms of the in-flight reconfiguration capacity of the TLC mission. That technological evolution is guided by the need to meet the multiple variations of operational requirements that arise during the operational life of the satellite, for example the unpredictable occurrence of new theaters or the need to guarantee the service even in the presence of interference.

In order to satisfy the even greater relevance of these aspects in the near future, the ADAPTIVE project aims to study an adaptive antenna system with beam steering, beam shaping, and anti-interference capabilities, characterized by the implementation of effective high-performance, broadband technology.

TECHNICAL BACKGROUND AND SOLUTIONS

In order to meet the introduced needs, SICRAL-1B, SICRAL-2 and ATHENA-FIDUS satellites have been equipped with technological solutions that allow the mechanical repositioning of the SHF and EHF band antenna beams and the electrical shaping of the coverage beam in the SHF band, which implements antenna nulling capability.
The technology that will satisfy the growing weight of the aforementioned needs is the advancement of the adaptive antenna functionality

in terms of (i) integration of a greater number of bands; (ii) an instant wideband solution; (iii) reduced size and power consumption for accommodation on small/medium platforms; (iv) limited complexity in terms of both design and integration on the satellite and (v) low insertion losses on the processed signal.

In more detail, the main objectives of the ADAPTIVE project are:

- Identification, through architectural trade-offs and performance analysis, of a reference architecture for the ADAPTIVE system;
- Specification, for the identified reference architecture, of the Beam Forming Network (BFN) section, based on True Time Delay Line (TTDL) technology and with MEMS switch technology (Figure 2);
- Design and implementation of the ground based SW of "ADAPTIVE Antenna Diagram Computing and Management" (A2-DCM) of the ADAPTIVE system, including the algorithms for computing the optimal BFN configuration. This component can also in estimate the performance of the various architectural solutions being evaluated (Figure 3);
- Design and development of a technological HW prototype of a BFN based on a True Time Delay Line (TTDL) with MEMS switch technology, specialized for the X band. Qualification for space use of the MEMS technology is at the basis of the innovative solution.

METHODOLOGY

The ADAPTIVE project is split into successive contractual phases, as shown in Table 1.

At the time of writing this report (February '24), Lot 1 results are complete, and Lot 2 will be activated according the successful outcome of performed activities.

The activities completed within Lot 1 include:

- The definition of user and service requirements for the ADAPTIVE system with beam-steering, beam-shaping, and nulling capabilities, and for the ground SW in charge of computing the BFN configuration and estimation of expected system performances;
- The identification of reference operational scenarios in the military bands of interest (UHF/SHF/EHF).

Based on the identified requirements and scenarios, The preliminary definition of the ADAPTIVE system and architectural trade-offs were carried out to evaluate the main points of interest for the identified technological options in order to support the identification of the reference architecture for the ADAPTIVE system.

The results of the performance analysis supported the identification of a reference architecture and architectural trade-offs. This analysis considered:

- Numerical models of the antenna solutions used for the trade-off;
- Figures of merit of interest for the different BFN technologies;
- Identified operative scenarios for the different military bands;
- Algorithmic component developed for the computing of the BFN optimal configuration.

The performance demonstration campaign was supported by a developed SW simulator. That SW, following further developments in the continuation of the study, will constitute the A2-DCM SW, i.e. a ground SW capable of supporting algorithm testing or demonstration activities and forming the basis for the development of specialized Beam-forming and Nulling SW for future Defence missions.

Moreover, the HW prototype of the TTDL that was preliminarily defined will be the subject of the design and implementation of the activities planned in the subsequent Lot 2.

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The main contributions to military research provided by the ADAPTIVE study, consider-

PROJECT PHASE		STATE	PLANNED ACTIVITIES
LOT	SUB-LOT		
1	1.A	Completed	- User and service requirements generation - Preliminary definition of the ADAPTIVE subsystem - Definition of the requirements of the SW prototype "ADAPTIVE Antenna Diagram Computing and Management" - A2-DCM - Performance analysis - Architectural Trade-Off
	1.B	Completed	- Performance analysis - cont. - Architectural Trade-Offs - cont. - Identification of the reference architecture - Definition of HW ADAPTIVE prototype - Design, development and testing of the SW A2-DCM prototype - Performance demonstration campaign
2	2.1	To be activated	- Specification of the ADAPTIVE subsystem demonstrator - Test campaign definition - Design of the HW TTDL technological prototype - Definition of the technology qualification campaign
	2.2		- Design and development of the verification test-bed of the ADAPTIVE subsystem - Upgrading and testing of the SW A2-DCM - Integration of the demonstrator and execution of the test campaign - Development and test of HW TTDL prototype - Definition and execution of the technology qualification campaign - Specification of the overall ADAPTIVE subsystem

Table 1 - Details of the contractual phases and activities planned for the project PNRM ADAPTIVE.

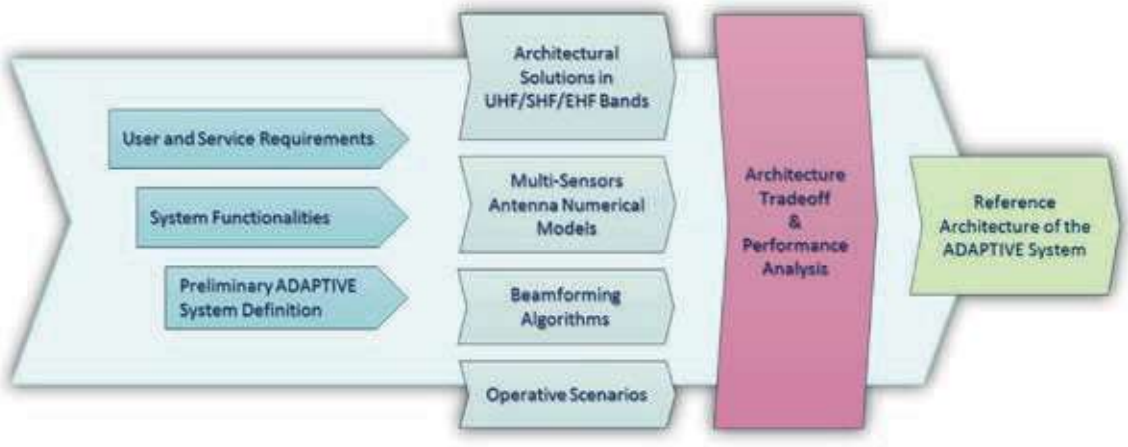

Figure 1 - Activities flow for the identification of a reference architecture for the ADAPTIVE System.

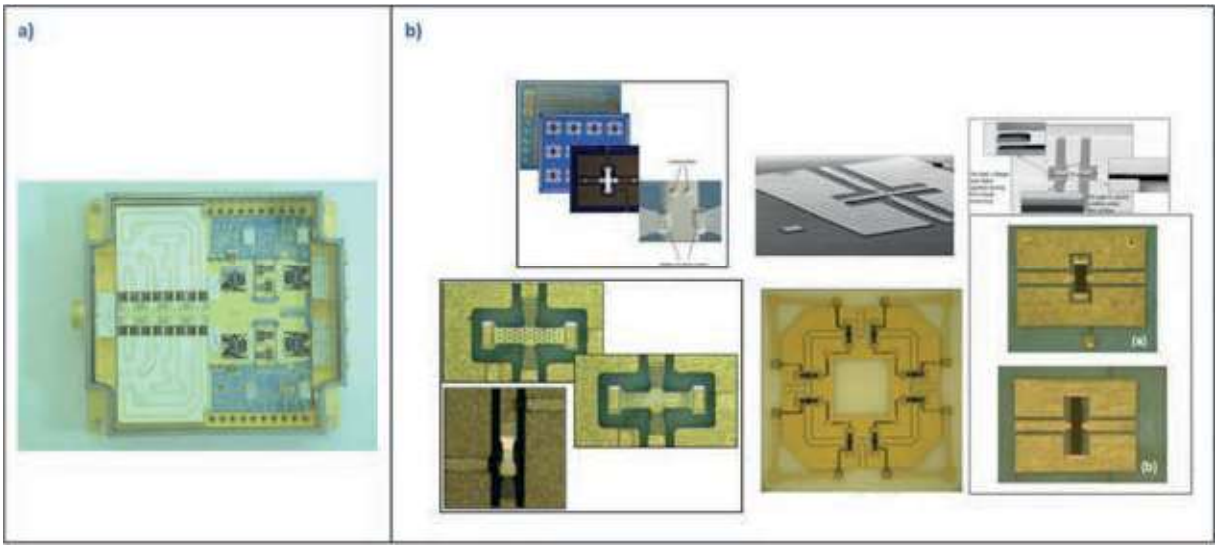

Figure 2 - Examples of technological solutions for the beam forming network (BFN): (a) True Time Delay Line - TTDL; (b) Detail of MEMS switches made in TAS-I.

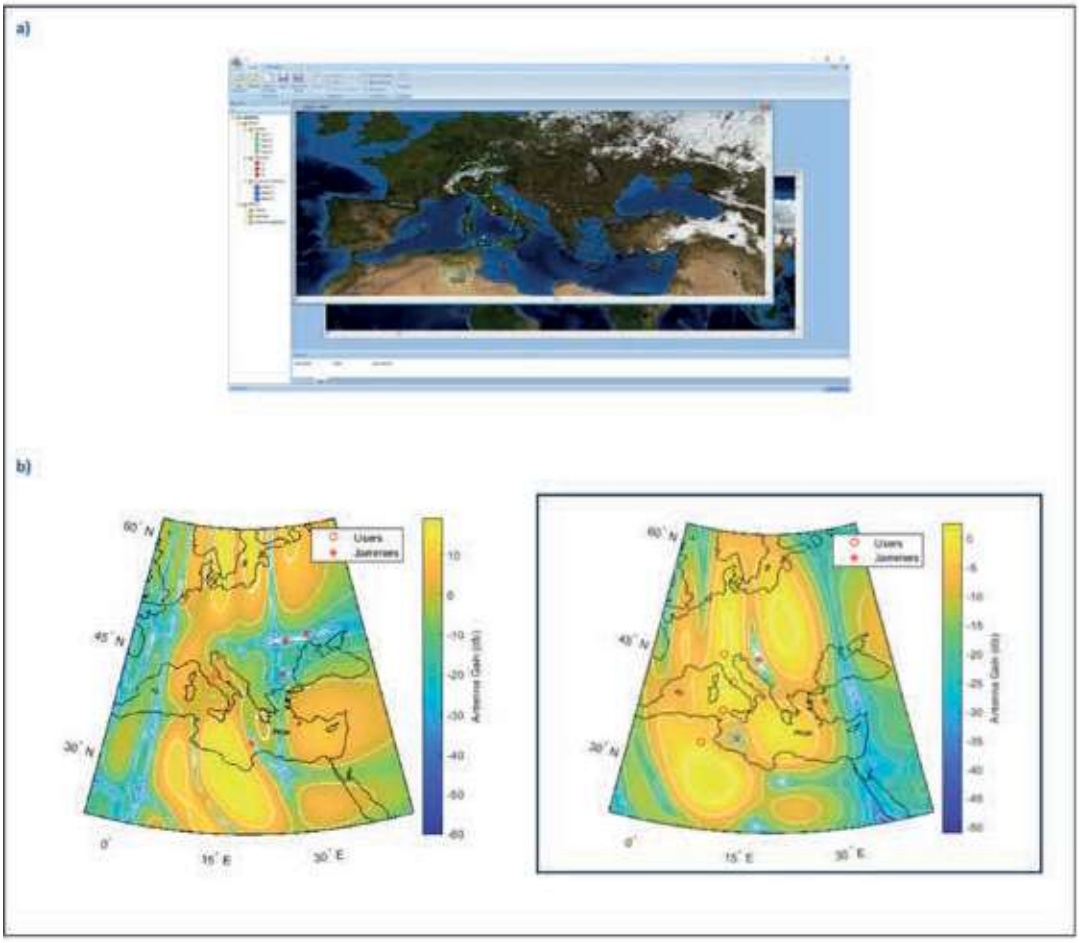

Figure 3 - Performance analysis through simulations: (a) Main view of the A2-DCM SW prototype for the computing and management of the BFN configuration and for the estimation of the system performance; (b) Examples of an optimized coverages on the basis of the different input constraints.

ing both the activities of lot 1 and lot 2 (still to be activated), mainly consist in the realization of the HW prototype of the BFN based on TTDL and MEMS switch technology (being qualified for space use within the same project), and in the creation of the A2-DCM ground software dedicated to the calculation and management of the antenna diagram and to the demonstration of system performance estimation, which can be specialized with algorithms for Defence missions.

These two components will represent a solid base of building blocks for the construction of a new generation adaptive antenna system for future SICRAL missions.

