European MUM-T (eMUM-T) Flight Demonstration within MUSHER Program

Lionel THOMASSEY
lionel.thomassey@airbus.com
MUM-T expert
Airbus Helicopters
Marignane, France

Stuart CURTIS
stuart.curtis@leonardo.com
Avionic System Autonomous Vehicle
Leonardo
Cascina Costa, Italy

Xavier Le Vern
xavier.levern@fr.thalesgroup.com
Senior System Architect
Thales
Valence, France

Daniel AIELLO
daniel.aiello@leonardo.com
T&I Project Engineer
Leonardo
Pisa, Italy

INTRODUCTION

In the frame of a 3 years (2022-2024) European Project (EDIDP frame), called MUSHER led by Thales involving European MODs (Italy, Spain, France), a Manned UnManned Teaming (MUM-T) study and MUM-T flight demonstration have been performed. The project has been co funded by Italy, France and Spain. Moreover, "This project has received funding from the European Defence Industrial Development Programme (ED1DP) under grant agreement No EDIDP-ACC-CH-2020-091-MUSHER".

This project has demonstrated that in Europe, different industrial companies and more especially two major helicopters and UAV manufacturers have been able to ensure interoperability (up to LOI4) between two helicopters and 2 UAVs at 1000km distance. This paper presents the works performed on the CONOPS, the MUM-T simulations and the MUM-T system architecture modelling under NAFV4 framework which have been realized to identify the crucial European MUM-T capabilities and services. Moreover, the paper presents the typology of the network used with the associated adequate communication protocol which has been developed in order to ensure the interoperability between MUM-T equipped helicopters and UAV payload and aerial platform. In addition, Thales have introduced the concept of the MUM-T Supervision Station in order to manage dynamically MUM-T support requests and services access authorizations, and also to ensure safety of operation by generating alarms (such as Proximity alarm, UAV/Helicopter allocated zones conflict). This project is a first step in the European MUM-T which will allow us to prepare the MDCC (Multi Domain Combat Cloud) level in the next few years.

MUSHER Overall Program Description

The MUSHER program has been organized with 10 work packages. Some of them was realized to design the future eMUM-T capability and while the others prepared the MUSHER flight demonstration.

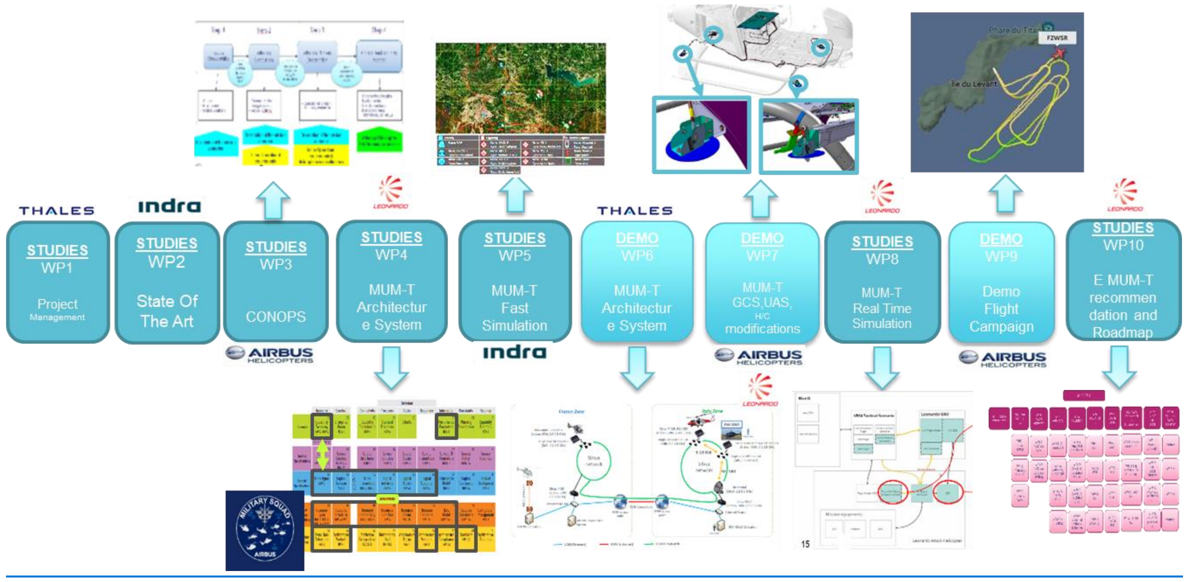

Figure 1: MUSHER Project Workpackages Breakdown

A SOTA (2021) has been established. A dozen of CONOPS have been described and modeled under the system engineering framework NAFv4. Moreover, the CONOPS have been modelized under VR Forces and through a real time simulation including a real helicopter simulator. In this paper, the Demonstration Flight Activities will receive special attention.

One important output of the CONOPS analysis is the identification of the mission phases where the MUM-T has a real added value. Another output has been the combined mode logic between the crewed platforms and the uncrewed ones.

Several aspects of System Engineering have been analyzed through the NAF V4 framework, including the communication logic, the protocols definition and the services for the Level-of-Interoperability (LOI) from level 1 to 4.

Thanks to these studies, the system of systems developed by the consortium has reached an interesting preliminary agnosticism level. It has been feasible to change the selected helicopters and UAVs during the project without interfering with the demo flight campaign's planning or content.

The simulation activities performed by INDRA have allowed us to extract some Key User Requirement which have been relevant to characterize each demo flight scenario objective. Lastly, the cognitive workload impact on the onboard H/C MUM-T operator has been addressed by the real-time simulation activity led by LEONARDO.

1. MUSHER project objectives

MUSHER project aimed at developing a generic European Manned Unmanned Teaming System allowing crewed rotorcraft platforms and uncrewed platforms from EU Forces to interoperate for the effectiveness in demanding missions.

The primary objective of MUSHER project was to develop the E-MUMT system both generic and free from proprietary standards, so that any industry may freely develop equipment/systems in accordance with such standard. The E-MUMT system will establish a sound interoperable approach and solution that could be proposed to NATO and IP partners for use when adopting such standards on rotorcraft crewed platforms and uncrewed platforms.

MUSHER project aimed also at introducing autonomy functions as much as possible given the time, budget and safety constraints. Full autonomy capability of uncrewed vehicles to take decisions to accomplish a mission order and capability of providing automated control of UAV payloads and navigation profiles from the crewed platform crew are key capabilities to reduce the cognitive burden for operators and then to increase the effectiveness rate in current and future operational scenarios. MUSHER project initiated a journey being further developed in future European Union driven projects towards the full system autonomy.

2. MUSHER project general methodology

To meet its goal, the MUSHER project has followed a structured methodology, ensuring quality and relevancy of the results.
The main steps of the methodology were:

1. **State of the art analysis**, performed at the begin of the project, this activity allows the consortium to have a comprehensive understanding of the worldwide advancement of UAV-helicopters cooperation developments, already met achievements and ongoing challenges.
2. **Operational analysis and CONOPS descriptions**. During this step, the consortium performed an in-depth study of future missions of military helicopters to analyze how to draw maximum operational benefits from cooperation between UAVs and helicopters. This activity results in a detailed description of missions and cooperation procedures, enabling an efficient cooperation of UAV and helicopters.
3. **System architecting and modeling**. During this step, based on established CONOPS, the consortium has designed a system of systems architecture that allow the implementation of the UAV-helicopter teaming capability with a high level of interoperability to support and perform all missions described in the CONOPS. The system architecture has been described in depth using the NAFv4 framework.
4. **System architecture test using simulations**. The consortium has executed several simulation activities (including fast-time automatic simulation and real-time man-in-the-loop simulation using realistic helicopter cockpit and UAV simulators) to test and consolidate the designed system architecture. This simulation resulted in recommendations and adjustments regarding the MUMT capability and the supporting system design.
5. **MUMT demonstration and experimentation**. To demonstrate the relevancy of the concept and the maturity of the architecture and its main components, the consortium has developed and implemented a demonstration system that included 2 helicopters, 2 UAVs with control stations, and a MUMT Supervision Station. This demonstration system was then used to perform a 2-week experimentation campaign, including 6 flight sessions. The campaign allowed to demonstrate all MUMT capabilities up to LOI4, with full interoperability between French and Italian assets, including reactive cooperation loop established in action by the MUMT Supervisor.
6. **Recommendations.** Using the results gathered all along the project, the consortium has defined a list of actions for the European Commission to pave the way for achieving a fully interoperable MUMT capability at European level by 2035.

