Digitalization, Cloud, Extended Reality and Connectivity for Remote Training and Support

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ABSTRACT

In the demanding field of Aerospace, Defence & Security, operative and maintenance personnel must demonstrate excellence in guaranteeing operation of systems. Training and remote support are therefore critical activities strongly contributing to achieving this goal. Satisfying highly standardized procedures and complex tasks, when performed in a traditional manner, presents significant drawbacks in terms of logistics, costs, safety & security and environmental considerations. Emerging technologies, particularly those promoting full interconnectivity, are promising innovative solutions to resolve these issues. This is being addressed in particular by the Modelling & Simulation as a Service (MSaaS) paradigm, while emerging technologies such as virtual, augmented and mixed reality (VR/AR/MR) provide revolutionary approach, able to drastically reduce costs and improve performances. In this context and within the ongoing digital transformation of the Group, Leonardo is developing innovative solutions for remote training and support through the development of an integrated Collaborative Digital Platform allowing customers to be fully assisted in operation, connecting remotely with experts and accessing all relevant documentation stored and referenced securely on a cloud. Nevertheless, the success for implementation and operation of such dedicated platform is predicated on considerations including full connectivity, data ingestion and processing, cloud computing and cybersecurity, artificial intelligence to name a few.

Keywords: Modelling & Simulation, Cloud Computing, Extended Reality, Connectivity, Training as a Service, Remote Training and Support.

1.0 INTRODUCTION

Over the last decade, the world and its Industry have entered what has been defined the Fourth Industrial Revolution. It has been characterized in particular by the emergence of innovative technologies and technics such as hyper-connectivity, AI, robotics, IoT, autonomous vehicles, additive manufacturing, nanotechnology, biotechnology, materials science, energy storage, quantum computing and more [1]. One of the most drastic shift in the way people used to operate and cooperate is the rise of platform technologies enabled in particular by digitalization. Most relevant industries are, in facts, currently in the midst of the now well-known Digital Transformation. While rarely using the term "revolution", the global defence field, including NATO, is certainly surfing the wave of Digital Transformation across many (if not all) sectors.

The Army requires the capability to prepare units in complex realistic environments, including flexible scenarios where threats and the Operational Environment (OE) change continuously, so as to ensure well-trained and ready personnel capable of conducting missions across the whole range of military operations. Leveraging on emerging technologies, the military is now more than ever focused on creating full spectrum Operational Environment (OE) capabilities and learning experiences to train and prepare units for future combat situations, which are shaped by global security that is volatile, uncertain, complex and ambiguous. Innovation in the use of Digital Technology has injected more and more capabilities in the military field. To a great extent, and according to the NATO Modelling & Simulation Master Plan, future military capabilities (i.e. doctrine, training, operations, etc.) will be developed and supported by Modelling and Simulation (M&S) [2,3]. To underline this importance, the NATO M&S Group (NMSG) within the NATO STO has set up a programme to propose, promote and coordinate cooperation among Alliance bodies, NATO member nations and partner nations to maximize the effective utilization of M&S solutions. According to their vision, it is essential that M&S services and tools are conveniently accessible to a large number of users as often as possible thereby enabling an "as a Service" approach to provide more cost effective availability of "on-demand" products, data and processes [4].

To enable this, many defence forces are attracted to Live, Virtual, and Constructive (LVC) environments for training purposes. Such an approach really pushes the limits of traditional training methods as it offers a safe, more realistic and immersive experience. It also provides an infinite space to conduct training as well as all variable threats needed for added realism. M&S as a Service (MSaaS) has been defined in the NATO STO Technical Paper MSG-131 [5]: "*M&S as a Service (MSaaS) is a means of delivering value to customers to enable or support modelling and simulation (M&S) user applications and capabilities as well as to provide associated data on demand without the ownership of specific costs and risks.*". This "as a Service" approach is driving the world-wide community in developing products that match this idea with the newest technologies and with the aim to get a significant modernization not only in terms of products, but also in their related business model and their impact on the relationship of the industry with buying authorities. Leonardo, as a leader in the international Land, Naval, Aerospace, Defence and Security sector, has been developing state-of-the-art solutions in line with these concepts.

The present paper describes and discusses some of the solutions developed by Leonardo, focusing mainly on innovative training purposes, which significantly disrupt conventional approaches. More specifically, the cloud platform OCEAN for delivering services is described, as well as an associated Synthetic Environment (RIAce) and a secured network infrastructure between M&S centres (SHORE). Furthermore, Extended Reality tools specifically designed for training purposes are also presented (Virtual Maintenance Trainers and Morpheus XR). At last, a remote support solution not based on M&S concepts is discussed (Collaborative Digital Platform). This selection of innovative solutions, leveraging on emerging technologies, have a significant impact not only on the effectiveness and efficiency of training and support activities but also on military logistics in terms of costs, time, effort and practices.

2.0 MODELLING & SIMULATION SOLUTIONS

2.1 Modelling & Simulation as a Service (MSaaS): Leonardo's solution OCEAN

As hinted in introduction, MSaaS is a mean of providing on-demand services to customers through cloud networking technology by a Cloud Services Provider (CSP), allowing access to applications, functionality and data of M&S without the need to be the owner of specific materials that make up the service. MSaaS is therefore relying on cloud computing which has five essential characteristics described in more details by the NIST [6]: On-demand self-service, Wide network access, Resource pooling, Rapid flexibility of use and Measured service. It keeps the underlying infrastructure, the requirements and details of the platform as well as the actual software "hidden" to the customer from a technological and administrative point of view, as the end user is seen as a "user of a service" rather than the "owner of a capability". This "as a Service" approach presents significant advantages such as "on-demand" offer and the possibility of sharing data, models, resources, practices, and any other theoretical or operational knowledge with the group adhering to the service thereby allowing a more effective exploitation of available resources. The use of M&S solutions has an increasing role in the management of critical situations and in complex operational contexts especially for planning, execution and management of training activities, as well as analysis and decision-making.

Leonardo has developed a platform, OCEAN (Open Cloud Environmental ApplicatioN), aiming to implement interoperable solutions that are federated and economical. OCEAN is an environment for orchestrating both physical and virtual applications and networks, equipped with a graphical and intuitive web interface (drag & drop), capable of creating and managing dynamic deployment of environments for products and services. Although OCEAN is essentially a "container of services", Leonardo has mainly used OCEAN as a platform for delivering Training as a Service (TaaS) solutions. Matching the MSaaS paradigm and combined to Extended Reality technologies integrating Synthetic Environment and Simulators/Simulation solutions, it enables not only the comprehensive management of training activities but also the precise and certified evaluation of students assured in particular by blockchain technologies promoting efficiency as well as savings in costs, time and effort.

