

Dynamic Airspace Re-configuration for Tactical Drone Mission Changes

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Abstract— Dynamic Airspace Re-configuration (DAR) has been identified within the Single European Sky Air Traffic Management Research (SESAR) Programme as one of the enablers for a more efficient and dynamic use of airspace volumes that are shared between unmanned and manned traffic domains. Within the ENSURE project of the SESAR 3 Industrial Research Programme, the Netherlands Aerospace Centre (NLR) investigated different use cases for state actors, such as the Royal Navy, who intend to make use of airspace volumes in close vicinity of the approach operations of Amsterdam Airport Schiphol for carrying out various sovereign tasks, e.g. for asset protection, emergency services and disaster relief operations. DAR procedures and software tooling for airspace managers and air traffic controllers were validated in human-in-the-loop real-time simulations on the NLR ATC Research Simulator (NARSIM). Results of human performance testing provide confidence that only minor refinements are needed before flight tests are carried out.

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

I. INTRODUCTION

An increasing number of drones or Unmanned Aerial Systems (UAS) is expected to operate at very low level (VLL) altitudes of up to 500 ft in urban and suburban areas in the near future (see also: reasoning statements in the preamble of [1]). In addition, high priority movements are also expected to be carried out by state actors, such as the military, emergency services and disaster relief organisations, at higher altitudes of up to 5000 ft in designated airspace volumes. Some of these volumes are expected to be located in the vicinity of civil airspace and may thus have an impact on the efficiency of civil flight operations [2]. As a consequence, it is essential to develop methods enabling Air Traffic Control (ATC) to safely manage crewed aircraft operations alongside UAS activity.

As part of the Single European Sky Air Traffic Management Research (SESAR) Programme, several projects were started in the early 2020s to investigate the integration of unmanned and manned traffic in non-segregated airspace. The SESAR Industrial Research Project AURA investigated requirements for an interface between airspace controlled by Air Traffic Control (ATC) units and highly automated U-space airspace for large numbers of unmanned aircraft in VLL airspace [3]. ATM U-space Shared Airspace (AUSA) was defined as a generic type of airspace that can be delegated between the two regimes by a process called Dynamic

Airspace Re-configuration (DAR). AURA results indicated that DAR processes needed refinement to better streamline communication between all actors. Furthermore, investigated U-space contingency scenarios showed that different types of situations needed different DAR approaches [4].

Within the ENSURE project, which is part of the SESAR 3 Industrial Research Programme, the DAR concept is currently further investigated by building the services and interfaces necessary on both the U-space Service Provider (USSP) side and the ATC side to support flexible airspace changes. The use cases defined by the validation team of the Netherlands Aerospace Centre (NLR) examined specific state actor operations to find a more dynamic and flexible way of utilizing airspace volumes that must be shared between civil traffic operations and unmanned priority operations. To that end, special use airspace volumes were divided into smaller airspace blocks that could be activated and deactivated via DAR processes. A DAR Manager (i.e. an airspace manager carrying out DAR procedures) was responsible for the process which worked in the same way as the delegation of AUSA volumes between ATC and U-space [5].

The NLR efforts mainly concentrated on dynamic mission changes for one or more military UAS flights monitoring high priority assets in the North Sea. These would lie close to approach operations into a major European hub, in this case Amsterdam Airport Schiphol. Another focus of the work considered contingency operations, where a UAS becomes non-conformant with the planned flight execution and may violate ATC controlled airspace volumes. Different traffic scenarios were considered.

This paper describes the improvements made by ENSURE regarding both DAR concept and procedure definitions, as well as the software tooling and automation for the DAR Manager and the Air Traffic Controllers (ATCOs) developed by NLR. The DAR Manager interfaces for assessing the potential impact of a DAR request on operations and for communicating airspace delegations with USSPs, UAS operators, and ATC are introduced and explained. Tests and operational validation exercises carried out on the NLR ATC Research Simulator (NARSIM) are presented and results concerning various aspects of software tooling usability, operational feasibility and human performance are analysed. It is expected that a future DAR implementation will enable a more dynamic use of airspace during the execution of a UAS flight as opposed to the current strategically planned use of reserved airspace several days before operation.

II. DYNAMIC AIRSPACE RE-CONFIGURATION

A. Initial Concept

The SESAR Industrial Research Project AURA was the first research initiative to describe a consolidated concept for Dynamic Airspace Re-configuration (DAR) for various interactions between manned and unmanned traffic in the vicinity of small and medium-sized airports [6]. The assumption was that a large number of UAS would be operating in designated VLL airspace volumes and needed access to airspace resources under ATC control. The VLL volumes were considered to be highly automated U-space airspace under service provision of one or several USSPs.

In order to find a solution for dynamically separating manned and unmanned traffic, AURA defined a new airspace category called ATM U-space Shared Airspace (AUSA). AUSA airspace is used for regions of Controlled Airspace (CAS) where both manned and unmanned operations can occur. AUSA airspace volumes are pre-defined and construed in such a way that it is possible for ATCOs to understand the operational implications of their delegation to U-space. Therefore, AUSA should only be applied in areas where it makes sense that both manned and unmanned movements have access to shared airspace resources.

The DAR concept and processes were consequently developed as an enabler for operational integration of manned and unmanned operations in AUSA airspace. DAR is an ATM-executed process to delegate responsibility for control of airspace volumes between ATM and U-space based on user demand for either manned or unmanned operations. It is executed by an additional ATC role in charge of managing the DAR airspace changes, called DAR Manager (DARM). Applying the DAR processes, the pre-defined AUSA structures change from being ATC controlled (traditionally called blue volumes in the AURA concept documentation) to being U-space controlled (orange volumes) and vice versa [8]. This subsequently prompts the question whether an AUSA delegation to either domain should be limited in time and whether a DAR request should contain an end time for the delegation or not. Airspace management, in general, is concerned with an allocation of airspace that serves a certain demand. Therefore, airspace volumes may have restrictions for certain movements or even prohibit certain types of traffic. Accordingly, it would make sense to assume that AUSA airspace, in certain areas, will have a default (blue or orange) status, and that changes in delegation of control only occur temporarily. This would also avoid the complexity of applying a DAR delegation on top of an existing DAR delegation.

