UAS In-flight Mission Changes: Exploring the Frontiers of Dynamic Airspace Reconfiguration

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***Abstract*— The ENSURE project is a fast-track initiative within the Single European Sky Air Traffic Management Research (SESAR) Programme, addressing the strategic domain of U-space and Urban Air Mobility. Its objective is to define and standardize a common interface and set of core services (also called Common Information Services, CIS) that bridge traditional Air Traffic Management (ATM) with U-space operations for unmanned aircraft. Building upon prior SESAR research on the integration of manned and unmanned traffic in shared, non-segregated airspace, ENSURE focuses on the operational realization of Dynamic Airspace Re-configuration (DAR). The DAR procedures and associated ATC support tools developed within the ENSURE project serve as a key enabler for the safe, efficient, and flexible management of shared airspace volumes. These airspace volumes are predefined and are commonly known as ATM U-space Shared Airspace (AUSA). By enabling the dynamic delegation of AUSA between ATM and U-space regimes, the DAR procedures facilitate the orderly segregation of traffic and reduce the risk of close encounters between manned and unmanned aircraft. As part of the DAR validation activities, the Royal Netherlands Aerospace Centre (NLR) examined several U-space use cases involving state actors, such as the Royal Netherlands Navy (RNLN), requiring access to airspace volumes in proximity to the approach areas of Amsterdam Airport Schiphol (EHAM). The related scenarios address the execution of sovereign tasks, including asset protection, emergency response, and disaster relief operations, thereby demonstrating the practical applicability of DAR in complex, mixed-traffic environments.**

This paper describes the results of UAS flight demonstrations in the Netherlands combined with a simulation of U-space services provision and Schiphol approach control, carried out by NLR as part of the final DAR validation activities. The NLR study investigates the critical limits of the DAR processes, particularly in accommodating in-flight mission changes for unmanned movements. Specific attention is given to assessing the timing of airspace change requests using DAR procedures, including in contingency situations. The results of this study contribute to the validation of the details of applied DAR procedures in a realistic operational context and the development of requirements for ATC tools supporting both DAR managers and Schiphol approach controllers, demonstrating their effectiveness in managing shared airspace dynamically and safely.

Keywords*— *UAS, U-space, air traffic management, dynamic airspace re-configuration, contingencies, NARSIM, SESAR

I. Introduction

It is anticipated that the number of Unmanned Aerial Systems (UAS) operating at low altitudes up to 500 ft in so-called very low level (VLL) airspace within urban and suburban environments will increase in the future [1]. Furthermore, the expectation is that state actors, such as the military, emergency services, and disaster relief organizations, will conduct priority operations at higher altitudes, up to several thousand feet, within designated airspace volumes. If these volumes are located in close proximity to civil airspace, the priority missions may heavily impact civil air traffic operations near airports [2].

Several initiatives were started as part of the Single European Sky Air Traffic Management Research (SESAR) Programme in the early 2020s to investigate the integration of unmanned and manned traffic in non-segregated airspace, such as the SESAR project INVIRCAT that looked at integration of fixed-wing drones into the operations of a regional airport [3]. Another project, called AURA, took a different approach. The project played a crucial role in defining ATM U-space Shared Airspace (AUSA), which is a generic type of airspace that can be dynamically delegated between Air Traffic Control (ATC) units and highly automated U-space airspace [4]. Essentially, it meant that non-segregated airspace was replaced by airspace that can be shared using a flexible segregation method called Dynamic Airspace Re-configuration (DAR).

DAR processes were defined and software prototypes for management of DAR requests (initiated on the U-space side) to an airspace manager, called DAR Manager (DARM), were developed. These developments served as an enabler for the necessary flexibility by enhancing communication among all involved actors, i.e. drone pilots, U-space Service Providers (USSP), Air Navigation Service Providers (ANSP) and Air Traffic Controllers (ATCO). Additionally, the investigation of U-space contingency scenarios revealed that different situations require tailored DAR approaches, underscoring the complexity of integrating unmanned and manned traffic in such shared airspace structures [5].

The DAR concept has been further developed in recent years within the ENSURE project of the SESAR 3 Industrial Research Programme by building the required services and interfaces for both U-space Service Providers (USSPs) and

Air Traffic Control (ATC) to enable flexible airspace management procedures for strategic, tactical and contingency use cases. In that context, the Netherlands Aerospace Centre (NLR) started an investigation of the controller interfaces necessary to accommodate priority UAS operations and the dynamic allocation of shared airspace between manned civil traffic and unmanned military missions in higher airspace (between 500 ft and 5,000 ft). Special use airspace volumes above the North Sea were divided into smaller airspace blocks that can be activated and deactivated for military use via DAR processes. These processes are carried out by a DAR Manager in analogy to the delegation of AUSA volumes between ATC and U-space actors [6]. A particular focus of the research was placed on tactical mission changes in special UAS operations, for instance an unmanned system operated by the Royal Netherlands Navy that is initially tasked with surveillance of anchorage areas along the Dutch coast and then rapidly needs to redeploy to protect a maritime asset located under one of the approach routes into Amsterdam Airport Schiphol (EHAM).

During several workshops with experienced Schiphol approach controllers and other operational experts, the AURA interfaces developed by NLR for the DAR Management and the visualization of airspace changes for approach controllers were re-evaluated in 2024. Additional interface requirements were established to account for the specific airspace structure and to allow for a more dynamic support of the DAR processes that were refined in the ENSURE concept documentation [7]. In particular, the DARM needed an interface that allowed for evaluation of different types of DAR requests when making a decision whether to accept or reject a request. Furthermore, the involved timing aspects for DAR processes had to be considered to raise the situational awareness of ATCOs and help them anticipate the operational consequences when ATC-controlled AUSA volumes are delegated to U-space, or in this case, military special use airspace [8]. Throughout 2025, the NLR validation team incrementally developed prototypes of ATC interfaces for the DARM and for ATCOs operating in the Schiphol Terminal Manoeuvring Area (TMA), and tested them during real-time validation campaigns [9]. The selected prototypes were used to address the remaining research questions during the final validation sessions in January 2026, which included a demonstration flight at the NLR Drone Centre in Marknesse (NL). The demonstration involved a drone that followed a flight plan (U-plan), which was converted within the ATC simulation in such a way that it appeared to be carrying out a priority mission in proximity of the Schiphol TMA.

This paper addresses the most important research questions of the ENSURE project investigated by NLR, and it describes the results of the final validation sessions. It starts with a description of the DAR concept and the different implementation phases of DAR requests that are initiated by a USSP. It provides a few details on refinements in the DAR processes that led to the development of the final Human Machine Interface (HMI) prototypes, and gives a description of the technical architecture that connected the drone flight operation in Marknesse with the ATC simulation in Amsterdam. It then focusses on the research results obtained during the final simulation campaign and ends with a future outlook on open issues that could not be addressed in ENSURE and on the developments that are necessary to enable the shared use of airspace on a larger scale.

II. Dynamic Airspace Re-configuration

A. *Initial Concept (AURA Project)*

The SESAR Industrial Research Project AURA was the first initiative to develop a consolidated concept of Dynamic Airspace Reconfiguration (DAR) addressing interactions between manned and unmanned traffic near small and medium-sized airports [10]. The project assumed that a significant number of UAS would operate within designated VLL airspace volumes, requiring access to controlled airspace resources in the vicinity of airports managed by ATC. These VLL airspace volumes were envisioned as highly automated U-space environments, provided and managed by one or more USSPs.

Interactions between ATM operations and U-space (as shown in more detail in Fig. 1) would occur if some of the unmanned vehicles needed to move between different VLL volumes or carry out missions within Controlled Airspace (CAS) at or in proximity of abovementioned airport environments, i.e. in the Aerodrome Traffic Zone (ATZ), the Control Zone (CTR) or the TMA.

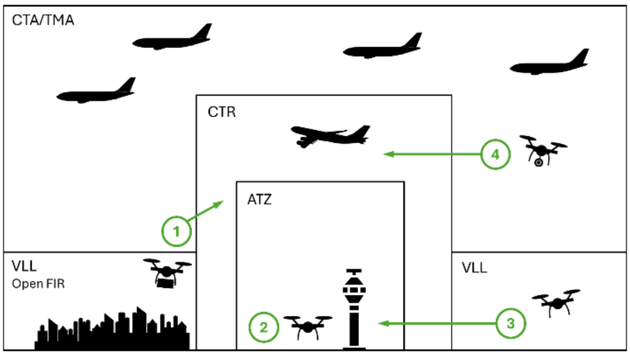

Fig. 1. UAS Interactions in AURA Operational Environment.

The AURA concept described several use cases for unmanned operations that would fall into different interaction categories with the following four categories describing the basic interactions with airport operations, as well as arrival and departure operations [11]:

- Interaction 1: Unmanned operation accessing CAS in a densely populated, urban environment.
- Interaction 2: Unmanned operation within an airport control zone (ATZ/CTR).
- Interaction 3: Unmanned operation accessing CAS from a dedicated U-space volume.
- Interaction 4: Unmanned emergency (high priority) traffic through a TMA and CTR.

In order to find a solution for dynamically separating manned and unmanned traffic involved in these interactions, AURA defined a new airspace category called ATM U-space Shared Airspace (AUSA).

AUSA airspace refers to portions of controlled airspace (CAS) where both manned and unmanned operations may take place (see Fig. 2). These airspace volumes are predefined and structured in such a way that ATCOs can clearly understand the operational consequences of delegating them to U-space. Accordingly, AUSA should only be implemented in areas where it is operationally meaningful for manned and unmanned traffic to share airspace resources.