By virtue of its open characteristics, OCEAN has been used successfully as a Concept Development & Experimentation (CD&E) tool in training situations including complex environments in which several simulators and services have to interact enabling the creation of such environments and providing all the needed resources to execute the simulation drills. OCEAN allows to support the entire life cycle of a complex system from design to development, integration, testing, verification, resilience analysis, operational and training operations as well as maintenance activities. The simulation elements and resources can all be managed by OCEAN, connected externally or internally as services, making OCEAN the manager of a very complex distributed environment. The innovation of OCEAN meets most of the highly demanding requirements that come from the military, from NATO and also from the European commission. More specifically, the platform provides the following functionalities:

- Management of critical situations (environmental disasters, terrorist attacks, military operations, etc.);
- Management of laboratories (i.e. any place and asset used for training) as well as real or virtual test benches both on local and geographic network;
- Concept Development and Experimentation (CD&E) to conceive, design and study in a simulated environment the adoption of new operational concepts (CONOPS) and existing resources or new acquisitions (CONUSE);
- Support engineering of complex systems throughout their life cycle (design, development, integration, logistic support and maintenance);
- Training of personnel on complex systems focused in particular on procedures, strategies and

decisions in relation to specific scenarios;

- Integration into the system of associated virtual and physical resources, including non-simulation resources (e.g. real systems or commands and control);
- Availability, Repeatability and Automation by virtue of the availability of models and simulations on demand and at all time;
- Increased capabilities by sharing and reusing resources (models, services, data) which extend the services leading to significant cost savings;
- Rapid adaptation to changing needs by virtue of its flexibility of use and the sharing of resources;
- Easy management of resources (HW & SW) without requiring any specific skill in cloud, virtualization and networking technologies;
- Reduction of inconvenience thanks to easier management of the set up (install, configure, etc.) of a complex system through friendly interface, navigation and access management;
- Reduction of the effort to allocate assets for training activities (hardware, rooms, skilled personnel, etc.);
- Significant reduction of human errors (the low-level instructions are hidden to the users thereby preventing making mistakes);
- Interface through convenient APIs (Application Programming Interface) to also enable interaction with external applications easily;
- Reduction of cost, time and effort as a result in particular of the ease of management of activities.

The functional architecture of the OCEAN platform (Figure 1) is structured on 4 levels. The core of the system consists of the services (Service Layer) which are performed in cooperation in a complex distributed scenario to achieve the required objectives. Communication between these services is possible through the Communication Layer which is composed of three buses (Figure 1) designed for the transit of congruent data specific to the type of service offered.

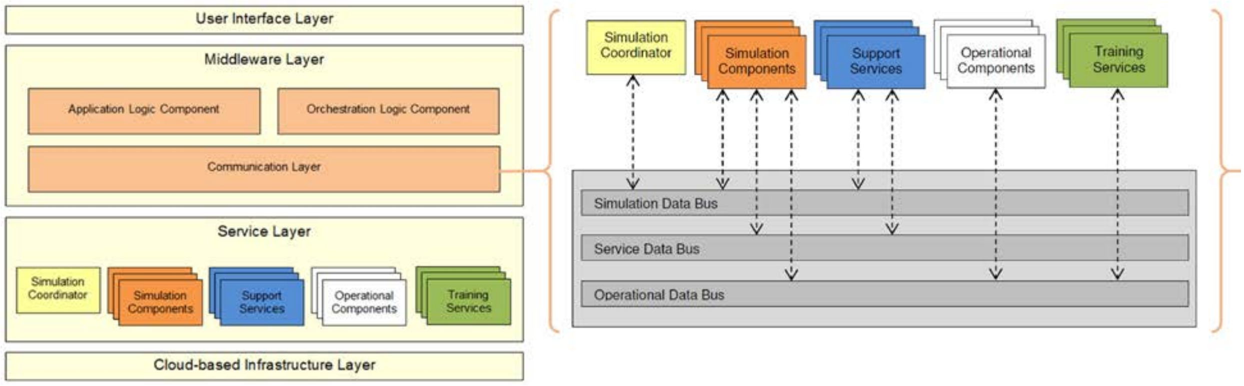

Figure 1: Functional architecture of OCEAN (left) and Communication Layer (right)

As mentioned previously, OCEAN is essentially an orchestrator system that aggregates new technologies and is able to provide services on demand. Containers, simulations of complex networks and the use of advanced graphics are elements of great interest. Although these technologies were unavailable in a cloud environment, they have recently reached a high degree of maturity to be incorporated into a single environment such as OCEAN. The system architecture includes a hybrid cloud capable of managing indifferently physical machines (e.g. real C2 consoles), virtual machines and containers. The platform is based on OpenStack installed within a VMware cluster [4]. OpenStack is an open source system that allows rapid expansion with external services. An “ad hoc” module has been developed for orchestrating physical/virtual networks, physical/virtual machines, as well as micro-applications (containers). Another qualifying element of OCEAN is the ability to manage high definition and complex 3D graphics, so that it can run demanding simulations that require advanced calculations on Graphics Processing Units (GPUs). The solution uses the software NVIDIA vGPU, installed on a physical GPU in a cloud or on a server, to create virtual GPUs that can be shared across multiple Virtual Machines (VM).

The idea of developing a heterogeneous service platform using a cloud system (public, private or both/hybrid) was conceived in accordance with the MSaaS paradigm to provide the maximum degree of freedom of use to the platform. Leonardo in collaboration with the NATO Modelling & Simulation Centre of Excellence (M&S CoE) in Rome, has used OCEAN for a series of exercises to provide Modelling & Simulation and Training services through the cloud for advanced military systems, also using virtual and immersive reality [7-10].

The availability of services is managed through a web portal (Figure 2) which has three main functions: Discover services, Compose and Execute sessions. The web portal enables access to the services and allows managing these services according to credentials. Users can access a marketplace-type catalogue, select the services of interest and integrate them together through an intuitive graphical interface in an easily reconfigurable and scalable way.

Figure 2: OCEAN access web portal

Over the years, the platform has been upgraded with a number of features making it extremely flexible and easy to use in the context of training (Figure 3), managing hardware, software, simulators, simulations, didactic material, and all other resources needed to create any complex scenario for training in all domains of application (Figure 4).