In addition, the ground SW component of A2-DCM may represent a potential ground technology that can be used with the satellite ground segment in support of the antenna's beam-forming and/or nulling capabilities, integrated into the current infrastructure, regardless of the technological solution implemented at the space segment level, thanks to the modular design of the technological solution and the numerical modeling of the antenna solution.

CONCLUSIONS

Once completed, the ADAPTIVE technological research project will strengthen the independence of the Italian national industry in the military SATCOM sector in new satellite missions that the Defence Administration intends to launch, as well as in the NATO requests for protected and flexible satellite capacity, as per Capability Package CP130.

The acquisition of a new space technology at the basis of the construction of the TTDLs, as foreseen in Lot 2, represents a winning strategy in terms of flexibility, performance and accommodation on small/medium platforms which are required for compatibility with the Italian Vega launcher. This is predicted by the results of the activities completed in the first contractual Lot 1, which focus mainly on the generation of user and service requirements, on the preliminary definition of the ADAPTIVE subsystem, and on the implementation of the prototype ground SW A2-DCM with the performances demonstration campaign through simulations.

These contributions, in line with the planned activities, form a solid basis for the development of the subsequent activities planned for Lot 2 (still to be activated).

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

PNRM	*Military Research National Program*
ADAPTIVE	*ADattività d'Antenna, su larga banda, per funzioni di beam steering e anti-interferente, con sviluppo di PrototIpo e ValidazionE*
TLC	*Telecommunication*
BFN	*Beam Forming Network*
MEMS	*Micro Electro-Mechanical Systems*
TTDL	*True Time Delay Line*
HW	*Hardware*
SW	*Software*
A2-DCM	*ADAPTIVE Antenna Diagram Computing and Management*
SATCOM	*Satellite Communication*

KEYWORDS

SICRAL, SATCOM, Beamforming, BFN, Anti-interference, nulling, anti-jamming, MEMS, TTDL, Broadband.

PROJECT INFORMATION

PNRM number:	a2017.166
Organization:	Direzione Informatica, Telematica e Tecnologie Avanzate (TELEDIFE), Segretariato Generale della Difesa e Direzione Nazionale degli Armamenti.
Responsible entity:	THALES ALENIA SPACE ITALIA SpA
City, Region:	Roma, Lazio
Project lead:	Giuseppe Matarazzo
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C3-LAB

Vector-borne infections pose a global threat to human healt. Deployed military personell are higly exposed to this risk. This project aims to equip the armed forces with innovative tools for the rapid diagnosis of arthropod-borne diseases, as well as to build a prototype insectarium in class 3 biosafety facilities for *in situ* experimental studies.

INTRODUCTION

At the end of the century, it was a widely held belief in the scientific community that the battle against infectious diseases was nearing its end. Conversely, the world has been experiencing an unprecedented phase of public health emergencies dominated by zoonoses (1). Among these, arbovirus diseases, namely infections transmitted by arthropods (Vector-Borne Diseases, VBD), play a main role (2).

VBDs have always posed a problem for military personnel. The operational theaters are mostly located in tropical areas of Asian and African continents where cyclic epidemics of infectious agents occur (3, 4). With the exception of a few agents, there are no vaccines or specific therapies against such infections. The most efficient way to protect military personnel is by risks assessment of the interested areas. and implementing all preventive, containment, and decontamination measures to reduce the risk of infection (5). Active monitoring of infectious agents, vectors, and the competence of the latter in transmitting the infection are closely connected to risk analysis.

The goal of the C3Lab project is to provide the armed forces with appropriate tools for the safe collection and identification of VBDs in operational areas, while offering methods for the specific, sensitive, and rapid detection of infectious agents arboured by the vectors.

TECHNICAL BACKGROUND AND SOLUTIONS

Active surveillance requires capturing vectors, classifying them, knowing the vector competence (potentially "transportable" agents) and estimating the density in the study area. Capture of vectors is generally performed using commercial traps, and subsequent classification is performed by experienced entomologists. However, capturing vectors with available tools does not contemplate keeping the captured specimens alive (mosquitoes and phlebotomus and ticks), thus not allowing for proficiency/xenodiagnostic studies which are necessary to have a complete picture of the vector's potential danger.

Two solutions were proposed for vector classification, the first by morphological identification based on a series of simplified iconographic cards accessible even to non-specialized personnel; the second entails the development of a vector classification protocol through image analysis using artificial intelligence algorithms.

For the study of vector competence, commercial traps were modified with the aim of keeping the collected specimens alive for later study in class 3 biosecurity facilities (BSL3).

Various procedures exist for detecting infectious agents, ranging from classical culture methods to the use of next-generation sequencing (NGS) methods. However, these techniques are not easily applicable in operational theaters as they require long processing times, true laboratories, and highly qualified personnel (6). Nucleic acid amplification technology (NAATs) is best suited for *in situ* analysis. This method has been extensively validated, and with the development of Real-Time PCR (7), analysis response times have been reduced to just over an hour. The instruments are of small size, and the reagents re-

quired can be lyophilized, thereby eliminating the logistics of the "cold chain".

METHODOLOGY

For vector classification, iconographic cards for quick identification of the main genera of mosquitoes on the planet have been produced . The cards focus on the most obvious diagnostic characters, furthermore, maps with the global schematic distribution of the vectors were also included. A secondary section (Figure 1A, 1B) with a typical dichotomous interpretation key was created with a direct iconographic reference that is immediately comparable to the reported definition. This allows immediate recognition with possible further investigation.

Furtermore, an artificial intelligent based approach is also in progress. Several panels of arthropod images were digitally acquired and processed by artificial intelligence algorithms. The analysis is based on Yolov5 software(https://docs.ultralytics.com/it/yolov5/). The program is designed for low-end hardware and was tested on a laptop with 8 MB RAM, Intel CPU, i5 64-bit processor, and 250 MB SSD hard disk. The algorithm was efficient in gender classification of mosquitoes. A lower efficiency was observed in the identification of phlebotomes (Figure 2A, 2B). The software's learning process is continuously evolving through continuous image acquisition.

About the xenodiagnosis studies, the commercial BG-Pro trap was modified by introducing an FTA card (https://it.vwr.com/store/product/565085/fta-card-whatmantm) imbeeded with a honey-based solution with 2% hydrogel in a 3:2 ratio at the collection chamber to ensure mosquito survival. The FTA card also enables the analysis of pathogen nucleic acids in saliva released by the vector during meals. Figures 3A, 3B show the collection and survival efficiency of species collected with modified BG-Pro trap compared with CDC trap, the latter considered the reference standard. The traps were tested in both Italy and Colombia. Of note, competence

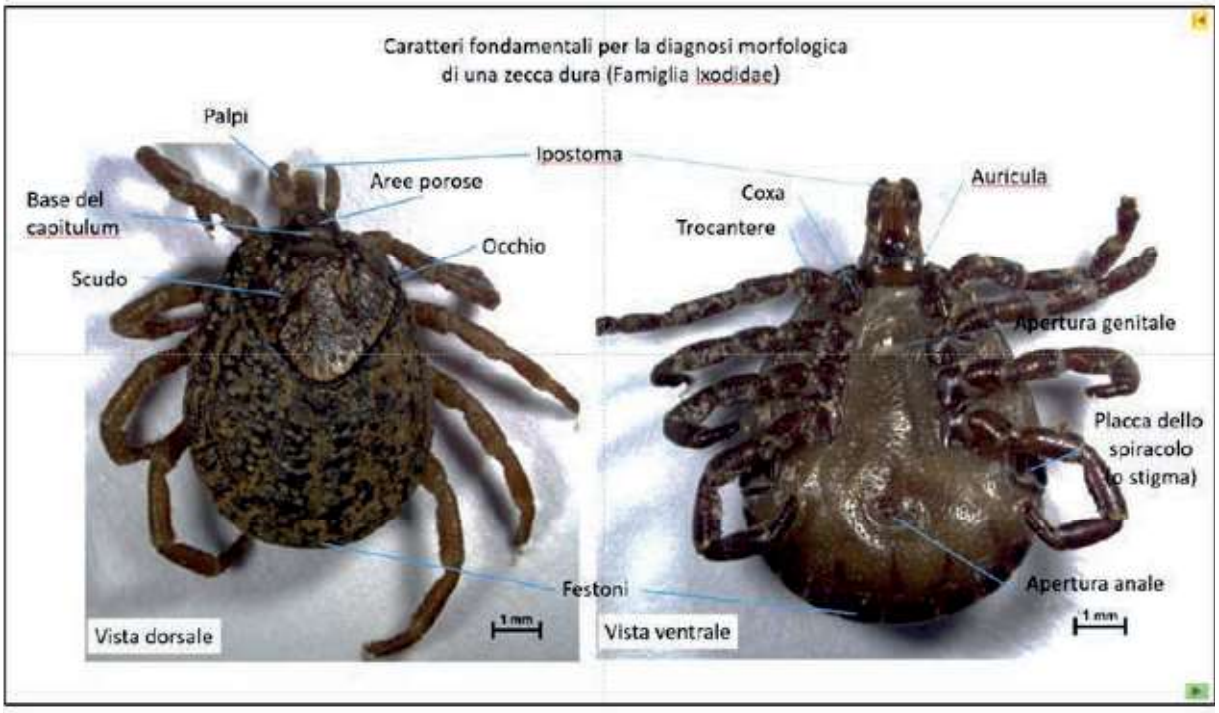

Figure 1A - In the panel, an example of a form for identifying ticks by basic morphological characters is shown.

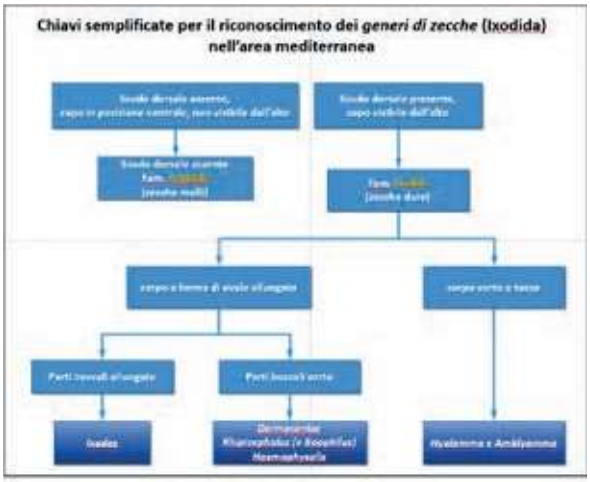

Figure 1B - An example of simplified dichotomous keys for the recognition of Ixodida mint genera is shown.