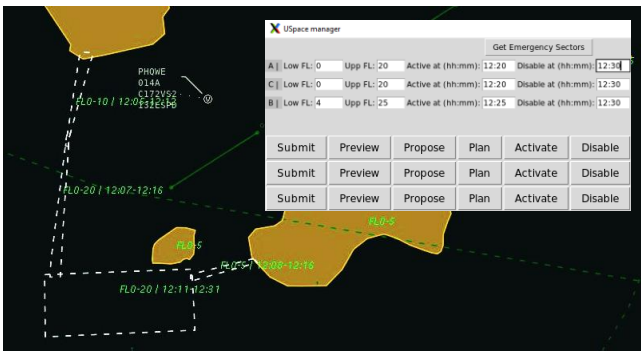


Fig. 1: Preview of DAR Request for ATCO and DARM (NARSIM/NLR).

The AURA project assumed that the airspace changes would only happen exceptionally and for a small number of unmanned movements. Real-time simulations carried out by NLR with experienced ATCOs in a highly realistic regional airport environment of Rotterdam The Hague Airport focused on particular operational scenarios for several UAS use cases. In these scenarios, a manned operation with higher levels of traffic, under both Visual (VFR) and Instrument Flight Rules (IFR), was disturbed by a DAR request. In all cases, the delegation was necessary to accommodate a contingency or emergency situation in U-space. Even though all DAR requests investigated in the AURA real-time simulations were based on contingency situations, i.e. with a certain amount of pressure on the DARM to facilitate the change, the procedure itself was based on a lengthy negotiation process with the ATCOs. Communication of the planned changes occurred via an intercom system, but also using an indication of the planned situation submitted to the ATCO surveillance screens. The DARM could also make specific changes to the airspace change request based on feedback from ATCOs or personal insights and observations (see Fig. 1). As a result, the negotiation process between all actors and its efficiency were considered suboptimal [5].

In summary, the AURA project laid down the first steps in defining a concept for DAR and came to the following conclusions [7]:

- ATCOs were satisfied with DAR visualisations.
- The presence of a DARM had added value and increased the Situational Awareness (SA) of ATCOs.
- Current and accurate information for ATCOs limited the impact of DARs on manned traffic.
- USSP-initiated DAR contingency requests in the airport vicinity had a large impact on efficiency.
- The DAR impact in terms of operational changes for ATC had to be clear at all times.
- A definition for the minimum separation between U-space airspace volumes and manned aircraft was required.

B. DAR Research Challenges and Concept Gaps

While the DAR procedures applied in AURA presented a solid basis for the DAR concept, several gaps and shortcomings were addressed at the beginning of the SESAR Industrial Research Project ENSURE, a fast track project to prepare implementation of U-space services for DAR. The major issue regarding both ATC- and USSP-initiated DAR requests rested in the efficiency of the process. The fact that the DARM would be able to change a request was considered unnecessary for ATC-initiated requests, and at least undesirable for USSP-initiated requests. Furthermore, the concept had to be scalable and still manageable for the DARM, meaning that strategic (i.e. planned before the day of operation) and tactical (i.e. executed on the day of operation) DAR requests would need to be aggregated before being sent to a DARM.

In AURA, DAR requests were related with contingencies and concerned a single UAS operation per request. In order to be able to also implement a planning process with tactical changes during the operation it was necessary to describe the DAR concept in such a way that the DARM could carry out

tasks efficiently and without loss of SA regarding the ATC operation. This meant that automation support for impact assessment of DARs needed to be improved as well.

The ENSURE project started with the definition of research challenges with respect to such an improved DAR concept implementation. These concerned the following:

- DAR operational concept scalability with large numbers of UAS and more complex UAS operations
- DAR concept improvements with an emphasis on process steps and operational stages, duration and frequency, operational response times, strategic DAR planning, and use of DAR in tactical and contingency or emergency situations
- Airspace Design (AUSA) with management of a group of small volumes relating to the same UAS mission
- Support tooling for DARM and ATCOs concerning DAR information content, DAR communication, DAR impact assessment, DAR decision making, and visualization of UAS movements
- Human performance aspects on the ATM side regarding roles and responsibilities, workload, SA and safety, team communication, and automation trust
- ATM working position set-up and location
- Communication between systems and actors, enabled by the Common Information Services Provider (CISP)

The latter issue particularly concerned the system architecture and the related technical requirements for services provided in the U-space and ATM domains. Both were taken as an input to the ATM operational simulations, but were not investigated in more detail. More information on the system elements and architecture can be found in [9].

A number of other topics were considered gaps in the concept or rather missing boundary conditions. While these topics were discussed extensively with project partners and subject matter experts, final answers were not always available before operational workshops and simulation activities took place. It mainly concerned the following:

- Separation standards for the different types of airspace, including safety buffers
- Prioritisation of UAS missions and DAR requests
- Management of VFR flights in AUSA U-space
- DAR changes and impact on the Reasonable Time to Act (RTTA) to avoid conflicts in AUSA U-space
- The integration of Continuous Safe Flight and Landing (CSFL) concepts in DAR processes (contingencies)
- Civil-military considerations

Workshops with operational experts were organised to find acceptable solutions to these aspects and a working method for the planned real-time simulations. Regarding the inclusion of military considerations, the NLR validation team collaborated with the Royal Netherlands Navy (RNLN) and prepared AUSA volumes and use cases that would match their requirements for communicating airspace needs with civil ATC. All concept changes were elaborated together with ENSURE partners.

C. Changes to the Concept

Based on the open issues identified in AURA and the defined research challenges, the ENSURE project introduced changes to the DAR concept and elaborated procedures. The major criterion for the development was scalability of the concept so that the aim of accommodating large numbers of UAS performing various operations could be achieved.

