SESAR JOINT UNDERTAKING

Final barriers characterisation

Deliverable ID:	**D4.2**
Project acronym:	**U-AGREE**
Grant:	**101167187**
Call:	**HORIZON-SESAR-2023-DES-ER-02**
Topic:	**HORIZON-SESAR-2023-DES-ER2-WA1-4**
Consortium coordinator:	**UPV**
Edition date:	**23 February 2026**
Edition:	**01.01**
Status:	**Official**
Classification:	**PU**

Abstract

This document presents the final characterisation of strategic and tactical risk mitigation barriers within the U-space framework, aligned CORUS XUAM ConOps Ed. 4.0 and coordinated with the ongoing activities within the CORUS FIVE project. It supports the development of simulation tools for validating integrated risk models, focusing on the capability and operational layers. The report outlines how U-space services mitigate UAS operational risks through a layered conflict management approach. It describes models of these barriers, detailing workflows and proposing performance metrics for evaluating their effectiveness in shared airspace.

Authoring & approval

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Organisation name	Date
UPV	15 Dec 2025

Reviewed by

Organisation name	Date
UPV	19/12/2020
EUROCONTROL	19/12/2022
EUROUSC ITALIA	19/12/2025
ENGage s.r.l.	22/12/2025
DLR	17/12/2025
COLLINS	19/12/2025
ENAIRE	19/12/2025
CRIDA	19/12/2023
INECO	22/12/2025
CRA	19/12/2025

Approved for submission to the SESAR 3 JU by

Organisation name	Date
UPV	23/12/2025
EUROCONTROL	23/12/2025
EUROUSC ITALIA	23/12/2025
ENGage s.r.l.	22/12/2025
DLR	23/12/2025
COLLINS	22/12/2025
ENAIRE	22/12/2025
CRIDA	23/12/2025
INECO	23/12/2025
CRA	23/12/2025

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Rejected by[1]

Organisation name	Date

Document history

Edition	Date	Status	Company Author	Justification
00.01	05 Dec. 2025	Draft	UPV	Creation of the document
00.02	15 Dec. 2025	Draft	UPV	Draft for internal discussion
00.03	19 Dec. 2025	Draft	UPV	Consolidated draft for internal review
01.00	23 Dec. 2025	Official	UPV	Final version for submission
01.01	23 Feb. 2026	Official	UPV	Final version for resubmission addressing the comments from SJU

[1] Representatives of the beneficiaries involved in the project.

U-AGREE

U-SPACE AIR AND GROUND RISK MODELS ENHANCEMENT

U-AGREE

This document is part of a project that has received funding from the SESAR 3 Joint Undertaking under grant agreement No 101167187 under European Union’s Horizon Europe research and innovation programme.

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1 Executive summary

This deliverable, D4.2 of the U-AGREE project, provides the final characterisation of strategic and tactical risk mitigation barriers within the U-space framework, based on the U-space ConOps Ed. 4 and on outcomes of both finished and ongoing SESAR projects. The document supports the development and adaptation of simulation tools for validating integrated risk models in WP5, focusing on the capability and operational layers of the U-AGREE solution.

The report outlines how U-space services serve as foundational elements for mitigating risks associated with Unmanned Aircraft Systems (UAS) operations. These services are designed to address hazards (e.g. mid-air collisions (MAC)). The document also highlights the layered conflict management approach inspired by ICAO's Global ATM Operational Concept (GATMOC) [3], distinguishing between strategic and tactical mitigation measures.

Strategic barriers defined in this document focus on pre-flight planning, organising the airspace to prevent conflicts before they arise by means of the strategic conflict detection and resolution functions defined in the U-space ConOps Ed. 4. These mechanisms aim to ensure that UAS operations are deconflicted to a given extent at the planning stage, based on declared 4D trajectories and airspace constraints.

Tactical barriers, on the other hand, operate during the flight to address emerging risk. These include conformance monitoring function, which detects deviations from the approved U-plan, and tactical prediction and resolutions, which provide UAS operators with guidance to avoid collisions with other aircraft. These barriers rely on digital connectivity and cooperative surveillance to support effective conflict avoidance.

The document introduces the model for characterising these barriers, detailing the operational workflows for each. It also presents the performance metrics that will be used to evaluate the barriers defined and the simulation framework for evaluating barrier effectiveness.

Overall, this deliverable lays the groundwork for a set of barriers that is a robust risk mitigation framework that enhances the safety and efficiency of UAS operations in shared airspace in mid to long-time high demand scenarios.

2 Introduction

2.1 Purpose and scope of the document

This document describes a set of risk mitigation barriers built on the U-space services as defined in the U-space ConOps [4]. The description addresses the capability and operational layers of the U-AGREE solution and aims to support the implementation or adaptation of the simulation tools that the research team will use in WP5 to validate the integrated risk models developed by the project.

2.2 Intended readership

This is a U-AGREE final document intended for public consultation. The project will leverage different State-of-the-Art simulators that have been developed for previous SESAR or national projects to build the simulators that will be used in WP5 to prove the U-AGREE concept. This document provides the details that the research team needs to adapt those existing simulators or implement ad-hoc capabilities specific to U-AGREE.

2.3 Background

U-AGREE is an Exploratory Research Project, which is the most fundamental research type of projects within the SESAR 3 Joint Undertaking framework. Nevertheless, this deliverable has drew inspiration from previous SESAR projects dealing with strategic and tactical mitigation of the risk posed by UAS operations. The way the mitigation barriers are characterised is based on the approach used in the BUBBLES and AMULED projects, as well as on other ongoing projects such as SPATIO. U-AGREE also pursues the maximum practical alignment with its sibling project CORUS FIVE, which aims to publish the U-space ConOps Ed. 5.

2.4 Structure of the document

The document is structured as follows:

- Section 1 contains the executive summary.
- Section 2 describes the purpose and scope of the document, identifies the intended readership, outlines the background of the document, details the structure of the document and lists the acronyms used throughout the deliverable along with their meaning.
- Section 3 introduces the approach to risk mitigation according to regulation 664 and describes the required capabilities.
- Sections 4 and 5 provide the description of the strategic and tactical mitigation barriers at operational level based on the U-space ConOps Ed. 4.
- Section 6 provides an overview of the performance parameters U-AGREE will use to describe the performance of the mitigation barriers and details the approach the project will apply to estimate them.

2.5 Glossary of terms

Term	Definition	Source of the definition
Autonomous Pilot in Command	An electronic system designated by the operator to conduct the flight with no human intervention within a predefined scope.	[33],[34]
Encounter	Event associated with the presence of an intruder.	[46]
Mid-air Collision	A MAC is defined as *an accident where two aircraft come into contact with each other while both are airborne*.	[55]
Near Mid-air Collision	An NMAC is a situation in which *two aircraft come within 100 ft vertically and 500 ft horizontally of each other while in flight*.	[46]
Remote Pilot in Command	The remote pilot designated by the operator charged with the safe conduct of a flight.	[35]
Small Near Mid-air Collision	An sNMAC is a situation in which *two small UAS come within 15 ft vertically and 50 ft horizontally of each other while in flight.*	[57]
U-plan	The term U-plan is used to mean a plan for a flight managed by U-space.	[4]

Table 1: Glossary of terms

2.6 List of acronyms

Term	Definition
ADS-B	Automatic Dependent Surveillance – Broadcast
ADS-L	Automatic Dependent Surveillance – Light
AO	Aerodrome Operation
AOM	Airspace Organisation and Management
AMC	Acceptable Means of Compliance
AMC&GM	Acceptable Means of Compliance and Guidance Material
ANSP	Air Navigation Service Provider
APIC	Autonomous Pilot in Command
ARA	Airspace Risk Assessment
AS	Alerting Service
ASM	Airspace Management Service
ASTM	American Society for Testing and Materials
ATAS	Air Traffic Advisory Service

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ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATFM	Air Traffic Flow Management Service
ATM	Air Traffic Management
ATS	Air Traffic Services
AUO	Airspace User Operations
AURD	ATM/UTM Research and Development Digital Twin platform
BVLOS	Beyond Visual Line of Sight
CIS	Common Information Services
CISP	Common Information Services Provider
CM	Conflict Management
CMS	Conformance Monitoring Service
CMX	Conformance Monitoring Exchange
CNS	Communication, Navigation and Surveillance
CS-ACNS	Certification Specification for Airborne CNS systems
CTR	Control Zones
DAA	Detect and Avoid
DAR	Dynamic Airspace Reconfiguration
DCB	Demand and Capacity Balancing
DRID	Direct Remote Identification
EASA	European Union Aviation Safety Agency
EGNOS	European Geo-stationary Navigation Overlay Service
E-SRM	Expanded Safety Reference Material
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment.
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAS	Flight Authorisation Service
FAX	Flight Authorisation Exchange
FIR	Flight Information Region
FIS	Flight Information Service
FL	Flight Level

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FTE	Flight Technical Error
GATMOC	Global ATM Operational Concept
GNSS	Global Navigation Satellite Systems
GM	Guidance Material
ID	Identification
IFR	Instrumental Flight Rules
IR	Implementing Regulation
MAC	Mid-air collision
NAVAID	Navigation Aid
NIX	Network Identification Exchange
NMAC	Near Mid-Air Collision
NOV	Normalised Operational View
NRID	Network Remote Identification
PBCNS	Performance-based CNS
PBN	Performance-based Navigation
PDE	Path Definition Error
RPIC	Remote Pilot in Command
RR	Risk ratio
RNP	Required Navigation Performance
RTCA	Radio-technical Commission for Aeronautics
RTK	Real Time Kinematics
RWC	Remain Well Clear
SAC	Safety Criteria
SAIL	Specific Integrity and Assurance Level
SDM	ATM Service Delivery Management
SES	Single European Sky
SESAR	Single European Sky ATM Research
SESAR 3 JU	SESAR 3 Joint Undertaking
SID	Standard Instrumental Departure
SITL	Simulation-In-The-Loop
SNE	System Navigation Error
sNMAC	Small UAS Near Mid-Air Collision

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STAR	Standard Arrival
TLS	Target Level of Safety
TMA	Terminal Manoeuvring Area
TS	Traffic Synchronisation
TSE	Total System Error
UAS	Unmanned Aerial System
USSP	U-space Service Provider
USS	UAS Service Supplier
VFR	Visual Flight Rules
VHF	Very High Frequency
VLOS	Visual line of sight
WP	Work Package

Table 2: List of acronyms

3 U-AGREE approach to risk mitigation

This section provides an overall view of how the risk posed by UAS operations can be mitigated by means of the provision of advanced (U3) U-space services [5] set out the Ed. 4.0 of the U-space ConOps [4]. The description in this section is kept at the capability level as described in the European ATM common reference architecture [6]. More detailed descriptions at operational level are provided in Section 4 below, whereas the service-level description will be provided in U-AGREE deliverable D2.6 Final OSED.