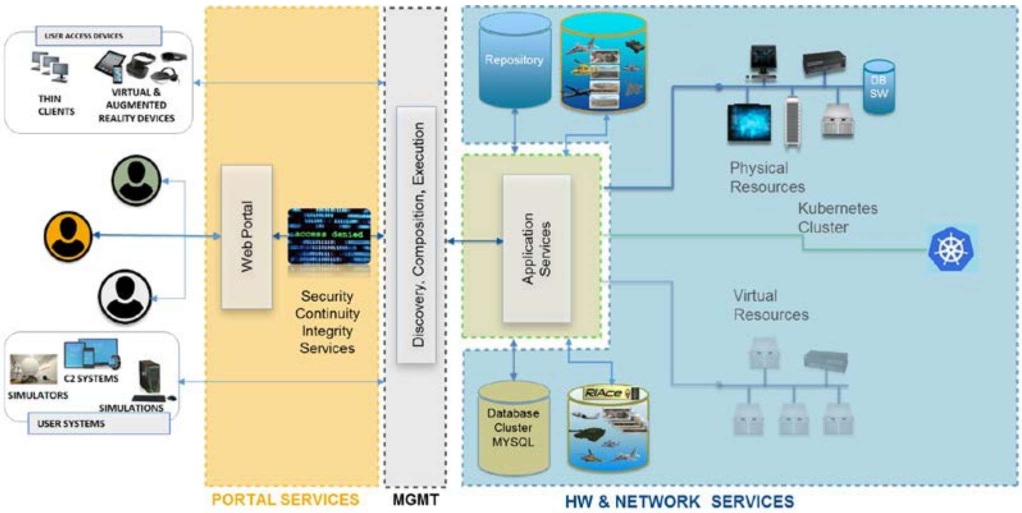

Figure 3: How OCEAN Works

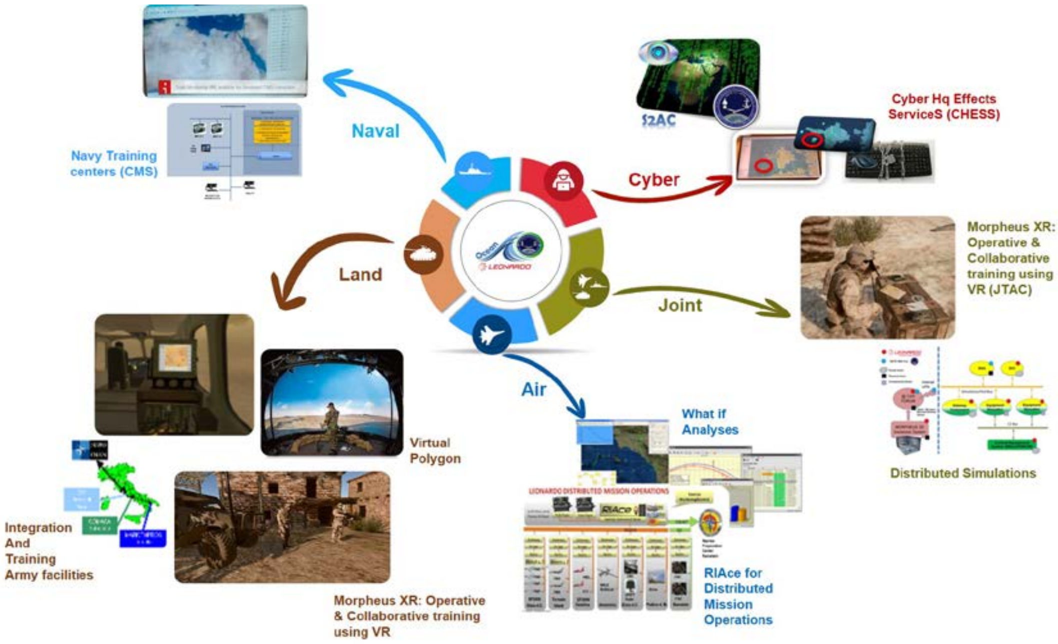

Figure 4: OCEAN Multi-Domain Application

2.2 Synthetic Environment: Leonardo's solution RIAce

A Synthetic Environment (SE) is a computer-based simulation that represents the world (or *a* world), usually a highly realistic operational space, within which any combination of "players" can interact. Players can be computer models, simulations, people or real equipment. The operational space can be environments of various categories from operational theatres with armed conflict or crisis management operations, to homeland infrastructure with factories and production facilities. These environments can be generated on a single computer or a large distributed network connected by a Local or Wide Area Network (LAN/WAN). The SE can be connected to a system that allows the visualization of the environment on screen (monitors, portable devices and simulators) or possibly associated to Virtual Reality (VR) techniques for a full virtual immersion in the simulation. In this latter case, it can be enriched with very realistic special effects and accurate behavioural models.

RIAce (Realistic Intelligent Agents for Computer Environments) is a Synthetic Environment designed and developed by Leonardo. Via High-Level Architecture (HLA) or Distributed Interactive Simulation (DIS), it is able to simulate and provide to different users, some of which may be remotely connected, either single events (e.g. "one-to-one" air-to-air engagements) or complex missions with the participation of air, ground and sea capabilities (e.g. COMAO: Composite Air Operation). RIAce allows the simulation of low and high intensity war scenarios including self-generated civil air traffic, merchant and fishing vessels, pedestrians and vehicle traffic on urban and country roads. Specific profiles can be associated to these models such as smugglers and traffickers of immigrants, rebels and other types of actors of interest for a realistic and engaging reproduction of a particular training scenario for military or emergency management purposes.

RIAce is based on a client-server architecture. The core component is the SE Server, while client applications consist in a series of Ownship-Related Modules (ORMs) including simulation models (for example flight models) that are hosted on the same Ownship processing system and defined as the Weapons System Simulation (Figure 5). RIAce therefore conveniently allows different simulators to be federated on the network to participate in a joint distributed exercise. A typical distributed simulation system architecture includes elements connected via LAN (e.g. local simulators on the same Operating Base) and other components connected via WAN (Figure 6) supporting HLA/DIS interface or via a proper gateway.

