The future of simulation exercises – Distributed/ Federated Real-Time Simulations in the context of Aviation

Teemu Joonas Lieb
Institute of Flight Guidance
German Aerospace Center (DLR)
Braunschweig, Germany
teemu.lieb@dlr.de

Thomas Damm
New ATM Concepts & Solutions
Deutsche Flugsicherung GmbH (DFS)
Langen, Germany
thomas.damm@dfs.de

Pierre-Yves Gauthier
Eurocontrol Innovation Hub
EUROCONTROL (ECTL)
Brétigny, France
pierre-yves.gauthier@eurocontrol.org

Edoardo Filippone
Department of Avionic Systems
Italian Aerospace Research Center (CIRA)
Rome, Italy
e.filippone@cira.it

Elizabeth Humm
Innovative Human Factors
Deep Blue Srl (DBL)
Rome, Italy
elizabeth.humm@dblue.it

Gunnar Schwoch
Institute of Flight Guidance
German Aerospace Center (DLR)
Braunschweig, Germany
gunnar.schwoch@dlr.de

Manfredi Pavone
Training & Simulation LoB
TXT e-tech (TXT)
Cologno Monzese, Italy
manfredi.pavone@txtgroup.com

***Abstract*— In the aviation context, Real-Time Simulations (RTS) are often used to support validation exercises since they are widely acknowledged as a way to support the validation processes of aircraft systems and Air Traffic Management (ATM) procedures. Due to the emergence of new airspace users such as Remotely Piloted Aircraft Systems (RPAS), Unmanned Aircraft Systems (UAS), Innovative Air Mobility (IAM), and other autonomous aircraft, and due to the emergence of innovative concepts such as UAS Traffic Management (UTM) and U-space, validation and verification (V&V) processes are becoming more and more complex. Additionally, there is a rise in the interoperability requirements for the validation infrastructures to support those new users and concepts, as well as ensuring connectivity between various simulators from different organizations. Moreover, new technologies and procedures must be developed, tested, and validated with particular recognition of the requirements for connection and interaction between the involved simulators, actors, and organizations. Often these are based on methods of sharing information and collaborative decision-making among various stakeholders of Air Traffic Systems (ATS). The Single European Sky ATM Research (SESAR) 3 VISORS project aims to address the increasing complexity of validation processes through distributed/ federated Real-Time Simulations (D/F-RTS). In addition to the investigation of new interfaces, protocols and datasets to be used for the information exchange among the actors of traditional and new users of the ATS, new methods and techniques will be developed to assess human performance and cybersecurity aspects in remotely conducted human-in-the-loop simulations. The main focus is to reveal the advantages and disadvantages of distributed/ federated simulations involving various organizations across several European countries compared to traditional simulations conducted at a single location. Therefore, this scientific publication offers a detailed examination of distributed/ federated simulations, focusing specifically on human performance, cybersecurity and economic efficiency. The paper provides a review of previous studies, analyses existing standards and protocols that form today's foundation for conducting distributed simulations, and discusses a variety of potential use cases to verify the feasibility of distributed/ federated simulations in the context of aviation. Special attention is given to the challenges of interoperability between simulators that represent emerging airspace users, such as air taxis and RPAS, with traditional ATM simulators, including cockpit simulators and air traffic control simulators. As a result, this paper outlines a proposed simulation architecture, leveraging the High-Level Architecture (HLA) and the Open European Validation Infrastructure Service (OEVIS) framework, and investigates the potential benefits of remote simulations for human performance assessments. By addressing these areas, the publication aims to contribute to the development of more robust, interoperable, and effective simulation environments.**

Keywords—distributed/ federated simulations, real-time simulation, new airspace users, human performance, cybersecurity, economic efficiency

I. INTRODUCTION

For decades now, Real-Time Simulations (RTS) using flight simulators and performing Human-in-the-Loop studies have been largely recognized as a means to support the validation and verification (V&V) processes of aircraft systems and Air Traffic Management (ATM) procedures and concepts [1], [2]. By the early 1970s, existing computer hardware had improved in a way to be considered for flight simulation purposes, and motion aircraft simulators such as the "Link Trainer" were already introduced earlier [3]. From the beginning, those simulators were used for training purposes and their crucial role in the validation process of new aircraft systems (e.g., fly-by-wire system) and procedures was soon understood. Today, with the development of new airspace users, such as Remotely Piloted Aircraft Systems (RPAS), Unmanned Aircraft Systems (UAS), air taxi vehicles and more autonomous aircraft in the last years, V&V processes are becoming progressively more and more complex. In addition, due to arising of new concepts and further expected innovations in the near future such as U-space in Europe and Unmanned Traffic Management (UTM) in the United States, V&V procedures will become even more challenging for traditional RTS infrastructures with long-established Human-in-the-Loop (HITL) flight and cockpit simulators. In consequence, both aforementioned factors lead to an increase in the interoperability requirements for the simulation and validation infrastructures including traditional cockpit simulators and air traffic control (ATC) simulators like tower simulators supporting those validation exercises of new systems and concepts in various operational conditions. Moreover, with the design and implementation of new ATM concepts on international level as it is planned by the Single European Sky ATM Research (SESAR) and the Federal Aviation Administration (FAA) NextGen office based on improved ways of organizing and sharing information as well as collaborative decision-making between the stakeholders of Air Traffic System (ATS), new technologies and processes have to be developed, tested and validated under specific recognition of the needs for connection and interaction between involved simulators, actors and organizations. As an example, in the SESAR context, the AURA project has performed distributed/ federated simulation exercises validating, among other, runway inspections performed by UAS and assessing its impact on the behavior of Air Traffic Controllers (ATCOs) when encountering a malfunction of the UAS [4]. Furthermore, the SESAR ERICA project investigated the ability of RPAS to fly Standard Initial Departure (SID) and Standard Arrival Route (STAR) procedures in Terminal Maneuvering Area (TMA) and how to respond to ATCOs clearances and instructions (e.g., vectoring) through distributed simulations [5]. Similarly, in 2017, the FAA NextGen Office has initiated with its UTM Pilot Program (UPP) a research framework to enable the development, testing, and demonstration of UTM capabilities, and to provide an infrastructure to allow for testing of future airspace users [6], [7]. In particular, the conceptual approach to utilize simulation as a service (SaaS) by taking advantage of cloud-based web-services in order to efficiently utilize resources (e.g., simulators, personal, participants) of different organizations across various countries has been a thematic topic of research initiatives [8] and is also being investigated in this publication.