DAR was consequently developed as an ATM process that dynamically delegates control of AUSA airspace volumes between ATM and U-space based on demand from manned or unmanned operations. The AURA concept introduced a DAR Manager (DARM) role to oversee these changes, thereby intending to reduce tactical ATC workload and a possible impact on the safety of manned operations. Unlike traditional static segregation, DAR had to provide finer granularity and adapt flexibly to traffic demand, enabling unmanned traffic access to airspace that would otherwise be restricted.

Through DAR, predefined AUSA structures could switch between ATC control (called blue volumes in AURA) and U-space control (orange volumes) [12]. This also raised the question of whether delegations should always be time-limited, requiring a specified end time in each DAR request. Since airspace management is about allocating airspace volumes to meet demand, AUSA sectors were considered to have a default status (blue or orange), with delegations applied only temporarily. Such an approach also prevented the added complexity of layering one DAR delegation on top of another.

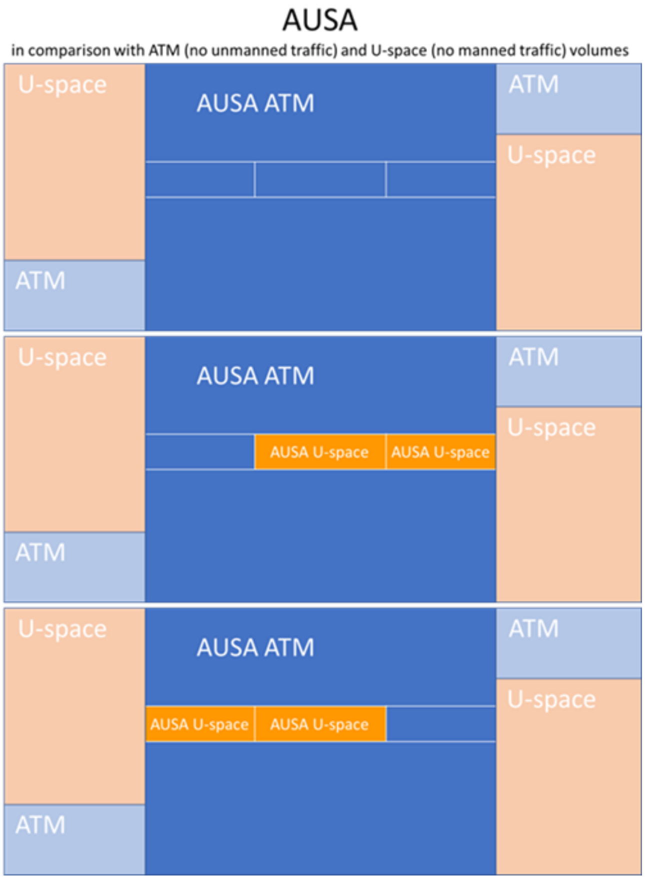

Fig. 2. Delegated AUSA U-space Corridor.

Fig. 2 shows a straightforward delegation example (top view, as would be visible on a surveillance screen) that builds a moving AUSA corridor, delegated to U-space, between two dedicated U-space volumes. This is only a specific example of what could be achieved with AUSA airspace delegation, but it also shows that the dynamic, demand-related character and a granular approach are at the very heart of the concept.

From an ATC point of view, it would mean that the AUSA volumes are ATC-controlled volumes that occasionally become unavailable due to DAR requests. However, it can be imagined that this concept would also work in the opposite direction and enable manned movements through USSP-controlled U-space VLL volumes.

The AURA project assumed that airspace changes would occur only occasionally and for a limited number of unmanned flights, and it was focused on contingency scenarios for interaction types 1, 2, and 3 as described above. This approach required that unmanned operations also needed to be strategically planned in advance, establishing a nominal mission before any contingency measure could be activated. To enable such missions, it was necessary to clearly define their objectives, assign priority levels, and assess the operational implications for ATC.

NLR then conducted real-time simulations in a realistic regional airport setting for Rotterdam The Hague Airport (EHRD) and its TMA. These simulations examined scenarios where delegating airspace to U-space due to contingency situations disrupted manned operations under Visual (VFR) and Instrument Flight Rules (IFR). The DARM could identify the predefined VLL U-space volumes on a surveillance screen and when triggered by an incoming contingency request would evaluate the proposed airspace changes and start a lengthy negotiation process with TMA and tower ATCOs. Furthermore, the DARM could make specific alterations to the contingency requests based on feedback from ATCOs or personal insights. This included a feedback loop with the USSP. As a result, the negotiation process and its efficiency were considered suboptimal [6].

B. *Refined Concept (ENSURE Project)*

While the AURA project provided a solid basis for a DAR concept, several gaps were identified and discussed at the start of the SESAR Industrial Research Project ENSURE, a fast track project to prepare implementation of U-space services for DAR. The main issue was process efficiency: allowing the DARM to alter requests was seen as unnecessary for ATC-initiated requests and undesirable for USSP-initiated requests.

Unlike AURA, where DARs addressed single UAS contingencies, ENSURE additionally aimed to support both strategic planning and tactical changes while keeping the DAR Management efficient and ATC situational awareness intact, demanding stronger automation options for DAR evaluation and impact assessment. This meant that, instead of intricate feedback loops, the DARM needed to take clear decisions on DAR requests based on all information sources that would reasonably be available, such as expected (manned) traffic demand.

Fig. 3 shows the actors in the refined DAR process and has a focus on tasks and interactions for requests initiated on the U-space side. A DAR request and related airspace changes could also be initiated by ATC (see arrows in the figure between tactical controller and DARM), but this led to different use cases that were investigated by other consortium partners.

The DAR process would start with a mission plan for a drone and the submission of a so-called U-plan (or UAS flight plan) from a drone pilot to the USSP for obtaining flight authorisation. If several UAS missions took place at the same time, this would require a U-plan aggregation process to be carried out by the USSP, identifying the exact airspace need and potential DAR requests to the responsible ANSP and thus the DARM and the involved ATC unit. It is important to consider that at this point the USSP could already consider possible prioritization issues, such as requirements for use of the volumes under certain external conditions. A consolidated DAR request would then be sent to the DARM via a Common Information Services Provider (CISP).

The CISP acts as the central, authorized source of truth for the digital information in the communication processes. Current discussions centre around the questions of organisation and certification of services. Many ANSPs argue that there should be a single, certified CISP per country, and they see it as part of a service provision [13].

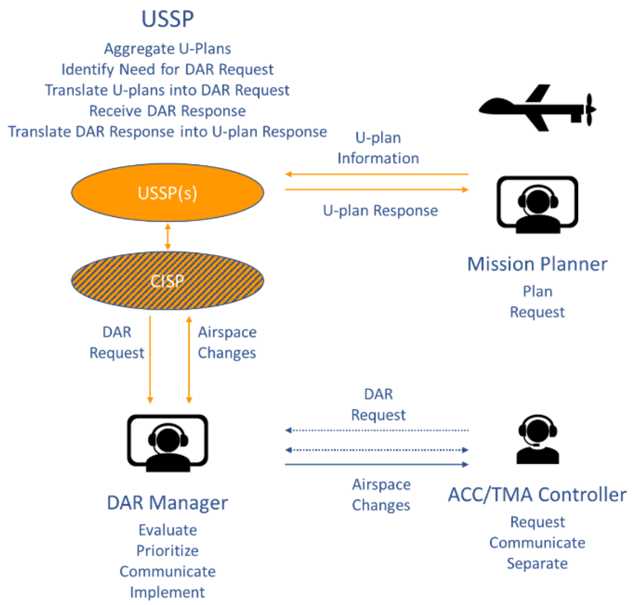

Fig. 3: DAR Process Actors and Information Flows.

When the information eventually appeared at the working position of the DARM for evaluation, instead of starting a lengthy negotiation process, the DARM would need to make a decision whether to accept or reject a request, under consideration of all relevant priority issues and his or her own knowledge of the ATC operation, with an easily configurable rationale message. This also meant that, in the event of a rejection, the USSP would need to identify all missions included in the DAR request and inform the relevant UAS pilots of the rejection of their U-plans. In that way, the DAR process was integrated with the flight authorization processes of a USSP, since a rejection from the DARM would be comparable or even identical to a rejection of flight authorization given by the USSP.

A DAR rejection by the DARM would thus lead to a restart of the DAR request process based on modified U-plans. Especially, when automated systems for the USSP would be involved, this was considered to be the most straightforward process [7]. An acceptance would implement the request, and it would lead to a visualization of the concerned DAR volumes on the surveillance screens of involved air traffic controllers, applying the tactical separations between manned civil traffic and AUSA volumes delegated to U-space via the DARM.

In addition, the concept incorporated airspace planning at both the day before operation (D-1) and the day of operation (D0), creating a structured distinction between strategic, long-term DAR planning and more dynamic, tactical requests, thereby strengthening both planning stability and operational flexibility.

The existing AURA procedures for USSP-initiated DAR requests (sometimes referred to as reverse DAR, with the normal DAR being initiated by ATC) were changed and refined (see also [8]) and the process flow already sketched above was divided into several phases (as is shown in Fig. 4).

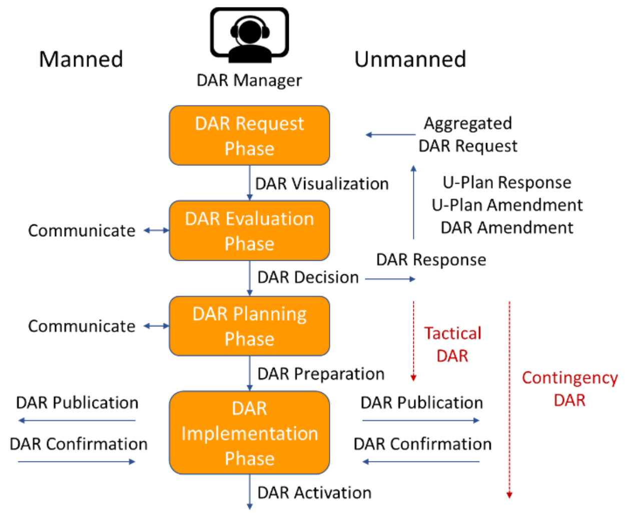

Fig. 4: DAR Process Flow for USSP-initiated DAR Request.