Figure 2A - After the "e-learning" process, the artificial intelligence algorithm analyzes the acquired image, generates the result by showing the detected specimens, highlighting and classifying them.

```
Fusing layers...
E:\Python39\lib\site-packages\torch\functional.py:445: UserWarning: torch.meshgrid: in an upcoming release, it will be required to pass the indexing argument. (Triggered inter
nally at  ..\aten\src\ATen\native\TensorShape.cpp:2157.)
  return _VF.meshgrid(tensors, **kwargs)  # type: ignore[attr-defined]
Model Summary: 332 layers, 7254689 parameters, 0 gradients
Image 1/48 C:\Users\silvestrini_francesc\Desktop\yolov5\test\images\CIL - 03.jpg: 416x320 12 Aedess, 6 Flebotomos, Done. (0.066s)
Image 2/48 C:\Users\silvestrini_francesc\Desktop\yolov5\test\images\CIL - 10.jpg: 416x320 4 Aedess, 6 Flebotomos, Done. (0.061s)
Image 3/48 C:\Users\silvestrini_francesc\Desktop\yolov5\test\images\CIL - 104.jpg: 416x320 7 Anopheless, 6 Culexs, Done. (0.054s)
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Figure 2B - Example of shell output after execution of the command in which the number of objects (in this case mosquito/flebotomus identification) identified per image are reported.

studies on phlebotomus collected in Tuscany (P. perfiliewi) to infection with Leishmania tropica (etiological agent of cutaneous leishmaniasis) gave a 23.4% positivity rate. This result demonstrates the competence of P. perfiliewi toward L. tropica and thus a potential risk of introduction of this pathogen in our country.

Finally, a panel of protocols for detection of pathogens by PCR, was both set up ex-novo or optimized based on methods already available in the scientific literature. In some cases, multiplex assays have been developed, as in the case of the bacterial agents Borrelia and Rickettsia or as for the simultaneous detection of Leishmania and Phlebovirus (Toscana virus) (figure 4). in Figure 5, the molecular protocols set up and/or optimized for the identification of pathogens carried by the studied vectors are shown.

CONCLUSIONS

VBDs is an important health risk to armed forces deployed in tropical-equatorial regions through the world. As indicated by the World Health Organization (WHO) in the document "Global Vector Control Response 2017-2030," climate change, tropicalization and desertification of areas with the consequent stable establishment of new vectors pose a global risk to human health (8). In the last decade, the European continent has recorded an increasing in arbovirus outbreaks (9).

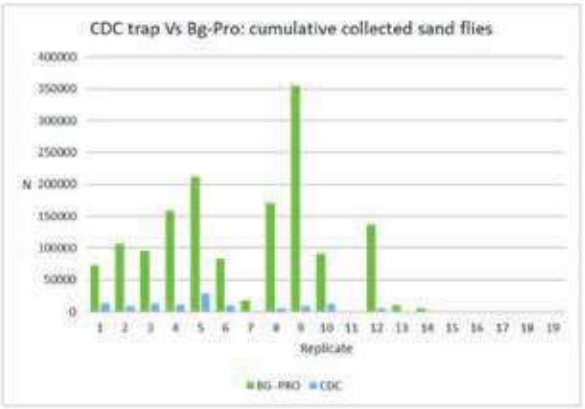

Figure 3A - The Scatter Plot shows on the abscissa the replicates of the collections performed and on the ordinates the amount of phlebotomes collected. In blue the results obtained with the CDC trap and in green the results obtained with the modified BG-pro. The test was performed in the municipality of di Magliano (Tuscany).

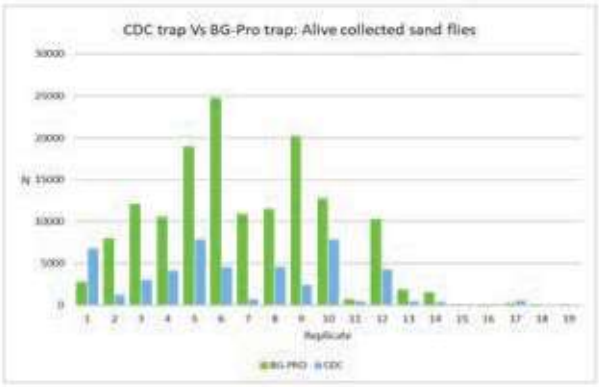

Figure 3B - Numerical estimates of phlebotomes captured alive with BG-Pro traps (green) and CDC trap (blue) in the different sampling.

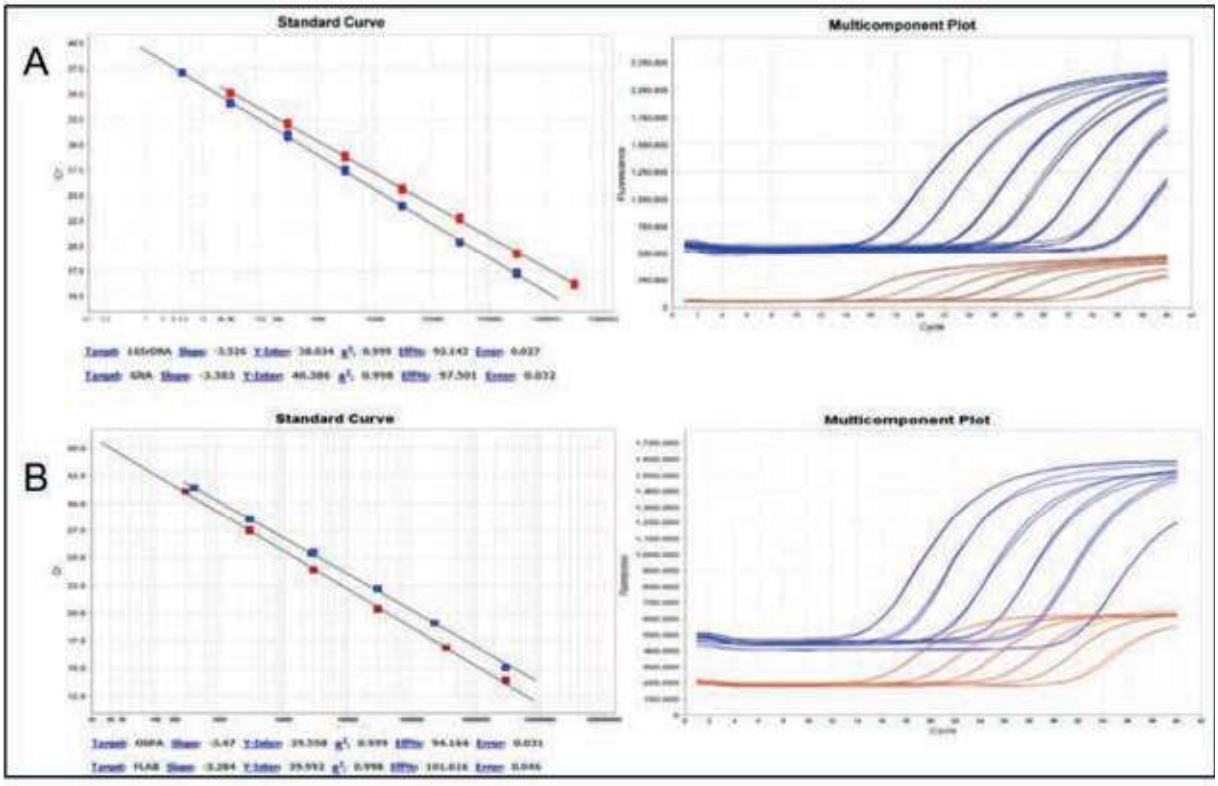

Figure 4 - Two Real-Time PCRs both performed in duplex mode (16Sr and OspA genes) for the agents Rickettsiae spp and Borrelia spp are shown. Standard curves of the same experiments obtained with serial dilutions of the two samples are shown in the left panel.

IDENTIFICAZIONE MOLECOLARE PATOGENI
PATOGENI IN ZECCHE

Patogeno	Modalità PCR
Borrelia spp	Monoplex/duplex
Borrelia sl complex	Monoplex/duplex
Borrelia TBFR group	Monoplex/duplex
Rickettsia spp	Monoplex/duplex
Rickettsia felis	Monoplex/duplex

IDENTIFICAZIONE MOLECOLARE PATOGENI
PATOGENI IN ZANZARE AEDES

VIRUS	Modalità PCR
Pan-alfavirus	Monoplex per identificazione rapida
virus Mayaro (MAYV) virus Chikungunya (CHIKV) virus dell'encefalite equina occidentale (WEEV) virus dell'encefalite equina orientale (EEEV) Venezuelan equine encephalitis virus (VEEV) Sindbis virus (SINV) Barmah Forest virus (BFV) Ross River virus (RRV) Chyong-myong virus (CNNV)	Nested e sequenza amplicone
virus Chikungunya (CHIKV) virus Zika (ZKV) pan-virus Dengue (DENV)	Triplex
Virus Dengue (DENV) Sierotipi 1,2,3,4	Quadruplex
virus West Nile (WNV) virus Usutu (USUV) virus dell'encefalite giapponese (JEV) Pan-virus dengue (DENV), virus Chikungunya (CHIKV), virus Zika (ZIKV) virus Dengue (DENV) Sierotipi 1, 2, 3, 4	Multiplex, stessa piastra, strumento e profilo termico
virus Febbre gialla (YFV) virus Rift Valley fever (RVFV)	Multiplex, stessa piastra strumento e profilo termico
virus dell'encefalite equina occidentale (WEEV) virus dell'encefalite equina orientale (EEEV),	Duplex

IDENTIFICAZIONE MOLECOLARE PATOGENI
PATOGENI IN ZANZARE CULEX

VIRUS	Modalità PCR
Virus WestNile (WNV) Virus USUTU (USUV) Virus encefalite giapponese (JEV)	multiplex stessa strumento e profilo termico
Virus encefalite equina occidentale (WEEV) Virus encefalite equina orientale (EEEV) Virus encefalite equina Venezuelana (VEEV)	Duplex (WEEV_EEV, Mono VEEV, multiplex stessa strumento e profilo termico
Virus della febbre gialla (YFV)	Mono

IDENTIFICAZIONE MOLECOLARE PATOGENI
PATOGENI IN ZANZARE ANOPHELES

PROTOZOI	Modalità PCR
Plasmodium spp P. falciparum P.vivax P. ovale P. malariae	Monomultiplex

IDENTIFICAZIONE MOLECOLARE PATOGENI
PATOGENI IN FLEBOTOMI

VIRUS	Modalità PCR
Pan-Phlebovirus	Mono, identificazione rapida
Phlebovirus RADI Phlebovirus CORFU Phlebovirus ARBIA Phlebovirus SFSV Sand fly Sicily Phlebovirus TOSV Toscana Phlebovirus SFNV Sand fly virus Naples Phlebovirus Punta Phlebovirus Ferno	Mono e sequenziamento amplicone
Phlebovirus TOSV Toscana	multiplex
PROTOZI	
Leishmania	Mono

Figure 5 - The figure lists all NAATs detectable pathogens set up *ex novo* and/or optimized in the C3Lab project split by competent vector.

In Italy, west nile virus is now endemic, chikungunya virus has already caused three epidemic events in 20007, 2012 and 2015 (10) while 81 dengue cases were recorded in 2023 (11-13).

The goal of the C3Lab project was to provide our soldiers with tools enable rapid and sensitive diagnosis of VBDs and to safely study vectors present in the areas of operation. The risk assesment by the real-time surveillance in the area of interest is of basic importance because, environmental fluctuations can result in a drastic change in the epidemiological picture in a relatively short time, especially in the spread of vectors.

The project, which is still ongoing, includes in its last phase the acquisition of a prototype BSL3 c laboratory/insectarium. This will allow for safe on-site work and the conduct of proficiency experiments and xenodiagnosis. Finally, the experience gained during the project will be made available to the national healthcare system.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

BSL3	*BioSafety Level 3*
NAATs	*Nucleic Acid Amplification Test*
NGS	*Next Generation Sequencing*
OMS	*Organizzazione Mondiale della Sanità*
PCR	*Polymerase Chain Reaction*
VBD	*Vectorn Born Diseases*

KEYWORDS

Vector-borne infections, BSL3 insectary, vectors control, field diagnostics, Vector-Borne Diseases, xenodiagnosis.

PROJECT INFORMATION

PNRM number:	a2018.057
Organization:	Direzione Generale di Commissariato e di Servizi Generali (COMMISERVIZI)
Responsible entity:	Istituto Superiore di Sanità
City, Region:	Roma, Lazio
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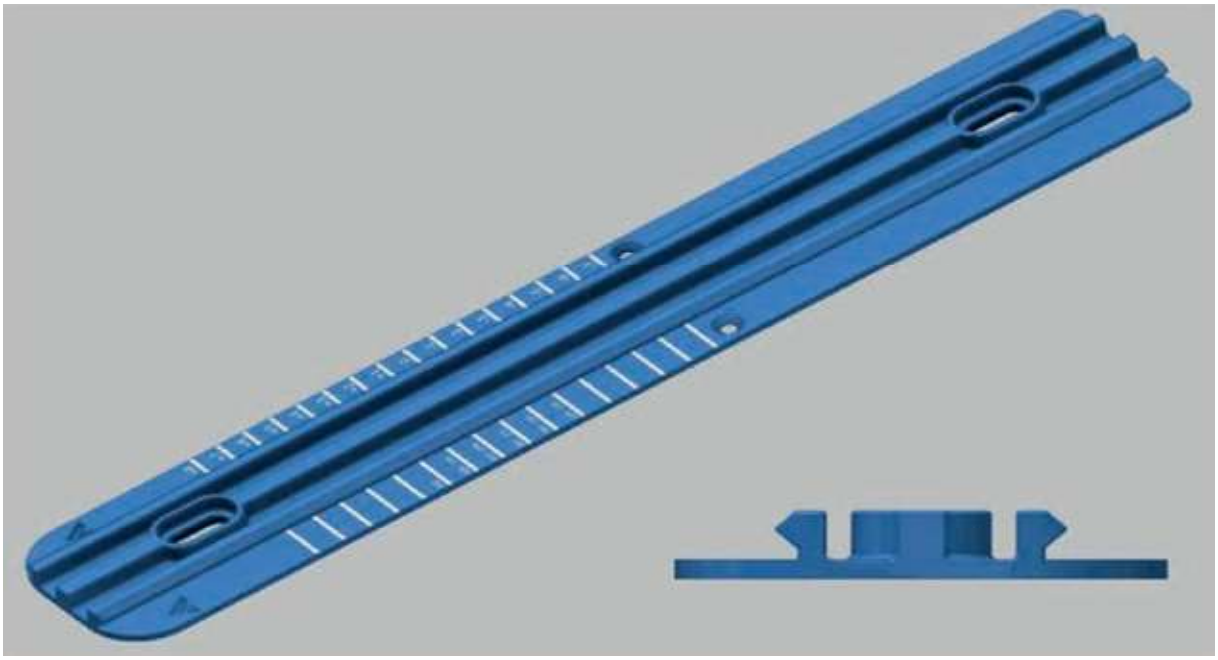
SKIING WITH DISABILITIES

The "Skiing with Disabilities" project aims to bring Armed Forces Veterans who have had serious injuries closer to winter sports. The aim is to create suitable materials to facilitate skiing and increase independence.
The project aims to make skiing easier and safer for amputee and blind skiers. We focus on 3 point: the construction technology and geometry of the ski, the specific plate/attachment system and a system of sensors.
The ski will be designed for standing skiers and by making a specific pair of skis also for athletes who use a prosthetic to ski with two limbs. Sensors will send data to the supervisor who will be able to interact with the skier in real time.
The ski will be constructed to be asymmetrical in the three directions while analysis sensors send data on terrain inclination, temperature, lack of motion, and accelerations provided (integrating data from the smartphone GPS) with specific emergency messages sent based on potential collisions, impacts, or environmental conditions that are too extreme. The supervisor will be able to receive position data and any emergencies through the supervisory software.



INTRODUCTION

The project PNRM 2020 – n. a2029.202 "Skiing with disabilities" has a target to project and to product skis and devices for skier with disabilities.
The project will include most of the common disabilities:

- Visually impaired skiers;
- Standing skiers (amputees)
- Sitting skier.