In order to account for the challenges mentioned above, validation exercises based on RTS are more and more often using a distributed/ federated real-time simulation (D/F-RTS) framework and thereby interconnecting remote locations ensuring the usage of various designated simulators, for example an air taxi simulator, in one simulation exercise. Furthermore, as a consequence of the COVID-19 pandemic, many activities in the V&V process started to be executed remotely. Foreseeing a possible reduction in the demand for mobility and an increase in the flexibility, both in time and required space, increasing interest is arising in assessing the possible impacts on the different aspects of the V&V process (e.g., human performance, cybersecurity) when they are executed in a distributed/ federated manner with remote participation of exercise subjects. Consequently, in the context of SESAR and FAA NextGen, the demand for D/F-RTS setups is expected to increase significantly in the future. However, aspects like the assessment of human performances (HP) or remote training could present a bottleneck in the multisite execution of D/F-RTS. Considering these aspects and the relevance that remote operations could have in a future (e.g., RPAS and UAS operations), this approach is being researched by this publication.

II. STATE OF THE ART

This chapter provides an overview of previous work and selected projects in the topic of distributed/ federated RTS.

A. *Previous Work and Projects*

Some distributed ATM simulations took place in the past by means of implementing the Distributed Interactive Simulation (DIS) standard [9]. In 2001, during the AVENUE project, a High-Level Architecture (HLA) was used to connect federated simulator couplings. Moreover, MITRE's AviationSimNet^{TM} tool, developed in 2003, was also based on HLA and was mainly used in the United States [10]. It is a real-time HITL simulation tool in order to study complex ATM situations and concepts. The French research and development project GAIA developed a federated airspace simulation system, called "Shared Virtual Sky", that was based on HLA as well. The developed platform enables various users to connect their simulators simultaneously to a realistic real-time aviation environment [11].

For decades, scientific research and international initiatives have focused on the development of distributed air traffic management systems and simulation environments. A notable contribution in this field is the Multi Aircraft Control System (MACS), which serves as a simulation tool aimed at enhancing the realism and flexibility of HITL air traffic simulations [12]. The MACS is designed to accommodate multiple participants within the same simulation, whether they are on-site or distributed remotely across various simulators. This capability enables the integration of various ATM simulators, such as NASA's Pseudo Aircraft System (PAS), NLR's Air Traffic Control Research Simulator (NARSIM), or the ODID-based ATC Interactive system for the future of air traffic control (SKYNET). In essence, [12] provides a comprehensive overview of the MACS design and highlights the advantages of connecting different, federated simulators together such as the benefits to collaborative work between several organizations and interoperability of highly specified simulators. In addition, publications such as [13], [14] and [15] have used HITL RTS to evaluate ATM systems and particularly the behavior of Air Traffic Controllers (ATCO) in stressful situations and scenarios. When it comes to quantitative measurements such as situation awareness or workload, one key factor is the number of participants in order to postulate generalized findings. However, all these publications have in common, that the number of exercise participants was highly limited leading to a reluctant interpretation of any findings when extrapolating their conclusions to other or all ATCOs, or even other participants in the simulations. A possible mitigation to overcome this challenge could be D/F-RTS as more exercise participants could be recruited due to travel and time savings for participants involved.

Finally, the SESAR 3 "Validation Infrastructure Adaptation and Integration" work package was a driver for interoperability of ATM validation platforms as the projects under its umbrella supported the systematic development of interoperability solutions connecting simulators from different ATM domains across multiple organizations with each other [16].

B. *Existing Standards and Regulations*

The EUROCAE working group "WG-81 Interoperability of ATM Validation Platforms", founded in 2009, created the standard ED-147 which specifies the requirements to reach interoperability between ATM validation platforms. Over the past years, feedback from various SESAR projects was also used to improve the ED-147. In recent years, the EUROCAE WG-81 developed the standard "ED-147B – ATM Validation Platforms Interoperability Specification" [17] and the standard "ED-148A – Guidance to Achieve ATM Validation Platforms Interoperability" [18] with the latest versions published in November 2021. Both standards address the challenges of interoperability between different aviation simulators and platforms in order to enable simulator connectivity and data exchange in a standardised manner.