DAR Request Phase. In this phase, UAS operators submit their operational intent through a U-plan to the Flight Authorization service, usually on or before D-1, with possible tactical updates on D0. Based on geo-awareness information, including airspace and manned traffic data, the USSP evaluates the plan and determines whether a DAR request is necessary. If required, the request is forwarded via the CISP to the DAR Manager for further processing.

DAR Evaluation Phase. Receiving DAR requests from the USSP, the DARM evaluates them using decision-support tools that assess traffic and airspace conditions across relevant time horizons. The applicable procedures depend on whether the evaluation takes place on D-1 or on D0 shortly before implementation. The phase concludes with the DARM accepting or rejecting the request, after which the response is sent to the USSP, which informs the affected UAS operators and, if necessary, initiates updates to U-plans and subsequent requests.

DAR Planning Phase. After a DAR response is issued, the request enters the planning phase, whose duration depends on the planning horizon. On D-1, this phase runs in parallel with USSP and UAS operator planning, allowing updated U-plans to generate revised DAR requests until the D0 plan is frozen. During this period, the finalized DAR information is available in both ANSP and USSP systems. On D0, tactical mission changes may require adjustments to the existing DAR plan, either as updates to the current plan or as separate requests assessed for operational impact. In urgent situations, the planning phase may be shortened or bypassed, with the process moving directly to DAR publication (see red arrow for Tactical DAR in Fig. 4).

DAR Implementation Phase. A planned DAR may be replaced or cancelled by the DARM at any point during the planning phase, with its operational impact reassessed prior to publication. Approximately 10 minutes before activation, the DAR enters the implementation phase, which follows a defined sequence (as shown in Fig. 5). Four minutes before activation, caution alerts are issued, by the USSP to UAS operators and by the ANSP to ATCOs, initiating the “amber” transition state [7]. Both USSP and ATC must then confirm compliance with the airspace change within 2 minutes. Once activated, UAS operators may use the delegated airspace volume. Deactivation follows the same process, including a second amber state, after which the airspace is returned to normal operations once it is confirmed clear of UAS traffic.

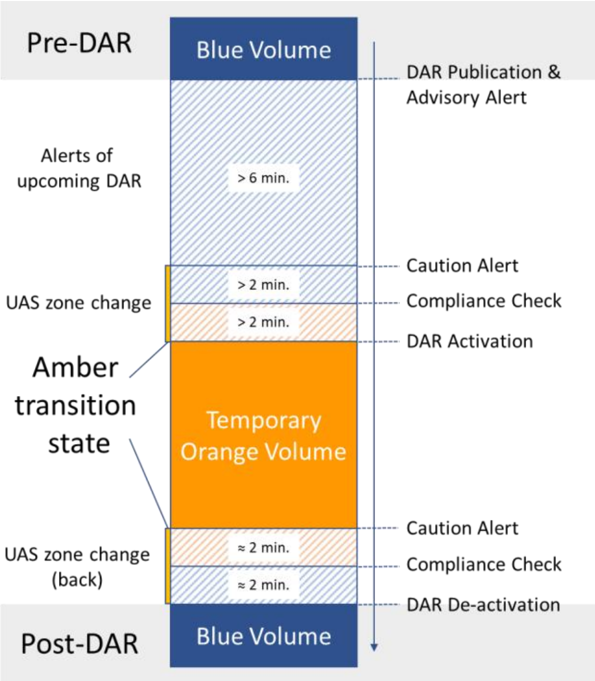

Fig. 5: DAR Implementation Phase (USSP-initiated).

As already mentioned above, the duration of each phase varies according to the type of DAR and its planning horizon. A strategic DAR involves an extended planning phase, becomes available on D-1, and is reassessed by the DARM (or a supervisor) at the start of D0. By contrast, a tactical DAR that is submitted shortly before or during UAS operations, is evaluated immediately and either accepted or rejected. If accepted, it is published without delay due to the involved time constraints (U-plans would prevent hovering or circling movements).

Contingency operations, such as urgent or high-priority emergency missions, follow a non-nominal workflow. When mitigation measures, for example an Emergency Response Plan (ERP), are activated, a DAR may be generated automatically, but only if there is a deviation from an active DAR in terms of volume claims. In such cases, the contingency DAR is presented only to the DARM, who confirms its reception. Contingency DARs are activated immediately on ATCO displays. Because some time may elapse before the UAS enters the additional AUSA required for ERP execution, the DARM could still coordinate with ATCOs to anticipate and manage any necessary adjustments to manned traffic operations. However, this would need to happen as early as possible, as all planning phases are bypassed (red arrow for Contingency DAR in Fig. 4)

In emergencies, where airspace is infringed (due to a violation of an internal U-space buffer) without indicated mitigation measures, UAS positions from the network identification service (Article 8 in [1]) are displayed on ATCO surveillance screens and an Area Proximity Warning alert is given to support separation management. If the infringed airspace is part of an AUSA volume, the DARM could theoretically add contingency volumes manually. However, doing so could distract controllers and divert their attention from managing the immediate situation. In all cases, the DARM retained ultimate authority to activate any additional DAR volumes.

C. *Concept Application Scenarios*

The DAR concept described in detail above, was developed together with ENSURE partners, but applied by NLR and a validation team consisting of (civil and military) operational experts and air traffic controllers to specific use cases and scenarios. Most importantly, the concept was expected to support operations of interaction type 4 (Fig. 1), which required different types of use cases and scenarios than used before in the AURA project. During workshops, the most appropriate scenarios identified described UAS surveillance missions along the Dutch coastline, as they would need to occur in proximity of Amsterdam Airport Schiphol (EHAM) approach operations. To account for this need, the NLR validation team collaborated with the Royal Netherlands Navy (RNLN) to define AUSA volumes above the North Sea on the basis of a UAS Test and Training Area (TTA) already in use (see red grid in Fig. 6). In addition, they developed several UAS mission plans for surveillance and inspection operations, illustrating how DAR could be applied by a military USSP to communicate airspace requirements with civil ATC.

Fig. 6: Sketch of an AUSA Airspace Grid in the North Sea Test Area.

Scalability of the operation was also seen as a guiding principle. The concept was designed to support increasing numbers of UAS conducting diverse operations while maintaining safe and efficient airspace management. Accordingly, negotiation processes were streamlined, and targeted automation support was introduced for both the DARM and the affected ATCOs to enhance human performance and operational robustness. Clear procedures were also established for both nominal and non-nominal scenarios.

The DAR concept is considered particularly useful in areas where UAS operations within U-space take place close to manned aviation. It is especially valuable when flexibility is needed to carry out UAS operations in controlled airspace volumes while minimizing disruption to manned flights. Using smaller airspace volumes increases flexibility and generally reduces the impact on conventional air traffic. The approach is similar to military airspace management. In military contexts, Flexible Use of Airspace (FUA) procedures are used to coordinate civil and military airspace needs [14]. Concepts such as Dynamic Mobile Areas (DMA) are part of broader Dynamic Airspace Configurations (DAC), which are currently being explored in SESAR 3 ISLAND and HARMONIC projects [15]. Therefore, if military airspace used for drone testing and training is viewed as a specialized form of U-space, DAR procedures could potentially be applied in a similar manner [16].

Accordingly, a realistic environment was designed as part of the so-called Dutch Cluster activities of the ENSURE project where operational use cases for dynamic use of airspace could be validated with a DAR Manager and ATCOs participating in real-time simulations and carrying out DAR procedures with support of advanced HMI prototypes.

III. Validation Environment and Use Cases

Workshops carried out in 2024 with operational experts having civil and military backgrounds focused on the working environment to be considered for the validation of different use cases. The use cases were tested and refined during the iterative HMI prototype development activities in 2025 and a final validation activity was carried out in January 2026 in connection with a real drone flight to validate them. The following gives an overview of the environment preparation activities and describes the use cases.

A. *ATC Environment*

Initially, it was discussed that operations further away from Schiphol had less or no consequences on manned operations, as they are executed at much lower altitudes than regular Schiphol inbound and outbound traffic flows. UAS missions that would be executed in the south of the TTA around windmill parks and anchorage areas, however, might have an impact if they were carried out close to approach operations with altitudes higher than 1,000 ft. This is shown in Fig. 7 where the TTA can be seen on top of the Schiphol arrival chart, with wind mill parks indicated in dark green and anchorage areas in orange.

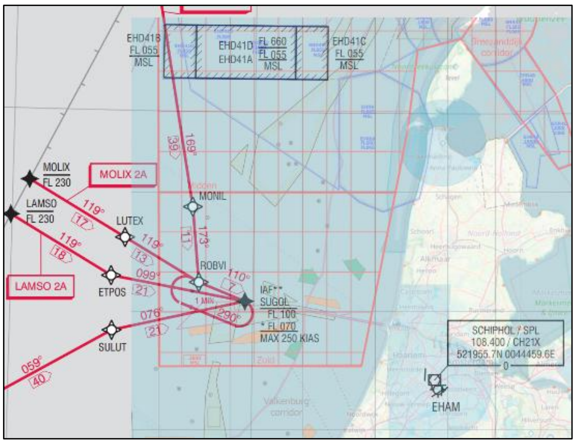

Fig. 7: Superposition of UAS TTA with Schiphol Arrival Chart [17].

UAS missions were usually launched from Maritime Airfield De Kooy (EHKD) near Den Helder (shaded circular area in the upper right of Fig. 7), but could also be initiated from ships and platforms at sea. Considering typical mission profiles, it was assumed that operations would vary between 500 ft and 5,000 ft, and would be carried out with fixed wing drones. But also flights with larger multirotor drones were considered. Essentially, this made no difference for the related DAR procedure, so the very details of the mission simply added to the realism of the simulation setup. Given that Schiphol TMA 1 already starts at 1,500 ft, there was a clear overlap between the defined AUSA volumes and approach responsibility areas (Fig. 8).