The purpose of the project is to permit to the veteran to practice winter sport and winter activities in an easier way, safer and with much more auton-

omy. The final goal is to realize a solution of items such as skis, bindings and devices (integrated sensors) customize on the single skier.

TECHNICAL BACKGROUND AND SOLUTIONS

Nowdays the skiing equipment designed spesifically for person with disabilities does not exist. The The person who want to start skiing have to do it with the equipment made for standard skier. That equipment do not care about limitations. Thestudy began with an analysis of the limitations to develop a proper equipment to increase authonomy, efficiency and safety. The roadmap is in two different and parallel way. The 1st is on developing skiis, plates and bindings made specifically for amputees or sitting skiers. The 2nd is to create a system of sensors and processor can guide the blind skier on the slope. These are the cluster of industries:

- GROOVES di Peter Hutta (chief of the working group) – HTUPTR66E16Z156H
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- MECH LAB srl – C.F. 02050510995
  Traversa della Ripolta n. 72-76 PRATO (PO)
- SESTO SENSO srl – C.F. 04179160264
  Via Terraglio 271/b PREGANZIOL (TV)

METHODOLOGY

The path was divided in stages with small target to reach in every stage before continuing with the following.

Models and prototypes were created and developed. Nowday we are at the end of the 2nd stage.

At the end of the 2nd step the project has realized some prototypes about:

- An asymmetric ski with different convergent angles for standing skier.
- Ski with elastomeric architecture specific to decrease the vibration with the snow.
- Big improvement of the plate between the ski and the binging. The link is locked in the rear part but free to move forward to get a better deformation of the plate and give a better stability and sensibility to the skier. This solution is made to get a better stability ad to prevent the unusual unlock of the bindings.
- Some prototypes have been made for the sensor devices; hardware and software to permit to the blind skier to get useful information about his positioning on the slope. In particular at the side of the slope will be placed some beacon and the skier will receive input with a vibration bracelets. This bracelet will indicate the direction to follow. Other sensor will give the information about hazard or extreme conditions such as potential collisions. The skier is in contact with a supervisor via device, this supervisor will receive the positioning data and emergencies. The hardware and all the wearable sensor are ergonomic. The work on the sensors is completed and the prototypization of the motherboard PCBA is done. (Annex 3).

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

In the next future the technology will open the possibility to ski to many more other people. The industrial production of the reached solution will lower the actual price of skiing for people with disabilities. These innovation could also be used for tactical skiing activities where the limitatios due to heavy weights and low visibility impact a lot on the skiing capacity. And more they could also be used in rehabilitation and re-education programs for post traumatic events.

That technology could be used in many other field at the moment not known.

CONCLUSIONS

The 2nd stage of the project is concluded with the realization of a prototype of an asymmetric ski, developed plate and a kit of sensors. The expected goal are reached.

On the solid reaching of the goal on the 2nd stage there is a strong interest to continue on the chosen pathway with the 3rd stage. The expectation of the elevation of the quality of living of the Vetaran are considerably high.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

PNMR	*National Military Research Plan*
RTI	*Rete Tecnica Industriale*
SCD	*Ski with Disabilitees*
CF	*Personal Tax Code*
SRL	*Low Responsability Society*
PCBA	*Printed Circuit Board Assembly*
GPS	*Global Positioning System*
FFAA	*Armed Forces*

KEYWORDS

Disabilitees, Ski, Plate, Sensors, Saefty, Indipendence, Sport, Veteran, Technology, Innovation.

PROJECT INFORMATION

PNMR Number:	2019.202
Organization:	Direzione Generale di Commissariato e di Servizi Generali
Responsible entity:	Grooves Ski di Peter Huta
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RESEARCH IN THE INTERNATIONAL CONTEXT

INTRODUCTION

In the context of international cooperation, both within Europe (mainly in coordination with the European Defence Agency - EDA), NATO, and outside of Europe, through bi-/multilateral agreements, Italy supports and has had significant and profitable collaborative technological research activities (R/T) in place for years.

Among the exemplary research projects of these R/T international cooperation activities, the following are highlighted in particular:

- (Italy - Israel cooperation area) “Real-Time Structural Health and Usage Monitoring Systems for Unmanned Aerial Systems” (RESUME);
- (EDA context/aegis) “Computational Modeling for long-term inter-sectoral advanced knowledge on Non Newtonian Fluid” (COMMON-LINK).

RESUME

The project RESUME (Real-Time Structural Health and Usage Monitoring Systems for Unmanned Aerial Systems) is an Italian-Israeli cooperation funded by the Ministries of Defence and part of a programme aimed at increasing joint research activities in the field of aeronautical structures. RESUME develops a system for the real-time monitoring of the state of structural integrity of an aircraft without pilot on-board (UAV, Unmanned Aerial Vehicle). Its architecture is based on a network of concentrated sensors (FBG, Fiber Bragg Gratings) to retrieve local strains. Such a data is sent to an original processing algorithm that identifies the possible presence of a damage. The information is then transferred to an interface software dialoguing with the operator, whom is postponed any operational decision to, on the mission protraction.
In RESUME, reference was made to several real structural elements of different sizes. The availability of the relative numerical models and the results of the experiments in laboratory and in wind tunnel environments, have allowed to collect a significant amount of information for the further development of the technology. Its current level, evaluated according to the scale of the TRL (Technology Readiness Level), is between 4 and 5, with significant elements of 6.

INTRODUCTION

The increased use of unmanned aerial vehicles (UAV) is a trend in the civilian and military sectors that has led to new regulations to ensure the safety of inhabited areas. STANAG 4671 regulates military UAV operation in open-areas (non-interdicted) with a maximum weight of up to 20 tons.
Consistent with this vision, real-time Structural Health Monitoring (SHM) systems, aim to instantly know the level of aircraft integrity, increasing the reliability of operations. It modifies the philosophy of maintenance, shifting the focus on the need, instead of the scheduling, then reducing costs.
The recognition of SHM as a reliable non-destructive inspection technique by certifying bodies is central to the implementation of new scenarios, and is crucial for the further expansion of composite architectures, which are essential to achieve significant reductions in weights and production costs.
For the latter, the current regulations require extremely expensive measures: for example, it is prescribed that the structure is able to fully withstand the design loads even in the presence of critical damage. This means thickening the material or using redundant mechanical connections, drastically reducing the expected benefits.

TECHNICAL BACKGROUND AND SOLUTIONS

RESUME implements an SHM system to detect structural damage in real-time, to ensure the operational safety (safety critical) of UAV in segregated airspace, and to reduce operating costs by switching from scheduled to on-demand maintenance. Key technologies are, Figure 1:

- **Optical fibres.** Flexible glass or plastic filaments through which light passes with high bandwidth, for considerable distances and with limited attenuation. They are of small section, passive, tolerant to the environmental condi-

tions, little sensitive to electromagnetic disturbances and easily integrable in the reference architectures and within the composites.

- **Fibre Bragg Gratings (FBG).** Regular engravings on the fibre optic, which absorb specific ranges of the spectrum of light passing through. If adherent to the structure, the absorption is modulated with the deformation, allowing the measurement of this latter from light signal reading.
- **FBG sensory networks.** Series of sensors distributed on the surfaces (or embedded within the structure) to be monitored to obtain dense information on critical regions such as the wing, for example to measure its deflection or to evaluate the effects resulting from bird impact.