The Simulation Interoperability Standard Organization (SISO) developed the HLA specification that was transitioned to the open IEEE standard 1516-2010 [19]. ED-147 implementations are based on several HLA Run-Time Infrastructure products (e.g., MÄK HLA RTI, Pitch HLA Evolved RTI) as they are robust and widely used in the area of simulator interoperability, especially in the military sector.

III. RESEARCH QUESTIONS

This scientific publication aims to investigate if D/F-RTS involving various flight and aviation simulators are a valid mean to assess disruptive aviation technologies and concepts from a human performance, cybersecurity and economical perspective. Stemming from this overall project objective, among other, three specific research questions have been raised that are expected to be answered by the planned VISORS validation exercises to be performed in Q1 2026. The following three research questions have been identified:

1) Research Question 1: Can D/F-RTS be used to assess new airspace and ATM frameworks (e.g., U-space) with remote participation of exercise subjects physically separated across different countries without negatively effecting human performance assessments?

2) Research Question 2: What standards, protocols and interfaces have to be used to ensure interoperability between disruptive simulators representing new airspace users (e.g., air taxis) and traditional flight simulators (e.g., cockpit simulators, Controller Working Positions) in a D/F-RTS framework?

3) Research Question 3: Are D/F-RTS a valid method to evaluate new approaches, concepts and systems in the aviation domain when considering their economical implications compared to traditional RTS performed at one location?

IV. EXPECTED SIMULATION INFRASTRUCTURE

This chapters details the expected simulation infrastructure during the VISORS experimental demonstrations utilizing D/F-RTS and lists the simulators of the various partners that are planned to be involved.

A. *High-level Architecture*

Interoperability is a paramount attribute that has been explored for decades in the ATM domain. More specifically, already in 2013, the EUROCAE WG-81 has issued a standard addressing the interoperability aspects of ATM Validation Platforms, referenced as ED-147, whereas ED-147B is the latest published version [17]. The core of the standard remains at an abstract level where the interoperability technology choice is open. However, the standard is also developing technology mappings to address generalities, recommendations and rules expected for reaching interoperability for given technologies (also known as "interoperability on the wire"). HLA is the first technology mapping addressed by the standard, considering that HLA has been specifically designed for distributed simulations. HLA provides an interoperable infrastructure that is specific to a given HLA product but offers application interfaces that are standardised (e.g., HLA IEEE 1516-2010 [19]). Thus, an ED-147 HLA implementation is achieved by selecting the technology, but there is a need for a specific HLA product supplier (e.g., HLA Pitch).

In principle, HLA mostly relies on the concept of federation which is a group of simulations and/ or simulators (called "federates") working together, as well as a run-time infrastructure (RTI) providing a middleware allowing the communications between the federates, and a Federation Object Model (FOM) defining the data objects and interactions shared amongst the federates according to publish-subscribe principles. For the planned demonstration exercises in the VISORS project, the deployed platform (i.e., OEVIS) is making use of the HLA Pitch Technology product, and integrate, on top of the standard HLA configuration, specific Pitch Boosters easing and simplifying the usual connection issues between different sites and implements standard security layers. Each simulator participating to an exercise operates remotely by connecting to the federation through a specific agent using the standardised HLA interfaces and the FOM. The agent is just connected to its local booster, itself being only connected to a central booster managing transparently and securely all the federates' interactions. This kind of configuration is known as a mesh topology. Fig. 1 shows the expected simulation architecture with different remote simulators being connected via cloud network using HLA in the VISORS demonstration exercises.

Despite ED-147 is also willing to address voice interoperability, the current progress of the standard is not sufficient for a concrete implementation. The project intents to mitigate the risk by using a voice communication system developed by one of the project partners based on the use of a licence-free commercial off-the-shelf (COTS) WebRTC audio streaming. The product will operate on the cloud, providing configurable remote audio positions through standard web browsers and supporting the planned ATCO-to-ATCO and ATCO-to-pilots communication based on frequencies.

B. *Involved simulators*

The validation exercises are involving the following simulators:

- EUROCONTROL ESCAPE: This is an en-route/TMA ATM simulator, with multiple control positions and its own Air Traffic Generator (ATG) with several pilot positions.
- DLR U-FLY: In the context of this publication, U-FLY is a remote control station for air taxi operators for planning, monitoring and analysing the flight and missions of one or more air taxis.
- DLR U-space environment: This tool provides basic U-space functionalities such as flight authorization and traffic information to the