As a consequence, the existing negotiation processes had to be simplified, automation support had to be introduced for both DARM and the affected ATCOs to optimize human performance, and clear DAR implementation procedures for nominal and non-nominal situations had to be defined. Additionally, airspace planning aspects on the day prior to operation (D-1) and on the day of operation (D0) were considered in order to make a distinction between long-term strategic planning of DAR changes and the more dynamic tactical DAR requests.

As an initial step, ATC-initiated and USSP-initiated DAR request procedures from AURA were changed and refined in collaboration with the developers of U-space services in ENSURE. This paper focusses on USSP-initiated DAR requests (sometimes also referred to as reverse DAR) as these may have a direct impact on manned operations, while ATC-initiated requests would assume that U-space volumes are already in place in the vicinity of an airport and need to be used by manned aviation thereby affecting the U-space operation. Generally, though, the introduced time frames and DAR communication and decision moments would be identical in both cases.

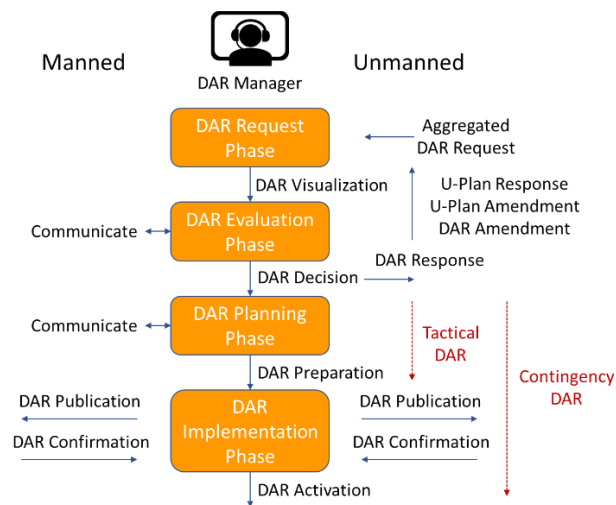


Fig. 2: DAR Process Flow for USSP-initiated DAR Request.

The USSP-initiated (reverse) DAR process flow shown in Fig. 2 consists of the following phases (see also [9]):

DAR Request Phase. In this phase, UAS operators specify their operational intent and prepare a U-plan proposal that is submitted to the U-space Flight Authorization service of the USSP. This usually happens before or on D-1, but U-plans may change up until D0 or even during D0 for tactical reasons. The USSP uses a Geo-awareness service (fed by all information available in the CISP on airspace and manned traffic data) to assess the received U-plans and the need to create a (reverse) DAR request. If a DAR request is necessary to accommodate the received U-plans, it will be promulgated via the CISP to the DARM.

DAR Evaluation Phase. In the early development phases of the concept, the request phase was followed by a proposal phase (see also [5]). However, this phase still included the complexity of negotiation procedures between DARM and ATCOs. AURA showed that the success and depth of such conversations would depend on local arrangements, i.e. the location of the DARM working position and available intra-centre communication equipment. Furthermore, it was found that the role of a DARM needed to be fulfilled by an experienced ATCO being able to make sector-wide decisions. The proposal phase was thus replaced by an evaluation phase, in which the DARM receives DAR requests from the USSPs and evaluates them using advanced tooling for probing both traffic and airspace situations at various points in the future. The evaluation phase ends with a decision made by the DARM on whether to accept or reject the DAR request, with a rejection being accompanied by a rationale statement. The DAR response is then promulgated to the USSP. The USSP identifies the affected U-plans and sends the respective U-plan responses to the UAS operators. This might then initiate a U-plan and DAR amendment process and a new request phase on the U-space side.

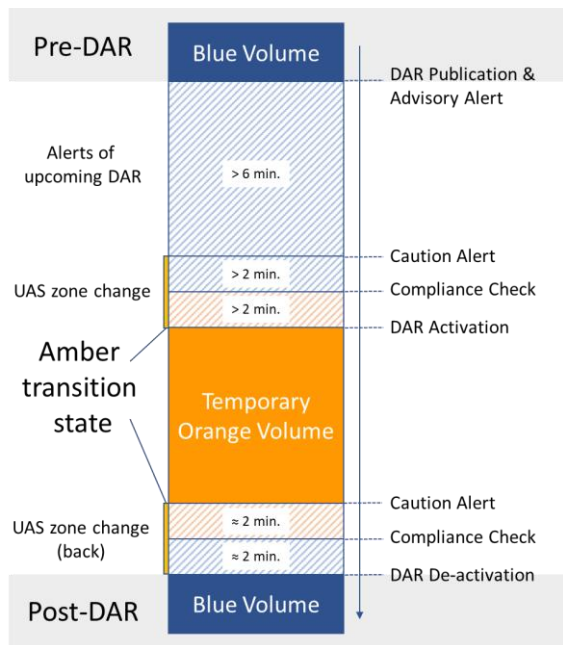


Fig. 3: DAR Implementation Phase (USSP-initiated)

DAR Planning Phase. When the DAR response has been promulgated, the DAR request will be in a planning phase. How long this phase lasts and what its purpose is, again depends on the planning timeframe. On D-1 this phase will run in parallel with USSP and UAS operator planning processes and USSPs might still issue a new DAR request based on received U-plans and U-plan amendments. This new request will then replace the earlier one up until a time at which the planning for D0 needs to be frozen. The complete DAR request information is available in the ANSP and USSP systems once the planning phase has started. If more dynamic changes, such as a tactical change of a UAS mission before or during flight, are required on D0, the specific DAR request would need to be added to the existing DAR planning for D0. One of the gaps in the current concept is the way in which such changes can indeed be integrated into the overall planning in U-space (see the earlier reference to RTTA) and whether to

consider the tactical DAR as an update to the current DAR or a second DAR that is visualized synchronously in the DARM tooling for impact assessment. The actual planning phase and the planning status of a tactical DAR may be reduced or eliminated in that case, as the urgency to implement the change would be higher and the process would continue with the DAR publication (see red arrow in Fig. 2).

