UAS In-flight Mission Changes: Operational Limits of Dynamic Airspace Re-configuration in Mixed ATM–U-space Environments

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The integration of unmanned aircraft systems (UAS) into non-segregated airspace shared with manned aviation requires new operational concepts that ensure safety, maintain efficiency, and support increasingly dynamic mission profiles. Within the SESAR 3 Joint Undertaking, the ENSURE project addresses this challenge through the development and validation of Dynamic Airspace Re-configuration (DAR), a mechanism enabling temporary delegation of predefined ATM U-space Shared Airspace (AUSA) volumes between Air Traffic Management (ATM) and U-space service provision. DAR is intended to support strategic planning, tactical adjustments, and contingency operations by dynamically allocating airspace resources according to operational demand.

This abstract presents the final validation results of DAR conducted by the Royal Netherlands Aerospace Centre (NLR), focusing specifically on operational boundaries under which DAR remains usable for air traffic controllers and U-space actors. The study investigates in-flight UAS mission changes, contingency procedures, and airspace infringements in complex mixed-traffic environments near Amsterdam Airport Schiphol. Particular emphasis is placed on timing constraints, human performance, and the usability of decision-support interfaces under realistic workload conditions [1].

Conceptual Background

The ENSURE DAR concept builds on earlier SESAR research, particularly the AURA project, which introduced the notion of ATM U-space Shared Airspace (AUSA) as pre-defined airspace volumes that can be dynamically assigned to either ATM or U-space operations. While AURA explored initial feasibility, it relied heavily on iterative negotiation between actors and lacked efficiency for time-critical operations. ENSURE refines this approach by introducing a structured DAR management chain involving U-space Service Providers (USSP), a Common Information Services Provider (CISP), and a dedicated DAR Manager (DARM), i.e. an airspace manager working within the ANSP environment.

In the refined ENSURE concept, UAS operators submit mission plans (U-plans) to a USSP, which aggregates demand and determines whether airspace allocation requires a DAR request. The request is forwarded via the CISP to the DARM, who evaluates it using decision-support tools and either accepts or rejects it. Acceptance results in activation of airspace delegation; rejection requires resubmission of modified U-plans. Unlike earlier concepts, the DARM does not modify requests, ensuring a clear separation of responsibilities and improving procedural efficiency.

DAR operations are structured into four phases: request, evaluation, planning, and implementation. A key design feature is the strict timing model in the implementation phase: publication occurs approximately 10 minutes prior to activation, followed by a caution phase at 4 minutes and a final

confirmation window at 2 minutes. This structure is intended to provide predictability for both UAS operators and air traffic controllers while maintaining flexibility for tactical changes.

Validation Environment

The validation was conducted in a high-fidelity human-in-the-loop simulation environment using the NLR ATM Research Simulator (NARSIM), integrated with a live UAS demonstration at the NLR Drone Centre. The simulated operational setting replicated Schiphol Terminal Manoeuvring Area (TMA) operations, including Independent Parallel Approaches to runways 18C and 18R. Realistic arrival flows, pseudo-piloted aircraft, and controller positions were combined with simulated U-space services and a DAR management workstation.

A military-like operational scenario was selected in which state-operated UAS conduct surveillance and response missions over the North Sea and along the Dutch coastal region. These missions intersect with high-density civil arrival traffic into Schiphol, requiring dynamic airspace delegation within AUSA volumes extending from mean sea level to a maximum altitude of 5,000 ft. The setup allowed evaluation of both nominal DAR operations and non-nominal cases, including tactical mission changes, emergency procedures, and airspace infringements.

Use Cases

Four representative use cases were implemented:

- Strategic DAR Planning and Execution: pre-planned airspace delegation defined on the day before operation (D-1) and executed on the day of operation (D0).
- Tactical Mission Changes: in-flight modifications of UAS missions requiring updated DAR requests with short reaction times.
- Contingency Operations (response-plan activation): emergency scenarios requiring immediate airspace reconfiguration.
- Airspace Infringements: UAS deviations from authorized volumes triggering proximity alerts and potential safety conflicts.

These cases were evaluated under varying timing constraints to determine operational boundaries of feasibility.

Human-Machine Interface Evolution

Three iterative Human-Machine Interface versions were developed. The initial design introduced a DAR Communication Tool and a DAR Impact Assessment Tool featuring time-slider-based prediction of airspace states. Although functional for single requests, this design led to high controller workload and limited situational awareness in multi-volume scenarios.

An intermediate design introduced layered DAR representations to distinguish between pending, active, and contingency requests. While this improved clarity in simple cases, it created cognitive challenges when multiple layers overlapped or changed rapidly. Controllers reported difficulty identifying disappearing or modified volumes, especially under high traffic load.