3. OPERATIONAL ANALYSIS & MUM-T CONOPS

WP3 enabled the consortium to conduct a detailed operational analysis of the future use of drones in cooperation with helicopters in future European military missions.

To analyze the CONOPS, we proposed a four-step working method, starting with mission characteristics and ultimately extracting the combined helicopter/drone modes required to ensure maximum interoperability.
The operational analysis began with the definition of a "System of Interest" (SoI) model established specifically for the MUM-T system of systems and the definition of a classification of drones and their relevance to cooperation with helicopters.
At the end of this study, the consortium obtained a detailed description of nine operational missions, based on 17 generic joint modes of action (basic actions combining drones and helicopters) that cover all possible missions.

All the missions and joint modes of action were validated by the headquarters involved in the study, namely: France, Italy, and Spain.
Beyond the description of the CONOPS, the main conclusions drawn from the operational analysis concern:

- **The safety of joint trajectories (between drones and helicopters)**
  It was clearly expressed by the Forces personnel that the cooperation of drones and helicopters in the same geographical area would only be acceptable to the extent that the architecture would be able to guarantee with a high level of confidence that there would be no collision between drones and allied helicopters.
- **Maintaining the discretion of the system**
  Similarly, the Forces reiterated that the implementation of drones in missions requiring a high degree of discretion of the system must not compromise this discretion. In fact, in high-intensity operations, the majority of the use of drones in support of helicopters will have to be done with the use of drones at low or very low altitude, that is, in altitude ranges comparable to those where helicopters must operate.
- **Control/supervision capability must be carried by the H/C unit**
  The Forces have indicated that since drones would make a significant contribution to the overall operational capability of a mixed unit, the resources needed to ensure control and supervision of the unit's drone component must absolutely be carried on the unit's vectors and that it is not feasible to rely on resources remaining in the security zone.
- **Workload of Helicopter Crews**
  It has been repeatedly stated that the cognitive load of helicopter crews engaged in combat missions is extremely high and that it will therefore be particularly difficult for the cockpit crew to control or supervise all or part of a drone's activities. This truth therefore leads, on the one hand, to seeking a high degree of autonomy for drones deployed in support of helicopters and, on the other hand, to planning for the implementation of resources dedicated to the control and/or supervision of drones acting for the benefit of the helicopter unit. Given the previous point, these resources will have to be carried by the helicopter unit, probably in the cabin of one or more aircraft.
- **Maintaining the maneuver tempo**
  The Forces have reiterated that the success of a helicopter mission often depends on maintaining its momentum, which prevents the adversary from effectively retaliating or implementing actions to counter it. In fact, it appears essential that the use of drones in these missions not be detrimental to the overall maneuver tempo, thus implying that the activities of drones and helicopters must be conducted in parallel, without imposing a holding phase on the helicopter.
- **MUM-T Supervisor Role**
  Cooperation loops between drones and helicopters will be established during the mission preparation phase, but it is clear that new cooperation needs will arise during mission execution, and the unit will have to deal with unforeseen situations. The CONOPS study identified a set of essential activities to ensure the effectiveness of drone support throughout a helicopter unit mission, thus

defining an operational role here called "MUMT supervisor." This operational role was the subject of dedicated activities in subsequent WPs.

The results of this work package informed the rest of the project's work, notably by providing a clear and detailed reference of operational needs and associated constraints.

4. System of systems architecture and modelization

Based on the CONOPS established in WP3, the consortium conducted a system architecture study to support drone-helicopter cooperation in future missions. This activity, carried out through co-engineering between Leonardo Airbus and Thales, was based on the NAFv4 (Nato Architecture Framework version 4) standard.
It enabled the design of a system architecture that would provide all the capabilities required for the missions and guarantee interoperability at the European level.
The design process was based on two reviews:

- SSR (System Specifications Review)
- SDR (System Design Review)

The diagram below illustrates the system views selected by the consortium to model the proposed system architecture.
(The views circled in red represent the scope of the SSR, and those circled in green represent the scope of the SDR).

Figure 2: NAF V4 FrameWork Overview

In total, approximately 250 system views were produced to define the system architecture supporting drone-helicopter cooperation capability by 2035. This work formalized the following elements:

- Key User Requirements (KURS)

• Standard operating procedures for the system
• Operational roles involved in drone-helicopter cooperation
• Exchange protocols
• Interfaces between system components

Following the last system review, two major activities were conducted:

• A Functional Hazard Analysis (FHA)/System Safety Analysis (SSA)

This safety analysis established target safety levels for the various functional chains of the cooperation system and provided a quantified objective for controlling the trajectory of drones operating in the same areas as helicopters. This objective quantifies the tolerable loss of integrity along the drone trajectory at 10-5h (which is "equivalent" to the integrity of a DAL B functional chain).

• A preliminary design of a MUMT supervision station

This activity, based on the definition of the MUMT supervisor operational role established in the system architecture, made it possible to establish a preliminary specification of the IHS of a supervision station, considering the various possible positions for this operational role.

The key output of the System-of-System architecture view were the Physical Views and Protocols that defined a Service oriented architecture implementable by the consortium partners in isolation.

5. Real Time Simulation

WP8 aimed to validate the generic e-MUMT system concepts (architecture, functions and protocols and main goals) through tactical real time simulation.

The simulator used for WP8 Real Time Simulation is made of:

- A dark room including the two visual system screens, the projectors and the two cockpits for the Pilot and the Copilot
- A control room including the scenario controller station
- A server room including the 4 racks containing the workstation

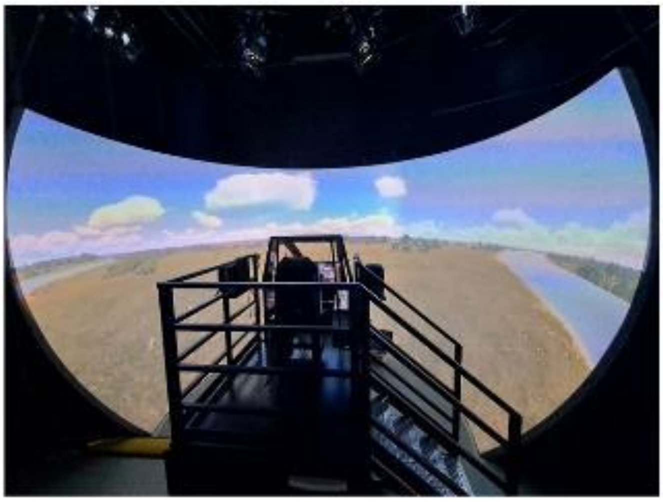

Figure 3: Pilot cabin external view

The simulator control room allows:

1. To monitor the simulation by a set of displays that are a replica of the Pilot/Copilot cabin ones.
2. To set and control the simulation by the IOS (Instructor Operating Station) and to communicate with Pilot and Copilot
3. To interact with the Tactical Scenario controlling the behavior of the scenario entities.