DAR Implementation Phase. On publication, at about 10 minutes before activation of the DAR, the implementation phase starts (Fig. 3). A rigid process is followed where caution alerts are sent to UAS operators by the USSP and to ATCOs by the ANSP. The caution alerts are given at least 4 minutes prior to activation of the DAR, and this is called the start of the “amber” transition state in the concept documentation [9]. Confirmation of compliance will have to be sent to the DAR by both the USSP and ATC within two minutes after the caution alert. When the DAR is activated, UAS operators can start their operations in the delegated airspace volume. Deactivation will happen in the same way as the activation process. Timeframes may be different, though, depending on the overall delegation time. On deactivation, manned flights can resume their operations in the changed airspace volume.

As was explained above, all of the mentioned phases may vary depending on the timeframe of the planning (D-1 or D0). Contingency and emergency operations represent unexpected operations with a certain urgency (high priority). They follow a non-nominal flow of operation. If information about the applied mitigation measures, such as an activated Emergency Response Plan (ERP), is available, a DAR can be generated automatically. This would only be necessary if there is a deviation from a currently active DAR, though, as nothing would change for ATC if the ERP operation took place within already active AUSA U-space. The contingency DAR, in that case, will only be presented to the DARM. While it could still take a while until the UAS reaches the additional AUSA airspace required for execution of the ERP, the DARM should discuss the issue as quickly as possible with ATCOs to be able to anticipate any operational changes necessary.

In case of emergencies that lead to infringements of airspace (at violation of an internal ASUA U-space airspace buffer) without any knowledge of mitigation measures being applied, the UAS position information available from the network identification service (see Article 8 in [1]) will be used to display the UAS on the surveillance displays of ATCOs, thereby supporting them in their separation task.

III. APPLICATION AREAS AND MISSIONS

A. General Application Areas

The ENSURE concept for DAR operations can generally be applied in areas where UAS operations in U-space occur close to manned operations, and where flexibility is required to execute UAS operations in controlled volumes with minimum impact on manned operations. The smaller such volumes are, the more flexibility will be available and the less impact on the manned operation is expected. There also is a resemblance with military operations, where flexible use of airspace procedures are used to plan and coordinate military airspace demand along with civil operations [10] and where concepts such as Dynamic Mobile Areas (DMA) are integrated in holistic approaches for Dynamic Airspace Configurations (DAC), currently investigated as part of the SESAR 3 ISLAND and HARMONIC projects [11].

This also means that, if military airspace for test and training exercises with UASs is seen as a special kind of U-space, DAR procedures can be applied accordingly [12].

B. Specific Missions and Use Cases

In order to find relevant use cases for operations in the Netherlands, NLR started collaborating with the RNLN who are developing UAS missions for some of their existing tasks which can be summarized as having the character of Intelligence, Safety and Reconnaissance (ISR) missions.



Fig. 4: Superposition of UAS Test and Training Area with Traffic Streams

For strategic reasons, the missions are usually carried out from either Maritime Airfield De Kooy (EHKD) close to Den Helder (shaded area in the upper right of Fig. 4) or from specially equipped ships along the coast. The range of UAS missions is expected to be large enough to cover even the more remote areas above the North Sea [12] at altitudes of beyond VLL (500 ft). Applying DAR to such missions, was expected to lead to more convenient and efficient procedures for RNLN and ATC The Netherlands (LVNL) regarding military airspace claims of volumes above the North Sea that come close to manned operations into Amsterdam Airport Schiphol (EHAM). What further made these missions ideal for the intended validation of DAR procedures, is the fact that they are rather flexible in nature. While it may be possible to strategically plan them, most missions will evolve or change while being executed and have high priority.

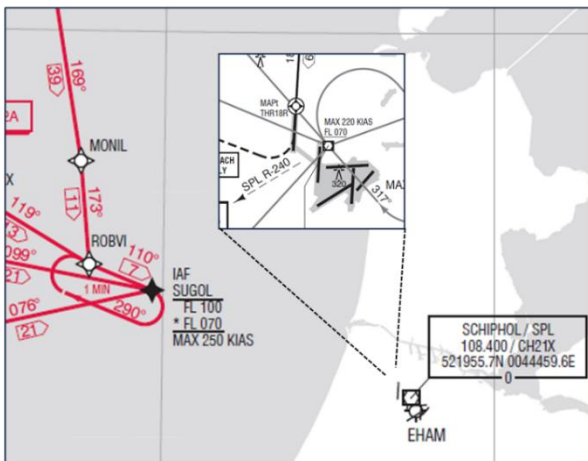


Fig. 5: Excerpt of EHAM Arrival Chart with Runway Locations [13].

The largest impact was expected to occur in the southernmost sectors of the UAS Test and Training Area (TTA). A superposition of the TTA with aggregated traffic flows during a typical day at EHAM is shown in Fig. 4. The TTA volumes are in red and extend from MSL up to 2000 ft. Green lines represent EHAM arrivals and blue lines are departures. Especially arrivals would be affected by DAR operations in this area, as they all descend from FL 070-100 at Initial Approach Fix (IAF) SUGOL (Fig. 5) down to 3000 ft on the downwind leg for runway 18R. During Independent Parallel Approach (IPA) operations towards runways 18C and 18R those flights would even have to reach 2000 ft, and the traffic would need to be merged with another arrival stream from the southern IAF RIVER. The following basic use cases were defined around this operation [9]:

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). The UAS will depart from the CTR of EHKD towards an area with several defined AUSA volumes in accordance with the mission requirements (e.g. wind farm inspection).

Use Case 2: Tactical Change of a UAS Mission. Strategic planning of a UAS mission and execution on D0. While the UAS is flying its planned mission, a change of its U-plan will occur due to changes in the mission requirements. This prompts a tactical DAR request.