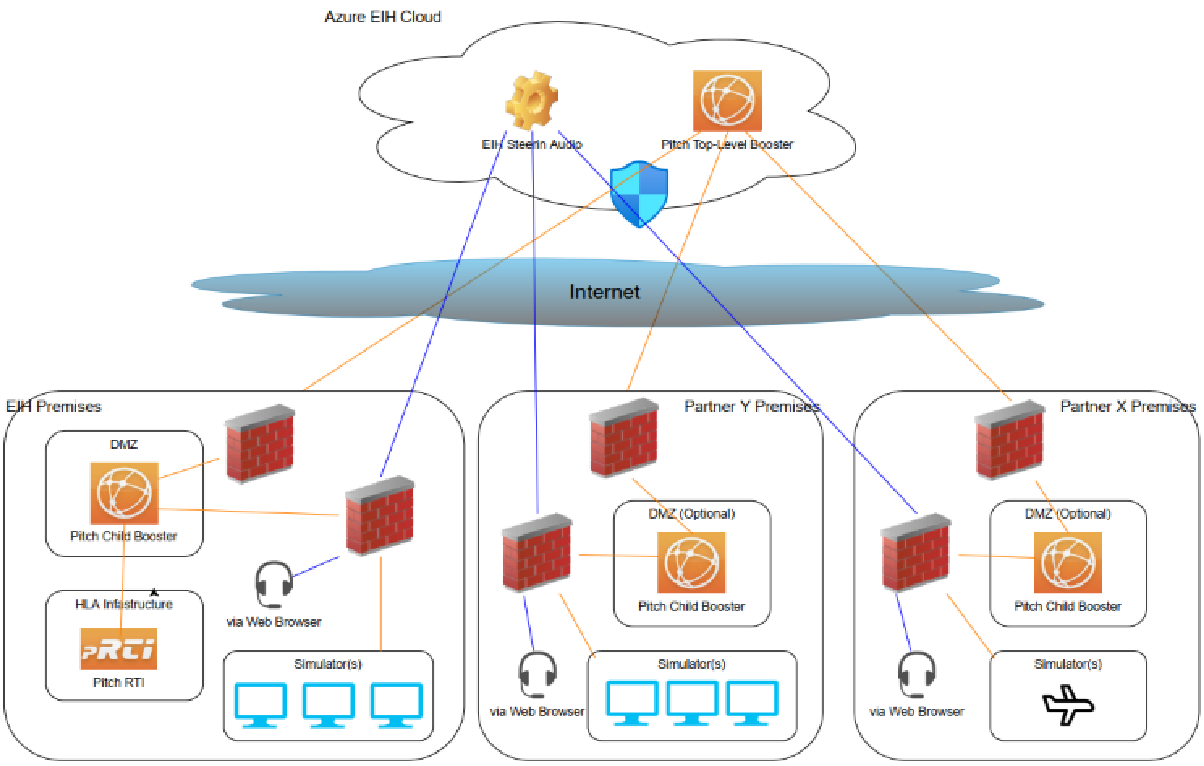

Fig. 1. D/F-RTS simulation architecture

connected UAS and air taxi vehicles, and their operators. It manages the unmanned air traffic and ensure conflict-free flight trajectories for all UAS (air taxis, drones, etc.).

- DLR DroneSim: The DroneSim is a real-time drone and air taxi simulation tool based on a Copter Flight Management System (CFSM), which is a modular flight management system for helicopters, unmanned multicopters and vehicles used in innovative air mobility concepts (e.g., air taxis). CFMS predicts a 4D trajectory of the planned flight in real-time and gives instant feedback whenever a mission parameter is changed, e.g. mission altitude or heading.
- DFS NEWSIM: This is an en-route/TMA ATM simulator providing controller working positions (CWP), an ATG with connected simulators for pilot positions and an exercise database.
- DFS TOSIM: The DFS TOSIM is a comprehensive tower simulation tool that merges multiple Controller Working Positions (CWPs) into a single, cohesive simulation environment. It features diverse simulator setups, ranging from a 4-monitor configuration to high-end front or rear projection systems. This enables a 3D view of the airport environment, providing a 180° to 360° panoramic display for an immersive experience.
- CIRA-FLARE-SIM: This simulator replicates a fully dynamic model (i.e., six degree of freedom) of a tactical Medium Altitude Long Endurance (MALE) RPAS integrated with a full-size reproduction of the remote pilot station including related Human-Machine Interfaces (HMI) and the hardware/software prototypes of the on-board Flight Control Computer (FCC). The piloting functionality is provided through specific interceptors (i.e., stick, throttle and pedals) and a dedicated HMI that works as a virtual cockpit for both visualization purposes (e.g., PFD, MFD, CDTI) and high-level command acquisition (e.g., flight mode or flight plan selection).
- CIRA-Manned Avionic Cockpit (CAM): A facility that allows a pilot to maneuver a simulated aircraft through a representative cockpit of a general aviation aircraft (i.e., CS-VLA/CS-23). This facility can be used for functional testing and/or assessment of innovative cockpit functionalities, typically related to Electronic Flight Instrument Systems (EFIS), or of other avionic devices by aircraft pilots.
- CIRA Scenario Simulator: This simulator includes all the variables for the realization of a complex simulation scenario. Specifically, several elements such as simulating different GPS satellite constellations, segregated areas or no-flight zones (NFZ) and air traffic with different categories and performances of aircraft. Additionally, navigation aid systems, weather hazard areas and other services including terrain and data log recording can be simulated.
- CIRA-CWP: This is an emulator of an air traffic CWP with a customized HMI prototype developed with the support of professional ATCOs. This HMI implements advanced functionalities to help ATCOs to manage both manned air traffic and RPAS, in both terminal and en-route traffic scenarios.

C. *Simulation Interfaces and Data Protocols*

The HLA FOM is the published interface between the federates. The FOM of the validation exercises implements the standard ED-147B Data Model where both data objects and interaction messages are standardised. The ED-147 objects mostly used by the exercises are “Aircraft” and “Transponder”. The interactions used are “AirHandoverAccept”, “AirHandoverRequest”, and “ATS_OLDI_CoordinationAndTransfer”. The FOM implementation applies a model-driven approach automatically translating the ED-147B UML model into an HLA FOM.

The protocol used on the wire is the one embedded into the HLA RTI of the chosen HLA product. Off-line data configuration (e.g., airspace definition, flights to be operated) are exchanged between exercises partners prior to the runs on ad-hoc file formats.