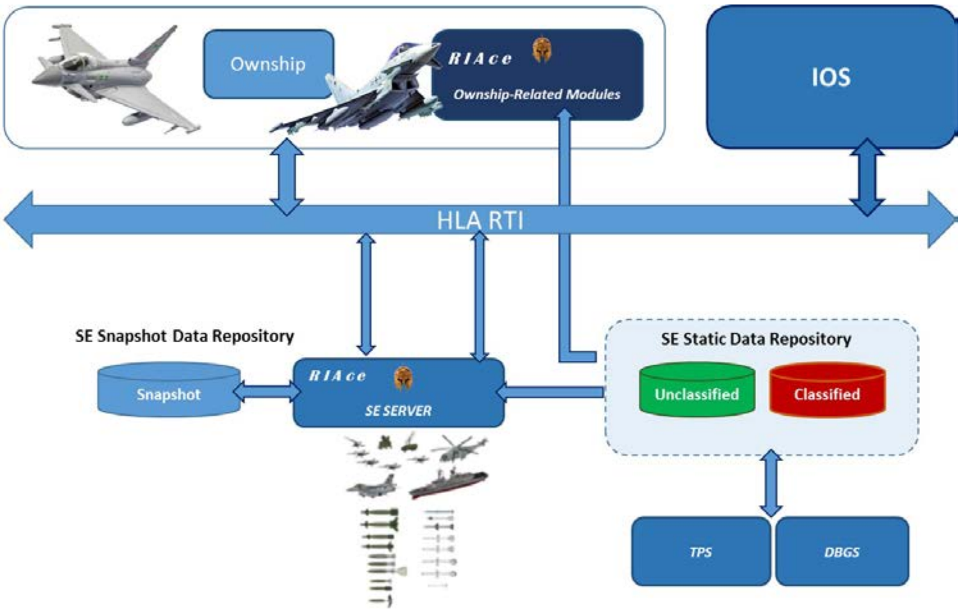

Figure 5: System architecture of the Synthetic Environment RIAce

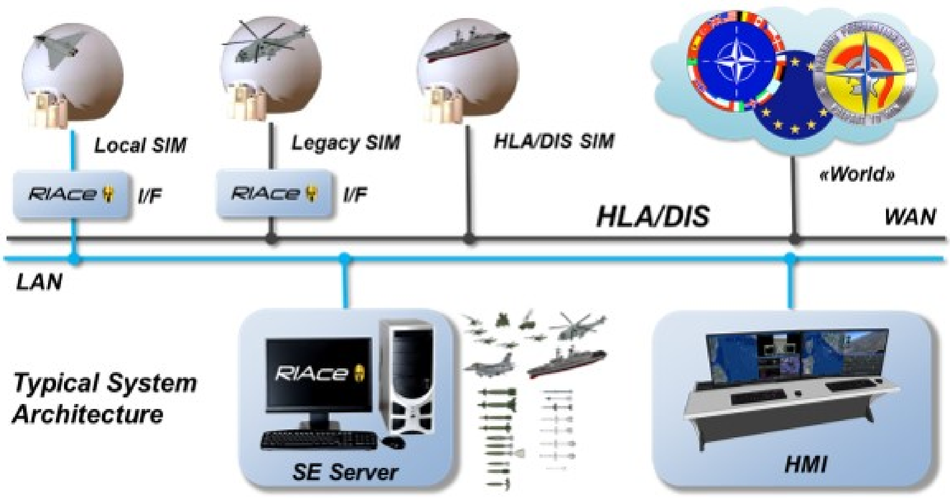

Figure 6: Example of a simple network federation with three simulators connected over LAN/WAN with RIAce

HLA/DIS interface allows for "remotization" of user control stations (role-play) and scenarios from RIAce servers. In this way, resources need not to be concentrated on the same location and can be conveniently shared thereby creating efficiency in the use of valuable assets. Using this unique feature, users (such as pilots) can either run local instances of a RIAce Computer Generated Forces (CGF) server that is started on their own platforms or the actual network architecture can include a hub hosting CGF servers where a large number of participants are connected in a star configuration in case a more complex simulation is needed. This latter architecture was used successfully for the Spartan Distributed Simulations Exercises (Spartan Alliance 18-8 and Spartan Warrior 19-2 [11-15]) in order to provide a single point of access to the Classified Combined Federated Battle Laboratories Network (CFBLnet). In these exercises, several flight simulators were connected via HLA/DIS to RIAce platforms that generated and distributed a complex scenario in which all connected simulators cooperated (Figure 7).

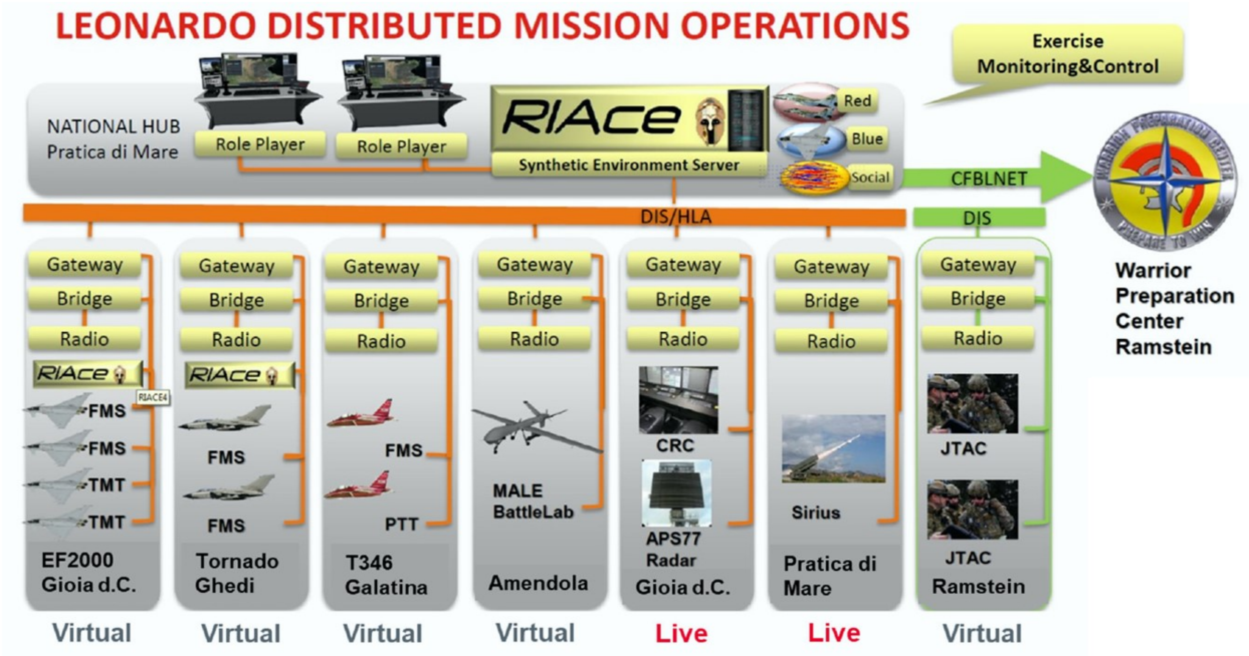

Figure 7: Network architecture with a central HUB used in the SPARTAN Alliance exercise

RIAce allows instructors to plan and execute autonomous networked missions (single/multi ownship) as well as COMAO coalition missions, which would otherwise be very difficult or impossible to coordinate, with emphasis on the following roles:

- Offensive/Defensive Counter-Air Operations (OCA & DCA);
- Quick Reaction Alert (QRA);
- Strategic Operations such as Suppression of Enemy Air Defence (SEAD);
- Support to Land Operations such as Close Air Support (CAS) or Joint Fires;
- Support to Maritime Operations such as Anti-Surface Force Air Operations (ASFAO) or Anti-Submarine Warfare (ASW);
- Imagery/Geospatial Intelligence (IMINT-GEOINT) collection;
- Tactical Ballistic Missile Defence (TBMD).

In support of the above, RIAce provides an interactive environment populated by synthetic players at different levels of fidelity/complexity to support projected missions as well as the ability to interconnect external simulations bringing additional players. The planning of missions and scenarios is based on an ATO/ACO concept (Air Tasking Order / Air Combat Order) to facilitate the preparation of multiple and complex COMAO missions on a realistic geographic scenario with the ability for instructors to define adequate parameters for the configurable characteristics of the synthetic players. CGF have an integrated level of knowledge allowing them to automatically customize their behaviour based on the roles selected by the user (for example Fighter SWEEP, Fighter ESCORT, STRIKE, SEAD, etc.) without the user having to build long and complicated doctrines.