Figure 4: Control room and Tactical Scenario Station

Tactical Scenario SW, based on COTS VBS4 (@Bohemia Interactive) and customized for the simulator, is available in the simulator Control Room. The Scenario Controller, sitting in front of VBS4 display, can interact and modify the Tactical Situation by playing the role of Friend or Hostile Units (Blue Forces and Op Forces). Blue forces can be controlled by the Scenario Controller or can follow predefined behavior or trajectories. Hostile units usually have artificial intelligence (AI), so their behavior is driven by VBS4 tactical scenario SW. The AI level can be set. As an alternative, the scenario controller can also assume the role of a hostile unit and act as a real time player. The Tactical Scenario communicates with the simulation thanks to custom plugins. They allow us to visualize the helicopter in the Tactical Scenario and to transmit information about the Tactical Scenario to the flight systems and the simulated sensors. The main plugins are the Helo Plugin that allows the communication between the helicopter and the Tactical Scenario and the UAV Plugin used for the communication between the UAV and the Tactical Scenario.

The increasingly complexity of modern aircraft and the need to fly in more complex missions generate high level of workload for the crew. The Infrared Stress Monitoring System (ISMS) is a project aimed at the validation of a metrics based on psychophysiological indexes to evaluate the real-time crew workload throughout their cognitive and stress behaviors. With the use of infrared cameras installed in the pilot and copilot cabins, which can be integrated with a smart watch, it is possible to retrieve Sympathetic and Parasympathetic systems data detected in Region of Interests (ROI). The infrared cameras do not increase the crew workload. Indeed, they are small devices positioned in front of the subject in a non-invasive way.

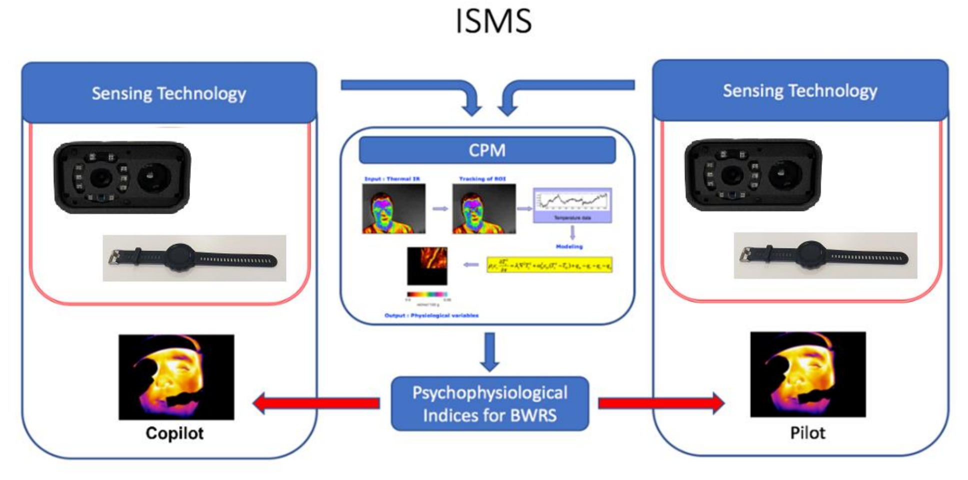

Figure 5: general overview of the ISMS software

The ISMS system allows us to retrieve the crew members' vital parameters and their behavior. In particular, it is possible to collect the following data:

- Subject Identification Code
- Facial Expressions
- Respiration
- Perspiration
- Sympathetic activity
- Stress
- Engagement
- Drowsiness
- Thermal comfort
- Workload (trained on the Bedford Workload Rating Scale (BWRS))
- Gaze tracking

As an illustrative example, the ROI processing by the ISMS system is shown in the following figure.

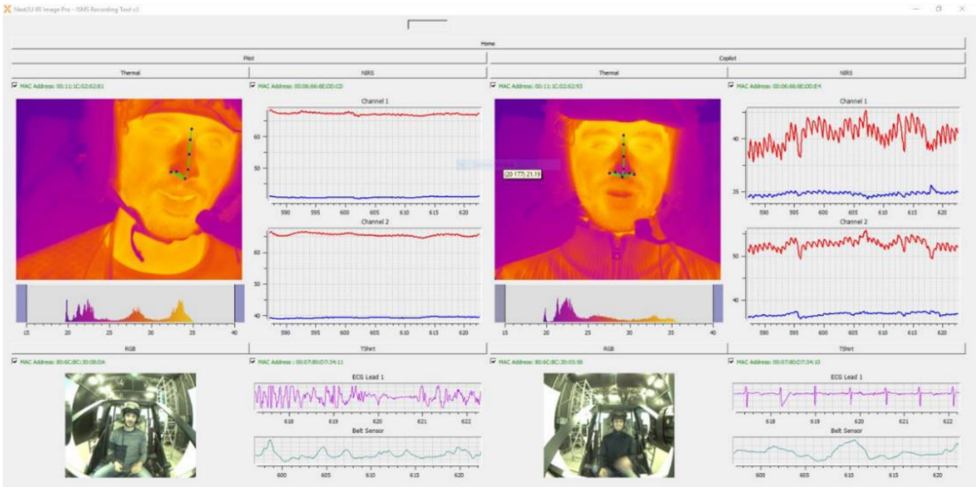

Figure 6: ROI processing by ISMS system

The outcomes gathered by using it while monitoring both the involved subjects (Pilot and Copilot) performing the flight simulation designed for the WP8 of the MUSHER project show a generalized medium-high level of workload for all the subjects, with a slightly better psycho-physiological state for the subjects more familiar with the system with respect to the subjects less familiar with it.

MUM-T Demonstrator Architecture

The objective of this work package was to design an experiment to measure the level of maturity of the cooperation capability available in the short term by leveraging existing industrial resources, adapted to the needs.

The activity, led by Thales, in association with Airbus Helicopters, Leonardo, and Space Applications, was conducted according to the following approach:

1. Identification of exploitable resources and associated limitations
2. Definition of realistic demonstration objectives
3. Definition of an experimental plan
4. Specification of the expected capabilities of the demonstration system
5. Specification of the demonstrator design and its components

The following diagram presents the architecture of the demonstration system that was designed.