V. VALIDATION EXERCISES

This chapter provides an overview of the foreseen experimental demonstration exercises in the VISORS project that are planned to be performed in Q1 2026.

A. *Use Cases*

In total, three different use cases are planned, each addressing different ATM environments, new airspace environments (e.g., UTM/U-space) and other airspace users, e.g., instrument flight rules (IFR) aircraft, air taxi, or RPAS.

1) ATM Use Case: This scenario explores the interaction and coordination between two ATM systems consecutively to the unplanned activation of a military area with a 10 minutes short notice. Controllers receiving crossing requests are coordinating with military trajectories for some flights going through the restricted area. Some of those trajectories are accepted, being possibly slightly changed by the military. On the other hand, several aircraft flying en-route are not accepted by military and have to be tactically rerouted using headings around the area before being applied direct routes to some points from the original route. Those direct routes have to be coordinated with next sector that belongs to a different ATC center managed by the other ATM system. The scenario takes place between Maastricht and Bremen air traffic control centers (ACC).

2) ATM-UTM Use Case: In this use case, two different scenarios will be simulated. Both scenarios explore the interaction and coordination between ATM and UTM systems during the operation of a scheduled air taxi flight in Munich. Additionally, both scenario are designed to address the challenges of coordination between traditional air traffic control (in this case, tower controller and approach controller), remote air taxi operators, (potentially) vertiport managers, and other airspace users. In the first scenario, an air taxi departs from a vertiport at the Munich Airport (ICAO code EDDM) with no pilot on-board and proceeds towards the Munich Olympiapark. The flight is a scheduled operation with an remote air taxi operator observering the flight continuously, and the vehicle follows a pre-planned route of waypoints and a given timetable, with no emergency situations or special priority over other air traffic. The flight operates at an altitude of 150 meters above ground level (AGL), a suitable altitude for urban air mobility operations within low-altitude airspace. In flight, it will take-off in the control zone (CTR) of Munich airport and transition to an U-space area. U-space services are deployed to ensure a smooth coordination with other airspace users. For instance, the Traffic Information Service (TIS) will provide real-time data of surrounding air traffic to the remote air taxi operator and relevant ATC personnel (if desired), and via the Flight Authorization Service (FAS) the air taxi flight will be authorized to enter the U-space area, ensuring, among others, a conflict-free route to its destination Olympiapark in Munich. Fig. 2 shows the planned flight route and the CTR zone of EDDM as well as the adjacent U-space area.

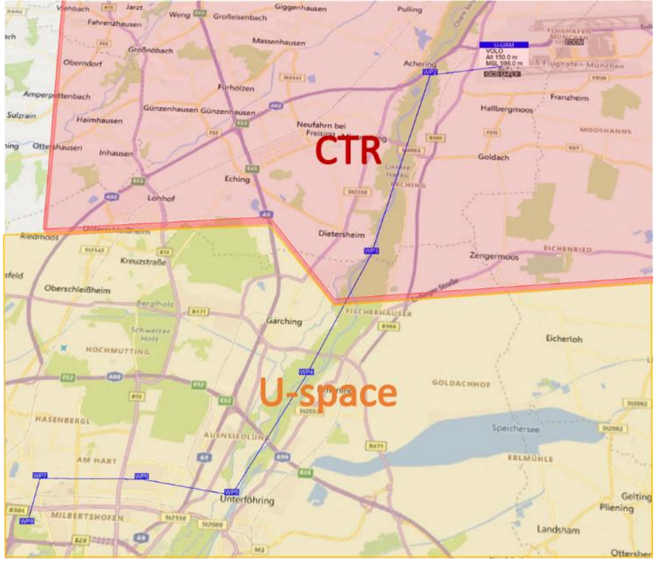

Fig. 2. Use Case #2: Planned flight route of air taxi from EDDM to Olympiapark Munich for the first scenario

The second scenario, is a similar flight from a vertiport at EDDM towards the Olympiapark Munich. The air taxi will take the same route and the same flight performance charateristics (e.g., flight altitude, speed). However, after entering the U-space area and flying for approximately one minute in this area, the air taxi passenger has an immediate medical event. The passenger presses a safety button in the vehicle which informs the remote pilot on ground about the medical event. Afterwards, the remote pilot orders the air taxi to fly back to the vertiport at EDDM using the same route. Hence, additional immediate communication and coordination between the remote air taxi pilot, air traffic control and other (potential) airspace users is foreseen.

3) RPAS Use Case

The use case relates to the investigation of integrating new and unconventional airspace users in one scenario. In fact, it is aimed to investigate the seamless integration of an RPAS in the civil unsegregated airspace, experiencing airspace class transitions and cross-border operations, also considering the possible occurrence of non-nominal conditions and contingencies. Specifically, a MALE-type RPAS, capable of performing medium altitude and velocity, leaves from the departure airport (e.g., EDDM) following a SID procedure and moves toward an arrival airport (e.g., EDDL), at a cruise speed of 200 knots (kts), with an estimated flight duration of about 30 minutes. After a standard departure procedure, the RPAS will transit between different airspace sectors. While flying the en-route phase of flight, the RPAS will then execute a cross-border operation, requiring the hand-over between different national ACCs. As it approaches the arrival airport, it is expected to perform an instrumental approach procedure, till the initial approach fix (IAF) where the simulated operation will end. Other aircraft, flying both visual flight rules (VFR) and IFR, are present during the flight, and will also request take-off and landing at the departure and arrival airports. Fig. 3 depicts the planned cross-sector flight route of the simulated RPAS as a graphical representation of the selected scenario.