As discussed in section 2.1, OCEAN is a platform able to deliver services. One of the most interesting application of OCEAN is delivering Training Services in which Synthetic Environments, VR technologies and Training Systems share their resource to create a unique federated M&S ecosystem consisting in a series of services and resources distributed on the cloud. These are interconnected via a communication layer, characterized by specific buses (see Figure 1), to allow for communication between the various services, the system management of OCEAN itself ("as a Service") and various physical resources (including users). The SE RIAce is also a federated service allocated within the cloud, essential for a multitude of training services. Training services (both for operative and maintenance purposes) are provided by a series of products leveraging in particular on immaterial and immersive VR solutions (see section 2.4) which can be shared within the community of users. Delivering Training Services using these solutions allows to create an agile environment for Live-Virtual-Constructive (LVC) training activities, defined by the United States Department of Defense in the Modelling and Simulation (M&S) glossary [16].

A typical framework can be described as follows:

- OCEAN, according to the MSaaS paradigm, provides the discovery of services, the composition of the applications, the provisioning of all virtual and real resources, the execution of the specific exercises and, eventually, the termination and release of the resources thereby saving associated costs, time and effort;
- RIAce provides complex scenarios (for example geographical locations with civil and military infrastructures), simulation results and models. These can furthermore be shared nimbly over the network;
- Morpheus XR, for example, allows the trainees to be immersed in such scenarios. The Virtual Reality products, described later in section 2.4, support the interaction between users and all the virtual assets (i.e. all virtual models coming from RIAce simulation).

2.3 Integrated Network: Leonardo's solution SHORE

Simulations are widely used for the development, integration or demonstration of systems at many Leonardo facilities. Interoperability among these facilities enables sharing resources, experience, infrastructures and simulated environments to achieve capabilities that go far beyond those of each individual centre. Many applications developed by Leonardo in the domain of MSaaS require a communication network infrastructure to be able to communicate not only with each site but also with external Agencies. To this end, SHORE (Simulation Hands-On, Review & Experimentation spaces) aims to establish a permanent network between M&S centres across the Leonardo Group also establishing bridges towards external agencies. Such networking transforms the current separated centres (engineering facilities, integration rooms, simulation laboratories, etc.) into a single structure to allow a seamless interoperability across the various simulation systems developed and running at different sites, without the need to move or duplicate them.

Figure 8: Example of implementation of SHORE network between Leonardo's M&S centres

The architecture of the network is scalable and any future centre can easily be added to those already in place. Figure 8 shows the current state of implementation of the network (in 2021) between selected M&S centres and Figure 9 shows the network connecting resources to different centres.

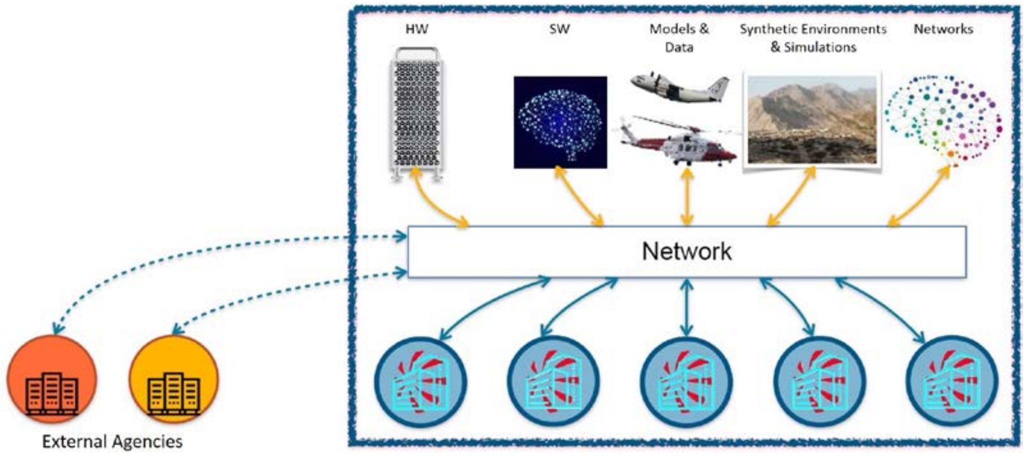

Figure 9: Leonardo's SHORE Network for establishing a permanent network between M&S centres across the Group as well as bridges towards external Agencies

The implementation of the network presents significant benefits:

- Reducing costs and optimization of time: sharing common resources allows savings in the assets acquisition (community of commodities), reduction of staff movements to reach all sites (distributed knowledge), as well as the optimization of investments by changing business models and approaches;
- Increasing the capacity to share and more importantly reuse resources: sharing of HW and SW, sharing and reuse of models, Synthetic Environments, simulations, data and more, shared access and network centralized/decentralized control;
- Rapid adaptation to changing needs: new HW & SW, different Models and Environments, Service network improvements;
- Increasing Cyber Security of applications, deployed in a closed and private Company network.

Using the SHORE Network, it is therefore possible to connect internal facilities with external customers or resources enabling the full implementation of the MSaaS paradigm and assuring the interoperability of systems.

2.4 Extended Reality

Virtual and Augmented Reality can be used for so-called Technology Enhanced Learning in a classroom. These technologies transport the user into an environment perceived as real and able to inspire emotions. The learning experience is significantly enhanced by these unique immersive capabilities which complement and possibly substitute to some extent classroom courses and prepare for Hands-On Training. Achieved by utilising informed instructional design, these attributes can reduce the cognitive load for learners, making knowledge transfer more effective. However, the adoption and the application of technologies for their use in education has and still is facing a number of challenges which include for example perception, health and whether using Extended Reality technics are actually more effective than conventional methods [17].

Some of the main capabilities and benefits of this modern approach to training, using virtual training over conventional training approaches "on the job", can be summarized as follows:

- Engage trainees using a fun, interactive and safe way of game-based learning, otherwise known as the gamification of training, which significantly shortens the learning curve;

- Share the same virtual training experience between trainees and/or instructors located at different locations and possibly at the same time and in cooperation;
- Familiarize with real system characteristics and perform activities in line with the physical constraints of the system components;
- Reduce significantly inconvenience associated to transportation (personnel and/or training assets), costs, time, pollution, health & safety protocols, etc.;
- Contain commissioning and operating costs as maintenance simulators are based on relatively cheap commercial hardware (basically a suitably sized and configured PC) on which the simulation software is installed or available as-a-service, as opposed to physical system representative of a real platforms for Hands-On Training activities;
- Maximize safety by virtue of the SE and digital interactions preventing the risk of injury or damage to operators or assets, respectively;
- Enhance practice and significantly reduce errors due to the unlimited availability on demand and on time of operational procedures which can be updated, integrated, paused and repeated;
- Select and perform any of the exercises/procedures available for a specific asset, as well as examination sessions. All actions can be recorded and can be played back step-by-step on the virtual model, while the associated technical publication (for example the maintenance procedure) is displayed. All steps of the performed procedure can be exported in video format, either to monitor a trainee's progress, evaluate performance or create video tutorials.