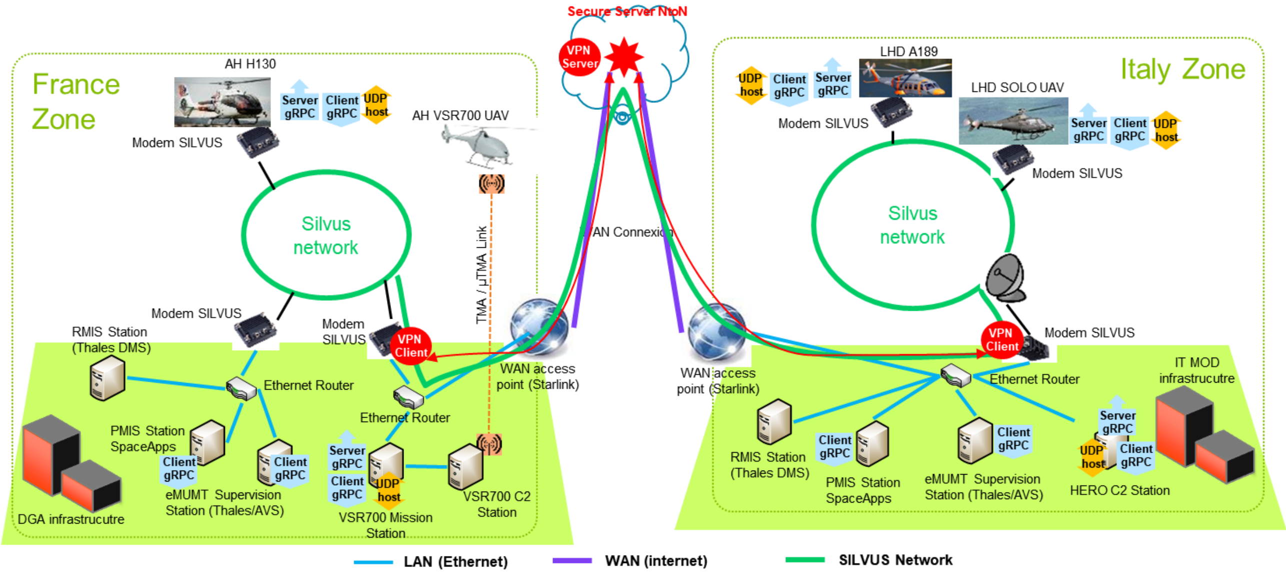

Figure 7: Overall Musher MUM-T Architecture

For the Proof of Concept demonstration, 'webservices' based upon gRPC were chosen as the enabling technology:

1. Open 'standard' (open source) https://grpc.io/
2. Client libraries in 11 languages
3. Highly efficient on wire and with a simple service definition framework
4. Bi-directional streaming with http/2 based transport
5. HTTPS/2 based upon TCP (reliable) and uses multiple independent streams on single HTTP connection

Below is the protocol stack produced in NAFv4:

Figure 8: Webservices Protocol Stack

gRPC supports pluggable security based upon TLS 1.3

1. Encryption: TLS encrypts the data being transferred to prevent eavesdropping by third parties. This ensures that the data remains confidential during transmission
2. Authentication: TLS uses certificates to authenticate the identity of the communicating parties. This ensures that the parties are who they claim to be, preventing man-in-the-middle attacks
3. Integrity: TLS ensures data integrity by using message authentication codes (MACs) to verify that the data has not been tampered with during transmission

The security model implemented on top of TLS also included Authorization to ensure that only authorized systems could request connection to and execute specific services of a UAV. The mission networking and authorization plan were created during the mission planning phase and distributed to the team. The Supervisor can modify the authorization plan during the mission to (1) introduce new actors and (2) upgrade authorizations for existing actors. This was demonstrated during the PoC Demo.

The Webservices required for the PoC Demo were agreed upon by the consortium and defined using Protobuf3. See below for an example service definition. This permitted each consortium member to develop their implementations independently using their preferred technology, and with regular integration sessions (face to face and remote) build up the multi-unit demonstration.

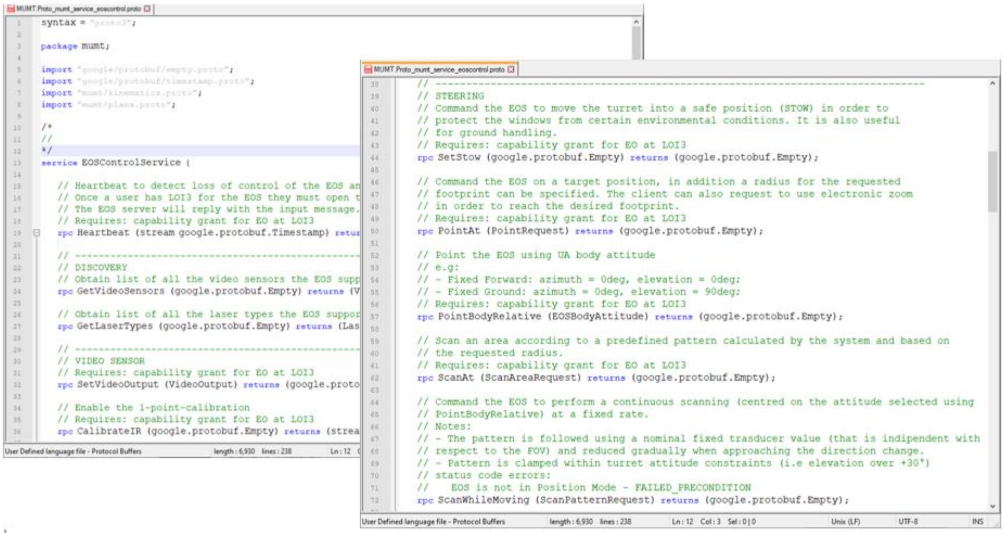

Figure 9: Example Service Definition defined in protobuf 3

All the industrial partners involved in the flight demonstration, have established common message formats to implement the LOI 2-3 & 4 MUM-T services.
The flight demonstration plan included the execution of eight drone-helicopter cooperation scenarios:

- S1: eMUMT supervision capability
- S2.1: Planned eMUMT LOI2 support
- S2.2: Reactive eMUMT LOI2 support
- S3.1: Planned eMUMT LOI3 operation
- S3.2: Reactive eMUMT LOI3 operation
- S4.1: Planned eMUMT LOI4 operation
- S4.2: Reactive eMUMT LOI4 operation
- S5: eMUMT control recovery

These scenarios allowed to demonstrate progressively the capacities for the LOI2, 3 and 4 for planned and reactive (meaning not planned during mission preparation) operations. Below is an example of Planned eMUMT LOI4 operation scenario.

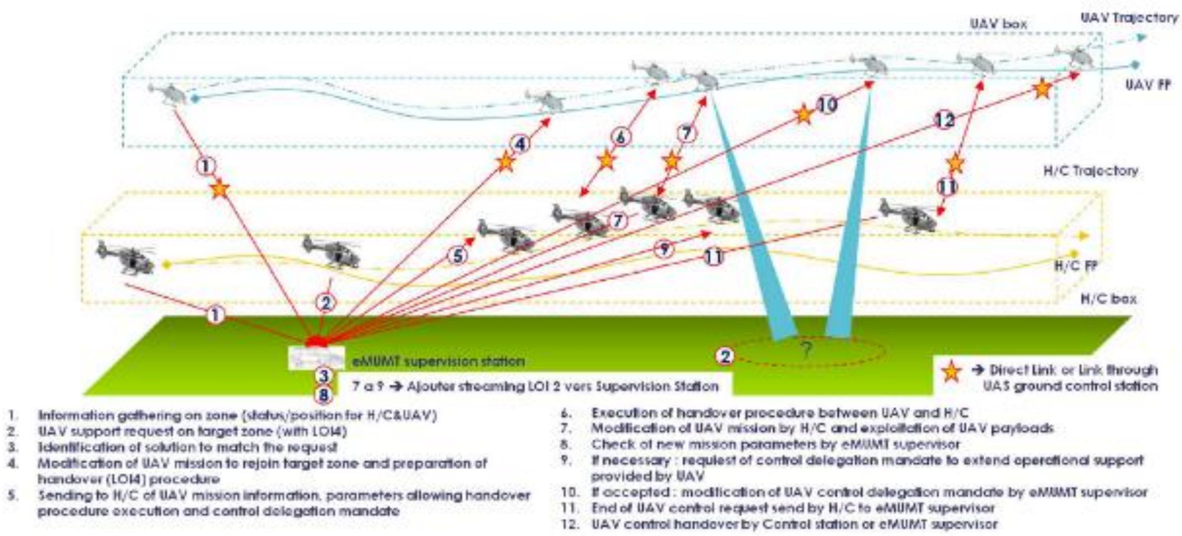

Figure 10: Example of Reactive eMUMT LOI4 operation scenario

Despite limited resources and tight schedule constraints, this demonstration plan covered most of the expectations expressed in the KURS in terms of interoperability level (LOI2 to LOI4), procedure type (planned or reactive), and operational resilience (supervision function and control recovery procedure).