3.1 Conflict management according to ICAO GATMOC

U-AGREE applies the approach set out by the ICAO in the Global ATM Operational Concept (hereinafter referred to as GATMOC) [3] to mitigate the risk posed by UAS operations, in line with the ICAO UTM framework [7] and the CORUS FIVE project approach [8].

3.1.1 Overview of the ICAO's GATMOC

According to ICAO's Procedures for Air Navigation Systems – Air Traffic Management (hereinafter referred to as PANS-ATM) [9], the Air Traffic Management consists of *the dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management — safely, economically and efficiently — through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions* Figure 1 lists the ATM services described in the PANS – ATM, including the subdivision of Air Traffic Services.

Air Traffic Management (ATM) ICAO DOC 4444	Airspace Management (ASM).	
	Air Traffic Flow Management (ATFM).	
	Air Traffic Services (ATS).	Air Traffic Control Service (ATC)
		Flight Information Service (FIS)
		Air Traffic Advisory Service (ATAS)
		Alert Service (AS)

Figure 1. Air Traffic Management Services.

- The **Air Space Management (ASM)** focuses on optimising airspace use through dynamic time-sharing and, when necessary, segregating airspace among different user groups according to short-term operational needs (see, for instance [10]).
- **The Air Traffic Flow Management (ATFM)** aims to maintain a safe, orderly, and efficient flow of air traffic by ensuring that Air Traffic Control (ATC) capacity is fully utilised and that traffic demand remains within the limits set by the appropriate authority.

- **Air Traffic Services (ATS)** are provided immediately before the flight and thoughout its execution and comprise [11]:
    - **Air Traffic Control (ATC)** exists to prevent collisions and to expedite and maintain an orderly movement of air traffic.
    - **Flight Information Service (FIS)** provides advice and information that support the safe and efficient conduct of flights.
    - **Air Traffic Advisory Service (ATAS)** enhances the effectiveness of collision-hazard information in situations where ATC is not available and where FIS alone is insufficient.
    - **Alerting Service (AS)** informs and assists relevant organisations when an aircraft is believed to require search-and-rescue support.

ICAO's ATM services are provided by the ATM system *through the collaborative integration of humans, information, technology, facilities and services, supported by air and ground- and/or space-based communications, navigation and surveillance* [3]

The ICAO ATM system is built from **seven interdependent components** that work together to ensure safe, efficient, and collaborative air traffic management worldwide:

1. **Airspace Organisation and Management (AOM):** Organizes and allocates airspace to balance access, capacity, and safety while accommodating different types of airspace users.
2. **Aerodrome Operations (AO)**: Encompasses all activities needed to manage aircraft movements on the ground and immediately surrounding airspace, including runway and taxiway operations.
3. **Demand and Capacity Balancing (DCB)**: Ensures that traffic demand is matched to available capacity across the network through strategic planning and flow management.
4. **Traffic Synchronization (TS)**: Manages the sequencing and spacing of aircraft to optimize traffic flow during en-route, arrival, and departure phases.
5. **Airspace User Operations (AUO):** Represents the flight planning and operational decisions made by airspace users to optimize their own mission goals within the ATM framework.
6. **Conflict Management (CM):** Prevents or resolves conflicts between aircraft through strategic separation planning, tactical control, and collision avoidance layers.
7. **ATM Service Delivery Management (SDM)**: Ensures that ATM services (ATS, AIM, MET, CNS, SAR, etc.) are delivered, monitored, and improved through proper oversight, performance management, and system-wide coordination

In addition to the ATM components mentioned above, the system also incorporates **Information Services**, which support the exchange and management of data required by the various services provided to airspace users and the processes that enable them.

3.1.2 The Conflict Management in the ICAO's GATMOC

Conflict management is the ICAO's GATMOC component aimed at limiting *to an acceptable level the risk of collision between aircraft and hazards* [3].

3.1.2.1 Hazards, risks and Target Levels of Safety.

According to the GATMOC, a hazard is *any condition, event or circumstance that could induce an accident*, encompassing:

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- other aircraft,
- terrain,
- weather,
- wake turbulence,
- incompatible airspace activity and,
- surface vehicles and other obstructions on the apron and manoeuvring area (when the aircraft is on the ground).

Hazards are qualitative by nature, but they can be characterised in terms of risk, which is a combination of the overall probability or frequency of occurrence of a harmful effect induced by the hazard, and the severity of that effect. For each hazard one or several Target Levels of Safey (TLS) are agreed to define what is commonly considered as acceptably safe (assuming implicitly that the risk will never be zero).

3.1.2.2 Layered approach to the Conflict Management.

Figure 2. The three layers of conflict management according to the ICAO's GATMOC.

Conflict management is structured in three layers, as illustrated above in Figure 2.

- **Strategic conflict management** constitutes the **first layer** of the conflict management process and is implemented through AOM, DCB, and TS. The term *strategic* is used in contrast to *tactical*. However, strategic conflict management is **not limited to the pre-flight phase**, as trajectory changes may also be made during the flight, and these require strategic conflict management as well.
- **Separation provision** represents the **second layer** of conflict management and is applied when the residual collision risk—after strategic measures—exceeds a predefined threshold. It is the **tactical** process of keeping aircraft separated from hazards by at least the appropriate **separation minima**. Separation is ensured by an agent known as the **separator** (either the airspace user or a ground-based separation service), operating within a conflict horizon[2] defined for each hazard.

[2] The conflict horizon is the distance ahead along an aircraft's trajectory within which hazards are considered for separation provision.

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- **Collision avoidance** constitutes the **third layer** of conflict management. It involves reactive measures automatically triggered when the onboard anti-collision system detects an imminent collision and issues resolution advisories to the crew. Although essential for safety, collision avoidance is **not considered part of separation provision**, but it must remain compatible with the separation modes applied to the aircraft.

The GATMOC identifies the following fundamental elements of conflict management:

- Strategic conflict management reduces the need for separation provision to a designated level.
- The ATM system minimizes restrictions on user operations; the predetermined separator is usually the airspace user unless safety or system design requires separation provision.
- The separator role may be temporarily delegated[3].
- Separation provision intervention capability[4] must be considered when developing separation modes.
- The conflict horizon is extended as far as procedures and information allow.
- Collision avoidance systems support ATM safety management but do not determine the required safety level for separation provision.
- Collision avoidance systems support ATM safety management but are not used to determine the target level of safety for separation provision. Collision avoidance and separation provision must be compatible, though independent.

3.1.2.3 Strategic conflict management according to ICAO's GATMOC

ICAO's GATMOC defines a strategic conflict as a situation where there is a competing demand for the airspace resource [3]. Strategic conflict management aims to manage airspace demand so that collision risk remains at a level where no tactical mitigation is required, or where the tactical conflict resolution layer can reasonably handle the residual risk.

The strategic conflict resolution layer makes use of three GATMOC concepts to achieve that goal: Airspace Organisation and Management (AOM), the Demand and Capacity Balancing (DCB) and the Time Synchronisation (TS). The AOM is in charge of defining and applying airspace structures to accommodate the different types of air activity, volume of traffic, levels of service and rules of conduct. The DCB component strategically evaluates system-wide traffic flows and aerodrome capacities to determine when, where and how airspace users can operate, while tactically mitigating conflicting needs for airspace and aerodrome capacity. TS pursues the tactical establishment and maintenance of a safe, orderly and efficient flow of air traffic. Traffic synchronisation is closely related to conflict management and demand and capacity balancing and all together will lead to a continuous and organised flow of traffic.

AOM, DCB and TS are implemented through the provision of two ATM services: the Airspace Management (ASM) service and the Air Traffic Flow Management (ATFM) service, as defined in Annex 11 to the Chicago Convention on International Civil Aviation [11] (Annex 11 hereinafter). In particular, the ASM defines volumes such as Flight Information Regions (FIR), Terminal Manoeuvring Areas (TMA) or Control Zones (a.k.a. CTR) and assigns them one of the seven classes of airspace defined in Annex

[3] In practice, the delegation always takes place from the service provider to the airspace user.

[4] *Intervention capability refers to the quality of humans and/or systems to detect and solve a conflict and to implement and monitor the solution* [GATMOC].

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11. The ATFM monitors the demand and the capacity of the airspace and implements measures aimed at balancing them, such as actions targeting the takeoff time of specific aircraft, rerouting them or assigning different flight levels. Although strategic conflict management is usually implemented in the pre-flight phase, this does not preclude the application of strategic measures to airborne aircraft—for example, when an airspace user requests a change to a previously agreed 4D trajectory while the aircraft is already in flight.

3.1.2.4 Separation provision according to ICAO's GATMOC

According to ICAO's GATMOC, separation provision is the tactical process of keeping aircraft away from hazards by at least the applicable separation minima. Tactical conflict management is applied when the residual risk after applying strategic conflict management measures is still deemed unsafe (i.e., it is above the applicable TLS). A tactical conflict is usually defined as the predicted convergence of aircraft in space and time that violates the prescribed separation minima [12]. The responsibility for detecting and resolving tactical conflicts can be assigned either to the airspace users (i.e. self-separation) or to a ground-based separation service, depending on the airspace class and on the flight rules applied by the aircraft –visual flight rules (VFR) or instrumental flight rules (IFR), as defined in the Annex 2 to the Chicago Convention on International Civil Aviation [13] (Annex 2 hereinafter). Air Traffic Control (ATC) is a part of the Air Traffic Services (ATS) — the Air Traffic Management (ATM) services provided to airborne aircraft — and is responsible for providing separation between IFR flights, or between IFR and VFR flights, depending on the airspace class. Airspace classes where separation is provided by ATC are collectively known as controlled airspace.

ICAO's PANS-ATM [9] set out two methods of providing ATC separation: procedural separation and radar separation. In procedural separation, a particular ATS route is allocated to each flight plan and Air Traffic Controllers (ATCO) monitor the execution of the flight based on positions reported by pilots using aeronautical Very High Frequency (VHF) radiocommunication. When ATCOs detect relevant deviations from the route centreline, they issue instructions to pilots to keep the assigned path. In radar separation, ATCOs receive real-time, frequently updated reports on aircraft state (position and speed) and status (e.g., emergency) from surveillance systems (primary or secondary radars, Aumatic Dependend Surveillance – B (ADS-B) receiving stations or multilateration systems) and provide instructions (a.k.a. vectors) to pilots to maintain specific lateral and vertical separation minima. In radar separation, ATS routes still provide structure to air traffic, enhancing predictability and simplifying flow management. Although radar separation relies on real-time surveillance, predefined routes assist with conflict detection and resolution, i.e. ATCOs may issue vectors to deviate from routes when needed, then direct aircraft to rejoin once separation is assured.