The above list of convenience strongly suggests that virtual training improves efficiency, safety, planning, evaluation and reporting of training activities while at the same time reducing significantly costs and time for both customers and Training Services.

2.4.1 Virtual Maintenance Trainer (VMT)

Aircraft maintenance activities performed by skilled aircraft technicians is vital to ensure the safety of air operation as well as to maintain efficiency and readiness of the fleet. These capabilities are achieved through theoretical courses held in structures [18] recognized by national and international aviation authorities such as the Ente Nazionale Aviazione Civile (ENAC) in Italy or the European Aviation Safety Agency (EASA). The theory is almost always complemented by practical activities on the job (Hands-On Training). A great part of these practical activities can be achieved by using modern training solutions such as Virtual Maintenance Trainers (VMTs), which allow both trainee and aircraft to operate in complete safety. A VMT is a user-friendly simulation-based training solution, which primary goal is to engage maintenance technicians and motivate them to learn by promoting the concept of gamification [19,20]. This brings about several benefits including savings in time and cost while enhancing the overall safety of task operations (for both the operator and the asset) and the efficiency of training. It includes a computer-based interactive 3D environment that reproduces the real life aircraft in a virtual immersive world and leverages on simulation models that replicate the behaviour of the aircraft main systems with a specific level of fidelity.

In such a virtual world, the trainee can get familiar with routine maintenance and repair of faults (even the most complex, critical or dangerous), before (and sometimes instead of) training with the real aircraft or equipment. The system guides the trainee to the correct application of the procedures bringing the so-called learning-by-doing approach to training. The trainee can also monitor the learning progress in order to stimulate the ability to analyse and identify faults. Using virtual training, trainees work in complete safety for themselves and for the system because the simulated environment prevents any typical dangerous conditions that can be present with working on a real aircraft such as for example high hydraulic pressures and electric voltages, heavy objects, sharp edges and many more. At the same time, any misguided action does not cause damage to the system and does not threaten the safety of the operator.

For over 10 years Leonardo Aircraft Division (LAD) and Leonardo Helicopters Division (LHD) have worked together to develop a common framework for an advanced VMT system characterized by a realistic virtual environment navigable with great ease [21]. Such high definition realistic environment has been obtained by effectively combining highly optimized 3D models to photographic textures taken from photographs of the real aircraft (fixed or rotary wings). The accurate model of the aircraft is placed into a virtual hangar where the typical Ground Test Equipment (GTEs) and necessary tools for maintenance have also been reproduced (Figure 10). GTEs provide in particular electric and hydraulic power to the aircraft systems when it is on the ground. The virtual GTEs and tools are also fully operating virtual copies of the real appliance including all connections to the aircraft.

Figure 10: M345 trainer aircraft (top) and AW101 SAR helicopter (bottom) VMTs

The graphic models of the assets are associated to related software models that simulate their behaviour, both in normal/degraded operations and in the presence of malfunctions. This part of the system has been developed using the simulation engine Distributed Maintenance Training Infrastructure (DMTI©), property of LAD. The simulation has been specifically targeting maintenance training purposes which is why the simulated aircraft and its systems is limited to on-ground conditions, the situation faced by maintenance personnel. All systems operation dynamics (for example the pressurization of the hydraulic system) are highly faithful to real-life behaviour including for example the alarm activation thresholds. Instrumentation in the cockpit has also been accurately reproduced: all switches, buttons, knobs and indicators on the instrument panels are operative as well as all displays where information related to systems appear (Figure 11).

Figure 11: M345 Trainer aircraft virtual cockpit

There is a general effort to maximize the reality in VR. This is for example the subject of AIR4MAM (Addestramento Immersivo e Manutenzione a distanza 4.0 per l'Aeronautica Militare) funded under the Piano Nazionale della Ricerca Militare 2019 (PNRM) [22, 23]. The AIR4MAM project aims to experiment the use of immersive virtual reality technologies and wearable haptic devices thereby producing a fully immersive, user-friendly and effective virtual training environment (Figure 12). The main goal is therefore to reach an extremely realistic and natural way of interacting with the virtual aircraft or equipment. An important objective of the project is to evaluate the risk of so-called cybersickness and assess possible approach to face undesirable consequences beyond the sickness itself in order to keep high the effectiveness of maintenance training [24]. Similarly, the convenience and effectiveness of haptic devices are studied both in terms of interaction with the virtual scene and operation with the virtual tools (e.g. wrench, screwdriver, etc.). In the near future immersive VR systems will be the state-of-the-art for aircraft maintenance training, as now happens for desktop VMTs. This technology and method increase the emotional engagement of the learner and consequently provide a better instructional experience in a safe and always-available environment, resulting in a more efficient approach to operational skills development.

Figure 12: Immersive VR operation

2.4.2 Morpheus XR: Immersive VR and MR Solution for Simulation and Training

Leonardo developed another system named Morpheus XR for immersive and interactive training in Virtual and Mixed Reality environments, which supports HLA protocols for the integration of simulation applications. While VMTs previously discussed focus on aircraft maintenance (fixed or rotary wings), Morpheus XR supports the practical phase of maintenance training of ground and naval equipment and is similarly characterized by a Computer Software Configuration Item (CSCI) together with a hardware device for VR. The system also adopts a Virtual Reality Environment global approach where it allows users to perform a number of activities in a synthetic and photorealistic environment including system familiarization as well as operative and maintenance procedures. It supports instructors during the preparation and execution of practical training while trainees experience virtual training in an easy and cost effective way without the need for transportation of personnel and/or equipment to training locations.

In addition to the outcomes listed in the introduction to section 2.4, the immateriality of the models allows their distribution on the network and their use remotely leveraging in particular on the platform OCEAN described in section 2.1. The combination of these solutions, Morpheus XR and OCEAN, provides on the one hand the virtualization of physical models, environments and scenarios while guarantees on the other hand the efficient management of network resources and the synchronous distribution of virtual contents. It offers an efficient, safe and cost effective approach to training of personnel on equipment operation and maintenance. It replicates a real environment/scenario in a safe virtual space, where trainees are able to move naturally and interact as if they were physically in presence of the real asset. Failures can attractively be simulated putting the trainee in face of real complex situations to be solved without the cost of using real physical assets that could be damaged and including scenarios which would be otherwise impossible to practice (for example during Hands-On Training).

Morpheus XR is based on a game engine (Unity 3D engine) that allows real-time rendering and interactions with the virtual objects or a physical mock-up, implementing physical constraints and operative behaviours. Thanks to a built-in gateway for the interoperability with HLA/DIS networks, operative training sessions can be performed in which the users can interact with a dynamic simulated scenario created and managed by the system. During an activity, the trainee can therefore interact with the asset components, choosing the correct tools to be used and operating on the correct parts, experiencing real-life constrains and limitations related for example to the size and position of specific parts (Figure 13).