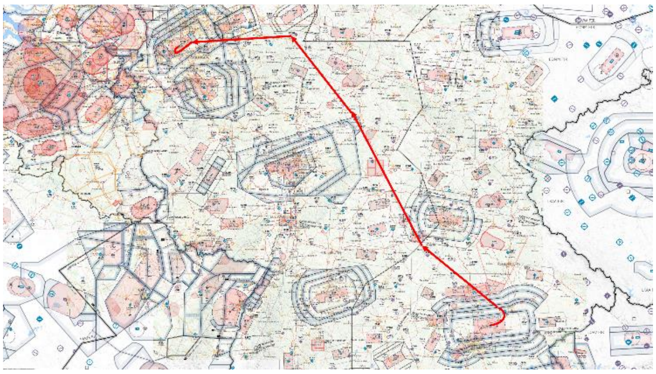

Fig. 3. Use Case #3: Planned flight route of an RPAS performing cross-border operation.

It is also expected that the use-case will investigate the adoption of a Detect and Avoid (DAA) system to support remain well clear procedure, and also non-nominal conditions or contingencies characterizing RPAS integration in unsegregated airspace, such as very-high frequency (VHF) voice communication disturbances and Command and Control (C2) link loss.

B. *Roles and Responsibilities*

For the conduction of the simulation exercises, Table I provides an overview of the foreseen roles and their responsibilities during the planned experimental demonstrations in the VISORS project. The table also illustrates in which use cases these human roles are foreseen to be involved. These responsibilities are only applicable to the planned experimental demonstrations in the project and do not necessarily reflect all roles and responsibilities during real operations.

TABLE I. ROLES AND RESPONSIBILITIES

Role	Definition and Responsibility	Use Case
IFR aircraft pilot	The aircraft pilot is responsible for aviating and navigating the aircraft based on pre-planned IFR routes, and for communicating with the different actors (e.g. air traffic controllers, other A/C pilots) in the operational environment. S/he is responsible for the safety and integrity of the aircraft throughout all flight phases.	1, 2, 3
VFR aircraft pilot	The aircraft pilot is responsible for aviating and navigating the aircraft by looking out of the cockpit window, and for communicating with the different actors (e.g. air traffic controllers, other A/C pilots) in the operational environment. S/he is responsible for the safety and integrity of the aircraft throughout all flight phases.	1,3
Remote pilot	The remote pilot of a UAS or an RPAS is responsible for aviating and navigating the uncrewed aircraft, and to communicate with other actors (e.g. air traffic controllers, other A/C pilots) in the operational environment. S/he is responsible for the safety and integrity of the aircraft throughout all flight phases. This role only differs from a traditional A/C pilot in that sense, that this person is operating from a remote position outside the aircraft.	2,3
En-route controller	The en-route controller is responsible for a specific sector in the airspace. S/he is responsible to ensure separation between the aircraft operating in this specific sector.	1,3
Approach controller	The approach controller is responsible for a specific sector in the airspace linked to the approach procedures to a specific airport. S/he is responsible to ensure separation between the aircraft operating in this specific sector.	1,2
Tower controller	The tower controller is responsible for a specific sector in the Aerodrome Traffic Zone (ATZ) of a specific airport. S/he is responsible to ensure separation between the aircraft operating in this specific sector.	1,2

VI. HUMAN PERFORMANCE AND CYBERSECURITY ASPECTS

This chapter provides an overview of the assessed human performance (HP) and cybersecurity aspects in D/F-RTS experimental demonstration in the VISORS project.

A. *Human Performance*

During the COVID pandemic, Human Factors (HF) practitioners were forced into considering the feasibility of collecting HP data in a remote V&V setting. One methodology that is commonly used for HP assessments, within the research framework of SESAR, is a standardised Human Performance Assessment process (i.e., SESAR Human Performance Assessment Process, [20]). This methodology aims to provide the necessary 'evidence' to show that consideration has been giving to all HF relevant to the introduction of the technical solution, or capability and that the total impact on HF has been measured and managed.

Across the period of COVID, projects were forced to adapt the HP assessment procedure to fit a remote situation. An example of such a project is the H2020-SESAR project ERICA (Enable RPAS Insertion in Controlled Airspace) [5]. All HP assessments were conducted remotely using online questionnaires. Another example, of a project that faced similar challenges, was H2020-CS2 HARVIS (Human Aircraft Roadmap for Virtual Intelligent System) [21]. The project aimed to identify how two cognitive computing algorithms, implemented in a digital assistant, could support the decision-making of single pilots in complex situations. Although the digital assistants were tested in an RTS, HF practitioners conducted the HP assessment from a distance through online questionnaires, debriefings over videoconferencing and observations made through cameras in the simulator. Therefore, so far, the need for remote HP data collection has been accommodated but its validity and fidelity have not been formally assessed. Moreover, growing complexity in ATM could bring increasing challenges in situational awareness, propensity for error and challenges associated with trust, which might require the increased deployment of more specialist HP measuring tools e.g. EEG, eye tracking, EDA. Therefore, it is important to further explore and understand the feasibility of conducting a high-quality HP assessment in a remote setting, without excluding the use of highly insightful and sensitive measurement tools. The planned experimental demonstration exercises in this VISORS project aim to address these challenges and to formally demonstrate the validity and fidelity of D/F-RTS on assessing HP aspects.