Use Case 3: Contingency Operation with Execution of ERP. Strategic planning of a UAS mission and execution on D0. While the UAS is flying its planned mission, a contingency will occur forcing the UAS to follow an ERP that may (or may not) lead to a DAR request.

Use Case 4: Contingency Operation with a Non-conformance and Infringement. Strategic planning of a UAS mission and execution on D0. While the UAS is flying its planned mission, a non-conformance alert will be received by the DARM. The UAS deviates from the expected profile leading to an infringement of ATC controlled AUSA volumes.

The investigations described below focussed on the first two use cases, but also addressed the two contingency use cases. While not all possible options for the contingencies could be simulated, results were obtained through debriefings and interview sessions discussing these issues.

IV. METHODOLOGY

A. Human Performance Assessment Planning

In order to prepare for the real-time simulation experiments, three workshops were held between May 2024 and February 2025 where experienced ATCOs (from the Netherlands and the UK) were introduced to the ENSURE concept and the development and assessment plans for the ATC interfaces. Valuable feedback was obtained regarding the earlier described DAR research challenges (see II.B) as well as the development activities for refining the DAR concept and the required additional software tooling for the DARM and the EHAM approach controllers. Especially the third workshop led to a further refinement of the tooling because ATCOs, who were very familiar with the investigated airspace, could already gain experience with a prototype version.

For the final preparation of the simulation exercises, several standard rating scales were selected to assess human performance during the experiment. They considered the earlier mentioned aspects of mental workload, team work, SA, and automation trust (see again II.B). Furthermore, debriefing and interview questions were devised that addressed details regarding the research challenges for the USSP-initiated DAR. The debrief also offered opportunities for the DARM and ATCOs to provide additional information that could be used to interpret the experimental results.

B. Simulation Environment

NLR prepared a real-time human-in-the-loop simulation environment of the necessary ATC environment for the EHAM DARM and Terminal Manoeuvring Area (TMA) ATCOs on the NLR ATM Research Simulator (NARSIM). The NARSIM Radar software simulates the most important aspects of an ATM system, i.e. realistic surveillance information and aircraft behaviour, all with highly realistic interfaces that ATCOs are used to work with. In addition, tooling for the management of the DAR requests had to be provided at the DARM working position (see Fig. 2), and the DAR changes had to be visualized on ATCO displays. Simulated manned traffic was controlled by pseudo-pilots communicating with the ATCOs via a radio- telephony system. For simulation of the military UAS movement, NLR connected NARSIM to the flight planning interface that will also be used for the live trial flight planned at later stages of the project. That interface is the ArduPilot Mission Planner.

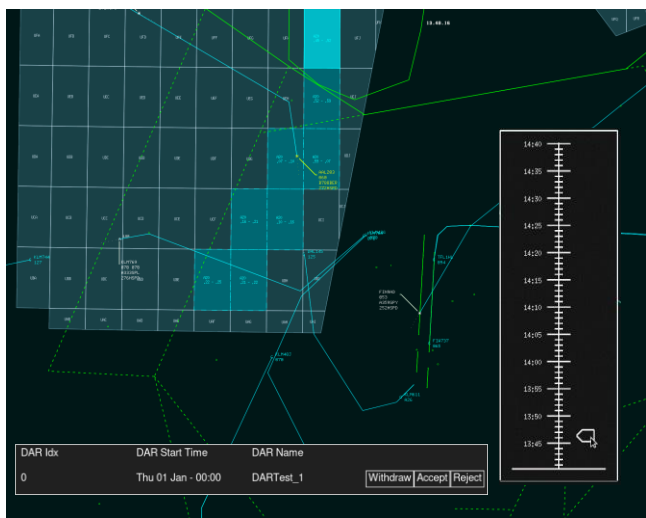


Fig. 6: DAR Impact Assessment Tool (DARM Working Position).

The additional software tooling for the DARM consisted of two components: the DAR Communication Tool (DAR-CT) and the DAR Impact Assessment Tool (DAR-IAT). Both are shown in Fig. 6 above, and it should be noted that the different components were magnified and moved to another location in this image for presentation purposes. DAR requests were presented in the DAR-CT, indicating an identifier, the DAR activation time, and a descriptive name for the DAR. The main component of the DAR-IAT is a time slider that projects all AUSA volumes contained in the request together with their start- and end-times on a surveillance display. In addition, when moving the slider, the future situation regarding the activated AUSA U-space volume and manned traffic was shown in a “ghost” view, i.e. ghost radar

blips were indicated with letter “G”, and both AUSA volumes and ghost flights were presented in a teal blue colour.



Fig. 7: DARM Surveillance Display after DAR Request Acceptance.

When the DARM made a decision to accept or reject the DAR request, a corresponding button could be pressed in the DAR-CT. In case of a rejection, a standard reason for the rejection could be chosen from a list, or a reason could be indicated using a free-text field. Finally, the DAR-CT also had a button for cancellation of the DAR. On acceptance of the DAR request, the DAR was activated and presented in another colour (amber) on the DARM surveillance display (Fig. 7). Ghost flights (and other requested but not yet accepted AUSA volumes), however, would still be shown in teal blue.

The elements added to the ATCO surveillance display for the Schiphol TMA were the active or soon to be active AUSA (military) U-space volumes (Fig. 8). 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, the colour of the timer turned to red one minute before reaching zero.

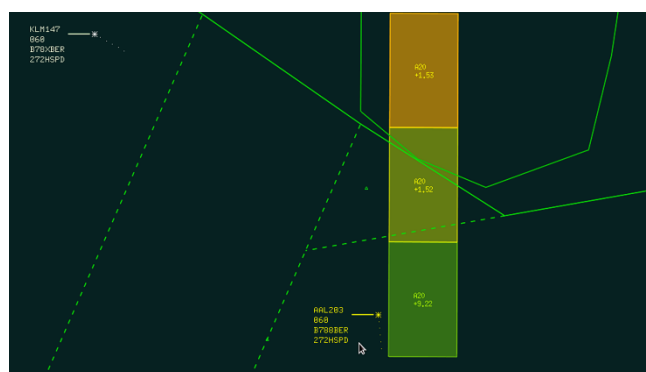


Fig. 8: ATCO Surveillance Display with AUSA U-space Volumes.