- **Algorithms based on strain.** They process the elongation of nearby sensors, identifying local stiffness variations related to damage even without he availability of a structural model. The proprietary methods behind the proposed technology have been developed through activities on pressurized tanks, fuselage elements and wing segments.
- **Real-Time algorithms.** They allow the management of information from the sensory network to one or more processing algorithms, and from these to an interface with the user, whom the decision on the final intervention is devolved to.
- **FEM modelling.** Numerical tool to support the understanding of structural physical processes, otherwise difficult to be properly characterized in laboratory. It allows a characterization of the effects of damage, providing important indications for decoding the acquired signals.

At the best knowledge of the project team, RESUME is the first aimed at demonstrating the integration and real-time automation of data collection and diagnostics.

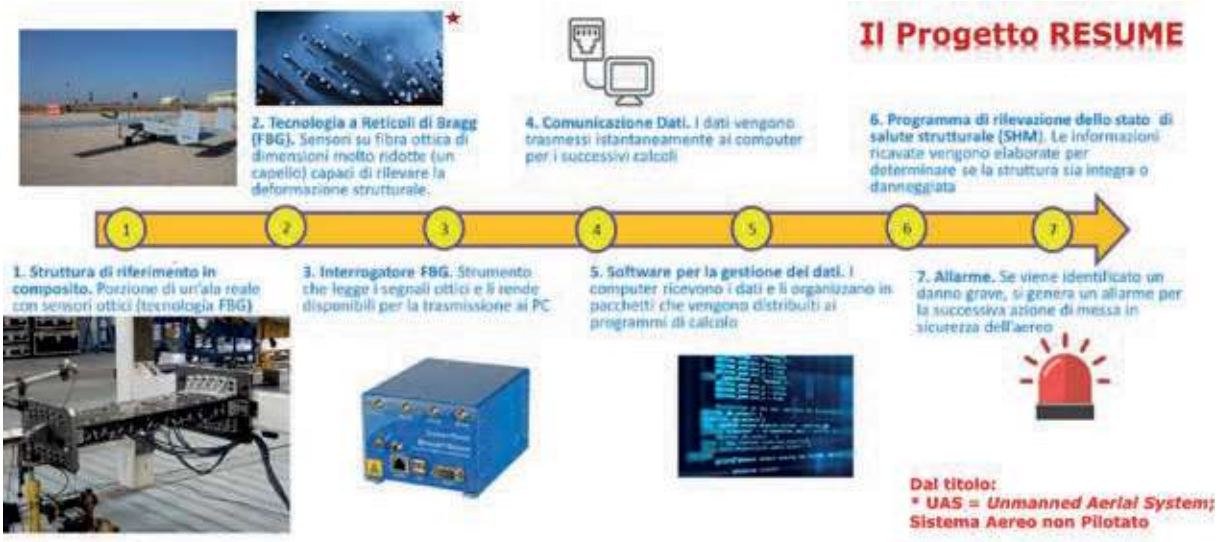

Figure 1 - Architecture and logic of the SHM system, developed within the RESUME project. 1. Reference structure available at Piaggio Aerospace and representing a full-scale section of a wing-box; 2. A pictorial representation of the Bragg gratings and the optical fibers; 3. One of the interrogators used in the project, Smart Scan II, capable of translating the optical signal into strain values; 4. Logical scheme of data communication from the interrogator to the PC; 5. SW of data management and organization, capable of ensuring a continuous flow of data to the 6. processing SW, able to identify the possible presence of structural damage on the basis of the anomalies recorded; 7. System feedback to the operator whom the decision to intervene in the air system is delegated to; the feedback is managed by a package of the same SW of data management and organization.

METHODOLOGY

The algorithm behind the developed technology is based on the identification of deformation anomalies, Figure 2. The analysis takes place through a comparison of the variations recorded along the measurement chain (spatial domain), and in time (temporal domain). The deformations are obtained from an FBG sensors array, arranged on the reference structure, Figure 3. The acquired data are managed by a real-time software with the dual purpose of: organizing the data into successive packets and transmitting them to an arbitrary number of processing codes; transferring the result of these elaborations and showing them to the aircraft, operator, Figure 4. The technology is demonstrated on three real-scale structural components of increasing complexity, representative of a medium-sized aircraft; in detail: a composite wing section of a wing box, a wing section of the P180, and a complete half-wing of an unmanned aircraft, Figure 5. In the first two cases, the tests were conducted in the CIRA and PAI laboratories, respectively, while the third experimental campaign was conducted in a wind tunnel at the IAI facilities. The analyses were always accompanied by numerical simulations (FEM) with the dual purpose of testing the ideal functioning of the implemented algorithm, and characterizing the structural deformation field under load. In the three cases considered, the developed SHM system made it possible to identify the damage location timely, Figure 6, Figure 7, Figure 8. To further verify the capabilities of the algorithm, a preliminary analysis on the probability of detection of the structural damage (POD) was performed, Figure 9. Finally, the analysis on the attained technological readiness level (TRL), Figure 10, indicated the proposed system classified between 4 and 5, having also achieved important elements of the level 6.

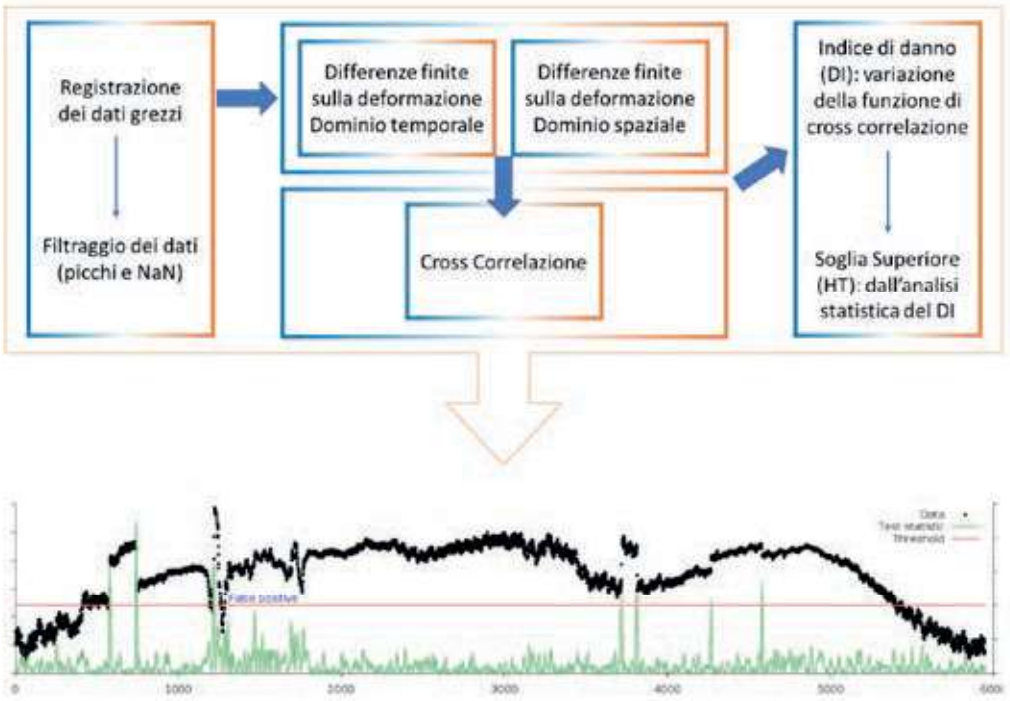

Figure 2 - Logic of the used SHM algorithm. Top: Essential schematization of data processing. Bottom: Typical strain diagram (black line) of a typical structural element as detected by a dense linear distribution of sensors; the presence of damage is evident (areas of more intense variation); result of data processing with a consistent indication of the areas where damage is present (green line), and threshold beyond which the system actually recognizes the presence of singularities (red line).

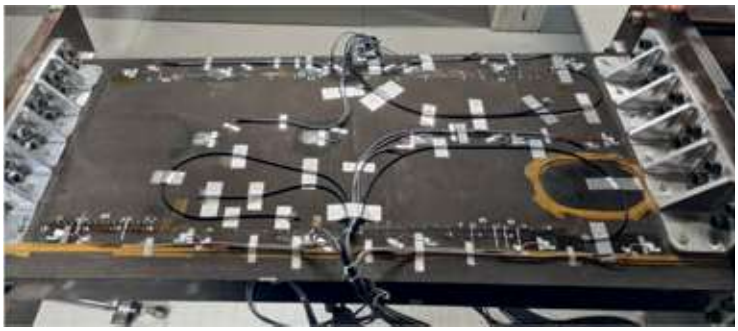

Figure 3 - Section of wing box instrumented with different series of FBG distributed on its surface. Invisible unless thoroughly analyzed, they correspond to the white markers distributed on a regular basis on the panel, traced to allow operators a faster match. The test article was installed in the climate chamber of the Piaggio laboratories.

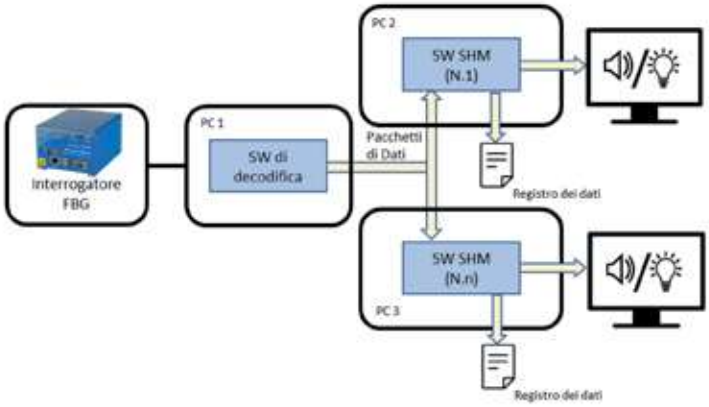

Figure 4 - Logical scheme of the data flow from the interrogator (the sensorized structural element is omitted from this diagram without affecting its meaning). Transferred through an Ethernet connection, they are organized into packets of a predetermined length with continuity and sent to one or more SHM software, inside the same or other computers. The results of the elaborations are then saved in a register through a special routine of the same real-time management code both as numerical evidence, and sent to the operator in the form of sound or visual alarm where the presence of structural damage is recognized.

Test article	Builder	Original FEM model	Adapted FEM Model	Experimental tests @
Composite spar	IAI	IAI	CIRA	CIRA
Wing box segment	IAI	Piaggio	CIRA	Piaggio
Wing of a UAV	IAI	IAI	CIRA	IAI

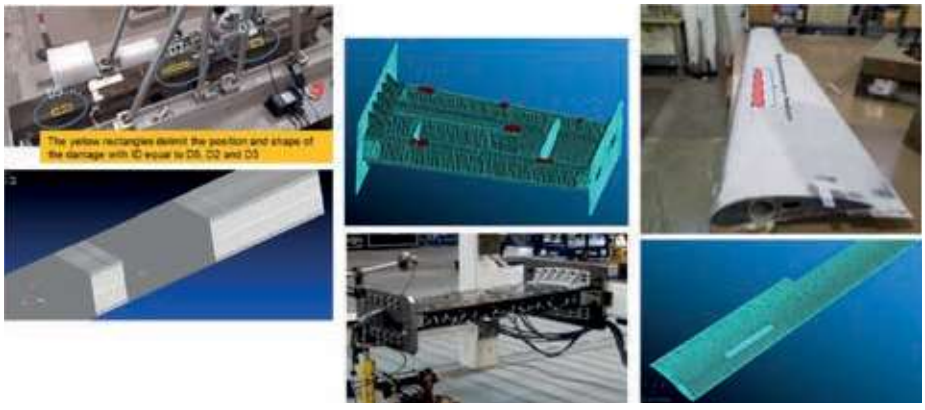

Figure 5 - Pictorial summary of the three test articles used in the project, sorted by increasing complexity from left to right. Both an image taken in partner laboratories and the respective FEM representation are shown. The positions of the imposed damage are reported in color. Left: composite beam. Center: wing box segment. Right: wing of a UAV.

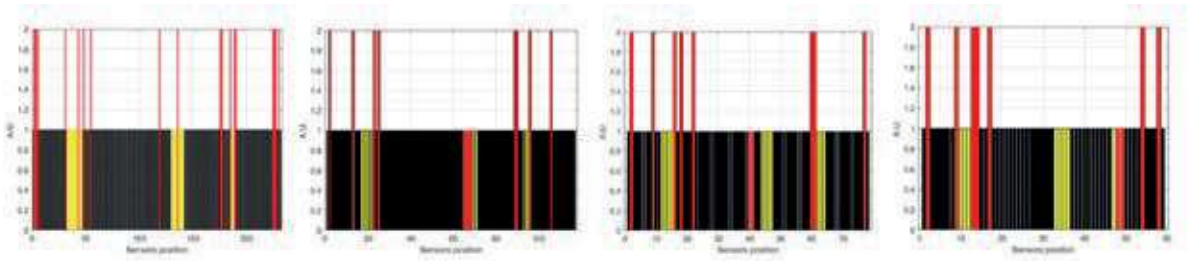

Figure 6 - Example of the results from strain data processing through the proprietary SHM algorithm on the composite beam. The black bars along the x-axis represent the single sensors; the yellow segments the position and the extent of the damage imposed; the red lines the intensity (y-axis, in non-dimensional units, AU) and the location of the sensors identified by the algorithm as close (or overlapped) to the damage zone. The figure shows the results of a sensitivity analysis conducted on the density of the sensory network from acquisitions conducted with a distributed fiber, capable of reading information every 2.5 mm, approximately. The data were then de-sampled to a density of 5, 10, 15 and 20 mm, whose outcomes are arranged from right to left. This is necessary to fully design the FBG sensor network to be used in application cases. In fact, at the current state of technology it is not yet possible to use systems distributed on board. It is possible to notice a slow degradation of the performance of the algorithm as the available information decreases, while still maintaining the ability to identify the damage.

Sensor ID	0	1	2	3	4	5	6	7	8	9
RT flexion						x	x	x	x	
HT flexion					x			x	x	
RT Compression						x	x	x	x	
HT Compression						x				

Sensor ID	0	1	2	3	4	5	6	7
RT flexion			x	x		x		
HT flexion			x	x		x		
RT Compression			x	x		x		
HT Compression				x		x	x	

Sensor ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RT flexion				x	x	x	x									
HT flexion				x	x	x	x									
RT Compression				x	x	x	x	x	x		x		x			
HT Compression				x	x	x		x	x	x			x			

Figure 7 - Example of the results of the SHM algorithm processing of signals derived from linear series of FBG of different pitch and length, arranged on imposed damage zones of the wing box section. Arrays have been used both embedded in the adhesive layer of the junction between the external panel and the stiffeners, and bonded on the surface. The dark boxes refer to sensors placed in damaged areas, while the light ones refer to intact parts. In the order, from left to right and from top to bottom: damage of 40 mm with an embedded sensory distribution for a number of 10 FBG and pitch equal to 10 mm; damage of 80 mm with an embedded sensory distribution for a number of 8 FBG and pitch equal to 20 mm; damage of 80 mm with a surface sensory distribution of 16 FBG and a pitch equal to 10 mm. The results show an excellent ability of the algorithm to detect the location of the fault and its extent. Some excursions outside the structural discontinuity are attributed to the propagation of its effect beyond its actual extension.

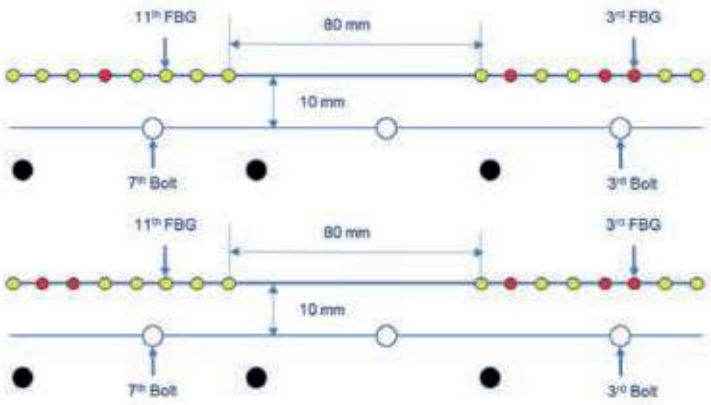