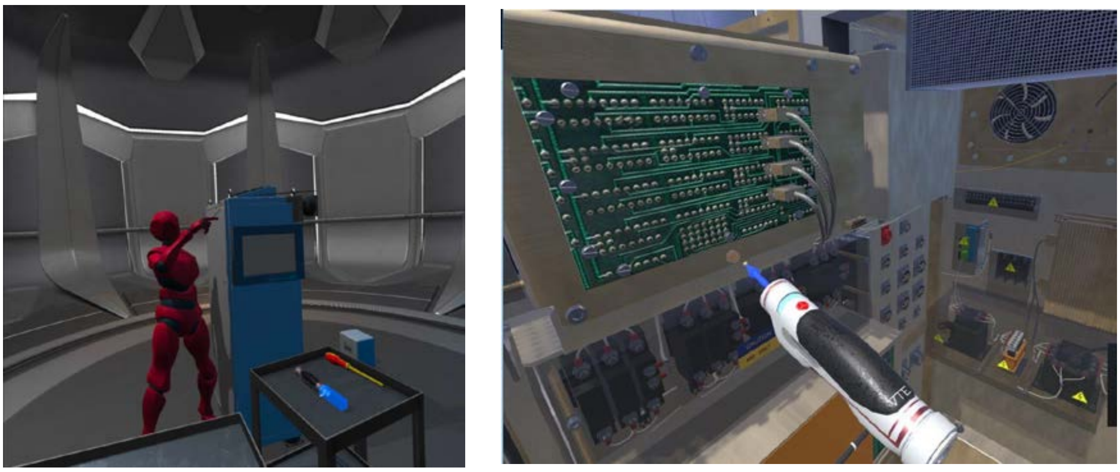

Figure 13: Example of an avatar of a technician in Morpheus XR and interaction with a virtual asset using a tool

3.0 REMOTE SUPPORT SOLUTION: DIGITAL COLLABORATIVE PLATFORM

A few years ago, a Customer Air Force faced a critical incident on a C-27J aircraft deployed in operation abroad: during taxi before take-off for an operative flight, the aircraft experienced damage on the main landing gear assembly and burst of one of the pneumatics. This real incident required the urgent dispatch of a dedicated contact team of experts available at the nearest Foreign Operative Base (FOB) to support the emergency, non-standard, maintenance with both expertise and material. This led to significant cost and delay to fully recover the aircraft, due in particular to the requisition of a military transport. For these reasons, Remote Support by means of live video connection rather than dispatching personnel on the field retained particular attention. This brought about a testing campaign to simulate different scenarios and in particular an innovative scenario to evaluate the possible implications of introducing Remote Support.

For this purpose, the following case incident was proposed: during taxi of an operative flight, one of the main tires exploded. This simulated event assumes the following damages and associated corrective actions:

- Structural damage of the covers and stone guards of the main landing gear compartment: the extent of the damage requires a non-standard repair that cannot be postponed or in other words "before next flight".
- Deformation and rupture of the Rim with dislocation of the relative bearing on the carriage axle: difficult separation requires an ad hoc, non-standard, disassembly procedure.

Different scenarios are compared. On the one hand, similarly to the real event described previously, three possible scenarios consider the dispatch of a contact team of experts consisting in two Crew Chiefs and one Technician on the field. These scenarios include the use of commercial flights and/or dispatched military transport flight (C-130J):

- Dispatch of a contact team available at the nearest FOB to the incident location with military transport flight.
- Dispatch of a contact team from the Customer Home Operative Base (HOB) to the nearest FOB by means of commercial flights, followed by military transport flight between the FOB and the incident location.
- Dispatch of a contact team from the Customer HOB to the incident location with military transport flight.

The total commercial travel time between the HOB and the nearest FOB is 3 days (round trip). The total travel time with military transport flight between the HOB and the location of the incident is 1 day (round trip). The total travel time with military transport flight between the nearest FOB and the location of the incident is 3 hours (round trip). The time to prepare for the mission is 1 day, while the actual time for the maintenance activity and recovery of the aircraft is 3 days. For the cost analysis, the simulation takes into account the cost per hour for the deployment of the military personnel, the additional daily cost for missions abroad and the cost per hour for the dispatch of an Italian Air Force C-130J aircraft. Moreover, the average cost for last-minute commercial flights between the Customer HOB and the nearest FOB is about 1000 €/person.

On the other hand, the innovative scenario considers the use of the Collaborative Digital Platform currently under development by Leonardo in collaboration with the Italian Air Force [22, 25]. The Collaborative Digital Platform aims to accelerate the "digital transformation" of technical and logistical processes and offer the infrastructure suitable for the progressive implementation of artificial intelligence tools that will be oriented towards a continuous improvement of the efficiency and effectiveness of maintenance operations, whether they are carried out at "home base" or in "operating theatre".

The macro objectives of the Collaborative Digital Platform are:

- Provide remote support on-demand to technical maintenance staff during field operations through the use of mobile devices, including wearable (Smart Glasses).
- Provide technical maintenance personnel in field operations with access to the technical content necessary for carrying out the activities (technical publications, procedures, data analytics, etc.) via digital connection.
- Provide technical maintenance personnel in field operations with access to training content (virtual tutorials, video tutorials, CBT / VMT) on an opportunity / need basis.
- Contextualize and objectify the execution of all technical-maintenance activities carried out in operating theatre by producing specific reports and digital logbooks.
- Synergistically integrate with a data collection platform with particular reference to the elements / data relating to the technical-maintenance interventions that took place during operational activities, supporting the development of data analytics and predictive maintenance activities also through the use of AI algorithms

The above-described solution will enable carrying out technical-maintenance support activities in a more effective / efficient way and provide operative personnel with a new type of support services. One element of the Collaborative Digital Platform is the remote support application which allows in particular to connect remotely operators/technicians to experts in order to accelerate workflows and decision-making processes by exploiting live video communication, augmented reality and sharing of digital content. The platform is accessible through either mobile or wearable technologies (such as cellular phones or head-mounted displays, respectively).

Using the remote support application, the operative team at the incident location and in presence of the damaged aircraft calls for assistance a team of experts which could be as diversified as needed and potentially located anywhere. This team of experts could consist in personnel from the Original Equipment Manufacturer (Leonardo) or qualified Customer’s personnel or both, in any case located far away from the incident location. The operative team exposes in details and in real time the issue to the team of experts with the support of live video communication. The team of experts evaluates the damage, guides remotely the operative team on the field during troubleshooting procedures and suggests and assists remotely the proper corrective actions. The team of experts leverages on functionalities such as annotations in AR and sharing of digital support material to provide assistance in the most effective way. An actual operative test has been carried out under similar conditions to those experienced during the real event described above (Figure 14) [26].

Figure 14: Test campaign of the Digital Collaborative Platform providing Remote Support to personnel on the field by a team of experts connected at distance.

The testing campaign proved the viability of using Remote Support as described to allow for recovery of the aircraft. At first glance, the obvious advantage of considering Remote Support primarily regards the reduction of time and cost associated to urgently dispatching a team of experts to the incident location. The different scenarios described in this section were compared in terms of time and costs in order to evaluate the possible benefit of Remote Support over conventional approaches to emergency maintenance operations. The following Figure 15 shows the comparison for total times and costs between the different scenarios envisaged.