C. Experiment Set-up

Given the limited number of participants, the use cases were not offered in a randomised order. A team of three former ATCOs with detailed knowledge of the airspace around EHAM executed all five scenarios.

For each of the first two use cases described in III.B, two 45-minute traffic scenarios were developed. There was a steady flow of inbound traffic into EHAM and the scenarios consisted of different UAS missions from EHKD towards an inspection area in the TTA (and back again) requiring a DAR:

- *Run 1.1: Execution of a strategically planned mission.* Single UAS mission towards a wind farm.
- *Run 1.2: Execution of a strategically planned mission.* Two UAS missions towards different anchor areas.
- *Run 2.1: Tactical change for planned UAS mission.* Mission object changes from wind farm to anchor area.
- *Run 2.2: Tactical change for planned UAS mission.* Mission object changes from one wind farm to another.

For the contingency use cases a preliminary run was executed without clear indication of the applicable procedures, as these were not fully elaborated at the ENSURE consortium level at the time of the simulation.

- *Run 3.1: Contingency DAR and violation of airspace.* Non-compliant UAS in an anchor area.

The ATCOs always participated in the same role. One ATCO was always the DARM, one was always at the position TMA-West Controller (TWEC) and one always acted as the Arrival (ARR) controller. The TWEC was responsible for separating inbound flights from IAFs SUGOL and RIVER from departures and feeding them into a single arrival stream for runway 18R to the ARR controller. Additional controller roles necessary to cover the complete TMA operation with a second arrival stream from the east and departures from runway 24 were automated (and without coordination).

After each scenario the participants were asked to fill in a set of rating scales. This set consisted of the following:

- Rating Scale Mental Effort (RSME) [14]
- Situational Awareness for SHAPE (SASHA) [15]
- (Short) SHAPE Teamwork Questionnaire (STQ) [16]

Besides the rating scales, open-ended questions were asked about the accessibility and timeliness of the provided information. Following the questionnaires, a short debriefing of the scenario took place, allowing ATCOs to provide immediate feedback. Observers from the validation team documented the initial reactions and remarks of the ATCOs.

After completing all use cases and having experienced the new situation in a number of settings, the ATCOs were asked to fill in an additional set of rating scales, which included:

- SHAPE Automation Trust Index (SATI) [17]
- System Usability Scale (SUS) [18]

In addition to completing the rating scales, participants were required to respond to an extended set of open-ended questions and to engage in a comprehensive debriefing session, during which numerous aspects of working with the DAR concept, as implemented in the ENSURE project, were discussed.

Thus, the emphasis of the experimental design was primarily on retrieving subjective data with respect to the implementation of the concept in the simulation environment and the usability and effectiveness of the provided tooling.

V. RESULTS

The results for the qualitative assessments of Mental Workload, Situational Awareness, Teamwork, and Trust are presented below. Each construct is examined using two complementary approaches:

- Quantitative analysis of questionnaire ratings, and
- Qualitative summary of participant comments gathered during debriefing sessions.

A. Mental Workload

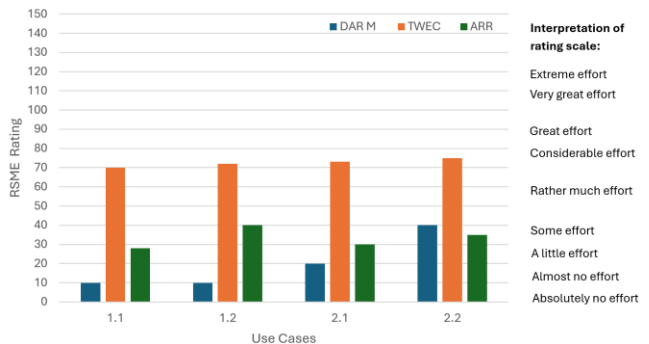


Fig. 9: Mental Workload (RSME) Ratings per Use Case.

The RSME (see Fig. 9) revealed a substantially higher mental workload for the TWEC compared to both the ARR and DARM across all use cases. The DARM most often reported the lowest mental workload. The ARR reported quite modest workload levels, compared to the other roles.

The TWEC position has been the busiest during baseline operations, therefore the result is not surprising. With the additional DARs in the TMA-West sector, a mental workload increase is perceived, which is according to the expectation.

The DARM mentioned that the changes in the DAR were unclear in Run 2.2. This seems to have caused an increase in workload.

B. Teamwork

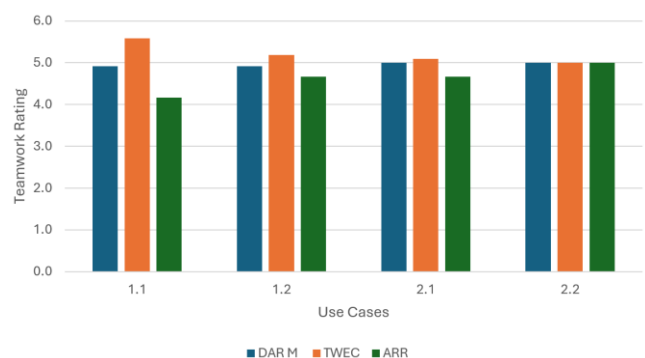


Fig. 10: Teamwork Ratings (STQ).

The teamwork ratings seem quite sufficient and stable across all runs, with values between 4.2 and 5.6 (scale 0 to 6) (see Fig. 10). The ARR initially reported a score of 4.2 and mentioned a feeling of being out of the loop. Later on it was noted that the DAR did not seem to affect the airspace under responsibility of the ARR and required no extra coordination. This may explain why the ARR ratings on teamwork increase over time.