3.1.2.5 Required Navigation, Communication and Surveillance (PBCNS) for procedural separation.

ATS routes are defined by references to sets of waypoints, which are determined using ground-based or space-based navigation systems (commonly known as navigation aids or NAVAIDs). For en-route operations, ATS routes consist of sets of usually parallel tracks—though they can occasionally cross—separated by a given lateral distance, known as 'route spacing', typically expressed in nautical miles, and arranged on parallel planes spaced by a specified number of flight levels (FL). ATS route structures are created in light of the expected demand, applying ICAO's ATS Planning Manual [12], and the spacing between them is specified in Annex 11 following the methodology set out in ICAO's Manual on Airspace Planning Methodology for the Determination of Separation Minima [14]. For landing and taking-off, Standard Arrival (STAR) and Standard Instrumental Departure (SID) procedures are also defined in a similar way.

ATS routes are the basis of one of the two ways tactical conflicts are managed by the ATM system, i.e., the procedural separation, in which aircraft are cleared by an ATS unit to fly along an ATS route. Aircraft are responsible for keeping as close as possible to the nominal route. The errors that affect the flight execution are the Path Definition Error (PDE), consisting of the difference between the intended trajectory and the one defined in the navigation system (usually neglected), the Navigation System Error (NSE), which refers to the difference between the actual position of the aircraft and the one reported to the crew by the navigation system, and the Flight Technical Error (FTE) which is driven by the crew or autopilot's ability to follow the defined route. Together, these three errors make up the Total System Error (TSE) [15]. The role of ATCOs is monitoring the execution of the flight based on aircraft's reported positions and instructing the pilot when relevant deviations are detected. The effectiveness of the ATCO depends, among other factors, on the accuracy of the reported position, the reporting frequency and the ATCO/aircraft communication delay.

Where procedural separation is applied, aircraft must meet specific performance-based navigation requirements established in [15]. State of the art Required Navigation Performance (RNP-X) standards intend to guarantee that aircraft remain within ±X nautical miles (known as the standard accuracy) from the nominal trajectory at least 95% of the time. RNP standards also require an airborne monitoring and alerting function that alerts when the applicable accuracy is compromised. On the other hand, RNAV-X standards have the same accuracy as the corresponding RNP-X one, but they do not require the onboard monitoring and alerting function. Separation minima also depends on the performance of the communication and surveillance system supporting ATCOs. The ICAO has introduced performance-based communication and surveillance requirements that jointly with the performance-based navigation requirements enable the definition of procedural separation minima [16], [17].

3.2 Conflict management in the U-space

3.2.1 The U-space framework

U-space services are defined as a *set of new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones*. *These services rely on a high level of digitalisation and automation of functions, whether they are on board the drone itself, or are part of the ground-based environment* [5].

The U-space is the European implementation of the ICAO's UAS Traffic Management – UTM – in [7], which is defined *as* ***a specific aspect of air traffic management*** *which manages UAS operations safely, economically and efficiently through the provision of facilities and a seamless set of services in collaboration with all parties and involving airborne and ground-based functions*. Therefore, a U-space operational concept shall be composed of the same or very similar components as those of the ICAO's GATMOC [3]. The main difference between them lies in the involvement of human in the processes. Whereas the role of humans is still crucial in most ATM activities, U-space was conceived with the idea of keeping the level of human intervention as low as possible.

Other relevant difference between ATM and the U-space is that, whereas in any volume of airspace ATS are provided to airspace users by a single Air Navigation Service Provider (ANSP), U-space services will be provided by several U-space Service Providers (USSP) in the same U-space airspace. Therefore, the role of Information Services (responsible for the exchange and management of information) in U-space airspaces becomes even more relevant and critical than in ATM, since safety critical information such as operational intents or surveillance data shall be exchanged not only between UAS operators and the USSP they are subscribed to, but also among all USSP active in a given U-space airspace.

3.2.2 Regulatory framework

Commission implementing regulation (EU) 2021/664 of 22 April 2021 [18] (Reg. 664 hereinafter) introduces the concept of U-space airspace as a UAS geographical zone as per Art. 15 of Commission Implementing Regulation (EU) 2019/947 [19] (Regulation 947 hereinafter) that is designated by competent authorities for safety, security, privacy and environment protection. UAS operations in U-space airspaces must make use of a set of specific U-space services.

Reg. 664 applies to all UAS operation categories defined in Reg. 947 with the only exceptions of the lowest-risk open category operations and the operations conducted under Instrumental Flight Rules (IFR). With regard to manned aviation, aircraft receiving air traffic control instructions shall be dynamically segregated from UAS by means of a Dynamic Airspace Reconfiguration (DAR) mechanism set out in [20].

U-space services set out in Regulation 664 address the following hazards:

- Mid-air collisions between UAS,
- mid-air collisions between UAS and manned aircraft,
- weather, and
- incompatible airspace activity.

According to regulation 664 the U-space service providers (USSP) operating in a U-space airspace must provide UAS operating therein:

- Network remote identification service,
- Flight authorisation service,
- Geo-awareness, and
- Traffic information.

Moreover, when deemed necessary by the competent authorities, any of these two additional services may be requested:

- Weather information.
- Conformance monitoring.

Beyond U-space services provided to UAS operators, Reg. 664 also requires that Common Information Services (CIS) are provided to USSPs and other relevant stakeholders with required information about the U-space airspace.

Competent authorities shall base the decision of designating an airspace volume as a U-space airspace on the outcomes of an Airspace Risk Assessment (ARA) process. The ARA will also help competent authorities determine whether the conformance monitoring and/or the weather information services need to be provided, as well as define the required UAS performance and capabilities and U-space services performance requirements. Moreover, specific airspace constraints and limitation can be also identified as a result of the ARA. All this information shall be made available through the CIS to the

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USSPs active in the U-space airspace. Common information services can be provided either by a federation of entities or by a single, designated Common Information Service Provider (CISP). In light of the operational scope of this document, the manner in which CIS are provided is not relevant. Therefore, the term CIS will be used throughout the remainder of this deliverable, without in any way precluding a centralised implementation.

3.2.3 Communications, navigation and surveillance in U-space airspaces

Reg. 664 assumes that U-space airspaces are cooperative environments in which UAS shall have a digital connection with a U-space service provider (USSP). The way this digital connection is implemented (provided by the USSP or developed by the USSP operator using an application programming interface – API – provided by the USSP), as well as the technology supporting that connection is not prescribed by Reg. 664. Nonetheless, the performance of the interface between the UAS operator and the USSP shall be defined as part of the performance requirements laid down by the competent authority that designates the U-space airspace.

UAS navigation systems are based on Global Navigation Satellite Systems (GNSS). They can make use of space-based augmentation systems (such as the European Geo-stationary Navigation Overlay Service, EGNOS), as well as ground-based augmentation systems (such as those based on the real time kinematic technique, a.k.a. RTK). Although ground-based augmentation techniques provide very good figures of accuracy, they do not guarantee integrity (for that purpose EGNOS-capable receivers must be used). Competent authorities shall establish UAS navigation performance requirements since this is a factor which affects the overall safety of the U-space airspace.

Surveillance in U-space airspaces is mainly cooperative. UAS report their timestamped 3D geodetic position, velocity (ground speed and bearing), as well as their status (contingency/emergency) through the digital connection with the USSP they are subscribed to (i.e., Network Remote Identification – NRID). USSPs exchange surveillance information by means of their network identification services to build a common picture of the UAS traffic in the U-space airspace.

Manned aircraft operating in U-space airspaces and not receiving air traffic control instructions shall be electronically conspicuous according to Commission Implementing Regulation (EU) 2021/666 of 22 April 2021 [21] (hereinafter referred to as Reg. 666). Electronic conspicuity (usually referred to as e-conspicuity) can be supported by different technologies:

- Automatic Dependant Surveillance – Broadcast (ADS – B), either at 1,090 MHz (extended squitter) or 978 MHz (universal access transceiver) according to [22], or
- automatic dependant surveillance – lite (ADS – L) using short-range device access at 860 MHz (SRD860), as set out in [23].

Although mobile networks are also envisaged as a possible e-conspicuity enabler, the corresponding technical specification (ADS-L MOBILE) is still under development, and no practical implementation has been reported yet.

With regards UAS, Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 [24], amended by the Commission Delegated Regulation (EU) 2020/1058 of 27 April 2020 [25], jointly referred to as Reg. 945+ hereinafter, lay down the requirement of Direct Remote Identification (DRID) for UAS of classes C1-C3 (intended for operations in the open category), and C5 and C6 for UAS operating in the specific category below a height of 120 m. The acceptable means of compliance with the DRID requirement is the standard EN 4709-002:2023 [26], which sets out a broadcast mechanism based on either Bluetooth (legacy) or Wi-Fi access technologies. There is no DRID requirement for aircraft operating in the certified category. It is worth noting that DRID is not intended to support UAS traffic management in U-space airspaces. Instead, it consists of a local broadcast primarily intended for law enforcement purposes and for addressing public concerns related to privacy protection.

Non-cooperative surveillance might be available in some U-space airspaces, especially leveraging third-party systems deployed for different purposes (e.g., counter – UAS systems) or even deployed on purpose.

When available, surveillance information from air traffic service units might be made available to USSPs as part of the common information services set out in Reg. 664.

3.2.4 Strategic mitigations in the U-space

The designation of a volume of airspace as a U-space airspace is, in itself, a long- term, strategic risk mitigation measure based on the AOM component of the ATM system. The rest of this section describes other short-term, pre-tactical mitigation measures based on the AOM, TS and DCB ATM system components.

3.2.4.1 Mitigation of the risk of MAC between UAS

In manned aviation, part of the AOM consists of developing airspace concepts aimed to meet explicit strategic objectives such as enhanced safety, increased air traffic capacity, and reduced environmental impact. These concepts may include detailed arrangements for the practical organisation of airspace and its users, based on specific CNS/ATM assumptions—for example, the structure of ATS routes and their spacing. In the context of performance-based navigation used in State-of-the-Art aviation, aircraft flying along ATS routes are requested to meet specific navigation performance requirements as described in Section 3.1.2.5.