The final design retained the layered approach but did not significantly alter the interface, as intermediate results indicated that visualization improvements alone could not resolve workload and situational awareness issues. Instead, emphasis shifted toward procedural constraints and timing rules [2].

Key Results

The validation results demonstrate that DAR is operationally feasible under controlled conditions but exhibits clear performance limits in time-critical scenarios.

For strategic DAR operations, controllers and DARM operators successfully managed airspace delegation with minimal workload. These cases were considered stable and suitable for operational implementation.

For tactical DAR changes, performance was highly sensitive to available reaction time. When approximately 10 minutes were available before activation, operations remained manageable, albeit with increased workload for tactical controllers. However, when the available time dropped below 6 minutes, situational awareness degraded significantly, and workload increased to levels considered operationally unacceptable. In a 3-minute scenario and in contingency cases with immediate activation, controller workload reached extreme levels, and decision support was insufficient to maintain stable performance.

For contingency operations, DARM workload remained relatively low, but situational awareness decreased due to reliance on layered visualizations and rapid state changes. Tactical controllers experienced the highest impact, particularly when multiple DAR updates occurred simultaneously.

For airspace infringements, results showed a strong dependency on alert timing. A 30-second warning buffer provided acceptable situational awareness and allowed controllers to react effectively. A 20-second buffer reduced awareness, while no buffer led to severe degradation in detection and response performance.

Human Performance Findings

Workload assessments and situational awareness ratings revealed consistent patterns across scenarios. Tactical controllers experienced significantly higher workload than the DARM, particularly under rapid DAR change conditions. Situational awareness decreased from near-optimal levels in stable scenarios to critically low levels in contingency situations.

Importantly, increased automation and visualization complexity did not consistently improve performance. Instead, rapid state changes and layered representations introduced cognitive overhead. Controllers frequently reported difficulty maintaining a coherent mental model of airspace status during transitions.

Operational Implications

The study identifies several operational thresholds for DAR applicability:

- Minimum practical publication-to-activation time: ~10 minutes
- Lower boundary for acceptable performance: ~6 minutes
- Contingency operations: require simplified or fully automated procedures
- Airspace infringement detection: ≥30 seconds alert buffer recommended

In addition, the results highlight structural constraints on USSP behaviour. Aggregated U-plans must avoid fragmented or short-lived airspace allocations, as these are operationally unusable for ATC planning. Similarly, frequent re-delegation of airspace volumes reduces predictability and increases workload.

Recommendations

Based on the findings, several key recommendations emerge:

- Regulatory separation minima of approximately 1.5 NM horizontally and 1,000 ft vertically should be maintained between manned traffic and active DAR volumes in absence of formal standards.
- USSP aggregation logic must ensure continuity, avoiding fragmented or short-duration volume allocations.
- DAR changes within 10 minutes of activation should be treated similar to contingency events, while changes below 6 minutes should generally be avoided.
- Visualization concepts for controller interfaces require redesign, prioritizing clarity of change over static representation of multiple layers.
- Improved automation may be required to handle rapid reconfiguration scenarios and maintain situational awareness.
- Clear prioritization rules for UAS operations, especially state-actor missions, remain a critical unresolved issue for future regulatory frameworks.

Conclusion

The ENSURE validation demonstrates that Dynamic Airspace Re-configuration is a promising enabler for integrating UAS operations into mixed manned-unmanned airspace environments. The concept is operationally viable for strategic planning and moderately time-flexible tactical operations. However, its effectiveness significantly decreases under quick decision-making conditions involving rapid mission changes or immediate contingencies.

The most critical limiting factors are not technological feasibility but human performance constraints, particularly workload and situational awareness degradation in rapidly changing airspace configurations. While the DAR framework provides a structured mechanism for airspace delegation, its operational success depends on strict timing rules, improved decision-support tools, and refined visualization strategies.

Future work should focus on automation of DAR evaluation, improved prediction of traffic-airspace interactions, and more robust integration between U-space planning systems and ATM tactical operations. These developments are essential for scaling DAR concepts to dense operational environments.

References

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Biography

Dipl.-Ing. Jürgen Teutsch

Jürgen Teutsch studied Mechanical Engineering with a major in Aerospace Engineering at the Technical University of Aachen (RWTH) with a final examination on GPS data analyses for space missions carried out at Delft University of Technology in 1995.

He joined NLR in 2000 as manager for Air Traffic Management (ATM) simulation projects. As validation specialist for real-time and fast-time simulations, he participated in international initiatives for the harmonization of ATM Research & Development and was contributing author of the European Operational Concept Validation Methodology (E-OCVM), the basic guideline for validation projects within the Single European Sky Research Programme, SESAR.

In recent years Jürgen took leadership in operational concept development and validation work within SESAR-2020 and SESAR-3 regarding unmanned operations and shared use of airspace between manned and unmanned traffic.