C. Situational Awareness

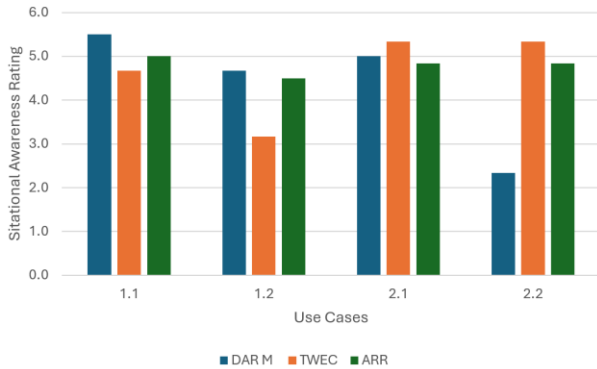


Fig. 11: Situational Awareness (SASHA).

The participant ratings of Situational Awareness (Fig. 11) show ratings around 4.5 on average (scale 0 to 6), which is a sufficient SA level. There are two ratings that are far below the average: the TWEC rating in Run 1.2 is around 3 and the DARM rating in Run 2.2 drops down to 2.3. The TWEC reported that in Runs 1.1 and 1.2, traffic was vectored around U-space volumes due to insufficient confidence that a level-off above U-space with a following descent to 2000 ft could have been accomplished given the high workload. This issue may also have caused the decrease in SA.

In Run 2.2, the SA of the DARM was significantly lower than during the other runs, presumably because it was unclear to the DARM whether a second DAR was requested in that use case or whether a new DAR would replace the previous one. The presentation of the DAR-IAT should be improved so that these cases are clear to the DARM.

D. Automation Trust

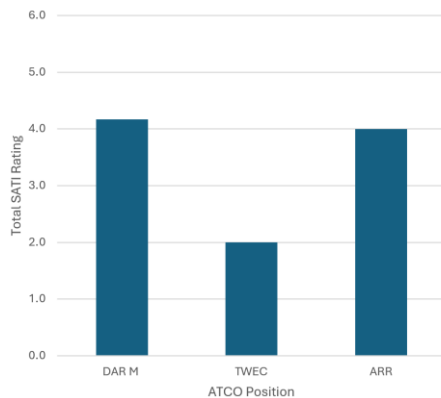


Fig. 12: Automation Trust Rating (SATI).

The DARM and the ARR rated their Automation Trust around a value of 4 (scale 0 to 6) on the SATI and the TWEC rated Automation Trust at 2 (Fig. 12), a much lower value.

The DARM was notified of the complete DAR request and had sufficient time to carefully understand the situation, whereas the TWEC only saw a planned airspace re-configuration from the time of its publication (10 minutes prior to activation), and did not have the same overview as the DARM. The TWEC was surprised by the re-configuration and may therefore have reported a low level of automation trust. The ARR was not much affected by the DAR, and as such had a positive trust in the system.

In addition to the evaluation of rating scales, debriefing sessions at the end of each use case and at the end of the day provided a more detailed and subjective interpretation of the experiences of the ATCOs with the system. No complete overview of the debriefing sessions is given in this paper, however, some of the insights gained from them, were used to explain the findings in the discussion section below.

VI. DISCUSSION

A. Concept feedback

Generally, the concept of AUSA was considered intuitive as it is similar to airspace reservations by the military. These airspace reservations are usually less flexible and dynamic, and they mostly concern the complete volume from MSL up to the operational ceiling of the TMA or surrounding Control Area (CTA). This meant that dealing with the flexibility of the DAR concept while experiencing a high workload in the TMA was more difficult for the ATCOs than working in a current-day pre-planned situation with a fixed airspace structure.

As was the case during the AURA experiments, ATCOs needed to make an assumption regarding the separation of manned traffic from AUSA U-space volumes. In analogy of what was currently used for military airspace, a separation distance from airspace boundaries of 1.5 nm horizontally and 1000 ft vertically was chosen. While ATCOs developed a preference to work towards the boundary of AUSA volumes during the simulations, they stated in debriefings that the actual separation would have to depend on what will be decided in the future regarding separation distances between IFR traffic and UAS flights. Based on that, it might be possible for ATCOs to consider the actual AUSA volume border as the limit of their operation with (smaller) buffers located fully inside the AUSA volumes.

Certain operations at EHAM, like the simulated IPA situation, they said, would need further assessments before the use of AUSA volumes in the vicinity of the arrival operation could be approved. This would especially be the case if the impact of a contingency in AUSA U-space airspace would cause an instantaneous change of the runway configuration or the end of the IPA operation. Generalizing, the situation close to an airport would be similar, where the DARM would need to know exactly what an airspace delegation means in terms of the use of runways or SIDs and STARs. Further out in the TMA, the consequences would be comparable, as the delegation of airspace might lead to a loss in solution space when separating aircraft, and thus to more operational uncertainty. Therefore, the DARM would only be in a position to accept or reject the use of a specific AUSA volume closer to the TMA, if the consequences were entirely clear and acceptable for the operation.

This again touches the subject of prioritization of the UAS operations in AUSA. According to the ATCOs, it would be necessary to protect the hub operation at EHAM, by only allowing access of a UAS to particular AUSA volumes that would affect the manned operation significantly if the UAS is indeed carrying out a high priority mission. While this could mean that the same AUSA volume could be occupied by unmanned flights with less priority, the USSP would need to ensure that these volumes are only active when flights with a high enough priority need to use them. Conversely, this would imply that volumes that are further away from the TMA and would not exceed 2000 or 3000 ft could even be planned as restricted volumes for unmanned operations for a longer

period of time, as they would not affect the manned operation at all. Thus, use of airspace should consider a cost aspect, meaning that the impact on current operations must be considered when delegating AUSA ATM airspace to U-space.

Accordingly, the use of the volumes must be regulated by state actors (under inclusion of aviation authorities), either via Letters of Agreement or via an Airspace Management Cell who would weigh the impact on the airport operation against the priority of a UAS mission for the more strategic planning. For shorter planning issues, local flow management (FMP) could reduce capacity for the airport or indicate that the use of certain volumes was not possible. Therefore, the DARM should be in close contact with the FMP and supervisors. If the DARM was a supervisor, it would need to be ensured that the additional responsibilities would not push the workload above acceptable limits and that the DARM was available for communication of airspace changes at all times.