Considering the projected number of UAS flights in U-space airspaces and their very different navigation performances, the definition of fixed routes with associated navigation performance requirements would not be feasible therein. Hence, U-space ConOps [4] sets up a kind of 'on demand' route structure based on an approval mechanism consisting of the following steps:

1. UAS operators must include in the U-plans submitted to their USSP the intended trajectory in the form of a series of 4D volumes which are defined in light of the flight uncertainty (i.e., the TSE) capped in the given probability of a 95%. In this way, the responsibility for defining of the accuracy of each route (i.e., the size of the 4D volumes) lies with the operators, based on their knowledge of the aircraft they intend to use for a given mission and the information provided by the USSP they are subscribed to on weather and CNS performance.
2. USSPs apply suitable 4D deviation thresholds defined by the competent authority on the basis of the outcomes of the air space risk assessment, pursuing a trade-off between the needs of safety and the efficient use of the airspace.
3. USSPs process every new 4D trajectory submitted by a UAS operator searching for overlaps in space and time with previously approved ones (i.e., strategic conflicts). Conflicting trajectories can be either:

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a. Rejected. In this case (which is the one considered in Regulation 664), the U-space service provider must inform of the reason for the rejection and may (optionally) provide free-of-conflict alternatives to the UAS operator. The UAS operator can accept any of the proposed alternatives or submit a new one independently. Notice that this procedure guarantees that all 4D approved trajectories remain separated by at least the required 'spacing distance', similar to how it is done with ATS routes in manned aviation. This approach enables the procedural-like tactical separation provision detailed later in Section 3.2.5.1. However, there is no agreed method to compute the deviation thresholds and the documents used to determine procedural separation minima [12], [14], [17] are barely applicable, beyond the basic idea that they must be compatible with the agreed TLS. EUROCONTROL is currently developing guidance material within the broader scope of ARA and several research projects like BURDI [27], SPATIO [28], or AI4HyDrop [29] have recently proposed methods to determine the size of the deviation thresholds. U-AGREE will apply the SPATIO's approach to compute them using the safety-oriented methodology set out in Section 5.
b. Conditionally accepted. Option (a) prioritises safety over airspace usage. While it may be effective in the short to medium term, it is unlikely to support the forecast increase in demand described in [30], [31]. Therefore, the U-space ConOps envisages the use of radar-like separation provision at the tactical layer, allowing a certain level of overlap that that leaves the residual collision risk above the TLS, with the tactical layer being used to manage that residual risk so that the overall riks remains below the TLS. Acceptable overlapping levels will be defined both pairwise (the likelihood of overlap between any pair of 4D trajectories shall not exceed a given threshold) and globally (the number of potential MACs to be managed at the tactical level shall not overload the separation-provision system).

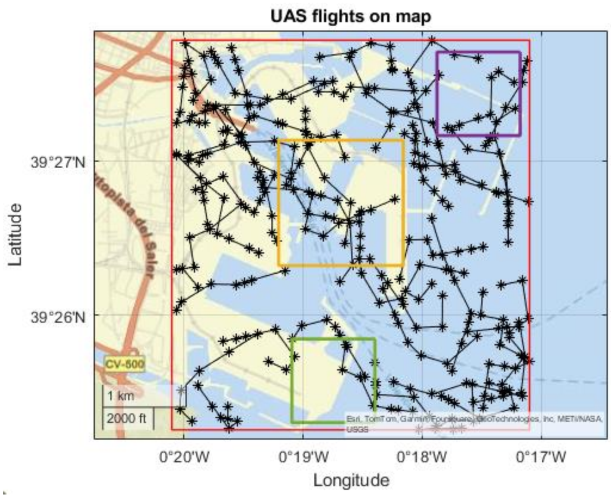
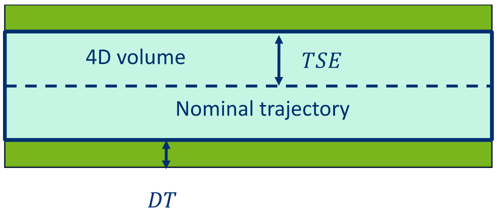
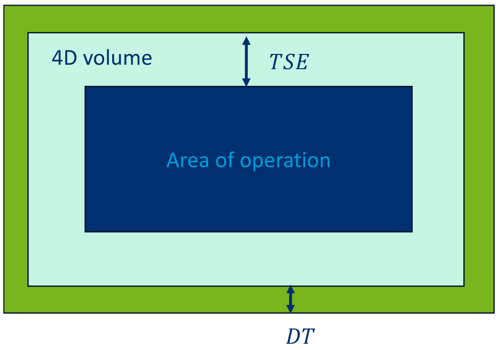


Figure 3. Examples of trajectories defined over the Port of Valencia area

Figure 3 provides examples of typical trajectories in a U-space airspace. Those trajectories can be classified into linear trajectories—defined by a set of waypoints specified by latitude-longitude coordinates, similar to ATS routes but generally more complex (black lines in Figure 3)—and area operations, represented by the green, orange, and purple squares in Figure 3. Figure 4 illustrates how deviation thresholds are added to the 4D operational volumes defined by UAS operators. While deviation thresholds are defined by the competent authority and common to all U-space operations, UAS operators are free to define the 4D operational volumes as large as they consider necessary to meet the 95% confidence throughout the flight. However, the size of 4D operational volumes may have a dramatic impact on the airspace capacity, regardless of the adopted conflict resolution mechanism. Therefore, as demand increases, area operations may be prohibited, and operations may be constrained by specific 4D operational volume size requirements (at least in the most capacity-demanding scenarios), which would lead to the concept of RNP U-space airspaces.



(a) Linear trajectory



(b) Area trajectory

Figure 4. Deviation on UAS 4D operational volumes.

Notice that because of the multi-USSP framework, USSPs need to exchange among them information on the operations they have authorised to identify overlaps between UAS 4D trajectories.

Before starting the operation, the UAS operator must request the activation of the authorisation. The corresponding USSP shall make a last check whether there are no UAS flying out of conformance with their authorised 4D operational volume (in case the conformance monitoring service is provided in the U-space aerospace) or non-cooperative UAS (in case that information is available) in the vicinity of the take-off. If no issue is detected, the USSP notifies the activation to the UAS operator. The entire process echoes the way flight plans for manned aircraft are filed with the ATC unit for approval prior to the flight, after which pilots are cleared by the ATC to proceed with the flight according to the approved flight plan.

U-space ConOps has adopted the notion of priority introduced by Regulation 664, meaning that higher-priority flight authorisation requests may override previously approved ones with lower priority, while requests with the same priority will be processed on a first-come, first-served basis. Therefore, during the time between the approval and the activation of a flight authorisation request, the USSP must continuously monitor for the arrival of higher-priority requests and withdraw earlier authorisations if necessary. Being safety-focused, U-AGREE will not address the impact of priority on the approved U-plans between the approval and the activation since this is mainly capacity-wise. Therefore, from the project's perspective, it will be assumed that the activation request occurs immediately after the authorisation. However, requests for high priority flights might impact lower priority UAS which are already airborne. In that case, the 4D trajectory of the lower priority aircraft must be updated or, if not, the flight authorisation withdrawn. In both cases, the USSP reroutes the affected UAS either to accomplish its mission without interfering the higher priority one or to safely land at one of the continued safe flight and landing locations identified in the U-plan. Rerouting can be also applied in case of contingency, helping the affected UAS implement its contingency procedures without interfering other flights.

3.2.4.2 Mitigation of the risk of MAC between UAS and manned aircraft receiving ATC instructions.

Regulation 664 prescribes the segregation of UAS and manned aircraft receiving ATC instructions. However, this does not preclude competent authorities from designating U-space airspaces within controlled airspace, provided that manned aircraft receiving ATC instructions do not regularly operate within them.

If a manned aircraft receiving ATC instructions needs to occasionally enter such a U-space airspace, the responsible ATC unit will initiate a Dynamic Airspace Reconfiguration (DAR) process. A DAR involves the temporary deactivation of part or all of the affected U-space airspace.

DARs are implemented in a stepwise manner:

1. In the transient stage, all UAS are instructed either to exit the affected portion of the U-space airspace or to safely land, following their contingency procedures.
2. Subsequently, the responsible ATC unit shall publish a temporary U-space airspace restriction for UAS, through the Common Information Services (CIS) for that airspace, effective until the manned aircraft exits the U-space.

The precise way DAR shall be activated remains still matter of research (e.g., the SESAR project ENSURE). As a result, this aspect falls outside the scope of U-AGREE. From the project's perspective, DARs will be treated in the same manner as any other dynamic airspace restriction, as outlined in Section 3.2.4.5.

3.2.4.3 Mitigation of the risk of MAC between UAS and manned aircraft not receiving ATC instructions

Manned aircraft not receiving ATC instructions can operate in a U-space airspace, either in controlled or uncontrolled airspace, provided they meet the e-conspicuity requirement laid down by Reg. 666. Upon the receipt of the activation request from a UAS operator the USSP shall check whether there will be e-conspicuous manned flights in the vicinity of the UAS trajectory. In that case the USSP shall reject the activation, inform the affected UAS operator and (optionally) propose an alternative. The U-AGREE strategic barrier model described in this document will address how such an alternative can be provided.

3.2.4.4 Mitigation of the risk posed by weather

When relevant, the competent authority that designates the U-space airspace can define weather minima and/or maxima. When defined, the USSP shall check that the intended operation is compatible with them at the time of the activation flight authorisation.

3.2.4.5 Mitigation of the risk posed by incompatible airspace activity

Competent authorities responsible for the designation of the U-space airspace shall determine the capacity and density of UAS operations in the corresponding U-space airspace based on the outcomes of the ARA and will publish them through the CIS. When processing a flight authorisation request, USSPs shall check that these values are not exceeded. In addition, competent authorities can define and publish through the CIS airspace limitations and constraints. USSPs shall check whether flight authorisation requests are compatible with existing airspace limitations and constraints, both at the time of the authorisation and at the time of the activation. In case the intended operational volume intersects geographical zones with restricted access, the USSP shall either:

1. List the specific entry permissions and/or requirements in the terms and conditions of the flight authorisation. This case was addressed in deliverable D4.1 as part of the initial barriers' model.
2. Check by electronic means (i.e., online databases) whether the UAS operation meets or not the entry permissions and/or requirements as part of the flight authorisation process. This case will be addressed in this deliverable as part of the final barriers' model.

Airspace limitations and constraints, as well as UAS geographical zones can be designated dynamically to face unexpected situations arising during regular operations. Some examples encompass:

- A reduction of the airspace capacity due to a sudden performance degradation of GNSS or public telecommunication networks.
- A no-fly zone defined as a result of a DAR.

In these or similar cases, UAS already airborne may require their flight authorisations to be updated or cancelled. In both cases, the USSP shall provide revised 4D trajectories to avoid the hazard either continuing the mission or safely landing at one of the continued safe flight and landing locations identified in the U-plan.

3.2.5 Tactical mitigations

In line with the GATMOC, separation provision in the U-space is the tactical process of maintaining aircraft at or beyond the applicable separation minima from identified hazards. Separation is provided within a conflict horizon that is defined in advance for each hazard type. Separation provision is an iterative process comprising the following steps:

1. Conflict detection, based on the current positions of the involved aircraft and their predicted trajectories with respect to known hazards.
2. Solution formulation, including the selection of appropriate separation modes to ensure that aircraft remain separated from all known hazards within the relevant conflict horizon. This entails:
   i. The designation of a separator, defined as the agent responsible for separation provision for a given conflict, which may be either the airspace user or a separation provision service provider.
   ii. The selection of a separation mode, understood as an approved set of rules, procedures, and conditions of application associated with specific separation minima.
   iii. The application of the selected separation minima.
3. Solution implementation, by communicating the selected solution and initiating any required trajectory modifications.
4. Execution monitoring, to ensure that hazards are avoided and that the applicable separation minima are maintained.

The selection of a separation mode shall take into account, among other factors, the required safety level, the nature of the activity and the hazard, the qualifications and roles of the involved actors, the

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performance of Communication, Navigation, and Surveillance (CNS) systems, prevailing meteorological conditions, and traffic density.