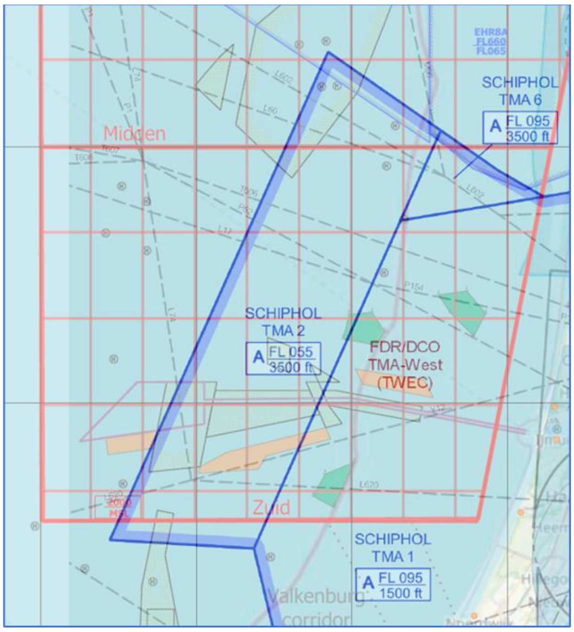

Fig. 8: Overlay of UAS TTA and Schiphol TMA Chart (Source: LVNL).

Both Fig. 7 and Fig. 8 show that arrivals from the west would be particularly affected by DAR operations in the southern TTA AUSA volumes. These flights descend from flight levels between FL100 and FL070 at Initial Approach Fix (IAF) SUGOL down to 3,000 ft on the downwind leg for runway 18R (see also Fig. 9). 18R is the runway closest to the AUSA volumes, and traffic flows approaching from SUGOL or the southern IAF RIVER are merged inside the TMA and vectored by approach controllers towards the runway.

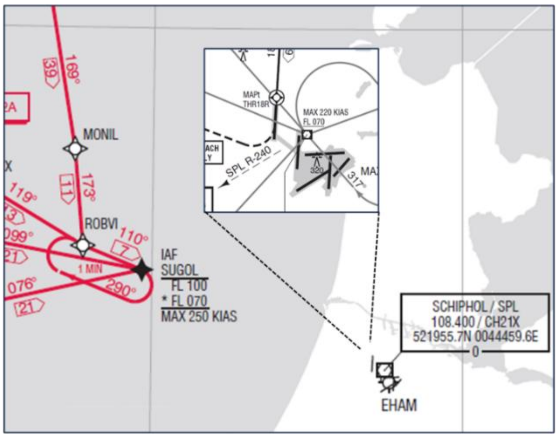

Fig. 9: Excerpt of EHAM Arrival Chart with Runway Locations [17].

During Independent Parallel Approach (IPA) operations to runways 18C and 18R, flights may need to descend even further down to 2,000 ft on the downwind leg towards 18R. This would make it more difficult for approach controllers to keep traffic above the AUSA volumes, as they would have to descend the flights more quickly once the AUSA volumes have been passed. In order to assess such a realistic high-impact scenario, all DAR use cases in the TTA were built around the typical Schiphol IPA operation.

B. Simulation Environment

Accordingly, NLR set up a real-time human-in-the-loop simulation of this ATC environment for the Schiphol DAR Manager and the TMA controllers using the NLR ATM Research Simulator (NARSIM). The NARSIM Radar software replicates key ATM functions, including realistic surveillance data, aircraft behaviour, and interfaces familiar to ATCOs. Additional software tools supported DAR management at the DARM position. Furthermore, the changes due to a DAR implementation had to be visualized on ATCO displays. Simulated manned traffic was controlled by real airline pilots who acted as pseudo-pilots and communicated with controllers via radio/telephony. In order to simulate military drone movements, NARSIM was connected to the ArduPilot Mission Planner. The same interface could be used to either simulate one or multiple drone flights, or plan and execute a drone mission in live trial flights.

Fig. 10: NARSIM Working Positions during Demonstration Flight.

It was assumed that each UAS, simulated or real, would send a U-plan to the USSP (which could be a drone fleet coordination centre for the military) for flight authorization, as was shown in Fig. 3. The USSP, which was simulated in NARSIM, would evaluate the incoming U-plans, and if it was discovered that a DAR request (TTA volume request) was necessary, a corresponding DAR request was sent via the CISP, also simulated in NARSIM, to the ANSP/ATC and thus the DARM working position. On rejection, the affected drone pilots would receive a response message with a rationale via the CISP and USSP, and on acceptance, the DAR was implemented on controller screens and a response was sent to the USSP and the drone pilots for acknowledgement.

C. Use Case Definitions

With this being the basic procedure for a USSP-initiated DAR request, the four investigated use cases shown below were defined. They correspond with what has been described in more detail in [7] and [8]:

Use Case 1: Strategic Planning and Execution of a UAS Mission. This use case covers the strategic planning of a DAR before the day of operation (D-1), and the implementation of a strategically planned mission in the tactical operation (D0).

Use Case 2: Tactical Change of a UAS Mission. This use case is based on the strategic planning of a UAS mission on D-1 and execution on D0. While the UAS is flying its planned mission on D0, a change of its U-plan occurs due to changes in mission requirements. This prompts a tactical DAR request.

Use Case 3: Contingency Operation with Execution of ERP. This use case is based on the strategic planning of a UAS mission on D-1 and execution on D0. While the UAS is flying its planned mission on D0, a contingency will occur forcing the UAS to follow an ERP that, depending on the volumes necessary to execute the plan may (or may not) lead to an additional contingency DAR request.

Use Case 4: Contingency Operation with a Non-conformance and Infringement. This use case is based on the strategic planning of a UAS mission on D-1 and execution on D0. While the UAS is flying its planned mission on D0, a non-conformance alert will be received by the DAR manager as the UAS deviates from the expected mission profile leading to an infringement of ATC controlled AUSA volumes.

It should be noted here that Use Case 4 considers the intrusion of controlled airspace with manned operations as the non-conformance, which triggers an alert based on the existing Area Proximity Warning (APW) system. Non-conformances may also occur in cases where a UAS, having received flight authorization from the USSP for a specific U-plan within an AUSA volume, subsequently deviates from that U-plan. According to the concept, the USSP would be able to communicate such a non-conformance to an ANSP, however, ATC might not be interested in being alerted since the entire volume is under responsibility of the USSP. Such a scenario was evaluated during final validation, with results reported in the concluding section of this paper.

IV. HMI Design and Prototyping

An iterative, short-cycle development approach was adopted for the HMI design to ensure a stable basis for incorporating evolving complexity and functional requirements derived from the concept development activities. This resulted in three successive design stages: an initial design covering the core concept elements for strategically planned DARs (Use Case 1), an intermediate design featuring improved visualizations, and a final design assessed for scalability, with specific attention to human performance and the ability to execute required actions within operational time constraints.

A. Initial HMI Design

For the first simulation sessions in March 2025, the basic interfaces for the DARM approach ATCOs were developed. The DARM interface consisted of an evolution of the AURA interface [11] called DAR Communication Tool (DAR-CT), and an advanced DAR Impact Assessment Tool (DAR-IAT).

DAR requests received from a USSP via the CISP were presented in the DAR-CT (mostly a single U-plan), indicating an identifier, the DAR activation time, and a descriptive name for the DAR. Buttons were available to accept the request, reject it together with a rationale for the rejection, or to withdraw (cancel) it. The latter functionality was not specifically part of the concept, but must be seen as a technical function to evaluate options for the later applied tactical changes in Use Case 2. The main component of the DAR-IAT was a time slider. All AUSA volumes contained in the DAR request together with their name, maximum altitudes, and start- and end-times were shown on the DARM surveillance display. When moving the slider, the future situation regarding the activated (AUSA) DAR volumes and manned traffic was shown in a "ghost" view, i.e. ghost radar targets were indicated with letter "G", and both AUSA volumes and ghost flights were presented in a teal blue colour. It should be noted that the projected active volume was highlighted (Fig. 11).

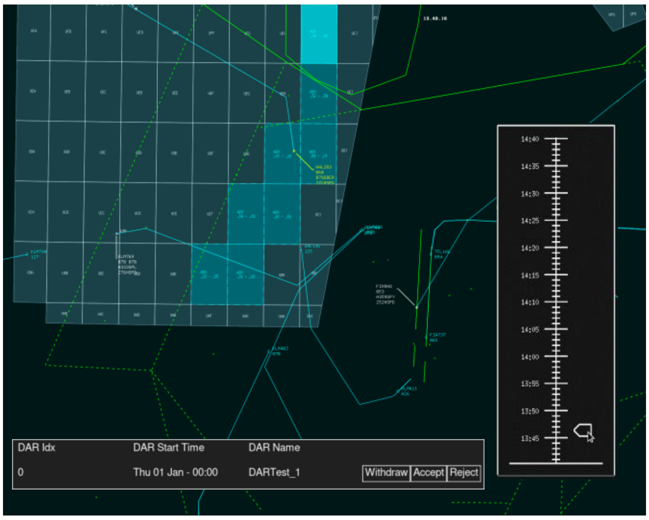

Fig. 11: DAR Impact Assessment Tool (DARM Working Position).

On acceptance of the DAR request, the DAR was activated in the ATC system and presented in another colour (amber) on the DARM surveillance display (Fig. 12). Ghost flights, however, would still appear in teal blue.

Fig. 12: DARM Surveillance Display after DAR Request Acceptance.