Finally, contingencies were only looked at in one particular run and discussed afterwards regarding the viability of such operations and the required tooling. It was decided that the concept for coping with such special circumstances required a more detailed approach. Further, several different scenarios would need to be set up to find results regarding the applicability of DAR changes in such cases and the required presentation on both DARM and ATCO working positions.

B. DAR Airspace Design

One of the most notable remarks when working with the TTA airspace design concerned the presentation of the different AUSA volumes when they were occupied. Especially when traffic into Schiphol was heavy and the workload for the TWEC was high, no consideration was given to the option of having aircraft fly over the volumes before descending further to the required altitude of 2000 ft. Instead, the volumes were avoided laterally, sometimes even when they were not active yet but marked in transparent green and yellow as a warning (as in Fig. 8). While it was thought initially that this situation could be mitigated by experience, i.e. via a learning curve, the TWEC consistently stated that, under higher workload conditions, reverting to completely avoiding the volumes was inevitable. There was insufficient time to consider altitude limits indicated for the active AUSA U-space volumes as the solution space, even when circumnavigation options became increasingly limited.

Several possible solutions to this dilemma were discussed, such as a larger or more visible indication of the altitude constraint as either the maximum AUSA volume altitude or the minimum usable altitude for ATC. Also colour indications were mentioned, which could be confusing, though, as colours are already used for DAR timing. So this would need to be looked at as an integrated visualisation solution, perhaps with the option to not show the planned levels below a certain altitude. More generally, during the workshops, ATCOs pointed out that some of the airspace blocks could be better aligned with the incoming traffic streams to not unnecessarily block airspace that is important for the approach operation. However, the basic idea of having consistent and evenly shaped AUSA volumes throughout most of the TTA was appreciated after the simulations and seemed to have no noticeable impact on the operation. It was therefore considered unnecessary to change the design.

Thus, in general, and from the viewpoint of the DAR concept, the different AUSA volumes, when delegated to

U-space, could have a very different impact on the ATC operation depending on where they are located and what altitude they reach. This impact could be assessed by a DARM every time an AUSA block is requested, but it could also be built into the design of the airspace. Eventually, it would mean that certain volumes could automatically be reserved for U-space when required with a simple notification to the DARM and without visualisation for ATCOs as there is no impact on the nominal operation. In the use cases presented, this would be a common military airspace reservation being processed by the EUROCONTROL network manager (via so-called LARA AUP/UUP messages). If there was a higher impact, as in the case of the AUSA volumes in the southeast of the TTA, there could be restrictions on their use, as has been suggested above. While this again reduces the flexibility of using the airspace, a cost function could help determine what volumes could be used under what kind of operational conditions. According to what ATCOs mentioned, this could be an initial step for further automating the role of the DARM, as decisions would then be built into the airspace design.

C. Human-Machine Interface (HMI) and Tooling

HMI and tooling were presented to the DARM and TMA ATCOs as described above (in section IV.B). While the indications to the ATCOs were already discussed, as they are related to the DAR concept and airspace design, there was also feedback from the DARM on the available DAR tooling.

The DAR-CT worked as expected, but it needs to make a clearer distinction between the different types of DAR (strategic, tactical, contingency) when UAS operations are scaled up and several additional DARs are received on D0. Also a standard list of rejection options should be available. Both situations were not foreseen in the developed scenarios, but software tooling would need to be adapted accordingly when fully implementing the DAR concept.

The DAR-IAT worked fine for one strategic DAR at the beginning of D0, but it needs some adaptation in case of tactical changes or DARs being added in the course of the day. In that case, it is important for the DAR 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 implemented tool gave priority to the changes overwriting the status of the currently planned active areas. While this was a change that could be easily accomplished by the software development team, it also showed that the complexity of the visualisation of different operational situations (for sufficient DARM and controller SA) may increase dramatically when the number of operations is scaled up.

VII. CONCLUSIONS AND FUTURE WORK

While the simulations were limited in scope regarding the number of simulation scenarios that could be run, they were considered highly realistic by the participants. Each scenario lasted between 45 and 60 minutes. The participants were all former ATCOs with knowledge of the EHAM airspace and the ACC and TMA sectors. Furthermore, all of them were either involved in AURA or had participated to the workshops prior to the simulations. As a baseline for comparison, they used their own experience with the actual environment and their knowledge of the NARSIM platform that they were also familiar with. Their feedback regarding future work therefore did not really focus on the simulation environment itself, but rather the improvements of the tooling, and the procedures.

Regarding the HMI and tooling, the suggested improvements will be considered in upcoming development activities and the simulation environment will be prepared for additional simulations later this year, in particular regarding the different contingency use cases. Associated research questions are concerned with the applicable warnings and alerts for all actors, if DAR presentations improve the situation or distract controllers, and if and under what circumstances the UAS positional information should be shown to them.

After these final simulations, a real UAS will be integrated into the NARSIM environment, making it possible to carry out a flight beyond visual line-of-sight (BVLOS) for the first two use cases in the TTA and presenting it as flying within the approach area of EHAM within the simulation environment. This will enable the identification of real-world challenges that may arise when receiving and implementing DAR on D0 within the ATC environment.

Furthermore, it is expected that future investigations will also look into the remaining concept issues of airspace definition, regulation of its use, prioritization of movements, a cost function for DAR operations (USSP-initiated or ATC-initiated), and also the separation issue between UAS movements and IFR traffic, which eventually determine buffer sizes between dedicated manned airspace volumes and AUSA U-space volumes. Examining these issues will facilitate the scalability of UAS operations and allow for the exploration of additional automation possibilities, including the potential application of Machine Learning (ML) and Artificial Intelligence (AI) techniques, to enhance the management of DAR requests.

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