The separation provision intervention capability is a key factor in the definition of separation modes, including the determination of both separators and separation minima. This capability refers to the ability of humans and/or systems to detect conflicts, formulate solutions, and implement and monitor their execution. It may be allocated to a separation provision service or to an airspace user and shall be defined in accordance with human factors principles and the intervention capabilities enabled by the available level of automation.

Figure 5 illustrates the different steps of the separation provision process, where the box labelled 'Surveillance' represents the gathering and processing (e.g., data fusion, tracking, etc.) of surveillance data using the technologies outlined in Section 3.2.3.

Figure 5. Separation provision process flowchart (from [32]).

The BUBBLES project proposed the set of separation modes listed in Table 3 [33].

Separation mode	Airspace volume[5]	Automation level[6]	Guidance	Conflict detection	Solution formulation	Solution implement.	Solution monitoring
1-O	X/Y	Level 0/Pilot-in-the-loop	Informative	RPIC	RPIC	RPIC	RPIC
2-O	X/Y	Level 1/Pilot-in-the-loop	Suggestive	DAA-RWC	DAA-RWC RPIC	RPIC	RPIC
3-O	X/Y	Level 2/Pilot-on-the-loop	Directive	DAA-RWC	DAA-RWC	RPIC (consent)	RPIC
4-O	X/Y	Level 3/Pilot-on-the-loop	Directive	DAA-RWC	DAA-RWC	RPIC (exception)	RPIC
5-O	X/Y	Level 4/ Pilot-off-the-loop[7]	Direct	DAA-RWC	DAA-RWC	APIC	APIC
1-U	X/Y	Level 0/Pilot-in-the-loop	Informative	RPIC	RPIC	RPIC	RPIC
2-U	Zz	Level 1/Pilot-in-the-loop	Suggestive	USSP	USSP RPIC	RPIC	USSP
3-U	Zu	Level 2/Pilot-on-the-loop	Directive	USSP	USSP	APIC+RPIC (consent)	USSP

[5] Updated in light of the U-space ConOps Ed. 4.
[6] Automation levels are labelled using both the original BUBBLES names and the levels of automation defined in the European ATM Master Plan 2025 Edition [34].
[7] Unless the operation exits the predefined scope, in which case the operation reverts to level 3.

4-U	Zu	Level 3/Pilot-on-the-loop	Directive	USSP	USSP	APIC+RPIC (exception)	USSP
5-U	Zu	Level 4/Pilot-off-the-loop	Direct	USSP	USSP	APIC	USSP

Table 3. Separation modes proposed by the BUBBLES project (from [33]).

The taxonomy of separation modes proposed by the BUBBLES project is driven by the level of automation and by the allocation of responsibility across the different steps of separation provision. This allocation is based on the intervention capabilities enabled by the corresponding automation level. The five uppermost rows in Table 3 correspond to cases in which separation provision is supported by a RWC function provided by an airborne DAA system and therefore fall outside the U-space scope of U-AGREE. The remaining six rows correspond to cases in which separation provision is supported by the subscribed USSP, with progressively decreasing involvement of the UAS operator in the separation process.

NOTE 1. In airspace volumes type Zz and Zu UAS equipped with DAA systems capable to provide a RWC function shall delegate the responsibility in the separation provision process to the corresponding U-space services provided by the subscribed USSP.

The taxonomy introduced in Table 3 can be further elaborated by accounting additional criteria for the 'Conflict detection' and 'Conflict resolution' functions in Figure 5. In [36], the authors present a thorough literature review of state-of-the-art conflict detection and resolution method and propose a **classification of conflict detection algorithms** according to the way trajectories are propagated to detect possible loss of separation and on the way uncertainty is accounted for in this process.

Conflict detection taxonomy [36]	Trajectory propagation	State-based
		Intent-based
	Predictability assumption	Nominal
		Probabilistic
		Worst-case

Figure 6. Multicriteria taxonomy of conflict detection functions according to [36]

State-based algorithms propagate trajectories using linear kinematic models that exploit aircraft state vectors (position, velocity, and, optionally, acceleration). Intent-based models make use of flight-plan information describing future manoeuvres.

With respect to predictability, nominal prediction neglects all sources of uncertainty (e.g. uncoordinated behaviour from other traffic, unknown wind, or state variations) when propagating trajectories, resulting in lightweight implementations. By contrast, worst-case assumptions account for all possible sources of uncertainty and therefore require a significantly higher computational effort.

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Probabilistic assumptions represent a trade-off between the simplicity of nominal prediction and the accuracy of worst-case approaches, by accounting only for the most likely trajectory changes. Encounter models, such as the one reported in [37], are instrumental for the implementation of probabilistic trajectory propagation, as they provide estimates of the likelihood of different manoeuvres. However, the lack of encounter models comparable to [37] that are applicable to U-space airspaces currently hinders the adoption of probabilistic trajectory propagation in that context.

Intent-based trajectory propagation can reduce uncertainty when using nominal prediction approaches. However, implementing intent-based conflict-detection algorithms within the U-space framework would require U-space Service Providers (USSPs) to exchange intent information while UAS are airborne. U-space ConOps Edition 4 refers to the exchange of U-plans during the in-flight phase and further notes that updated U-plans with reduced uncertainty could be used for this purpose (e.g. accounting for the actual take-off time would significantly reduce temporal uncertainty). Nevertheless, the exchange of U-plans for airborne UAS between USSPs remains a subject of ongoing research, and several relevant research questions are still open. These include, among others, the appropriate temporal and spatial scope of such exchanges, and whether the 4D volumes defining the trajectories contained in U-plans should be used directly or transformed into waypoint-based trajectory representations.

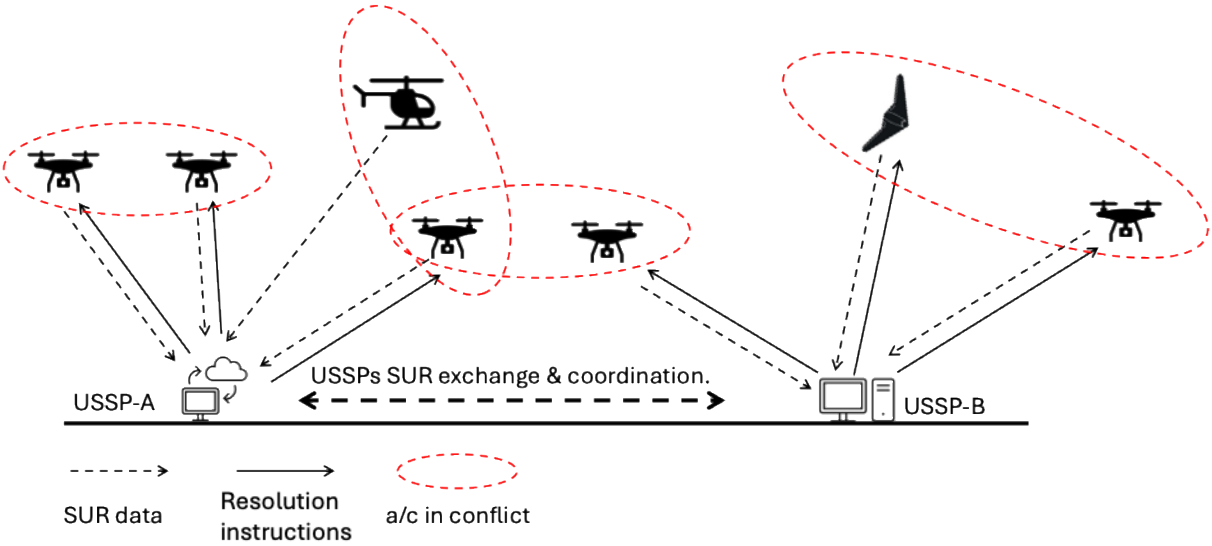

Figure 7. Tactical conflict detection and resolution architecture in the U-space

Conflict-resolution algorithms are commonly classified as either centralised or distributed. However, the classification proposed in [36] does not fully capture the specific characteristics of multi-USSP U-space airspaces, as illustrated in Figure 7. In such environments, USSPs provide centralised resolutions to their subscribed UAS operators while, at the same time, needing to coordinate among themselves, as in distributed approaches. This multi-USSP architecture requires information exchanges that introduce additional latencies, which must be taken into account in the design of conflict-resolution algorithms. In light of this hybrid architecture, USSPs may apply intent-based trajectory-propagation methods with reduced uncertainty when predicting conflicts involving their own subscribed UAS operators, since they have access to the complete 4D trajectories contained in the U-plans they process. In principle, USSPs could even apply ad hoc resolution policies for their served UAS operators in pursuit of optimised solutions.

However, such an approach could lead to uncorrelated resolutions, which in shared environments such as U-space airspaces may have undesirable side effects that require further investigation. For conflicts involving UAS served by different USSPs, the distributed methods described in [36] remain fully applicable, provided that the additional latencies introduced by inter-USSP data exchanges are properly accounted for. Distributed conflict resolution methods can be classified into implicit coordination and explicit coordination approaches. Implicit coordination does not require communication between the separator agents (i.e., USSPs) since the conflict resolution is based on a set of agreed rules. Implicit coordination can be further broken down into prescribed and reactive methods. Prescribed conflict resolution consists of the application of a set of Right-of-Way rules, similar to the ones described in ICAO's Annex 2 [13]. In the reactive resolution case, aircraft apply an agreed method that will provide resolution instructions according to the conflict geometry (e.g., the *shortest-way-out* principle for pairwise conflict resolution [38]). Explicitly negotiated resolution methods rely on direct communication between aircraft, eliminating uncertainty about intruder behaviour through shared intent information. Conflicts are resolved either via negotiation to reach a globally optimal solution or through prioritisation schemes that limit interactions and avoid deadlocks. Given bandwidth constraints, communication frequency and the number of message exchanges must be optimised, with explicit break conditions to prevent indefinite negotiation.

The use of different Machine Learning (ML) approaches for both prescribed and negotiated resolutions have recently emerged as a very promising alternative to conventional methods. In [39], the authors present a thorough description of state-of-the-art ML-based methods for tactical conflict resolution, describing their advantages (especially their ability to adapt to new scenarios and learn from new data leading to a continuous performance improvement over time) The main challenges ML-based conflict resolution techniques are facing right now are complexity, convergence, and onboard resource limitations, as well as ensuring scalability and robustness in high-density traffic and unforeseen situations. In addition, limited explainability of the decision-making process hinders verification, certification, and operational trust. Key research needs identified in [39] include the development of hybrid conflict-resolution approaches that integrate classical and learning-based methods to leverage their complementary strengths, the incorporation of advanced optimisation techniques into classical algorithms to improve efficiency and solution quality, and the advancement of explainable artificial intelligence (XAI) methods to ensure transparency, interpretability, and trust in decision-making processes.