The elements added to the Schiphol approach controller surveillance display (Fig. 13) were the active or soon to be active DAR volumes. The active DAR volumes were presented in orange, volumes for which the caution alert phase had already started were shown in yellow (4 minutes before activation), and volumes for which the publication phase had started (10 minutes before activation) were presented in green. As in the case of the DARM display, the volume names were also indicated inside the volumes. Instead of the start- and end-times for activation, though, a timer was given to indicate the duration until activation (or de-activation). As a final warning of the upcoming volume change, the colour of the timer turned to red.

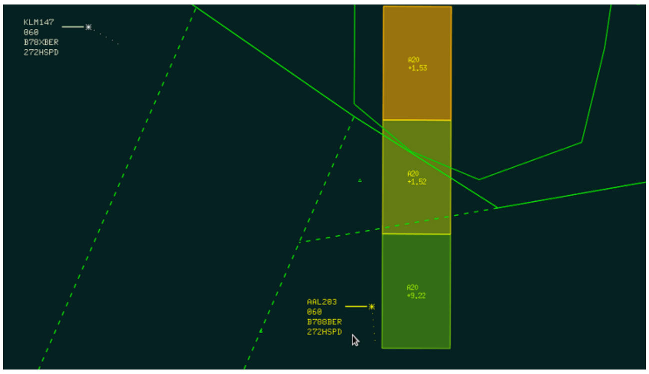

Fig. 13: ATCO Surveillance Display with AUSA U-space Volumes.

The full simulation setup and results of the validation activity related with the first prototype were presented in [8]. Several aspects regarding the concept and measured human performance were highlighted. They concerned missing regulations for distances between manned traffic and active DAR volumes (1.5 nm horizontal and 1,000 ft vertical were eventually chosen), missing regulations for use of the AUSA volumes and the related issue of UAS priorities, and a notably high workload of the TMA West controller. The main focus was on improving the HMI, though, for better support of controllers and the DARM in planning and managing traffic.

The DAR-CT needed to make a clearer distinction between the different types of DAR (strategic, tactical, contingency), especially when UAS operations were scaled up and several DARs (or DAR updates) were received during the tactical operation. Also a standard list of rejection options had to be added (instead of the provided free-text option).

The DAR-IAT needed adaptation in case of tactical changes or DARs being added in the course of the day (Use Case 2). In that case, it was important for the DARM to be able to still see all currently planned active DAR volumes (in amber) while assessing the impact of the changed or added DAR and the timing of expected traffic with active volumes (in teal blue). The complexity of the visualisation of different operational situations (for sufficient DARM and controller situational awareness) was expected to increase dramatically for a scaled up operation.

Even though the operation and interface proved to work efficiently for a single UAS mission planned on D-1, the situation was expected to change drastically on D0 with tactical changes and a scaled up operation. Most of the mentioned issues required an adaptation of the DARM interface, but also the visualization of AUSA volumes and DARs in the ATCO interface was considered sub-optimal for future validation activities.

B. *Intermediate HMI Design*

The successive validation activities in July 2025 had a comparable setup with the same use cases and some more challenging scenarios regarding UAS traffic volume and contingency situations. The overall result was expected to show indications of an improvement in terms of usability of the working environment.

The presentation of several DAR requests on the DAR-CT had to be managed in such a way that the requests could still be evaluated in the DAR-IAT. In particular, it was expected that DAR requests of a different type, such as a tactical DAR change or a contingency request, could potentially be received simultaneously. As a consequence, it was decided to present different requests in different layers, using the DAR-CT as a selection tool for each of these layers.

Another change concerned the presentation of the TTA itself. In Fig. 11 and Fig. 12 it can be seen that all available AUSA volumes were shown continuously, making it more difficult for the DARM to observe Schiphol traffic (real or ghost). Therefore, the changed DAR-IAT (Fig. 14) only presented the volumes affected by a request. All other unconcerned AUSA volumes would not be shown on the surveillance display.

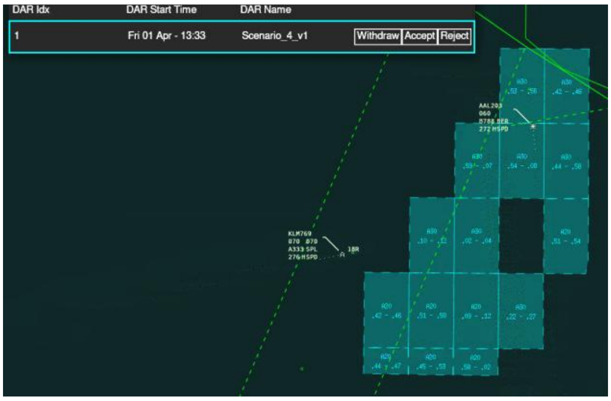

Fig. 14: DARM HMI without Indication of Unplanned AUSA Volumes.

Fig. 14 also shows that the DAR-CT would now include a frame with the same colour as the selected DAR volumes, which could be either a DAR request (teal blue), an implemented DAR (amber) or a contingency DAR (rose-coloured). If the different types of DAR, as a worst case, were sent to the DARM at the same time, this could thus have led to a situation as indicated in the following figures. When selecting a specific layer in the DAR-CT, each layer became visible to facilitate a better understanding of the situation and thus to enable the DARM to compare the different DAR layers. This is shown in Fig. 15 for the implemented DAR, in Fig. 16 for the pending DAR request and in Fig. 17 for the contingency DAR request. Fig. 18 shows the DARM surveillance screen together with the DAR-CT without selection of a specific layer.

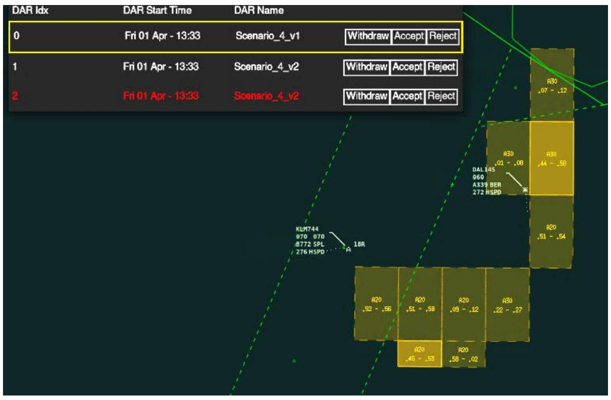

Fig. 15: DARM HMI with Selection of Implemented DAR.

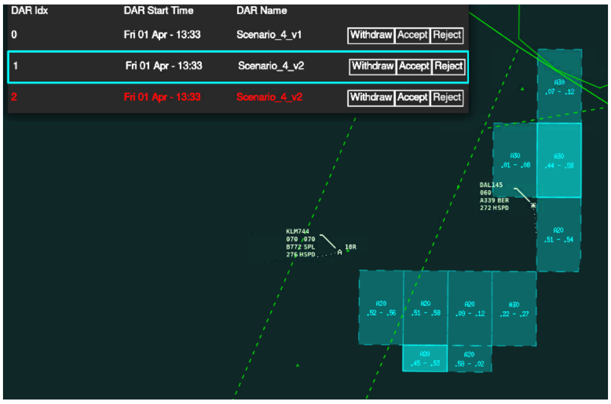

Fig. 16: DARM HMI with Selection of Pending DAR Request.

Fig. 17: DARM HMI with Selection of Contingency DAR Request.

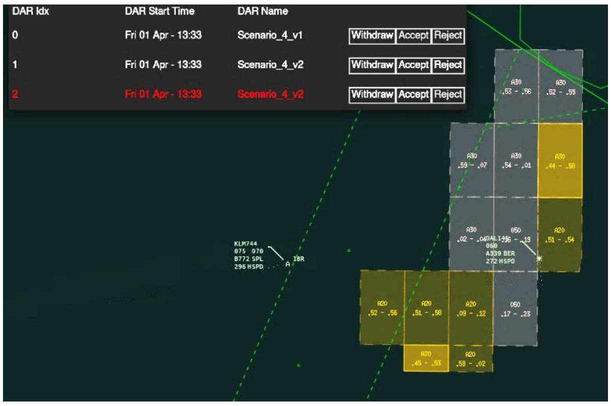

Fig. 18: DAR HMI without Layer Selection.

In that case the most important volumes were shown on top. The figure shows the currently implemented DAR in amber, as usual, with the active volumes highlighted, and a (slightly rose-coloured) contingency DAR request (third row in the DAR-CT, in red) which is layered on top of the implemented volumes due to its absolute priority.

Together with the contingency request in Fig. 18, a new (pending) DAR request has been received (second row in the DAR-CT) that is not visible as the implemented DAR did not change. This choice was made for clarity of the presented example. This also means that the pending DAR request is to be found in the layer underneath the implemented DAR. While this presentation appeared to be much clearer and very useful for the scaled up operation, it also had its limitations as is demonstrated with this example.

Feedback on the presentation of implemented DARs on the ATCO surveillance display concerned the chosen colours of the volumes. As has been explained above, each of the colours in Fig. 13 represented a different phase of the DAR implementation (as given in Fig. 5). The overly salient colours orange, yellow and green were used as a transparent layer, which made it very difficult to spot and monitor manned traffic flying over these volumes, especially on the rather dark surveillance screen of approach controllers.