Furthermore, metrics for evaluating demonstrated performance and capabilities have been put in place, associated with a specification of the technical recordings to be carried out during the experiment and a specification of tools for processing and analyzing the results.

MUM-T Demonstrator NETWORK & communication

To create a link between both countries (each hosting one half of the demonstration system on a dedicated test range), a Starlink connection was used. Network security has been implemented both on the MUM-T local network and of course on the Starlink connection.

Concerning the MUM-T datalink, since the beginning of the MUSHER program, all the industrial partners have agreed to use a common COTS solution datalink already known by AH and LEONARDO: Silvus Manet.
The modem used on the H/Cs, on the UAVs and on the Ground Control Stations was the SC4400E.

For export control reasons, AIRBUS performed the demonstrations in France on the Le LEVANT island while LEONARDO in Italy in the airport “Taranto-Grottaglie”.
This scenario could correspond to a case where two allied countries want to check their interoperability capacity before to go to a common war theatre.

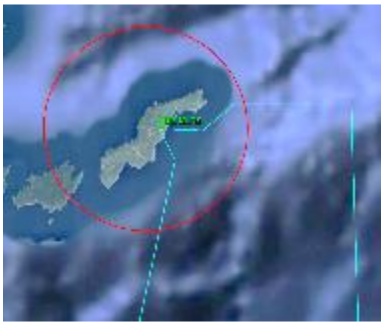

Figure 11: MUSHER Flight Demo Area in Italy & France

MUM-T IMPLEMENTATION ON AIRCRAFTS & GROUND STATIONS

1. **Helicopter and UAS implementations**

The main preparation activities for the flight demonstration concerned the MUM-T modules in the helicopters, in the UAVs, on the Ground Control Stations and on the MUM-T Supervision Station. The crewed and uncrewed aircrafts involved are described below.
Leonardo provided the following means to support the demonstration:

1. SW-4 Solo OPV (Optionally Piloted Vehicle)
2. SW-4 Solo Ground Control Station
3. AW189 twin-engine, super-medium-lift helicopter

Figure 12– SW-4 Solo and AW189 (for reference only)

AIRBUS provided the following means to support the demonstration:

- VSR700 UAS

Figure 13: VSR700 UAV

- The Flight LAB Helicopter based on a H130 light helicopter

Figure 14: H130 Flight Lab Prototype

This demonstrator offers the capability to integrate a MUM-T operator on the front or on the rear of the cabin in addition of a shelf where the on boarded MUM-T control station and the Silvus Manet equipment will be installed.

Moreover, this helicopter is equipped with a landing skid on which the 4 antennas will be implemented.

2. Physical Design

The AW189 is equipped with a mission system for in-cabin use (Mission Console Computer) that is ergonomic, integrated and independent of the cockpit avionics, but with which it can interact to receive information or send commands.

All the new crewed MUM-T features are integrated into Mission Console Computer, already part of Mission Management System (MMS). No systems outside of the Mission Console have been changed:

The following figure shows the overall functional architecture of the AW189 and SW-4 Solo assets used during the demonstration

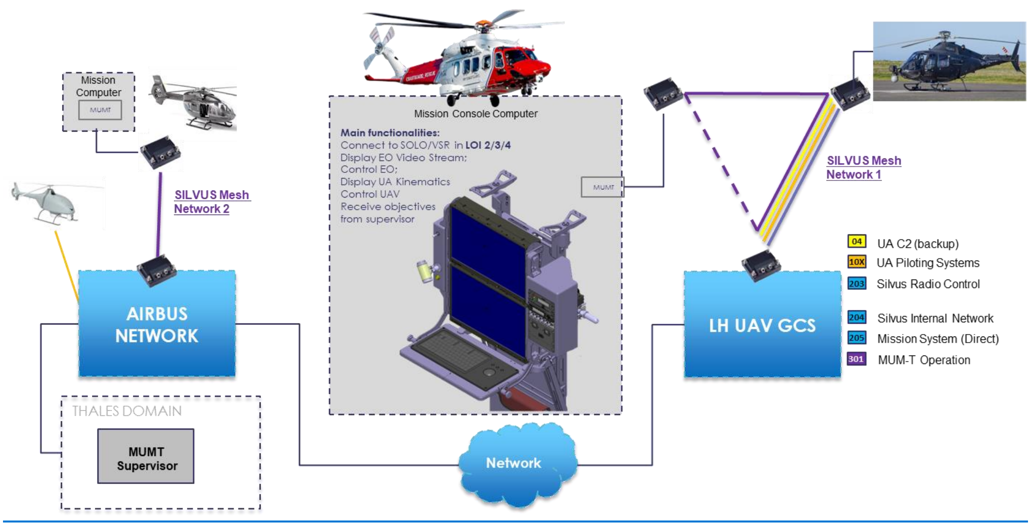

Figure 15 – Overall AW189-SW-4 Solo Functional Architecture

Regarding the Silvus Streamcaster data link, it was already installed on the AW189 prototype.

Two antennae were installed on the tail and the other two were installed on the bottom of the aircraft.

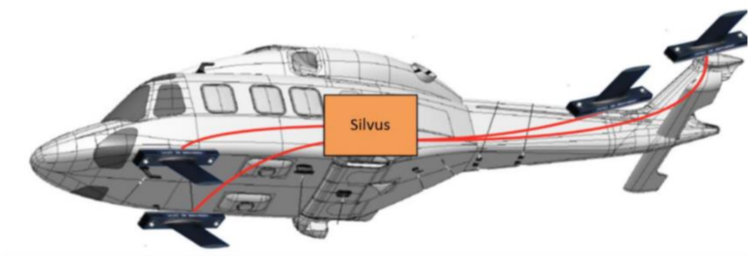

Figure 16 – Antenna position on AW189

Figure 17 – Antenna 1 and Antenna 2 (TOP) installation

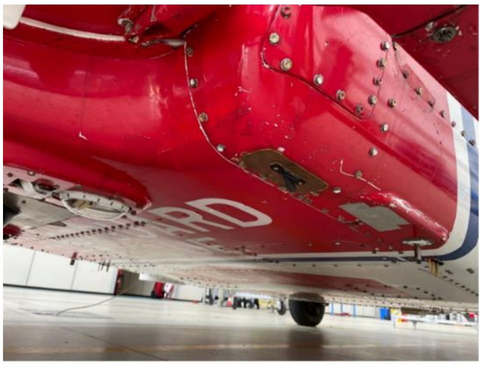

Figure 18 – Antenna 3 and Antenna 4 (BOTTOM) installation

The SW-4 Solo OPV is composed by the following components:

1. **Mission Control Station (MCS)**.
2. **Remote Piloted Aircraft (RPA)**.
3. **Data-Link System**.

Only software modifications have been carried out on the SW-4 SOLO OPV to implement the e-MUMT fucntions, because Silvus modem and antennae were already installed.

Concerning the AH MUSHER implementation, the system of systems architecture was the following one. We had a Main Ground Control Station and a Remote Control Station onboard the helicopter. The S/W was the same on the both C2 stations.