Figure 8 - Example of the damage detection by the SHM system on damage imposed on a specific segment of the UAV wing for two different wind tunnel flow speeds. In this case, the irregularity is represented by the removal of some bolts, arranged with a pitch of about 40 mm, between the upper panel and the main beam. In detail, the removed bolts are shown in white, while in black they are those whose condition is not altered. FBG sensors are distributed over sequences of 8 elements each, with a pitch of about 10 mm. In the figure; those identified by the algorithm as close to the damage zone are reported in red, while the ones close to intact areas are depicted in yellow. The indications obtained are generally stable, while a certain deviation from the actual irregularity areas is linked to the presence of additional structural singularities such as those resulting from the presence of ribs.

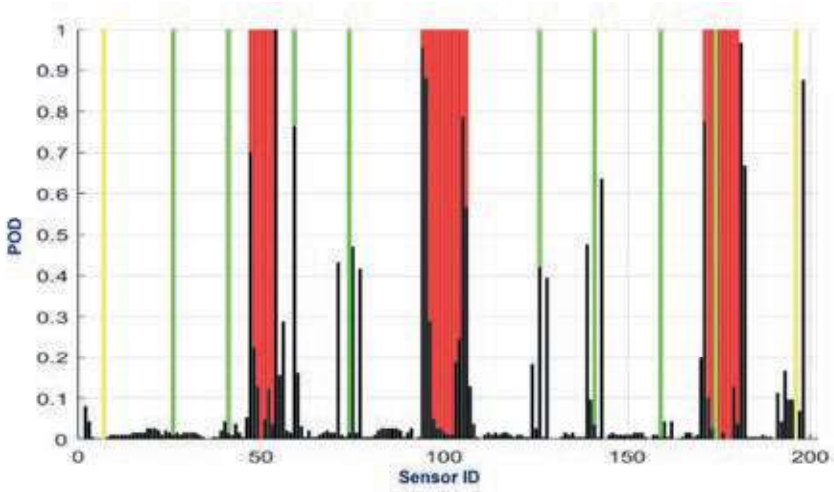

Figure 9 - Results of a survey concerning the Probability of Detection, conducted on the FEM model of the composite spar. The test article was subjected to a normal load, moving in the longitudinal direction with a pitch of 8 mm. The sensory network has a step equal to the one with which the structure loading is performed. At each analysis, the attribution to the single sensor with the presence of the discontinuity in its vicinity by the SHM algorithm is recorded. The number of occurrences on the totality of the conducted investigations represents the probability with which this identification takes place, reported as a normalized value on the y-axis. The positions of the side supports are shown in yellow, the extension and the position of the imposed damages are reported in red, the position of the sensors (the height of the bars representing the normalized value of the POD) are in black, and the discontinuities of the thickness of the upper panel of the beam are in green. The analysis confirms the ability of the algorithm to detect the presence of the faults, particularly with regard to its edges, where the discontinuity of the strain function is more evident.

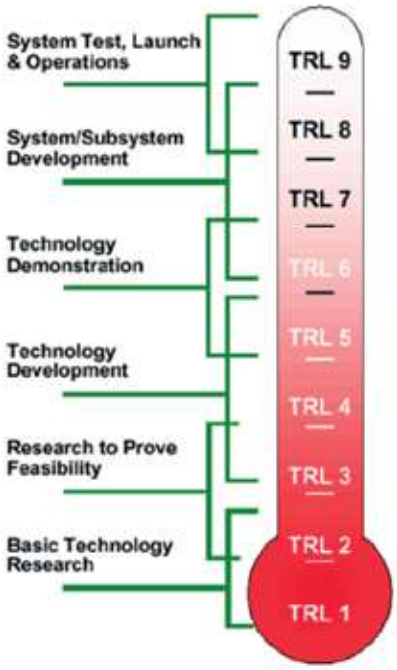

Figure 10 - The analysis of the technological level of the proposed system, resulting between 4 and 5 with elements of the level 6, falls in the interval corresponding to the development phase, and immediately before the demonstration segment. The analysis was conducted through the tool defined by the working group participated by NASA, (US) National Aeronautics and Space Administration, and AFRL, (US) Air Force Research Laboratory, by Nolte and others (version I.2beta). Nominally, the achievement of TRL 4 corresponds to a laboratory-validated technology, that of TRL 5 to a technology validated in an industrially relevant environment, and that of TRL 6 to a technology demonstrated in an industrially relevant environment (credits: NASA graphic showing Technology Readiness Levels, 17 December 2004, http://as.nasa.gov/aboutus/trl-introduction.html, by NASA/Airspace Systems (AS), https://commons.wikimedia.org/wiki/File:NASA_TRL_Meter.png.

POTENTIAL TECHNOLOGY APPLICATION AND EXPLOITATION

The study is part of a strategy aimed at developing an architecture that allows the safe conduct of the mission of unmanned aircraft, providing the airplane with significant capacity of damage assessment, by continuously transmitting information on the state of structural health to the operator, Figure 11. In a more advanced scenario, the aircraft could be capable of autonomous decisions based on the acquired info, and properly processed by the onboard computer. In this sense, technology is aimed at both civil and military uses, albeit with different declinations. Similarly, although developed for the aeronautical sector, it is transferable to other means of transport, from space, to naval and land vehicles, as well as to generic industrial plants, notwithstanding the specific operating specifications and materials used. The working group, which shares decades of experience on these issues, has used this technology on missile components and is currently involved in applications on cryogenic tanks. By integrating UAV management features, specialist aspects of multifunctional aerostructures and materials, as well as integrated sensors and adaptive

structures, the study finds a solid foundation in partner research and development.

CONCLUSIONS

The research has allowed further enhancements of the SHM technology currently being developed by the partners. From a technical standpoint, a remarkable result was obtained by expanding its applicability to on-board systems, starting from laboratory architectures. According to the main objective of the project, an innovative tool has been introduced that allows the real-time transfer of the acquired data to various SHM software packages, till providing a timely feedback to the ground operator. The number of PC and installed codes depends exclusively on the capabilities of the network and the computers themselves. Beyond individual specific improvement actions on various specialist aspects, the developing architecture can be completed by the implementation of remote data transmission between the various elements of the acquisition and processing chain (interrogator, PC, alarm system), based on the same Ethernet protocols already used in the laboratory and wind tunnel environments.

Conducted in an international context, the activity has further strengthened the level of collaboration between transnational partners, with complementary skills but with significant overlapping. Therefore, technological enhancement has been balanced between innovative aspects, guaranteed by the fusion of different experiences, and the consolidation of the available capabilities of the National actors.

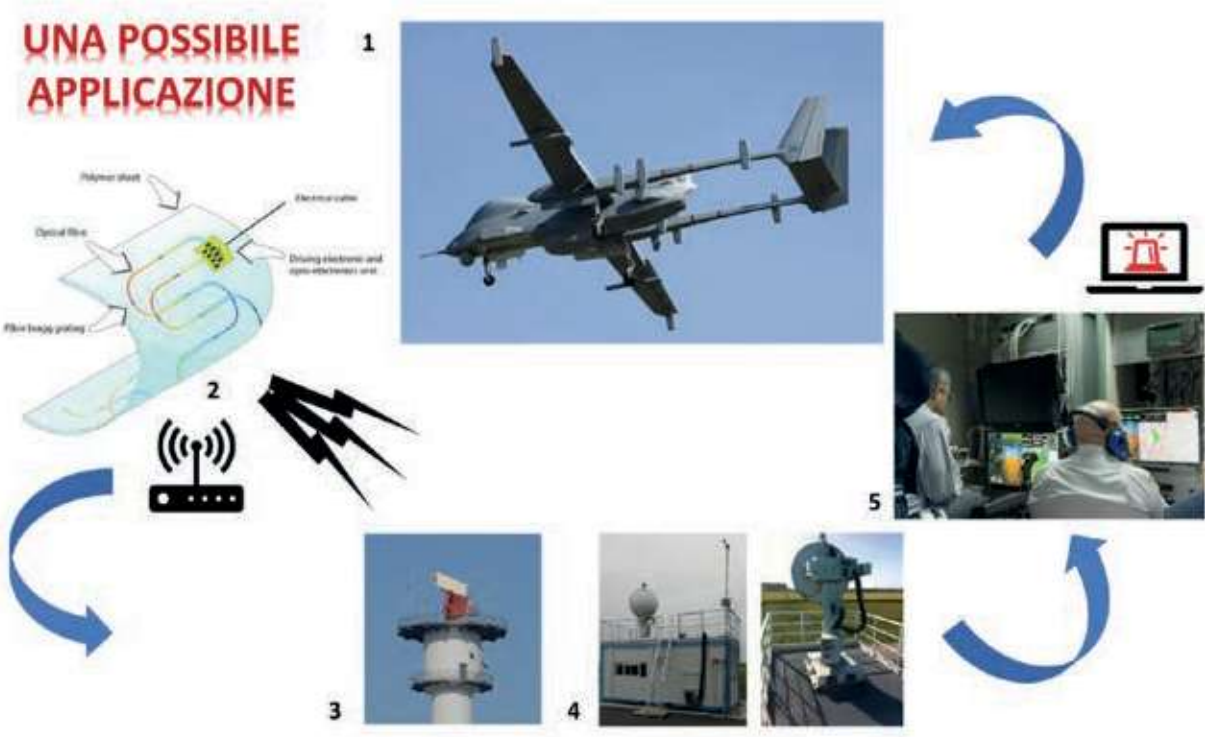

Figure 11 - Scheme of a possible application of the technology, with due reference to the photographs and drawings reported: 1. Unmanned aircraft (UAV) IAI Heron, 4X-UMG IAI UAV Heron in Emmen, Switzerland, https//common/s.wikimedia.org/wiki/File:4X-MUG_Andreas-Weber.jpg; https:///creativecommons.org/licenses/by-sa/4.0/deed.en; 2. Optical sensory network integrated within a structure, https://en.wikipedia.org/wiki/File:PhosFOS_flexible_skin.jpg, https//creativecommons.org/licenses/by/3.0/; 3. Radar tower at Frankfurt airport, Germany, https://commons.wikimedia.org/wiki/File:Radar_tower_airport_Frankfurt_-_Radarturm_Flughafen_Frankfurt_-_03a.jpg, https///creativecommons.org/licenses/bysa-/3.0/deed.en; 4. Mobile Ground Station, CIRA; 5. Ground Station, Interior, CIRA (4 e 5, images taken during the experimental tests of the RAID and GRADE projects, SESAR funding program of the European Union).

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AFRL	*(US) Air Force Research Laboratory*
AU	*Adimensional Unit*
CIRA	*Centro Italiano Ricerche Aerospaziali (the Italian Aerospace research Centre)*
DI	*Damage Index*
DNA	*Direzione (Italiana) Nazionale degli Armamenti (Italian National Armaments Direction)*
FBG	*Fibre Bragg Grating*
IAI	*Israel Aerospace Industry*
NASA	*(US) National Aeronautics and Space Administration*
PAI	*Piaggio Aerospace Industries*
PC	*Personal Computer*
POD	*Probability of Detection*
RTI	*Raggruppamento Temporaneo di Imprese (Temporary Grouping of Enterprises)*
SGD	*Segretariato (Italiano) Generale della Difesa (Italian Defence General Secretariat)*
SHM	*Structural Health Monitoring*
TRL	*Technology Readiness Level*
UAV	*Unmanned Aerial Vehicle*
UAS	*Unmanned Aerial Systems*

KEYWORDS

Composite structures; Structural damage; Structural health monitoring; Integrated sensing; Optical sensors; Fiber Bragg Gratings; Real-time processing; Damage identification algorithms; Damage characterization; Adaptive structures.

PROJECT INFORMATION

PNMR Number:	PA ISR-ITA 2019/3
Organization:	Directorate of Air Armaments and Airworthiness (ARMAEREO)
Responsible entity:	CIRA, Centro Italiano Ricerche Aerospaziali, associated in RTI with Piaggio Aerospace Industries
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COMMON-LINK

Electro-/Magneto-Rheological Fluids (ERFs/MRFs) are smart materials whose behavior can be controlled by an external electric or magnetic field. The acquisition of enhanced knowledge on their behavioral principles is fundamental to fully exploit their capabilities. The research project has the ambitious objectives to enhance the knowledge on ERFs/MRFs and, in turn, to demonstrate the potential applicability of innovative devices of military interest based on such materials. The objective is achieved by improving the knowledge on the behavioral principles of ERFs/MRFs through the development of computational modelling tools combined with experimental tests. Such body of knowledge will be exploited to foster the design and development of ERFs/MRFs based demonstrators. The computational models are validated by benchmarking the results with experimental data that are used to guide the optimization of nanoparticle synthesis/functionalization and fluid prototyping. Finally, the selected ERFs/MRFs will be embedded in two demonstrators (upper limb exoskeleton - ERFs based, adaptive shock absorber - MRF based) to showcase the technology capabilities. The knowledge acquired and the computational tools can be exploited in the future to develop new devices suitable for the military sector. Unclassified. Based on Foreground Information under EDA Contract No B.PRJ.RT.980 covering the Ad Hoc Project entitled “COMMON LINK”.