B. *Cybersecurity Aspects*

Ensuring cybersecurity in D/F-RTS environments is critical to maintaining data integrity, confidentiality, and availability. The VISORS project will study and address the complexity of cybersecurity challenges in distributed simulation environments, where the lack of proper secure implementation may compromise data integrity, synchronization between simulators, and operational continuity. Potential threats include unauthorized access, communication protocol intrusions, data manipulation, denial-of-service (DoS) attacks, and man-in-the-middle (MITM) attacks during data exchanges between federated simulators. To mitigate these risks, a multi-layered security approach is essential. Secure communication channels should be established to prevent data interception and tampering. Possible solutions could be Transport Layer Security (TLS 1.3) or Internet Protocol Security (IPSec) for data encryption, and Virtual Private Network (VPN) to create secure tunnels for communication. Role-Based Access Control (RBAC) and Multi-Factor Authentication (MFA) should be implemented to restrict unauthorized access to critical simulation components. Regular vulnerability assessments and penetration testing should be conducted to identify and remediate security weaknesses in the simulation environment. Implementing a secure Federation Gateway can further control authentication and authorization among participating simulators. By integrating these cybersecurity measures, the federated real-time simulation can ensure resilient and secure interoperability, safeguarding mission-critical operations against evolving cyber threats.

C. *Economic efficiency*

As part of the VISORS project an initial cost-benefit analysis will be conducted for evaluating the economic and financial implications of transitioning from traditional RTS performed at one location to D/F-RTS simulation infrastructure. The primary objective is to compare the financial impacts of conducting simulations at a centralized location—where participants travel to a single site—with remote simulations, where the involved simulators and the participants are spread across multiple locations and connected via a shared simulation architecture. This distributed system allows simulators from different organizations or geographical areas to interact and collaborate in real-time, which could potentially lower costs and expand accessibility. The analysis will consider several key cost factors, including travel expenses, accommodation, and catering costs (such as hotel bookings, food, and beverages) typically associated with on-site simulations. In contrast, remote simulation infrastructure incurs costs related to the setup and maintenance of the technological framework required for such an operation. These costs may involve significant investments in software, hardware, and network resources, alongside the time and effort required from simulation experts to integrate and manage the remote systems effectively. Moreover, there may be additional expenditures for licensing fees and ongoing subscription costs for specialized simulation platforms. The analysis will also consider the potential benefits of remote simulations, such as reduced travel time, increased flexibility, and the ability to involve a wider range of participants without the logistical constraints of a physical location. The analysis provides a comprehensive comparison of the total costs and potential savings, ultimately helping organizations decide the most economically viable approach for conducting real-time simulations.

VII. OUTLOOK

In Q1 2026, the abovementioned RTS experimental demonstration exercises are planned to be performed in a distributed/ federated manner involving multiple simulators from different organizations across Europe, including CIRA, DFS, DLR, and EUROCONTROL, working together in a collaborative HLA simulation infrastructure. The three distinct mentioned use cases will be simulated through specific scenarios as outlined in chapter V. The primary objectives of these experimental demonstration exercises are to assess human performance factors, evaluate cybersecurity aspects, and to compare the effectiveness of distributed simulations in comparison to traditional, localized demonstration exercises at one simulation site. Specifically, the expressed research questions (cf. chapter III) will be addressed and answered. By involving aircraft pilots and remote pilots managing different airspace users, and personnel from air traffic control, the experimental demonstration exercises will provide insights into how distributed/ federated simulations effect the assessment of human performance and cybersecurity aspects. In addition, the exercises will include an assessment of the economic implications of distributed/federated simulations. This evaluation will explore the potential cost savings and efficiency gains of such an approach compared to traditional methods that require centralized infrastructure. Overall, these exercises aim to provide critical data on the feasibility and benefits of distributed/ federated simulations, with a focus on human performance, cybersecurity, and economic efficiency. The findings will inform future developments in aviation training, testing, and operational procedures.

ACKNOWLEDGMENT

This project has received funding from the SESAR 3 Joint Undertaking under grant agreement No 101167000 under European Union’s Horizon Europe research and innovation programme.

REFERENCES

[1] M. Baarspul, "A review of flight simulation techniques," Progress in aerospace Sciences, vol. 27, issue 1, pp. 1-120, 1990. ISSN 0376-0421. doi: https://doi.org/10.1016/0376-0421(90)90006-6

[2] E. Pastor, M. Perez-Batlle, P. Royo, R. Cuadrado, and C. Barrado, “Preparing for an Unmanned Future in SESAR Real-time Simulation of RPAS Missions,” Proceedings of III SESAR Innovation Days (SID), Stockholm, Sweden, November 2013.

[3] R. L. Page, “Brief history of flight simulation,” SimTecT 2000 proceedings, pp. 11-17, 2000.