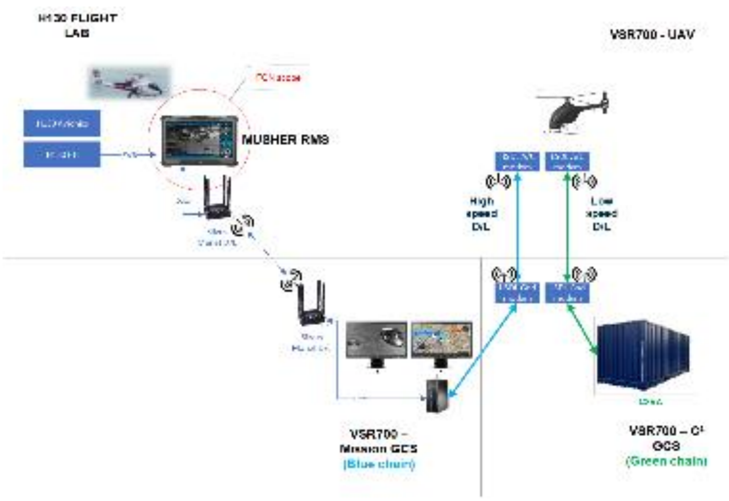

Figure 19 – Overall AH MUM-T Architecture

On the helicopter we have implemented the SILVUS modem, the 4 antennas and the C2 remote station

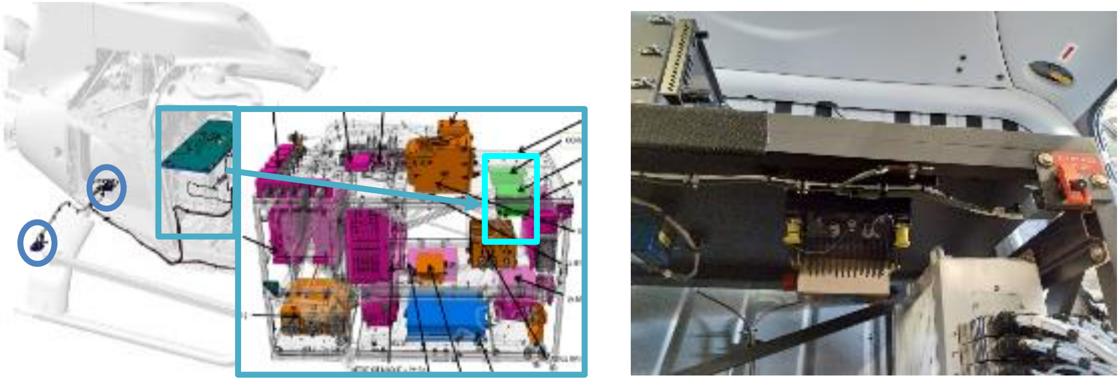

Figure 20– Silvus Modem Installation

The antennas are installed on the landing gear skids on the front and the rear of the helicopter and tilted to the ground.

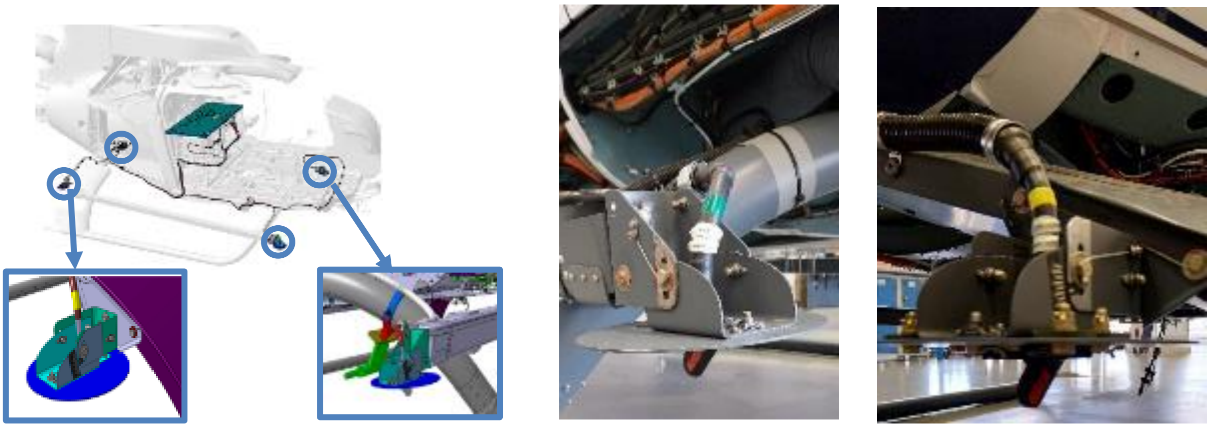

Figure 21– Antenna Installation

Figure 22 – Remote Control Station Onboard H/C

On the ground, we have the UAV piloting capability and the aerial asset station on one window and the MUM-T payload station on another one. On this last station, we have the LOI2 LOI3 LOI4 capability on several UAV, the payload handling and until 2 videos broadcasting or one video and the map.

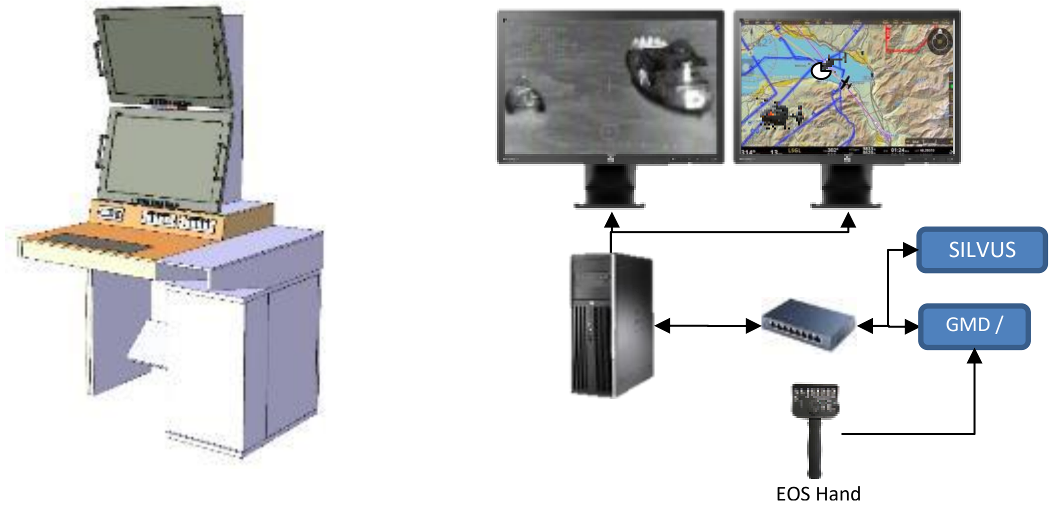

Figure 23 – Main Ground Control Station

The C2 station is connected to Italy through Starlink.