INTRODUCTION

The next decades will see the pervasive inclusion of classes of smart materials represented by high performance Electro-/Magneto-Rheological Fluids (ERFs/MRFs) in Industrial/Defence applications. ERFs and MRFs belong to a particular sub domain of the class of Non Newtonian Fluids whose behavior can be controlled by an external electric or magnetic field. The full applicability of such innovative materials will result, in turn, in a strong revolution characterized by the birth of adaptive devices and subsystems (e.g. adaptive shock absorbers, innovative exoskeletons, critical electronic subsystems, innovative coolant fluids, innovative ballistic protection sustained by artificial intelligent control algorithms). It is worth to say that the development of efficient and robust materials/devices for military applications requires considerable research efforts to understand their intriguing ERFs/MRFs behavior in specific operating conditions and to steer the production/characterization techniques. In short, the capability to develop Innovative Devices based on ERFs/MRFs, able to adapt their characteristics to the working conditions, goes hand in hand with the acquisition of enhanced knowledge on their behavioral principles. The development of demonstrators for the chosen target applications benefitting from validated computational models represents the scope of the COMMON LINK project.

TECHNICAL BACKGROUND AND SOLUTIONS

A multi disciplinary approach comprehending chemistry, material science, computational modelling and mechanical/control engineering has been chosen as the COMMON-LINK way forward to proceed. Validated predictive models, advanced

nano structures production techniques and standardized characterization methods are required to support design engineers for the use of ERFs/MRFs for industrial purposes. The project has been therefore divided in 4 main research areas:

- Key Area 1 (Modeling): to develop/optimize computational models for ERFs/MRFs either by simulating particle interactions in the fluid carrier and by prescribing complex rheological constitutive relations to predict their material functions in a variety of flows. The two approaches are complementary since the former can determine the overall behavior and trends of dense suspensions depending on the features of the particles (shape, size, coating, surface roughness, external electro/magnetic fields, etc.) but it is limited to small fluid volumes while the latter can cope with larger volumes of fluid but it needs the identification of a continuum constitutive relations and related parameters.
- Key Area 2 (Nanoparticles synthesis): dedicated to synthesis/production of materials (nanoparticles) according to the guidelines obtained from Key Area 1;
- Key Area 3 (ERFs/MRFs Development): where ERFs/MRFs are prototyped and characterized giving feedback to Key Area 1 and Key Area 2 for both computational models and production processes optimization;
- Key Area 4 (Target Military Application): to define functional requirements and technical specification for the demonstrators to be developed. With the main military objective to design, develop and test one or more target demonstrators tailored to the military sector based on the manufactured materials.

METHODOLOGY

The Key Area 1 activities are focused on predicting the behavior and flow of ER/MR fluids. After developing ERFs/MRFs constitutive models and the relative computational tools (Figure 1a-b), the dynamics of the dense suspensions based on the Immersed Boundary Method were studied. Simulation campaigns were carried out to analyze the effects of particle shape, size, concentration and electromagnetic properties. The cases investigated showed that both ERFs/MRFs model predictions are in good agreement with the experimental data. A set of constitutive relations for a variety of ERF/MRF fluids was obtained and will be used to develop ERFs/MRFs behavioral models in simple and complex flows. The Key Area 2 activities are focused on the synthesis and characterization of nanoparticles of metal oxides and oxyhydroxides for ERFs and MRFs applications. Both commercially available and in-house synthetized particles were characterized, and the synthesis process is been optimized in terms of output stability, quality and quantity. In addition, particle engineering was performed to enhance the Rheological effect (e.g. functional groups, particle coating). The particles were then used to prototype several ERFs/MRFs samples (Key Area 3), which are then investigated by means of physical-chemical and electro-mechanical characterizations, to identify the most suitable candidate to be used in the ERFs/MRFs demonstrators (Figure 1c). Regarding the Key Area 4, an investigation of potential military applications exploiting ERFs and MRFs was performed. Two applications were selected for the project, resulting in the following two demonstrators: upper limb exoskeleton (ERFs based); adaptive shock absorber (MRF based). For each demonstrator, the functional requirements, technical specification and test plan were identified, and were used to tailor the design phase. In particular, after an in-depth analysis of the state of the art, the concept, preliminary and executive designs of the demonstrators were performed (Figure 1d-e).

POTENTIAL TECHNOLOGY APPLICATIONS AND EXPLOITATION

The project activities are broadly enhancing the knowledge in ERFs/MRFs computational modelling and nano-material synthesis/characterization, and

Figure 1 - (a-b) Modeling example of (a) ERFs and (b) MRFs. (c) Nanoparticles synthesis and fluid prototyping. (d-e) Executive design of (d) ERF-based and (e) MRF-based demonstrator.

will provide a proof of concept of the usefulness of such technology. The knowledge acquired and the computational tools developed can be exploited in the future to develop several key potential applications for the ERFs/MRFs technologies. In the vehicular domain, they can be used in semi-active shock absorbers to increase performances (e.g. adherence, comfort) and safety of vehicles in different operating conditions; they can also be used in smart clutches/brakes to increase performances (e.g. applied torque/force) and device lifetime. Alternatively, they can be used as "Vibration Damping Systems", improving shot precision on target for ballistic applications or improving noise reduction, comfort and safety of structure and hull in naval applications. If embedded in wearable orthosis/exoskeletons, they can be used to increase human capabilities (e.g. load capabilities, shot precision on target for snipers), or in soldier training (e.g. on camp target/ships).

CONCLUSIONS

The final scope of the COMMON-LINK project is to prove the potential application of innovative devices based on ERFs/MRFs in the military domain. Such devices will be able to enhance the capabilities of platforms and subsystems by adapting their characteristics to the work conditions. Such final objective will be reached by enhancing the knowledge on the behavioral principles of ERF/MRF through computational modelling and experimental testing and by the design and development of ERF/MRFs based demonstrators. Achieving this objective will enable the future development of new devices suitable for the military sector. A set of constitutive relations for a variety of ERF/MRF fluids was obtained using the constitutive models and the relative computational tools developed, and will be used to develop ERFs/MRFs behavioral models in simple and complex flows, to be able to predict ERFs/MRFs performance in different device geometries. Several ERFs/MRFs samples were prototyped, using both commercially available and in-house synthetized particles after extensive characterization. In the next phases of the project, the nanoparticles synthesis and the associated ERFs/MRFs will be optimized in terms of performance and manufacturing process. Finally, the most suitable candidate will be embedded in the ERFs/MRFs demonstrators designed to provide evidence of the technology capabilities.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

ERFs	*Electro-Rheological Fluids*
MRFs	*Magneto-Rheological Fluids*

KEYWORDS

Electro-rheological Fluids, Magneto-rheological Fluids, Modeling, Particle dynamics, Constitutive models, Nanoparticles, Synthesis protocols, Robotics, Exoskeleton, Shock absorber.

PROJECT INFORMATION

PNRM number:	PA B.PRJ.RT.980
Organization:	European Defence Agency
Responsible entity:	Signo Motus s.r.l. as consortium coordinator. Altri membri: Consiglio Nazionale Delle Ricerche (IT) - Università di Roma Tor Vergata (IT) - Brno University of Technology (CZ) - University of Luxembourg(LU)