NOTE 2. In the UAS operation context, the collision avoidance function is usually provided by state-of-the-art airborne DAA systems and therefore lies outside the scope of U-AGREE [40]. The provision of such a function using ground-based systems is particularly challenging because of the very short timeframe available for collision-avoidance manoeuvres, which are typically modelled assuming pilot initiation within approximately 5 s for initial responses and around 2.5 s for subsequent or more automated responses in airborne collision-avoidance systems [41], [42]. Nonetheless, U-AGREE will assess the applicability of ground-based safety nets similar to the Short-Term Conflict Alert (STCA) [43] used in manned aviation to UAS operations in U-space airspaces.

3.2.5.1 Mitigation of the risk of MAC between UAS

Procedural-like separation

Procedural-like separation corresponds to the BUBBLS separation model 1-U in airspace volumes X/Y. This separation mode represents the lowest automation level (Level 0) in which USSPs support the human operator only in basic information acquisition, exchange, and analysis, but all decisions and actions are taken and implemented by the human operator. This is the separation provision process shrined in Reg. 664 and is expected to be the baseline for European ATM around 2030, with more advanced automation introduced progressively thereafter. According to this regulation, USSPs shall provide UAS operators with traffic information including the timestamped position, speed, heading and emergency status (when known) and UAS operators shall take the relevant action to not collide with other UAS.

Beyond this purely tactical mitigation, USSPs can reinforce the effectiveness of the strategic mitigation set out in Section 3.2.4.1 by monitoring flight execution and issuing warnings when UAS fly outside the authorised 4D volumes (if requested by the competent authority that designated the U-space airspace). This is, in some sense, similar to the monitoring and warning capability requested of onboard equipment for RNP navigation [16], with some relevant nuances:

1. Monitoring and warning are provided by a ground-based system instead of by airborne equipment subject to stringent requirements (e.g., EASA CS-ACNS [44]). This relieves UAS operators from the need to equip their aircraft with expensive systems, but imposes additional requirements on the USSP systems.
2. Conformance alerts are provided not only to non/conformant aircraft but also to other nearby aircraft as part of the traffic information. This reinforces UAS operators capability to avoid MAC with third-party, non-conformant UAS.

Reg. 664 introduces an optional capability that further enhances the effectiveness of the strategic deconfliction of 4D trajectories: USSPs can issue preliminary conformance alerts to UAS operators when their aircraft fly outside the operational volumes declared in the flight authorisation request, but still within the 4D trajectory.

Radar-like separation

Radar-like separation, as defined in the BUBBLES separation methods 2-U to 5-U, entails increasing levels of automation and correspondingly reduced human intervention, and is envisaged to be progressively deployed from 2030 onwards in line with the European ATM Master Plan vision [34]. Radar-like separation relies on the provision of tactical conflict detection and tactical conflict resolution services, as described in the U-space ConOps Ed. 4, while not precluding the parallel provision of strategic conflict detection and resolution services. However, unlike the procedural-like separation prescribed by Reg. 664, overlapping 4D trajectories are not automatically rejected; instead, they may be accepted provided that the residual risk remaining after the strategic conflict resolution process can be effectively managed by tactical services. Conformance monitoring remains a valuable, RNP-wise complement to strategic conflict resolution by supporting UAS operators in maintaining operations within the limits of the approved 4D trajectories. Moreover, non-conformance alerts are a valuable input for separation provision, especially in the case where intent-based trajectory projection algorithms are used. tactical conflict detection and resolution services are responsible for identifying and resolving any potential loss of separation

3.2.5.2 Mitigation of the risk of MAC between UAS and manned aircraft

Manned aircraft receiving ATC instructions shall be segregated from UAS in U-space airspaces in controlled airspace by means of the DAR mechanism according to Reg. 664. The segregation of aircraft receiving ATC instructions and UAS receiving U-space services will be in force until the full integration of ATM and U-space becomes a reality, something which is not expected to happen before 2045 according to the European ATM Masterplan.

In case USSPs fail to keep UAS outside the portion of U-space deactivated because of the DAR or a manned aircraft receiving ATC instructions enters the portion of the U-space not affected by the DAR, USSPs will help UAS operators to avoid the collision hazard by providing increasingly automated services, enabling BUBBLES separation modes 1-U to 5-U, with the particularity that manned aircraft will have always the Right-of-Way. To help USSPs support UAS operators in avoiding manned aircraft receiving ATC instructions, the corresponding ATS units will provide USSPs with information about manned aircraft through the CIS.

Aircraft not receiving ATC instructions are considered ordinary participants in U-space airspaces, as they are allowed to operate therein provided that they meet the e-conspicuity requirements laid down in Regulation (EU) 666/2023. Therefore, the collision risk due to MAC between UAS and this type of manned aircraft will be mitigated by the provision of tactical separation according to the BUBBLES separation modes 2-U to 5-U, supported by increasingly automated tactical conflict detection and tactical conflict resolution services.

3.2.6 Required capabilities

The following table (Table 4) outlines the key capabilities of the project, in line with the AMPLE3 definition [45].

Capability	Description
Airspace Capacity Information Provision (incl. Capacity Changes)	The ability to determine the capacity (present, future) of airspace, including ad hoc changes due to circumstances (e.g. weather).
Airspace Separation Minima Management	The ability to define and manage the separation minima for a specific airspace (U-space).
Dynamic Airspace Reconfiguration	The ability to modify temporarily the U-space airspace in order to accommodate short-term changes in manned traffic demand, by adjusting the geographical limits of that U-space airspace.
Pilot Situational Awareness (airspace)	The ability to visualise own aircraft position and surrounding traffic information in context (e.g. airspace status).
RNP Based Operations Execution	The ability to fly RNP routes (En Route airspace, TMA airspace, low level IFR routes) and conduct RNP based procedures (e.g. parallel approaches).
Self-separation	The ability to separate own aircraft from surrounding traffic.
Trajectory Conformance Monitoring	The ability to anticipate/detect deviations from trajectory agreement during execution.

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U-space Communication Coverage Provision	The ability to provide the link, coverage and monitoring of the air-air, air-ground and ground-ground communication to facilitate the interaction between U-space stakeholders.
U-space Navigation Coverage Provision	The ability to provide navigation support (providing the link, coverage provided and monitoring) for the planning, recording and controlling the movement of an aircraft from one place to another.
U-space Surveillance Provision	The ability to facilitate the provision of ground and air surveillance data from different sources to track and fuse for determining the position of the unmanned aircraft.
UAS Operational Planning	The ability to plan UAS missions considering all relevant information, such as meteorological information, aeronautical information, other UAS flight plans and applicable rules and traffic information.
UAS Procedure Design	The ability to interface with ATC to define a set of procedures for some mission types where there may be an impact on ATC; the procedures ensure clear and unambiguous UAS operation and provide an appropriate flow of information between the UAS operators and ATC. Such procedures will allow UAS to fly in controlled airspace and near airports with more flexibility and procedural approval/rejection based on agreed rules.

Table 4: Capabilities associated with the U-AGREE project

4 U-AGREE strategic barriers' final model

4.1 Introduction

This section introduces the final strategic mitigation barrier model within the U-space framework. The definition of this final model is based on the U-space ConOps Ed. 4 [4] and is aligned, to the maximum practical extent, with the ongoing work under CORUS FIVE. Taking as its baseline the provisions set out in Reg. 664 and the accompanying AMC and GM [5], which establish the operational and technical foundations for the safe integration of UAS into shared airspace, the final model aims to increase airspace capacity to accommodate the forecast demand while effectively mitigating the risks associated with UAS operations

The following subsections outline the operational flow for the strategic mitigation, from the definition of U-plans to the request for acceptance. Once acceptance is granted, the process continues with the request for activation and the continuous check to detect changes that might increase the risk and react to mitigate it to acceptable levels. Each step of this process is supported by operational views (NOV-5), providing explanations of the process that ensure clarity and traceability within the regulatory framework.

4.2 Definition and submission of U-plans

According to the applicable regulation, UAS operators are required to submit a UAS flight authorisation request to the subscribed U-space Service Provider. This UAS flight authorisation request is commonly known as U-plan; this term originates from the CORUS-XUAM ConOps [4].

The Easy Access Rules for U-space [20] (GM1 Annex IV UAS flight authorisation request referred to in Article 6(4)) specifies the minimum information to be contained in the U-plan.

For the purposes of this initial characterisation and to support the operational diagrams developed in this project, the required information has been grouped into three information flows:

- **Drone information**: contains information about the UAS that will perform the operation.
- **Operator information**: contains information about the operator who will conduct the operation.
- **Operation information**: contains the information about the intended trajectory of the flight.

Each information flow contains the corresponding data fields established by the regulation (see Table 5).

Information Flow	Representative Data Fields
Drone information	– UAS unique serial number. – UAS category. – UAS aircraft class. – UAS type certificate (when applicable). – Identification technology. – UAS specifications (e.g. endurance).

Operator information	– UAS operator registration number.
Operation information	– Mode of operation (SAIL of the operation if needed). – Type of flight. – 4D trajectory. – Continuous safe flight and landing (CSFL) alternate vertiport.

Table 5: U-plan information flows and corresponding data fields

UAS operators can either select a CSFL from a list of suitable safe locations published through the CIS(P) or propose their own locations, provided they demonstrate that landing at those locations is acceptably safe. In the first case, the roles and responsibilities for conducting the risk assessment and for publishing the list of CSFLs are still a matter of research and lie outside the scope of U-AGREE. In the second case, a procedure shall be in place to verify whether landing at the locations proposed by UAS operators is acceptably safe. In both cases, the air and ground risk models under development within U-AGREE might be used to conduct the risk assessment.

The flight trajectory shall be defined using one or more 4D volumes, each with an associated entry and exit time. UAS may operate outside the defined 4D volumes for no more than 5% of the time, as required by the Reg. 664. The size of the 4D volume must account for potential deviations from the desired path, e.g. due to wind gusts.

Once the U-plan is completed, the UAS operator submits the request for acceptance of the U-plan to the USSP.

4.3 Initial processing: approval/withdrawal of U-plans

Upon receiving the U-plan, the USSP initiates the acceptance phase through its Flight Authorisation Service (FAS). To provide acceptance of the U-plan, the USSP shall check that:

- The U-plan is complete and correct.
- The U-plan 4D trajectory, with the deviation threshold added, is free of intersection with
    - other U-plans (from the designated USSP and also other USSPs),
    - prohibited geographical zones, or
    - U-space airspace restrictions and temporary limitations – Dynamic Airspace Reconfiguration.
- The U-space maximum capacity and density are not reached.
- The CSFL locations within the U-plan correspond to the list published through the CIS(P) or are acceptably safe.

The workflow of the acceptance of a U-plan in the final strategic mitigation barrier model includes the Strategic Conflict Resolution function in line with the U-space ConOps Ed. 4.

This information is contained in different information flows, presented in Table 6.

Information Flow	Representative Data Fields
U-space requirements	– U-space maximum capacity and density. – Deviation Threshold.