[4] G. Schwoch, T. J. Lieb, and H. Lenz, „Flight testing drone contingencies during runway inspection in U-space shared airspace,” In 2023 Integrated Communication, Navigation and Surveillance Conference (ICNS), pp. 1-7, IEEE, Herndon, VA, USA, April 2023. doi: 10.1109/ICNS58246.2023.10124322

[5] A. Manzo, G. Riccardi, G. D’Angelo, G. Pompei, D. Taurino, A. Ghita, and S. Cusimano, “Sesar PJ13 Erica – Enable RPAS Insertion in Controlled Airspace-Validation experiment for the long-term integration of RPAS in an Italian TMA air traffic scenario,” In *Journal of Physics: Conference Series*, vol. 2526, no. 1, pp. 012103, June 2023. doi: 10.1088/1742-6596/2526/1/012103

[6] M. Hatfield, C. Cahill, P. Webley, J. Garron, and R. Beltran, “Integration of unmanned aircraft systems into the national airspace system-efforts by the university of alaska to support the FAA/NASA UAS traffic management program,” In Remote Sensing, volume 12, issue 19, pp. 3112, September 2020. doi: https://doi.org/10.3390/rs12193112

[7] R. D. Johnson, P.H. Kopardekar and J.L. Rios, “FAA/NASA UAS Traffic Management Pilot Program (UPP),” In FAA/NASA Unmanned Aerial Systems Traffic Management Pilot Program Industry Workshop (No. ARC-E-DAA-TN54065), March 2018.

[8] M. Mirz, S. Vogel, B. Schäfer and A. Monti, "Distributed real-time co-simulation as a service," In 2018 IEEE International Conference on Industrial Electronics for Sustainable Energy Systems (IESES), Hamilton, New Zealand, April 2018, pp. 534-539, doi: 10.1109/IESES.2018.8349934

[9] IEEE Standard Association, “IEEE Standard for Distributed Interactive Simulation (DIS) – Communication Services and Profiles,” IEEE 1278.2-2015, November 2015. Available at: https://standards.ieee.org/ieee/1278.2/6202/

[10] P. Brown, D. Bodoh, J. Finegan. P. Liguori and M. Pollack, “AviationSimNet – Integration Manual,” The MITRE Corporation, McLean, Virginia, USA, August 2016. Available at: https://apps.dtic.mil/sti/pdfs/AD1107252.pdf

[11] The Aviation Guy, “Shared Virtual Sky: Leading the Way Toward Enhanced European Air Traffic Management,” February 2013. Available at: https://aviationguy.com/tag/shared-virtual-sky/

[12] T. Prevot, “Exploring the many perspectives of distributed air traffic management: The Multi Aircraft Control System MACS,” In Proceedings of the HCI-Aero, vol. 149, pp. 154, October 2002. Available at: https://cdn.aaai.org/HCI/2002/HCI02-024.pdf

[13] M. S. Zamarreño, R. M. Arnaldo Valdés, F. P. Moreno, R. J. Delgado-Aguilera, P. M. López de Frutos, and V.F. Gómez Comendador, “Methodology for Determining the Event-Based Taskload of an Air Traffic Controller Using Real-Time Simulations,” Aerospace 2023, vol. 97, Septmeber 2023. Available at: https://doi.org/10.3390/aerospace10020097

[14] F. Trapsilawati, Y. Liu, H. J. Wee, H. Subramaniam, O. Sourina, K. Pushparaj, S. Sembian, P. Chun, Q. Lu and C.-H. Chen, “Perceived and Physiological Mental Workload and Emotion Assessments in En-Route ATC Environment: A Case Study,” Transdisciplinary Engineering: A Paradigm Shift, IOS Press, vol. 5, pp. 420–427, 2017. doi: 10.3233/978-1-61499-779-5-420

[15] V. Socha, L. Hanáková, V. Valenta, L. Socha, R. Ábela, S. Kušmírek, T. Pilmannová, and J. Tecl, “Workload Assessment of Air Traffic Controllers,” Transportation research procedia, vol. 51, pp 243–251, 2020. doi: https://doi.org/10.1016/j.trpro.2020.11.027

[16] SESAR, “Today´s partners for Tomorrow´s aviation,” SESAR Joint Undertaking, 2009. Available at: https://www.sesarju.eu/sites/default/files/SESAR_Bochure.pdf

[17] EUROCAE, “ED-147B – ATM Validation Platforms Interoperability Specification,” November 2021. Available at: https://eshop.eurocae.net/eurocae-documents-and-reports/ed-147b/

[18] EUROCAE, “ED-148A – Guidance to Achieve ATM Validation Platforms Interoperability,” November 2021. Available at: https://eshop.eurocae.net/eurocae-documents-and-reports/ed-148a/

[19] IEEE Standard Association, “IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) – Framework and Rules,” IEEE 1516-2010, August 2010. Available at: https://standards.ieee.org/ieee/1516/3744/

[20] SESAR PJ19, “SESAR Human Performance Assessment Process V1 to V3 – including VLD,” Project Number 731765. H2020-SESAR-2019-1. EUROCONTROL. Edition 00.03.00. January 2020. Available at: https://www.sesarju.eu/sites/default/files/documents/transversal/SESAR%202020%20-%20Human%20Performance%20Assessment%20Guidance.pdf

[21] C. Bejarano, A. L. Rodríguez Vázquez, A. Colomer, J. Cantero, A. Ferreira, L. Moens, A. Duchevet, J-P. Imbert and T. De La Hogue, “HARVIS: dynamic rerouting assistant using deep learning techniques for Single Pilot Operations (SPO),” Transportation Research Procedia. Volume 66,. Pp. 262-269. ISSN 2352-1465. December 2022. doi: https://doi.org/10.1016/j.trpro.2022.12.026