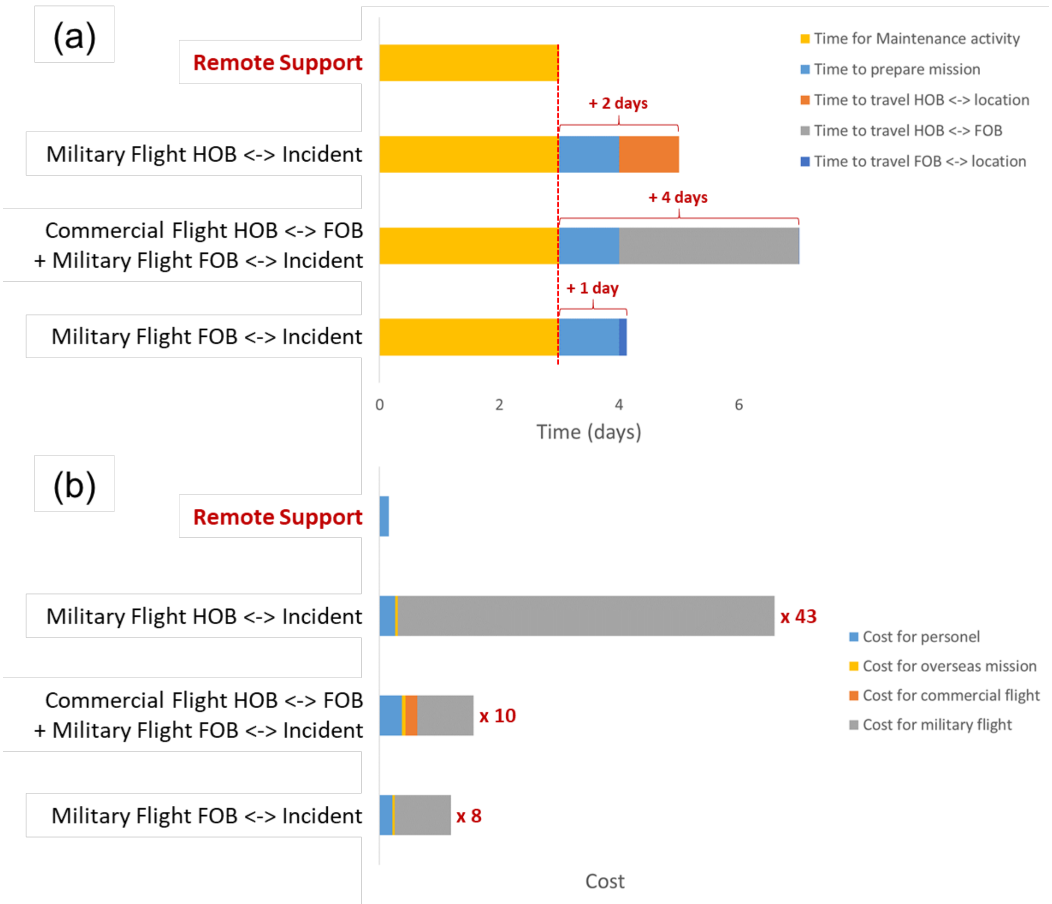

Figure 15: Comparison of the total (a) times and (b) costs between the different scenarios for emergency maintenance

In Figure 15, it is clear that both cost and time to recovery of the aircraft are significantly reduced by the implementation of Remote Support over conventional dispatch of a contact team of experts from either the nearest FOB (if available) or from the Customer HOB. The use of Remote Support through the remote support application briefly described above allows to save at least 1 day to full recovery of the aircraft with respect to dispatching a contact team possibly available at the nearest FOB and as many as 4 days with respect to dispatching a contact team from the HOB by means of commercial flights (Figure 15(a)).

Another clear observation is the significant cost associated to the urgent dispatch of a military flight which tremendously increase the total cost of operation (Figure 15(b)). Compared to the use of Remote Support, dispatching a military aircraft (C-130J) for a relatively short flight from the nearest FOB already increase the cost of operation by 8 times, while dispatching a military aircraft all the way from the Customer HOB brings the cost of the operations to as much as 43 times more.

From the cost/time comparison as well as experience from the actual operative test to validate the viability of Remote Support using the remote support application, a number of advantages, constraints and limitations associated to the implementation of Remote Support for maintenance activities, in particular emergency maintenance, could be identified and are reported in the following Table 1.

Table 1:Advantages, constraints and limitations to the use of Remote Support for maintenance activities

Advantages

- Significant reduction of time to initiate the unscheduled maintenance activity and the exchange information
- Significant reduction of costs associated to the dispatch of a contact team of experts
- Significant reduction of time associated to the dispatch of a contact team of experts
- Increase the availability of logistic support
- Continuous monitoring of all activities

Constraints

- Availability and consistency of safe and secured connection
- Availability and readiness of connecting devices on the field and/or on board
- Availability of spare parts, tools and maintenance equipment on the field
- Security, safety and confidentiality of sensitive data shared through the collaborative platform

Limitations

- Risks of reduced autonomy and expertise in decision making
- Certification/validation of maintenance operations carried out through Remote Support
- Solution not applicable to all possible events

4.0 CONCLUSION

A selection of mature solutions developed and commercialized by Leonardo to support innovative approaches to Training and Support was discussed. In the midst of Digital Transformation, these solutions leverage on emerging technologies to enable Modelling & Simulation as a Service, Extended Reality and remote connectivity. Leonardo developed in fact a complete suite of products and services from cloud platforms (OCEAN, e-Learning and Collaborative Digital Platform) and Synthetic Environment (RIAce) to Extended Reality products (Virtual Maintenance Trainers and Morpheus XR) to assist military customers.

Traditionally, training and support activities have been crippled by significant drawbacks not only in terms of logistics (costs, time and availability) but also with regards to efficiency, workload and safety. Transportation of personnel and materials has often been needed. Capabilities have been limited to ensure the safety of people (both mental and physical) and the security of assets. Methods that have been used relatively successfully in the past have become obsolete.

The use of digital resources, simulations and platform technologies significantly disrupts – enhances – capabilities for training and support with outstanding potential in the demanding field of Defence. As regards to training on the one hand, it enables access to products and services on-demand, at all time and as many times as needed. Furthermore, it allows training for emergency and dangerous situations without any risk of harm to either the trainee or the asset. For support on the other hand, it significantly reduces time and costs related to urgent interventions as well as enabling interventions integrated with potentially unlimited digital resources.

As much as new capabilities are emerging, new threats and limitations also arise. In particular, accessing these "connected" capabilities necessitates careful considerations on connectivity and security. Although solutions exist, in terms of hardware/software development, cryptography and cybersecurity for example, confusion due to the plethora of immature products or services as well as the lack of standards and late certifications must be a matter of great concern in the near future.

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