U-space constraints	– Geo-zones. – U-space airspace restrictions and temporary limitations.
Dynamic Airspace Reconfiguration	– DAR activity period: Start and end dates of applicability. Hours of activity, if applicable. Possible event-based activation (very unlikely due to the nature of DARs). – Geometric data of the DAR. – Type of DAR restriction.
Flight Identification Operation information	– U-plan (see Table 5).
U-plan response	– Response of acceptance to the 'terms and conditions' after acceptance of the U-plan by the USSP.

Table 6: Information flows involved in the process of acceptance of a U-plan and their corresponding data fields

Although the FAS is the specific U-space service responsible for processing U-plans, this deliverable focuses on an **operational perspective** and will not address the services at that level. In the operational views included in this deliverable, the term 'USSP Operations' is used to represent the broader set of functions performed by the USSP. This terminology aligns with terms used in SESAR projects, and Reg. 664 refers to the USSP both as a service provider and as the actor responsible for delivering multiple U-space services. Therefore, the use of 'USSP Operations' in the diagrams is consistent with both the regulatory framework and the operational modelling approach adopted in SESAR-aligned projects.

The operational view is included in the Appendix A – Figure 13 It illustrates the U-plan acceptance workflow, showing the interactions between the UAS operator, the USSP, and other relevant services such as the Common Information Services (CIS). The diagram highlights the validation steps, data exchanges, and decision points that lead to either approval or rejection of the U-plan. This integrated view ensures that the acceptance process is coordinated across the U-space.

In addition, a step-by-step explanation is provided to clarify the acceptance process, detailing the responsibilities of each participant and the sequence of necessary actions to reach a decision:

1. The **UAS operator** shall initiate the request for acceptance of the U-plan, providing the U-plan information; **UAS information**, **operator information** and **operation information** (see Table 5).
2. Upon the receipt of the U-plan, the **USSP** shall assign a unique flight ID and set the status to 'Submitted'.
3. The U-plan will be stored in the **USSP** database to keep a record of the received U-plans.
4. The **USSP** shall check for possible conflicts affecting the U-plan by assessing possible intersections with the information received from the **Common Information Services (CIS)**. **CIS** shall provide the **U-space requirements** and the **U-space constraints** (see Table 6 for more information about information flows).
    a. In the event the 4D trajectory contained in the submitted U-plan intersects UAS geographical with specific access conditions, the **USSP** shall either:

i. If it is possible to verify by electronic means whether the operation meets the applicable access conditions, the **USSP** shall change the status of the U-plan to 'Withdrawn' if it does not.
ii. If it is not possible to verify by electronic means whether the operation meets the applicable access conditions, the **USSP** shall continue with the assessment of the U-plan and, in the event it is authorised, list the applicable access conditions in the terms and conditions of the authorisation.

b. In the event the 4D trajectory contained in the submitted U-plan intersects UAS geographical with access restrictions (i.e., no-fly zones, including those defined as a result of the activation of a **DAR**), the **USSP** shall change the status of the U-plan to 'Withdrawn'.
c. Due to the inherent criticality of **Dynamic Airspace Reconfigurations** (**DARs**), the USSP shall perform a dedicated verification of the U-plan to determine whether it intersects with any temporary U-space restrictions proposed by ATC units. For this purpose, the **USSP** shall submit a specific request to the **CIS**, which shall provide information on the **DARs** (see Table 6 for details on the information flows) that are active at the time the request is received, as well as on those DARs that are scheduled to become active within a maximum of 10 minutes after receipt of the request. The latter applies where the ATC unit–CIS communication is implemented in accordance with the AMCs to Reg. 664 (GM2 to Article 4, Dynamic Airspace Reconfiguration) [20]. To support subsequent USSP actions, in particular the activation of U-plans, the USSP shall record in its database the identifiers of the DARs that interact with the U-plan, classifying them according to whether they are currently active or scheduled.

5. Next, the USSP shall search for any intersection between the 4D trajectory contained in the U-plan and those in other already approved U-plans. In both cases, the applicable deviation threshold shall be added to the 4D volumes defined by the operators in the U-plans prior to the search for overlaps. The **Flight Authorisation Exchange** (**FAX**) supports the exchange of information about U-plans from other USSPs. In addition, the USSP shall check the information with their own records. For this step, the goal is to identify overlaps between 4D trajectories. Therefore, only the information flow **operation information** and the **flight unique ID** will be needed. If no overlap is found, the USSP shall change the U-plan status from 'Submitted' to 'Accepted' and notify the UAS operator about the **terms and conditions** of the acceptance of the flight. Otherwise:
   a. In the event the 4D trajectory in the submitted U-plan intersects other trajectories of the same or higher priority in the 'Accepted' status, the **USSP** shall provide informative guidance to the UAS operator, as well as suggestive guidance whenever possible.
   b. In the event that the 4D trajectory in the submitted U-plan intersects other lower-priority trajectories with 'Accepted' status, the **USSP** shall change the status of the latter from 'Accepted' to 'Withdrawn' and proceed as in the case (a) with the affected UAS operators.
6. If the **USSP** provides suggestive guidance to UAS operators when 4D trajectories contained in U-plans of different priority overlap, as described in (5):
   a. The Strategic Conflict Resolution (SCR) function shall constantly monitor the FAS, working in a 'listen mode', which means that it will only be launched if an overlap has been detected within the U-plan.
   b. If an overlap has been detected, the **USSP** automatically reads its data and obtains its 4D trajectory.

   c. **USSP** will use the SCR function to search for an alternative route that avoids any conflict in space and time with the overlapping U-plan.
   d. If the **USSP** finds an alternative 4D trajectory compatible with the original waypoints, it shall notify the UAS operator about the **terms and conditions** of the acceptance of the flight, including the alternative 4D trajectory (i.e., suggestive guidance) as an annex, along with the reasons for the rejection of the original 4D trajectory (i.e., informative guidance).
   e. If an alternative 4D trajectory is not found, the **USSP** shall notify the **UAS operator** the rejection of the U-plan, providing informative guidance (i.e., indicating the reason for the rejection).
7. The **UAS operator** shall receive the response to the request for acceptance of the U-plan and will have to assess the response received from the **USSP**:
   a. If the U-plan has been rejected, the **UAS operator** shall evaluate the cause of the rejection and modify the U-plan according to the information received. Once the U-plan is modified, the UAS operator will start the request for acceptance process again.
   b. If the U-plan has been accepted and does not overlap with other 4D trajectories, the **UAS operator** shall assess the **terms and conditions** provided by the **USSP** and send the decision to the **USSP**:
      i. If the **UAS operator** accepts the **terms and conditions**, the U-plan status shall be set to 'Accepted'. In the event the **terms and conditions** include specific access conditions to UAS geographical zones intersected by the 4D trajectory, the acceptance of the **terms and conditions** by the **USSP** implies the formal recognition that the operation complies with those conditions.
      ii. If the UAS operator rejects the terms and conditions, the U-plan status shall be 'Withdrawn'.
   c. In case the U-plan 4D trajectory intersects with another 4D trajectory contained in U-plans of higher priority, the **UAS operator** shall assess the annex of the **terms and conditions** provided by the **USSP**:
      i. If the **UAS operator** accepts the **terms and conditions**, the U-plan status shall be changed to 'Accepted' and the 4D trajectory shall be updated according to the guidance proposed by the **SCRS**.
      ii. If the **UAS operator** rejects the **terms and conditions**, the U-plan shall be set to 'Withdrawn', and the 4D shall remain as the overlapping trajectory.

With this process, the correct assessment of potential risks and conflicts is ensured, aligning with the regulatory framework and supporting safe airspace management.

4.4 Activation of U-plans

If the U-plan has been accepted, the UAS operator should request the activation of the U-plan before the take-off. This step ensures that the operation that is about to begin remains free-of-conflict, based on the most up-to-date information.

To achieve the activation of the flight, the USSP shall check that:

- The U-plan is activated within the time frame, when specified.
- The U-space airspace is not subject to dynamic airspace reconfiguration.

- The U-plan 4D trajectory, including the deviation threshold, is free of intersection with:
  - other U-plans (from the subscribed USSP, as well as from other USSPs),
  - prohibited geographical zones,
  - U-space airspace restrictions and temporary limitations – Dynamic Airspace Reconfiguration,
  - manned aircraft in a state of emergency,
  - cooperative but non-conforming drones or non-cooperative drones, or
  - e-conspicuous manned aircraft.

Despite the similarities between some steps in the acceptance and activation processes, some new information flows are required in this case. A summary of the information flows involved in the activation of the U-plan is provided in Table 7.

Information Flow	Representative Data Fields
U-space requirements	– U-space maximum capacity and density.
U-space constraints	– Geo-zones. – U-space airspace restrictions and temporary limitations.
Dynamic Airspace Reconfiguration	– DAR activity period: Start and end dates of applicability. Hours of activity, if applicable. Possible event-based activation (very unlikely due to the natura of DARs). – Geometric data of the DAR. – Type of DAR restriction.
Flight Identification Operation information	– U-plan trajectory information (see Table 5).
Manned aircraft information	– Information about manned traffic in state of emergency.
Non-cooperative drones information	– Information about non-cooperative drones in the trajectory of the UAS.
E-conspicuous manned traffic information	– Information about e-conspicuous manned traffic in the trajectory of the UAS.
Non-conformant drones information	– Information about non-conformant drones in the trajectory of the UAS.
U-plan state	– Response to the operator about the state of the U-plan.

Table 7: Information flows involved in the process of activation of a U-plan and their corresponding data fields

The operational view presented in the Appendix A– Figure 14 shows the activation of a U-plan workflow. This view also includes the key validation steps and interactions between the UAS operator and the services involved in this phase.

Below is a detailed walkthrough of the activation workflow, outlining the responsibilities of each actor involved in this process and the data exchanged between them.

1. The **UAS operator** shall request the activation of the flight before take-off.
2. Once the request for activation is received, the **USSP** shall proceed with the check for intersections with the U-plan. The first check the USSP shall perform is to evaluate if the U-plan still complies with the **U-space requirements** and the **U-space constraints**, information provided by the **CIS**. This is a key step to evaluate with new possible restrictions, e.g, no-flight zones.
3. The **USSP** shall continue the checking process by identifying if there is any intersection with other U-plans already accepted, from the main USSP or other USSPs (through FAX). This step ensures the U-plan does not interfere with new accepted U-plans with higher priority.
4. To complete the activation process, the **USSP** shall check that in the proximity of the UAS take-off point:
    a. There is no manned traffic in state of emergency in the proximity of the take-off point, based on the information received through the **CIS**.
    b. There are no non-conformant UAS, both operated by subscribed UAS operator and by third-party UAS operator, based on the information provided by other USSPs through the **Conformance Monitoring Exchange (CMX)**.
5. As in the U-plan initial processing, the **USSP** shall check for any potential interference with new temporary U-space restrictions activated by ATC units, as well as verify whether the **DARs**, that were not active at the time of the request, have finally been implemented or have undergone any changes. To do so, the **USSP** shall send the **CIS** the IDs and the previous status of the DARs that were checked during the initial processing of the U-Plan, and the **CIS** shall respond by providing the information on those **DARs** classified as active during the initial processing of the U-plan, as well as the information on any new DARs communicated by the ATC units to the CIS in the period between the U-Plan approval and activation.
6. Upon completion of the check, the **USSP** shall notify the UAS operator about the request for activation of the flight:
    a. If there is no overlap affecting the 4D trajectory contained in U-plan, the USSP shall notify the UAS operator about the activation of the flight and update the state in the database to ‘Activated’.
    b. Otherwise, the USSP shall inform about the rejection of the activation and update the state of the flight to ‘Withdrawn’ in the database.
7. Lastly, the **UAS operator** shall receive the answer to the request:
    a. If the flight has been activated, the UAS operator shall proceed to initiate the flight within the timeframe defined by the USSP.
    b. In case the flight has been rejected, the UAS operator shall not start the flight and shall apply for a new authorisation.