1. **Starlink Dish + Power supply (PSU) + Cisco Router**

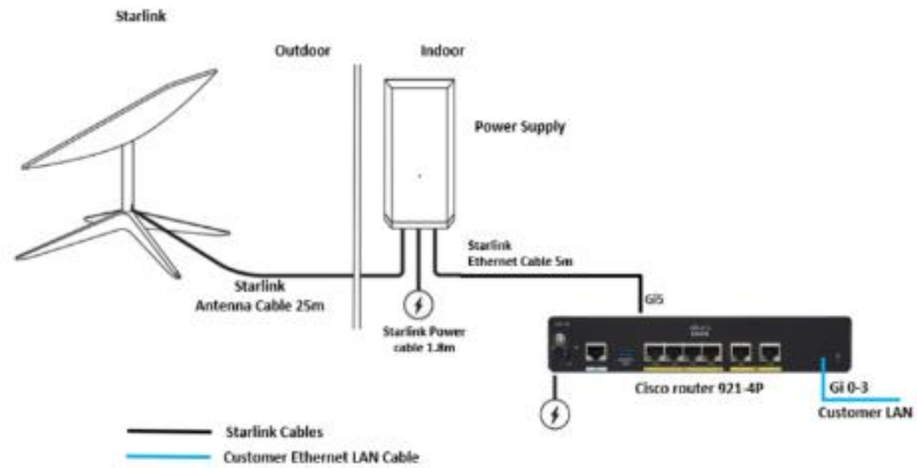

Figure 24 – Starlink connection

Within MUSHER, both H/C and UAV manufacturer have implemented the MUM-T capacity on their aircrafts which are equipped with different mission, navigation, communication systems.

Thanks to a dedicated and common MUM-T protocol layer, MUSHER has demonstrated the European capacity to develop a eMUMT capability.

3. MUM-T SUPERVISOR CONCEPT and IMPLEMENTATION

Origins of the introduction of the eMUMT supervisor

Two main factors led to the introduction of this new operational role:

- The clearly stated need to make drone-helicopter cooperation capability responsive, i.e., the ability to establish cooperation loops during operations that were not planned during mission preparation. This requires numerous capabilities, including:
    - o Access to an overview of available resources (current or upcoming drone missions, capability of vectors to meet the need, compatibility of drone mission plans with the support requirements to be met, etc.)

o Access to 3D coordination elements allowing drone flight plans to be redefining in real time to meet the new need

o Expertise in drone mission planning (across a wide range of vectors) allowing the selection of the best solution to meet the support requirement and the rescheduling of the drone mission during the action to meet it

o Mastery of the technical aspects related to drone-helicopter cooperation (communications configuration, interoperability of protocols and messaging, etc.)

• The cognitive load problem for helicopter crews, which severely limits their ability to devote part of their attention to deploying a drone. From the helicopter crew's perspective, drone support must be a factor in improving mission efficiency and safety and must therefore not involve an additional workload. It is therefore inconceivable to expect the helicopter crew to perform complex replanning or technical reconfiguration actions in flight. Similarly, the implementation of cooperation with the drone must be optimized in terms of workload (either through automation provided by the drone or through the support of a third-party operator for the deployment of the drone in support of the helicopter) so as to focus the helicopter crew's activity solely on the drone's crucial actions. Furthermore, the cognitive load problem is also present at the tactical commander level (*), who will have very little opportunity to devote time to activities related to the use of drones in the mission he commands and the establishment of cooperation loops between the various resources at his disposal (helicopters and drones).

Note (*): Cognitive overload at the tactical commander level is almost systematically reported during operational feedback.

In fact, the addition of an operational role dedicated to these activities of managing and implementing drone-helicopter cooperation appeared necessary to avoid compromising the operational gains expected from this cooperation.

Operational Role of the eMUMT Supervisor

The role of the eMUMT supervisor was illustrated in the various scenarios presented in the CONOPS and is integrated into the designed system architecture.

The eMUMT supervisor reports to the tactical commander and acts on his behalf:

• By executing the tactical commander's orders relating to the adaptation of cooperation loops between drones and helicopters (communication configurations, adaptation of access rights settings, modifications to drone mission profiles, etc.). A delegation between the tactical commander and the supervisor can be established for cooperation-related decision-making in order to relieve the tactical commander.

• By controlling drone operations for the benefit of the tactical unit (in particular by ensuring compliance with the segregation of flight areas to ensure operational safety and by monitoring potentials/capabilities/milestones to ensure consistency with the mission plan)

• By handling non-compliant situations relating to drone operations for the benefit of the tactical unit (e.g., designating a new controller for a drone if the link with the original controller is interrupted)

• By adapting the planning of cooperation actions to respond to changes in the tactical situation (granting additional control rights for a tactical actor on a given drone)

In addition, and optionally, the supervisor may:

• Assume control of a drone to relieve the helicopter crew of this implementation or address a non-compliant situation rendering the designated controller unable to fulfill their role (overload, degradation of the link, combat damage, etc.)

• Modify the parameters of a drone's mission (flight plan, Capability exploitation...) to optimize the use of drones for the tactical unit's mission

• Manage the insertion of drone resources provided as reinforcement into the tactical unit's maneuver (on-the-fly planning).

This role involves taking into account an extended area of operation potentially extending beyond the mission area, since drone resources may come from outside the area of operation, and addressing a complex situation by anticipating future developments while managing both operational and technical issues. This is therefore a particularly demanding role in terms of cognitive load and will therefore prove tiring during long missions. These dimensions will need to be taken into account in the final detailed design of the monitoring station.

4. MUMT Supervision Station for Demonstration

The eMUMT Supervision Station developed by Thales to support the demonstration has allowed during operations to affect IP for new comers, to process MUMT support requests send by helicopters crew, and to allocate MUMT services authorization for each assets. Moreover, it has been possible to ensure operation safety thanks to alerting function identifying immediately any dangerous situation (as proximity between 2 assets, or flight zones disrespect). In case of tactical Commander need, the Supervision Station was able to transmit new orders (observation points and flight plans) for UAVs controllers

Tactical Situation Cartography and network supervision	LOI authorization, MUMT services status & Alerting
	

Figure 25 – MUM-T Supervision Station

5. Demonstration FLIGHT INSTALLATION

To perform the demonstration, two dedicated MUM-T bases have been built with shelter for supervision station, main ground control station, telemetry truck, and all the needed antennas.

The following pictures present an example of the overall MUM-T installation in France.

Example of MUM-T base

Figure 26 – MUM-T Base Exemple

MUMT MISSION PREPARATION STATION

In parallel, two specific tools have been developed to prepare and debrief the MUMT mission. Concerning the preparation mission tool (developed and provided by Space Applications), 4 activities have been implemented.

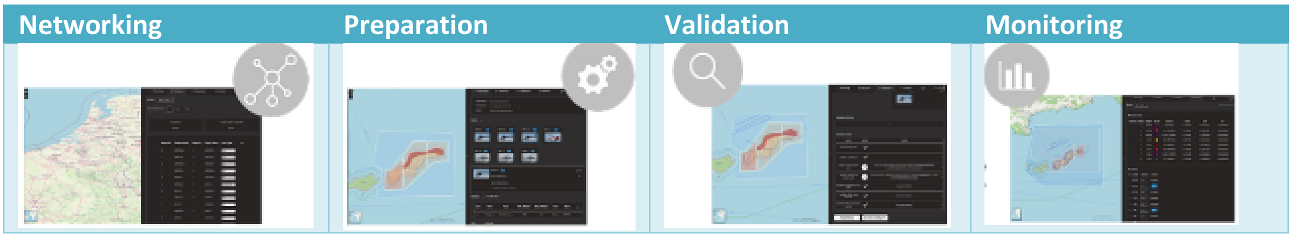

Figure 27 – MUM-T Préparation Mission Station

MUMT MISSON DEBRIEFING and analysis STATION

Finally, the debriefing MUM-T mission tool (developed and provided by Thales DMS Portugal) has allowed to replay the mission (asset route, assets mission plan, assets data & video, asset attitude and altitude, free text exchange) and to deliver Mission KPIs calculation (such as reactiveness and accuracy, transit time, latency, delay to access to the level of LOI 2, 3 & 4, % of lost message).