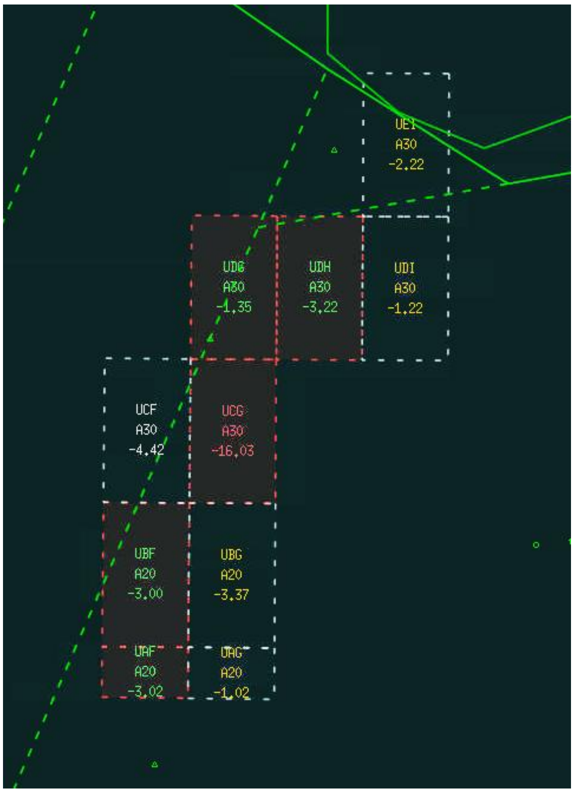

Fig. 19: ATCO Surveillance Display with Changed Colour Statuses.

Instead, HMI designers and ATCOs agreed on a number of changes that would render the volumes and their statuses less dominant while retaining the signalling effect. This meant that the colour red, which is usually a colour that should be used with caution on a surveillance screen, could be added to represent active volumes, as can be seen in Fig. 19.

In more detail, what can be seen expresses the following:

- All volumes have a dashed outline starting from their publication (i.e. the beginning of the implementation phase)
- The publication phase starts with a white outline and a white timer (usually 10 minutes prior to activation)
- To represent the caution alert, the timer would change to an orange colour less than 4 minutes prior to activation
- On activation, the outline of the volume becomes red and the colour of the time depends on the duration of the delegation
- The colour of the time inside the activated volume remains red, as long as the time to deactivation is longer than 4 minutes
- Again, as a caution alert, the time changes to green in the activated volume, if the time to deactivation becomes 4 minutes or less

The full simulation setup and results of the validation activity related with the intermediate prototype were presented in [9].

In summary, no general suggestions for improvement could be made, as it was assumed that the layered presentation was the best option to present the differences between DAR requests. Nevertheless, it was also indicated there might still be a better option to highlight a change with all layers superimposed. In the current setup there was a difference in priority, meaning that the current DAR was placed on top of the requested DAR. This was obviously not problematic for added volumes, but disappearing volume claims were hard to spot. The option to reject a DAR request with a rationale was also appreciated, however, the free-text field was considered a necessary addition.The presentation of the volumes on the ATCO displays was considered clear and acceptable, more intuitive than in the first session, and generally less intrusive. Still workload issues could no fully be resolved.

Regarding the concept, a particular issue was highlighted. In some situations, in which the DAR volumes were delegated back to ATC, they suddenly reappeared and became active again shortly afterwards. This was in line with the DAR request from the USSP, and was based on the U-plans of the UAS flights considered. However, ATCOs expected that the USSP, when aggregating the U-plans, should also consider minimum re-delegation times.

C. *Final HMI Design*

The final HMI design that was going to be used for validation of contingency use cases and critical timing situations to assess the limits of DAR applicability and usefulness, did not change significantly from the one used in the intermediate assessment (only minimal colour changes were applied). The main reason was that no general improvements could be indicated in the intermediate session. Furthermore, it was expected that most of the results of the final validation activity might mostly impact requirements regarding the DAR concept and procedures. A suppression algorithm for sudden reappearance of volumes was not fully implemented in the USSP emulation either, as it could be prevented by a smarter choice of U-plans.

The validation activities were carried out in January 2026 and included a real UAS flight in connection with the NARSIM platform in all contingency scenarios. The flight was performed at the NLR Drone Centre in Marknesse (NL) using a coordinate transformation that made the UAS appear in the TTA on controller surveillance screens with adapted altitudes and speeds. The flight was mainly added for technical demonstration and was shown as a target in contingency situations where a UAS was leaving the delegated AUSA U-space volume without being authorised to do so. Such infringements were shown on controller displays as APWs.

One of the major assumptions in this final activity considered a restriction in terms of DAR planning on D-1. As earlier simulations had shown, given the complex traffic situation at Schiphol, it only made sense to provide the option to plan one DAR request for the day of operation within a specific time window. Traffic volumes were adapted to that situation and were at medium to high levels (rather than very high or low traffic situations). Accordingly, only one DAR request was shown on the DARM interface containing multiple consecutive, but also simultaneous volume requests in line with the aggregated U-plans. The original request was thus implemented and the scenarios were then chosen in such a way that a changed request or a contingency request could be applied. This not only proved to be an assumption that made the operation more stable and feasible, but also reduced complexity regarding the chosen interfaces.

V. Validation Methods of Demonstration Activity

The final Dutch cluster validation activity in ENSURE included a demonstration flight aligned with the scenarios for USSP-initiated DAR requests (Fig. 20). As explained above, the actual flight took place at the NLR Drone Centre, and it was carried out within reserved airspace (EHR66). Technically, both the U-plan and the UAS state information were communicated with the USSP emulation in NARSIM.

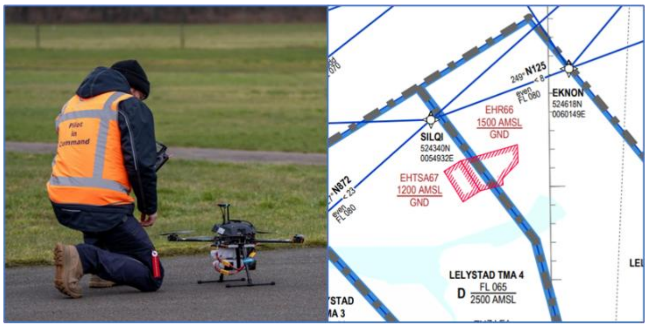

Fig. 20: Demonstration Flight at NLR Drone Centre in January 2026.

Apart from the technical validation, the activity had several other objectives, namely the validation of a DAR re-planning under timing constraints, the management of traffic during contingencies and airspace infringements, and a general assessment of the impact of different DAR requests on human performance.

The same working position setup for the DARM and the two TMA controllers was used as in earlier validation activities (as shown in Fig. 10), i.e. the TMA West controller (TWEC) vectoring arrival traffic from IAF SUGOL (Fig. 9) and RIVER (in the south) towards the downwind leg of runway 18R and separating it from departures from runway 24, and the arrival controller (ARR) lining up traffic for runway 18R. It should be noted in that regard that traffic towards Schiphol from the east was not managed by a human controller as there was no impact from the DARs. It was automated and landed on runway 18C following IPA rules. Furthermore, traffic from and towards Schiphol Area Control Centre (ACC) sectors was automated as well. Arrivals were handed over to the TWEC in an orderly fashion. The simulation scenarios contained between 24 and 32 inbound flights per hour (about 20 flights per hour via SUGOL) and between 12 and 15 outbound flights per hour to manage in TMA West in the peak time of the ATC simulation, which lasted for about 30 to 45 minutes.

The timing window for the DARM having to change a DAR was assessed conducting the following scenarios:

- Tactical Change of DAR/UAS Mission (Use Case 2) with 12-minute time limit until implementation (**2.1**)
- Tactical Change of DAR/UAS Mission (Use Case 2) with 6-minute time limit until implementation (**2.2**)
- Tactical Change of DAR/UAS Mission (Use Case 2) with 3-minute time limit until implementation (**2.3**)

Contingency DARs were requested in two situations:

- Non-conformance and Contingency DAR with ERP (Use Case 3), followed by infringement (**3.1**)
- Non-conformance and Contingency DAR with ERP (Use Case 3), which can be seen as a tactical DAR change with 0-minute time limit until implementation (**3.2**)

In order to assess airspace infringements, the following scenarios were conducted:

- Airspace Infringement (Use Case 4) in Schiphol TMA with 20 s alerting buffer inside DAR volume (**4.1**)
- Airspace Infringement (Use Case 4) in Schiphol TMA without alerting buffer inside DAR volume (**4.2**)
- Airspace Infringement (Use Case 4) in Schiphol TMA 30 s alerting buffer inside DAR volume (**4.3**)

Finally, scenarios without DAR requests were carried out as reference for human performance impact assessment:

- Reference without DAR and Use Case 2 traffic (**R2**)
- Reference without DAR and Use Case 4 traffic (**R4**)

Again ATCOs made the assumption that separation distances between manned aircraft and activated DAR volumes would be at 1.5 nm horizontal and 1,000 ft vertical. While rejection of a U-plan was still possible, the DARM accepted all DAR requests continuously communicating the impact on operations with the TWEC. All ATCOs were experienced controllers with detailed knowledge about the approach operation and capable of making decisions that would be in line with the TMA working methods.

Participants were asked to fill in questionnaires after each experiment and at the end of the day, which assessed specific operational aspects of the scenarios, the experienced workload, situational awareness (SA) and teamwork aspects. Since the aim was to find differences between the mentioned scenarios, participants were asked to remain in the same working position/role during all simulation runs.

VI. Final Validation Results

The results of the final validation activity can be broadly characterized as relating to the DAR concept, technology support and human performance impact.

Regarding the concept, the nominal DARM tasks (i.e. assessing DAR impact and deciding on its implementation with sufficient time given, as in Use Case 1) were considered to be manageable by a sector planner or supervisor role with the support of the interfaces, if such a position was already available (examples of units without such roles were given). Furthermore, manageability of the task depended on the frequency of DAR periods, how long they were, and how many changes occurred (Use Case 2). The same was true for the tasks of the TWEC whose workload depended on these conditions. Training requirements would be limited, though: it was mentioned that a few working days may be sufficient. It was also confirmed that a detailed knowledge of TMA patterns and procedures was necessary to carry out the DARM task.