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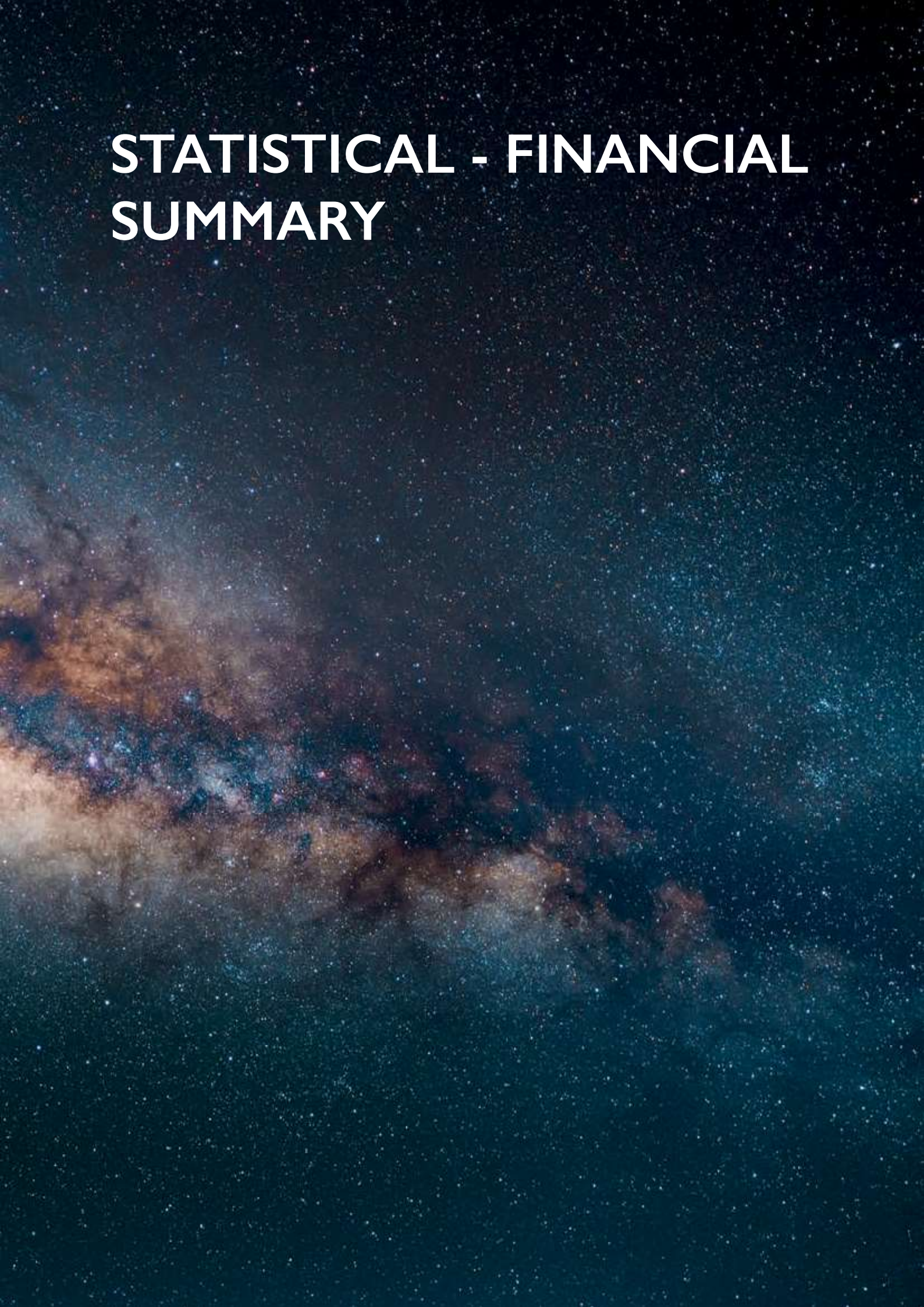
STATISTICAL - FINANCIAL SUMMARY



STATISTICAL - FINANCIAL SUMMARY

DISTRIBUTION OF FUNDING BETWEEN PNRM AND INTERNATIONAL PROGRAMS

The breakdown between projects of the National Military Research Plan (PNRM): projects within the European Defence Agency (EDA), projects deriving from Framework Agreements with the academic sector, technological research activities of the Defence Test Centers and international programs (multilateral and bilateral) referring to the year 2023 is shown in table 1.

Type	N. following phases of ongoing projects	N. new projects
PNRM	40	31
EDA	1	2
Framework Agreements	4	5
Test Centres	5	5
Bi-Multilateral	5	2

Table 1 - Distribution of mandates carried out in 2023.

BREAKDOWN OF NATIONAL FUNDING BY CAPABILITY/TECHNOLOGICAL AREAS

The annual distribution of national funding for capability/technological areas may vary based on the operational priorities expressed in the Defence sector. The national projects for the year 2023 were selected based on the criteria established in the address of the Minister of Defence and updated by the Chief of Defence Staff, favoring project proposals relating to the following application/technological clusters:

- **C2 and Multi-Domain situation awareness**: solutions capable of receiving, merging and representing in an integrated manner the data coming from sensors and military systems belonging to the five Operational Domains (land, maritime, air, cyber and space), Intelligence Surveillance & Reconnaissance (ISR).
- **Space technologies**: asset defence, Military Satellite Communications (MILSATCOM), Earth Observation, access to space, Space Domain Awareness (SDA), In-Orbit Servicing, Electromagnetic Spectrum Surveillance, stratospheric platforms.
- **Cyber technologies**: solutions for achieving awareness, defence and attack capabilities in the cyber domain.
- **Protection and enhancement of the soldier's capabilities**: human enhancement, awareness, defence and offense, reduction of the negative effects of illnesses.
- **Autonomous Systems**: technologies for the development and contrast of Robotic Autonomous Systems, Unmanned Systems (UxV).
- **Artificial Intelligence Solutions**: big data management and standardization of heterogeneous data (e.g. sensors, systems and databases), complementary automation of remotely guided systems in non-permissive EM environment, swarm intelligence, precision targeting.
- **Countering "emerging" threats**: directed energy weapons (including development of offensive capability), weapons capable of guaranteeing access to areas protected by Anti-Access/ Area Denial (A2/AD) systems or counter-A2/ AD, activities Cyber combined with Electronic Warfare actions (Cyber ElectroMagnetic Activities), hypersonic weapons.
- **Underwater**: technologies for controlling the underwater dimension and for the operational

effectiveness of the vehicles and devices that operate there.

- **Urban warfare**: technologies for the control of urban territory and for the operational effectiveness of the military vehicles and devices that operate there.
- **Sustainability, security and energy resilience**: solutions for reducing the logistical and environmental footprint, security and energy efficiency of military infrastructures and vehicles (smart buildings, Nearzero Energy Building, field structures, biofuels and hybrid propulsions, storage, renewable energy sources in military sector, energy management system and diversification of supply systems).
- **Bio technologies** (Bioinformatics, Biosensors and Bioelectronics), **smart materials and nano technologies**, strengthening and development of **CBRN** defence capabilities.

The identification of priority clusters has allowed for more effective and efficient planning and management of resources, directing technological research activities to the achievement of objectives consistent with the capacity needs and current priorities of the Armed Forces and minimizing the fragmentation of the technological sectors and the dispersion of resources across multiple and diversified activities, not all of which are specifically aimed at bridging the capability gaps identified at an operational level.

Technology Area (cluster)	% Funds	Number of projects
C2 and Multi-Domain situation awareness	9,7%	3
Space Technologies	16,1%	5
Cyber Technologies	6,5%	2
Protection and enhancement of the soldier's capabilities	16,1%	5
Autonomous Systems	6,5%	2
Artificial Intelligence Solutions	9,7%	3
Countering "emerging" threats	12,9%	4
Underwater	6,5%	2
Urban warfare	0,0%	0
Sustainability, security and energy resilience	9,7%	3
Biotechnologies	6,5%	2
TOTAL	**100%**	**31**

Table 2 - Breakdown of new national projects launched in 2023 with respect to the priority capability/technological clusters indicated by the Chief of Defence Staff.

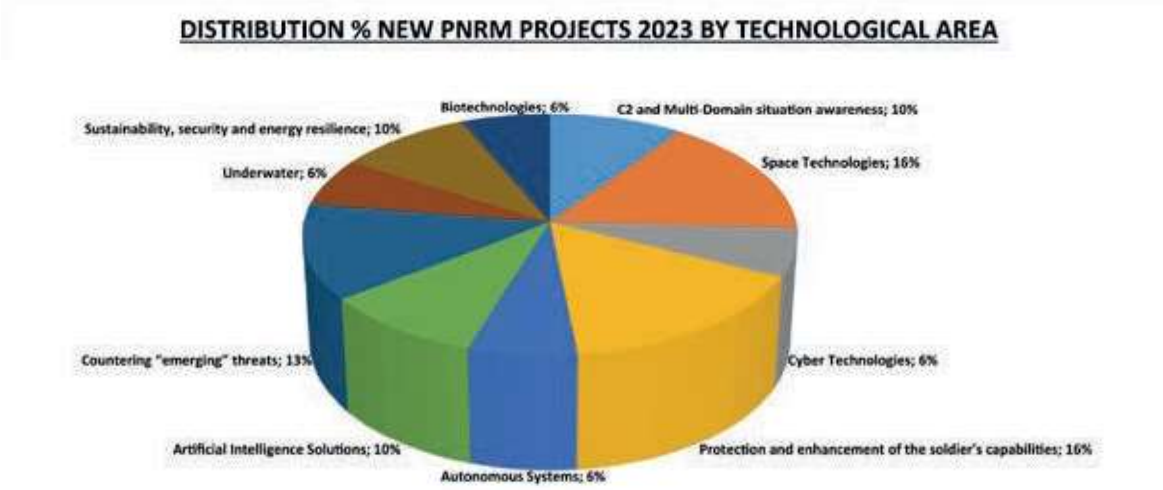


Figure 1 - Breakdown of new national projects launched in 2023 with respect to the priority capability/technological clusters indicated by the Chief of Defence Staff.

ABBREVIATIONS AND ACRONYMS

2-MF	Multi-Functional Modular Frame
AD	Amministrazione Difesa
AES	Advanced Encryption Standard
ALW	Airborne platform effects on laser systems and warning sensors
AODV	Ad Hoc On-Demand Distance Vector
AU	Actuation Unit
BEE DDS	Implementazione Leonardo dello standard DDS
BER	Bit Error Rate
BFN	Beam-Forming Network
BLOS	Behind Line Of Sight
C2	Comando & Controllo
CDMA	Code Division Multiple Access
C4ISTAR	Command, Control, Communications Targeting Acquisition and Reconnaissance
CIRA	Centro Italiano Ricerche Aerospaziali
CPA	Sistema Cooperativo basato su Percezione Aptica
COFDM	Coded Orthogonal Frequency Division Multiplexing
CMC	Materiale Composito a Matrice Ceramica
C/SiC	Composito con matrice di SiC rinforzato con fibre di Carbonio
COTS	Commercial Off-the-Shelf
CSM	Communication Spectrum Monitoring
CU	Control Unit
DIRCM	Directed Infrared Countermeasure
DDS	Data Distribution Service
DF	Direction Finding
DM	Directional Modulation (Modulazione Direzionale)
DT	Dimostratore Tecnologico
DVB-T	Digital Video Broadcasting-Terrestrial
EMI	ElectroMagnetic Interference
ESM	Electronic Support Measures
EFT	Electronic Functional Tray
ETSI	European Telecommunication Standards Institute
ELINT	Electronic INTelligence
EM	Engineering Model
E2E	End-to-End

EGSE	Electrical Ground Support Equipment
EDA	European Defence Agency
ENIVD	(European Network for Diagnostics of "Imported" Viral Diseases)
EOT	Energy on Target
FM	Flywheel motor
GHIBLI	Galleria la plasma da due MW presso il CIRA
GUI	Graphical User Interface
GFT	Geometric Functional Tray
GIM	Gimbal motor
GIS	Geographic Information System
GPS	Global Positioning System
GPU	Graphical Processing Unit
GEOINT	GEOspatial INTelligence
HfB2	Diboruro di Afnio
IDS	Intrusion Detection System
INS	Inertial Navigation System
ISR	Intelligence Surveillance and Reconnaissance
It-MoD	Italian Ministry of Defence
IMINT	Image INTelligence
ISL	Inter Satellite Link
IR	Infrarosso
J/S	Jammer-to-Signal ratio
LEO	Low Earth Orbit
LC	Load Case
LT CES	Communication Electronic Support Measures
LICOLA	Low Interceptable Communication Link Antennas
MCMG	Mini Control Momentum Gyroscope Assembly
MAC	Medium Access Control
MALE	Medium Altitude Long Endurance
MANET	Mobile Ad-hoc Networks
MCS	Mission Control System
MS-DEP	Multi-Sensor Data Exploitation Platform
MWS	Missile Warning System
NEC	Network Enabled Capability
NCS	Network Control System
OBL	Optical Break Lock
OMG	Object Management Group

ABBREVIATIONS AND ACRONYMS

OTW	Other Than War
OBP	On-Board Processing
PCR	(Polymerase Chain Reaction)
POC	Posto Operatore Centralizzato
P/F	Piattaforma
P/L	Payload
POI	Point Of Interest
RMSE	Root Mean Square Error
RIFON	Rete Interforze in Fibra Ottica Nazionale
RPAS	Remotely Piloted Air System
RSV	Reparto Sperimentale di Volo
SATCOM	Satellite Communication
S/C	Spacecraft
SIMP	Solid Isotropic Material with Penalisation
SHF	Super High Frequency
SIC	Carburo di Silicio
SICRAL	Sistema Italiano per Comunicazioni Riservate ed Allarmi
SiC/SiC	Composito con matrice di SIC rinforzato con fibre di SIC
SOTA	State Of The Art
TA	Technical Arrangement
TAPR	Aeromobile a Pilotaggio Remoto
TAS-I	Thales Alenia Space Italia
TAKS	Topology Authenticated Key Scheme
TRL	Technology Readiness LevelDMA
TRM	Traffic Resource Manager
TRM-DB	TRM Data Base
UV	Ultra Violetto
UHF	Ultra High Frequency
VANET	Vehicular Ad-Hoc Networks
VFT	Volumetric Functional Tray
VHF	Very High Frequency
WP	Work Package
WIFI	Wireless Fidelity
WIDS	WPM-based Intrusion Detection System
WSN	Wireless Sensor Network
WHO	(World Health Organization-Organizzazione Mondiale della Sanità)
ZrB2	Diborure di Zirconio

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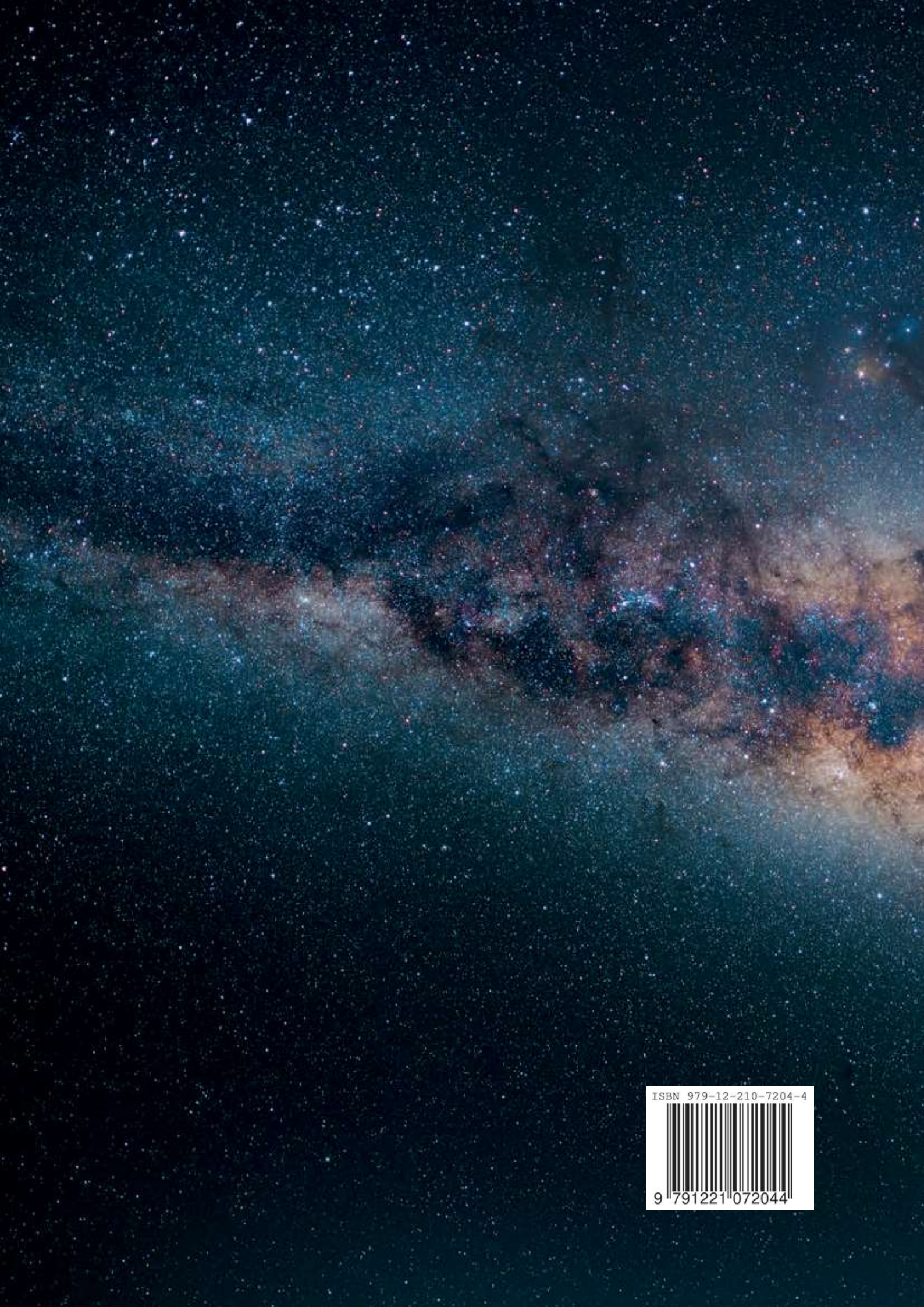

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