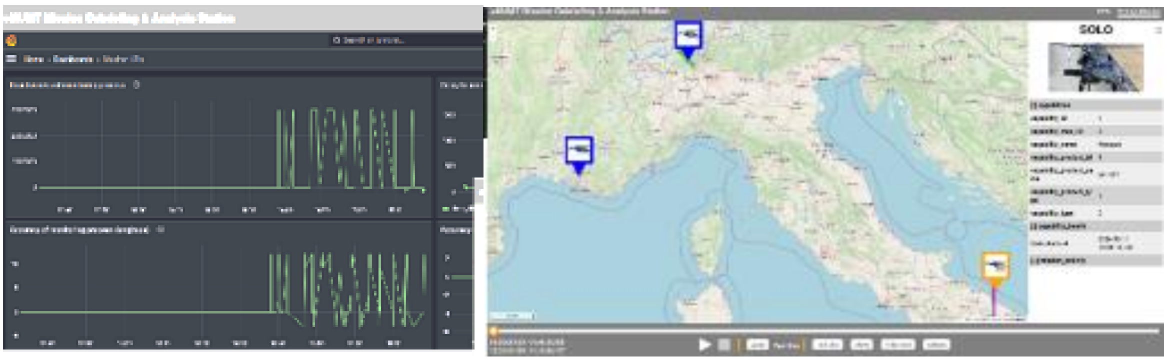

Figure 28 – MUM-T Mission Debriefing Station

MUMT FLIGHT TESTS CAMPAIGN

The experimental campaign took place from September 30 to October 10, 2024, at the CEM sites on the Ile du Levant and a testing area located in Grottaglie, Puglia, Italy. The resources deployed at both sites were linked in real-time thanks to a secure data exchange infrastructure based on Starlink connections and a protected server (NtoN and VPN) provided by Thales.

The resources deployed by the manufacturers included:

- 2 helicopters: Airbus H130 FlightLab & Leonardo AW189
- 2 drones: Airbus VSR700 & Leonardo OPV SW-4 SOLO
- 2 Thales MUMT monitoring stations

Figure 29– AH aerial assets and Supervision H130 & VSR700 from Airbus Helicotpers and MUMT Supervision Station from Thales

Figure 30 LHD Assets during MUSHER Demo

The experimental campaign comprised six flights for a total of eight hours of recording time.

The test campaign tested and validated 100% of the targeted functional scope, namely all eight scenarios planned in the experimental plan. In total, the consortium performed 28 LOI2 procedures, 14 LOI3 procedures, and 14 LOI4 procedures during the campaign.

All interoperability configurations were tested and validated (H130-VSR700, H130-SOLO, AW189-SOLO, AW189-VSR700), including functional exchanges via the data exchange infrastructure between the experimental sites. Similarly, all functions of the MUMT monitoring station were tested and validated.

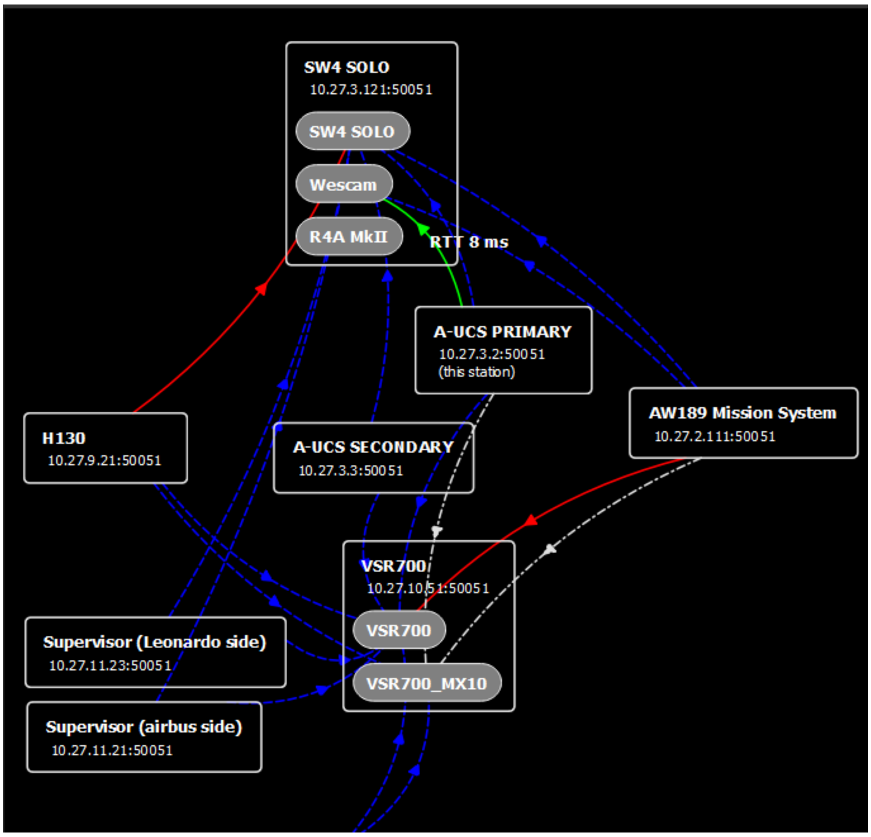

Figure 31: SW-4 SOLO Ground Control Station view of connected assets

Beyond the success of this experiment, the following limitations should be noted:

- The experiment was primarily technical and did not include a representative operational scenario.
- The experiment was highly directive and scripted, as it was geared toward validating technical functions rather than operational procedures.

Therefore, future projects should capitalize on this technical success to focus on technical-operational experiments.

The main lessons learned from the post-experimental activity of data processing and analysis of the recordings are as follows:

- Proper functioning of the protocols created and developed for the purposes of the experiment and representative of the target architecture defined in WP4.
- Obtained convincing results relating to the key performance characteristics of the MUMT system:
    - o Average access time to LOI2 of 5s (between 2 to 9 seconds, mostly depending of quality of connectivity on communication network)
    - o Average access time to LOI3 of 15s (between 2 and 43 seconds, mostly depending of quality of connectivity on communication network)

- o Average access time to LOI4 services of 30s (between 9 and 51 seconds, including manual operators actions to validate request and also depending of quality of connectivity on communication network)
- o Re-tasking time (flight plan modification at the request of the supervisor) less than 1 minute (including manual processing of the request by operators)
- o Good responsiveness of the eMUMT Monitoring service (Updates the situation of supervised actors to the second, equivalent to the call frequency of gRPC services)
- o Excellent robustness of the Supervision Alerting service (No errors or inconsistencies detected)

• Confirmation of the benefits of the technical solutions used: gRPC exchange protocol, "Meshed" network for communications between actors

CONCLUSIONS

This European project provided an ideal environment for advancing the development of the European MUM-T system. Numerous Ministries of Defense and a wide range of industrial partners were involved. The project enabled comprehensive exploration of various domains, including the study of CONOPS, communication protocols, cognitive workload, operational procedures, and the integration of equipment tailored to the requirements of a system-of-systems dedicated to MUM-T.

The flight demonstration leveraged all preliminary theoretical studies and facilitated the presentation of realistic scenarios to our clients, achieving interoperability up to the LOI4 level.

Furthermore, due to various circumstances over the course of these three years, it was necessary to replace helicopters and/or drones without compromising the integrity of the developed architectures. The new assets, featuring different mission or navigation systems, were successfully incorporated, thereby demonstrating the agnostic-by-design capability of our MUM-T system.

This study offers valuable insights into the potential future of European MUM-T, although further in-depth investigations remain necessary.

REFERENCES

L. Thomassey, L. Arlen; "TEAMX or Manned and Unmanned Cooperation", VFS Annual Forum 2021