For non-nominal tasks, tactical DAR changes included, the situation looked differently, which was reflected by human performance measurements and was partly due to limited or not entirely sufficient automation support. This was especially true for the TWEC, whose tasks did not change, but who experienced very high workload due to the processing of additional information provided by the DAR visualization, and had to manage the related reduction in operational flexibility for the incoming traffic.

To understand the impact of non-nominal scenarios on human performance, it should be noted that the reference did not represent a situation with the same amount of unmanned traffic, as this would have led to worse results for the entire operation, given that much larger volumes of airspace would have been evaded. This could already be seen in operational efficiency values. Fig. 21 shows that the differences in average time spent or distance travelled inside the TMA between the reference and the tactical DAR solutions (Use Case 2) were much smaller than between the reference and infringement scenarios (Use Case 4), for comparable traffic. This was even true for DAR usage in the contingency situation with ERP. An aircraft was considered present in the TMA from being on the frequency until landing (for arrivals) and from take-off until leaving the frequency (for departures).

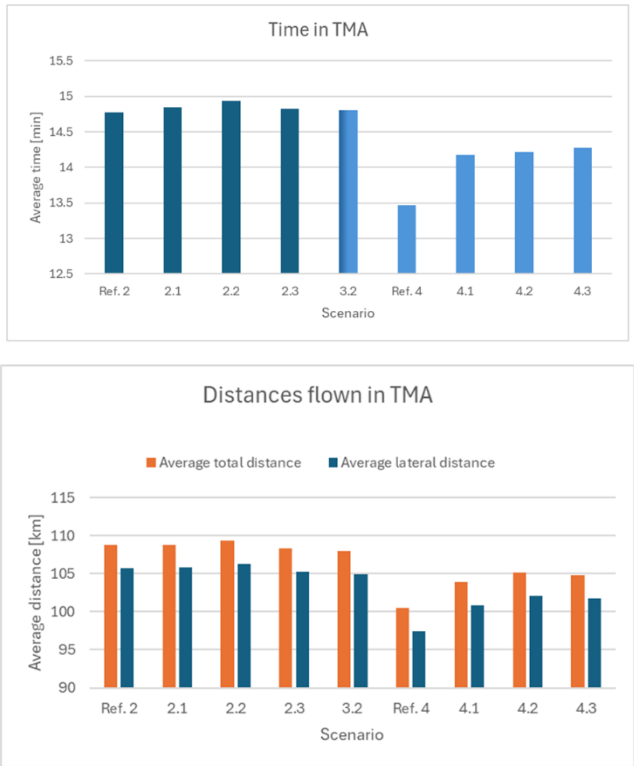

Fig. 21: Average Time and Distance of Aircraft in TMA.

This means that the reference scenarios must be seen as a completely undisturbed situation and any comparison would thus indicate the size of the operational impact of the specific DAR solution or use case situation when using the automation, rather than an improvement of an operational situation that is achieved by use of the automation.

Several selected human performance observations are presented in the following that were corroborated or further explained during debriefings after the simulation runs and at the end of the demonstration campaign.

Fig. 22 shows RSME ratings [18] for both DAR solution runs (Use Case 2, including Run 3.2 with a contingency DAR, i.e. no time for decision making or DARM intervention) and the infringement situations (Use Case 4 with different internal buffer times).

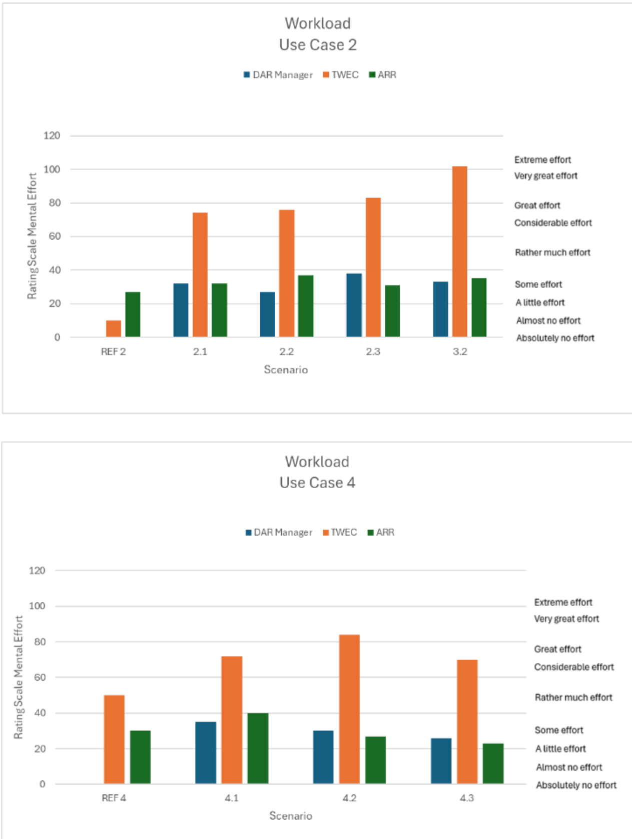

Fig. 22: RSME Workload Ratings

For Use Case 2, the reference was easily manageable for tactical controllers with just a little or some effort. The controller affected by the DAR change, the TWEC, though, indicated considerable effort with increasing workload when shorter implementation times were required. This was in line with the expectations, in particular when considering that the contingency run (3.2) was leaving no time for impact assessment and operational preparation, thus resulting in no pre-emptive support by the DARM and an extreme effort rating. Based on this result and discussions with controllers, it was concluded that tactical DAR changes with a time window around the 10-minute publication time stamp (see Fig. 5) were still manageable for the TWEC, albeit with high workload. Situations in which less than 6 minutes were available to implement a DAR change resulted in increased workload that was insufficiently supported by the system, thereby reducing manageability. Support by the DARM, while appreciated in such situations, was also not sufficient to reduce workload for the TWEC. DARM workload stayed low in all situations, with only marginally higher workload when current and changed DAR reservations were compared within limited time available, using the DARM HMI.

For Use Case 4, the workload rating in the reference was a bit higher for the TWEC, but still rather low. In case of an airspace infringement, it increased towards considerable effort, and in case of no timing buffer inside the activated DAR volume, it even increased towards great effort, a workload rating comparable with a very sudden DAR change, but still lower than the rating for a contingency DAR.

Situational awareness ratings (Fig. 23) showed very similar results for the TWEC in Use Case 2, with the Eurocontrol SASHA ratings [19] (scale from 0 to 6 with 6 being perfect SA) reducing from 5 to 3 between the reference situation and a contingency DAR. Here, it was noted that also the SA rating of the DARM reduced to a rating under 4 for the contingency situation. During the debriefing, the DAR mentioned that all efforts went into supporting the TWEC, while SA had to be built up using the layered DARM HMI, which was a bit cumbersome.

Regarding Use Case 4, SA ratings also supported the workload results, with the exception that SA was also rated lower with an earlier APW indication (20 s time buffer). After the debriefing, it was found that the TWEC and DARM did not really notice the drone target because of the surrounding traffic situation. SA was also lower without the time buffer and highest (rating of 5) with a 30 s time buffer.

Fig. 23: SASHA Situational Awareness Ratings

The workload and SA ratings were further supported by additional safety questionnaire results. These also hinted at remaining issues with the visualization of DAR volumes on the tactical controller displays.

Fig. 24 shows that, generally, proactive management could often be applied and the overall level of safety was maintained. However, for tactical DAR changes, the necessary information supporting decision making was rarely available for the TWEC.

Fig. 24: Selected Operational Safety Ratings

This was not indicated for Use Case 4. The result was mentioned in debriefings, and the conclusion was that visualization changes or improvements could not be expected in infringement situations as the APW was an appropriate warning, while there was still room for improvement when presenting changing DAR volumes.

Finally, intense discussions with the participating controllers led to the conclusions that, for the prototypes, an improved concept for presentation of DAR changes in multi-volume requests and related contingency requests (with very restrictive timing windows) will have to be found in the future. While team communication was mostly positively assessed, the final validation hinted at problems regarding the provided system information and resulting situational awareness of controllers, especially the tactical controllers. In addition, the DARM presentation of consecutive incoming requests still required further refinement prior to operational implementation. This impression was supported by final assessment ratings on automation trust [21] and system usability [22]. Overall ratings for automation trust remained relatively low, around 3 on a scale from 0 to 6, and system usability reached values of about 50 points (out of 100) on John Brooke's rating scale. Both results were an improvement from earlier assessments, though.

VII. Recommendations for Future Work

Based on all observations made above and the detailed results obtained after the final validation activity, several recommendations were made for both concept and developed interfaces:

- Without clear indications in regulations or concept descriptions, provide a separation distance from airspace boundaries of 1.5 nm horizontally and 1000 ft vertically in analogy of what is currently used (in the TMA) for military airspace.
- Prioritization of UAS movements is (still) an open issue. State actors should provide clear regulations. These could also apply to the use of AUSA volumes by vehicles with a certain priority under given operational circumstances in nearby ATC controlled airspace.
- DAR requests with multi-volume reservations must be provided by the USSP without unusable volume gaps. This means that they have to be smooth regarding volume altitudes (e.g. it is not useful to have a lower volume surrounded by higher volumes), and they have to be balanced regarding timing (e.g. it is not useful to have an unclaimed volume that is available for less than 10 minutes, as traffic cannot be prepared to use it). This will put constraints on the USSP that will have to consider these issues in aggregation of U-plans and the preparation of the DAR requests.
- Reconsider the current visualization concept for DAR volumes on the surveillance displays of TMA controllers. Visualization needs to result in a detailed understanding of rapid volume changes as they may occur when there are UAS mission changes that need to be considered quickly, or contingency operations that will start quickly to mitigate a non-conformance. This must prevent the detected reduction in situational awareness of tactical controllers who are confronted with rapid changes of the operational environment in high workload situations.
- The layered DAR view of different types of DAR requests communicated via the DAR-CT could not efficiently be used by the DARM. Differences between implemented DARs and DAR changes were not apparent and the DARM had to move between layers frequently to get a better understanding of the operational situation and the impact of the change. A different option has to be found to highlight changes between DAR requests, more specifically, between the currently implemented DAR and a change, either due to a changing UAS mission requirement, or due to a contingency and non-conformance. One of the options mentioned was to separate change requests into a cancellation request and a new request. The new request, must still contain the current reservations that were not cancelled to provide a consistent picture of the situation.
- In line with the previous recommendation, any DAR change that cannot be evaluated and accepted prior to 10 minutes (publication time) before the first planned DAR volume activation should become a contingency request. In some operational environments, the time window for evaluation of the request by the DARM may be reduced, leading to shorter times between publication and activation. But publication time, in general, should not be less than 6 minutes before the first activation.
- Buffer times for alerting of an infringement from an AUSA volume delegated to U-space into ATC controlled volumes should at least be 30 seconds. They could also be determined in separation distances, but these may be different for unmanned vehicles and depend on regulations.
- Non-conformant UAS targets inside a contingency DAR volume may be visualized to the DARM on request. While there is no strict requirement to see UAS targets inside activated DAR volumes, there should still be a possibility to see them, if desired, inside a contingency volume to identify the non-conformant UAS.
- There must be appropriate phraseology or a tool to communicate a DAR and its consequences between DARM and ATCOs. This is a rather unspecific requirement, but the DARM indicated the necessity to better indicate to tactical controllers what volumes are affected. Thus, the DARM might want to be able to click any AUSA volume and make it briefly appear (i.e. unintrusive) on the tactical controller surveillance screens. This indication feature should be in line with the general presentation philosophy on the ATC working position.

VIII. Concluding Remarks

After more than two years of preparation time regarding the ENSURE concept, several workshops and intermediate simulations, NLR managed to set up a highly realistic operational environment, with three controller working positions, one for a DAR Manager (DARM), and two for Schiphol approach controllers (TWEC and ARR) managing traffic under Independent Parallel Approach (IPA) conditions towards runway 18R, as well as a connection to the NLR Drone Centre and a specific flight that could send U-plans to a USSP, simulated on the ATC validation platform NARSIM, and would also be visible in flight on controller surveillance screens flying inside or outside AUSA volumes, if necessary.

The concept was developed collaboratively with project partners through participation in concept-related activities [7]. In parallel, use cases were prepared reflecting the need of the Royal Netherlands Navy to conduct flexible UAS operations in close proximity to Schiphol approach traffic within the UAS Test and Training Area. This area consisted of multiple smaller airspace volumes that could serve as AUSA volumes, as defined in the concept. DAR processes enabled dynamic delegation of airspace for military UAS missions. In this case, the military was assumed to act as USSP for their own missions. Accordingly, specific UAS missions were defined and used as underlying U-plans for aggregation by a USSP module in NARSIM that would also generate the relevant DAR requests and present them to the DARM.

The DARM operated two interfaces: one for communication of DAR requests (DAR-CT) and one for impact assessment (DAR-IAT). TWEC and ARR were provided with visualizations of the requests and their operational consequences on surveillance displays. Two prototypes based on a common presentation concept were developed. Most presentation aspects were positively evaluated during earlier validation activities [9]. The HMI concept was considered feasible for nominal operations, provided that clear separation information between aircraft and active DAR volumes was available. Recommendations focused on improving support for U-plan and DAR modifications during ongoing DAR execution.

Particular attention was given to handling multiple consecutive DAR activations within a single request using smaller volumes, which was expected to improve operational efficiency. However, this increased interface complexity and required additional training effort.

Overall, the tool functionalities largely fulfilled the expected requirements and supported the various phases of DAR activation and deactivation for military U-space actors. Where limitations were identified, recommendations were made for further interface improvements. These included introducing layered views for different DAR request types within the DAR-CT and enhancing visualization of DAR volume statuses at tactical controller positions to provide more intuitive information without adding to already high workload levels.

Nevertheless, the final demonstration activities showed that the concept, including its realization via the final prototype, still needs improvements to increase the situational awareness of all actors, reduce workload for tactical controllers and present coherent and correct information on DAR activations and UAS movements. Especially, in rapidly changing situations, when UAS missions and U-plans are changed leading to a new DAR request, more clarity on impending airspace changes will be required by both DARM and tactical controllers. Potentially, the application of Machine Learning and Artificial Intelligence techniques will be able to enhance automation and the management of DAR requests under time-critical conditions.

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REFERENCES

[1] European Commission, "Commission Implementing Regulation (EU) 2021/664 of 22 April 2021 on a regulatory framework for the U-space," Published in: "Official Journal of the European Union," Document 32021R0664, Brussels: European Union, April 2021.

[2] J. Teutsch, "Dynamic Airspace Re-configuration for Drones with Varying Mission Requirements - The Evolution from Project AURA to Project ENSURE," Research Paper for SESAR Innovation Days 2023, SESAR-JU, Brussels, 2023. DOI: 10.61009/SID.2023.1.21

[3] J. Teutsch, C.C. Petersen, "Communication Latency and Loss for Integrated IFR-RPAS Movements in the TMA," Research Paper for 22nd Integrated CNS Conference published in "2022 ICNS Proceedings", New York City: IEEE Publications, April 2022. DOI: 10.1109/ICNS54818.2022.9771512

[4] EUROCONTROL, "U-space Concept of Operations (ConOps)," Fourth Edition, Brussels: SESAR 3 Joint Undertaking, July 2023.

[5] AURA Consortium, "AURA Solution 2 Validation Report," AURA D3.2.090, Ed. 00.01.00, Brussels: SESAR Joint Undertaking, January 2023.

[6] J. Teutsch, C.C. Petersen, "Dynamic Airspace Re-configuration for Manned and Unmanned Operations in Shared Airspace," Research Paper for 24th Integrated CNS Conference published in "2024 ICNS Proceedings", New York City: IEEE Publications, April 2024. DOI: 10.1109/ICNS60906.2024.10550738

[7] ENSURE Consortium, "ENSURE Solution 2 SPR-INTEROP-OSED Part I, Intermediate Version," ENSURE D3.12, Brussels: SESAR 3 Joint Undertaking, January 2025.

[8] J. Teutsch, C.C. Petersen, T.J.J. Bos, G.D.R. Zon, Niklas Mekelburger, "Dynamic Airspace Re-configuration for Tactical Drone Mission Changes," Research Paper for 44th Digital Avionics Systems Conference 2025 published in "2025 AIAA DATC/IEEE 44th Digital Avionics Systems Conference", New York City: IEEE Publications, September 2025. DOI: 10.1109/DASC66011.2025.11257397

[9] J. Teutsch and T.J.J. Bos, "Advanced Controller Interfaces for U-space Initiated DAR Requests above VLL Airspace," Research Paper for SESAR Innovation Days 2025, Brussels: SESAR Joint Undertaking, December 2025. DOI: 10.61009/SID.2025.1.28

[10] AURA Consortium, "AURA (ATM U-space InteRfAce) Solution 2 Initial Concept Description," AURA D3.10, Ed. 01.00.00, Brussels: SESAR Joint Undertaking, September 2021.

[11] J. Teutsch, C.C. Petersen, G. Schwoch, T.J. Lieb, T.J.J. Bos, G.D.R. Zon, "On the Impact of UAS Contingencies on ATC Operations in Shared Airspace," Research Paper for 23rd Integrated CNS Conference published in "2023 ICNS Proceedings", New York City: IEEE Publications, April 2023. DOI: 10.1109/ICNS58246.2023.10124297

[12] AURA Consortium, "AURA Solution 2 Consolidated OSED," AURA D3.2.020, Ed. 01.01.00, Brussels: SESAR Joint Undertaking, February 2023.

[13] EASA, "U-space workshop: from the concept to implementation", Event Materials, Cologne: EASA, June 2023

[14] EUROCONTROL, "Advanced FUA Concept," Edition 1.0, Brussels: EUROCONTROL, July 2015.

[15] P. Criscuolo, L. Perrotta, G. Di Bitonto, G. Grani, "Enhanced Dynamic Airspace Configuration Algorithm," Research Paper for 14th SESAR Innovation Days, Brussels: SESAR 3 Joint Undertaking, November 2024.

[16] J. Teutsch, "Dynamic Airspace Re-configuration for Drones with Varying Mission Requirements - The Evolution from Project AURA to Project ENSURE," Research Paper for 13th SESAR Innovation Days, Brussels: SESAR 3 Joint Undertaking, November 2023.

[17] LVNL, "AIP The Netherlands," Part 3, Aerodromes (AD) EHAM, Amsterdam: LVNL, April 2025.

[18] F.R.H. Zijlstra, "Efficiency in Work Behaviour: A Design Approach for Modern Tools," Doctoral Thesis, Delft: Delft University Press, November 1993.

[19] E. Jeannot, C. Kelly, D. Thompson, "The Development of Situation Awareness Measures in ATM Systems," Document HRS/HSP-005-REP-01, Brussels: EUROCONTROL, June 2003.

[20] J. J. Roessingh, G.D.R. Zon, "A Measure to Assess the Impact of Automation on Teamwork," Document HRS/HSP-005-REP-07, Brussels: EUROCONTROL, October 2004.

[21] P. Goillau, C. Kelly, M. Boardman, E. Jeannot, "Guidelines for Trust in Future ATM Systems: Measures," Document HRS/HSP-005-GUI-02, Brussels: EUROCONTROL, May 2003.

[22] J. Brooke, "SUS: a 'Quick and Dirty' Usability Scale," in P. W. Jordan, B. Thomas, B. A. Weerdmeester and I. L. McClelland (Eds.), *Usability Evaluation in Industry* (pp. 189–194). London: Taylor & Francis, June 1996. DOI: 10.1201/9781498710411