This process ensures that only authorised operations proceed under safe and coordinated conditions.

5 U-AGREE tactical barriers' final model

5.1 Introduction

This section presents an initial model for the characterisation of tactical mitigation barriers within the U-space framework, focusing on the operational level. These barriers are intended to reduce risks that may arise during the execution of the UAS operations. The model is developed in alignment with the European regulations for U-space.

Two specific tactical barriers have been identified in the U-space ConOps: **Conformance Monitoring** and **Tactical Conflict Resolution**. Their function can be mapped to traditional ATM components, including communication (for real-time data exchange between actors), navigation (to ensure adherence to planned trajectories), surveillance (for tracking UAS positions), conflict detection (for identifying potential trajectory deviations) and airspace management (for maintaining safe separation in shared environments).

Although the implementation of these tactical barriers depends on specific communication and surveillance capabilities, detailed performance specifications (e.g. latency, accuracy, update rate) are not yet defined in the current regulatory framework. Therefore, further work is required to establish these technical requirements to ensure consistent and effective deployment of the barriers.

As in the previous section, each tactical barrier will be accompanied by an operational diagram (NOV-5) to illustrate the interactions between the relevant actors and the flow of information.

5.2 Conformance Monitoring

The purpose of the Conformance Monitoring barrier is to detect deviations between the actual trajectory of a UAS and its approved U-plan. This barrier enables the timely identification of non-conforming behaviour, allowing for appropriate mitigation actions to be taken by the UAS operator.

As stated above, this is an operational explanation of the barrier. Although the service responsible will be Conformance Monitoring, it will be represented as part of USSP operations.

To perform the Conformance Monitoring, the USSP will check for any possible deviation from the 4D authorised trajectory, including the deviation thresholds applied during the authorisation phase. Additionally, in line with Reg. 664, the Conformance Monitoring barrier allows for optional verification of the UAS's position against the 4D trajectory and the provision of a preliminary alert to the UAS operator.

For clarity, a diagram illustrating possible infringements is included in Figure 8. In this diagram, the blue volume represents the 4D trajectory defined in the U-plan, while the orange one indicates the deviation threshold established during the authorisation process. If a deviation occurs beyond the deviation threshold volume, a non-conformance alert will be triggered. Conversely, if there isn't non-conformance, but the USSP detects an infringement from the original 4D trajectory into the deviation threshold, a preliminary alert will be raised.

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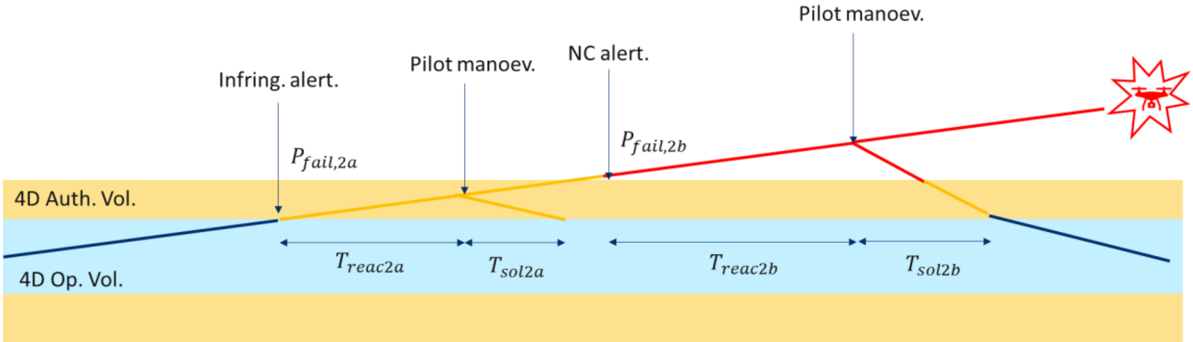

Figure 8. Conformance Monitoring alerts overview

The information flows involved in this process are presented in Table 8.

Information Flow	Representative Data Fields
Network Remote Identification	– Message that contains the information needed for the Network Identification, including the geographical position of the UAS.
UAS track	– Represents the track of the UAS.
Operation information	– Provides information about the operation of the UAS, including the 4D trajectory.
Conformance Monitoring alert	– Contains information about the alert of the Conformance Monitoring.

Table 8: Information flows involved in the Conformance Monitoring and their representative data fields

The operational view of the Conformance Monitoring process is presented in the Appendix A – Figure 15.

To clarify, a detailed step-by-step explanation is provided below:

1. The **UAS operator** shall report the state vector (i.e., 3D position, ground speed and heading) and status information to the USSP through the **network remote identification** connection to the subscribed USSP.
2. The **USSP** shall receive the network remote identification from their subscribed UAS and produce the **UAS track**.
3. The **USSP** shall compare the real-time information about the flight execution to the 4D trajectory recorded after the pre-flight authorisation process.
4. Based on that comparison, the **USSP** shall identify whether there is a non-conformance with the authorised 4D trajectory, including the deviation threshold:
    a. In the event of non-conformance with the UAS operation, the USSP shall provide an alert to the non-conformant **UAS operator**, as well as to **any other active USSP** in the U-space airspace through the **CMX**.
    b. In case there is not a non-conformance, the **USSP** shall continue the process.
5. If the operation is conformant, the **USSP** shall check whether there is an imminent operation of the UAS that infringes the 4D trajectory defined in the flight authorisation request (i.e., without accounting for the deviation threshold):

   a. If there is a potential infringement, the **USSP** shall warn the **UAS operator** with a preliminary alert.
   b. If there is no potential infringement, the **USSP** shall finalise this process and will wait for the next network remote identification report.
6. Upon receiving an alert, the **UAS operator** shall manoeuvre to return to the authorised 4D trajectory.

By enabling the early detection of deviations from the approved U-plan, Conformance Monitoring supports timely mitigation actions that help prevent potential conflicts or airspace infringements.

5.3 Tactical conflict prediction and resolution

U-space ConOps Ed. 4 identifies two functions related to the provision of separation to airborne UAS:

- Tactical conflict prediction, and
- Tactical conflict resolution.

This surveillance information needed to ensure the detection of potential conflicts is embedded within different information flows, shown in Table 9.

Information Flow	Representative Data Fields
Network identification	– Message that contains the information needed for the Network Identification, including the geographical position of the UAS.
Conflict horizon traffic information	– Information provided by the ATSP (through the CIS) – Complementary traffic information about uncontrolled manned aircraft
Guidance	– Instructions to perform a manoeuvre to avoid a separation loss
E-conspicuity information	– Information about the traffic in the conflict horizon to the UAS

Table 9: Information flows involved in the Tactical Conflict Prediction and Resolution and their representative data fields

The operational view presented in the Appendix A – Figure 16 illustrates the key components and workflows of the traffic information.

Presented below is a step-by-step outline of the operational process for the tactical conflict detection and resolution:

1. The **UAS operator** shall report the state vector (i.e., 3D position, ground speed and heading) and status information to the USSP through the **network remote identification** connection to the subscribed USSP.
2. **USSPs shall obtain the conflict horizon** applicable to their served UAS from the **CIS**.
3. **USSPs shall obtain the separation minima** and the corresponding look-ahead time applicable to their served UAS from the **CIS**.
4. For each UAS operated by subscribed **UAS operators** (usually known as *ownship*), **USSPs shall obtain network remote identification reports from other UAS** within a given conflict horizon (usually known as *intruders*), either directly from their served UAS or other USSPs through the **NIX**.

5. The **USSP** shall produce UAS tracks to produce smoothed state vectors of the UAS within a given conflict horizon to identify the intended route of the UAS.
6. The USSP shall receive alerts about non-conformant operations of UAS operators served by other USSPs though the CMX
7. **USSPs shall project the trajectories** of all UAS within a given conflict horizon.
8. **USSPs shall detect** whether there will be a **loss of separation** between any pair of ownship-intruder.
9. If the time to the loss of separation is equal to or smaller than the look-ahead-time, the **USSP shall declare a 'conflict'**.
10. **USSPs shall provide** their served UAS with the appropriate **guidance** (informative or directive) **to resolve the conflict** by applying the prescribed separation mode[8]. Regardless of the type of guidance provided by the USSP, UAS operators involved in conflicts with non-conformant UAS shall be informed.
11. **USSPs shall monitor the evolution of the conflict** (e.g., by continuously comparing the time to the loss of separation to the look-ahead time) and issue updated guidance in case the initial resolution is not effective.

[8] Competent authorities shall prescribe a particular separation mode based on the outcomes of the airspace risk assessment and the expected demand (more automated separation modes support higher demand than those relying on a human-in-the-loop). The manner in which prescribed separation modes are described lies outside the scope of U-AGREE; however, a possible option would be to refer to industry standards, as is commonly done for Detect and Avoid systems.

6 Mitigation barriers' characterisation

6.1 Performance metrics

ASTM Standard Specification for Detect and Avoid (DAA) System Performance Requirements [46] (referred to as ASTM F3442 hereinafter) describes the mitigation effectiveness of such a system by means of the so-called Risk Ratio (RR), defined as the ratio between the probability of a Near Mid-Air Collision (NMAC) in case of encounter when the risk is mitigated by the DAA system and the same unmitigated probability of the same event (i.e., when no mitigation is applied):

$$RR_{DAA} = \frac{P(NMAC|Enc)}{P_0(NMAC|Enc)} \quad \textbf{Eq. 1}$$

where the subindex 0 stands for the unmitigated probability.

In a similar way, the ASTM Standard Specification for UAS Traffic Management (UAS) Service Supplier (USS) interoperability [47] (referred to as ASTM F3548 hereinafter) also describes the combined effectiveness of the strategic deconfliction of operational intents (i.e., 4D trajectories) and conformance monitoring by means of the comparison between the mitigated and unmitigated probabilities of MAC.

U-AGREE will follow a similar approach to that of ASTM to characterise the mitigation effectiveness of the mitigation barriers build on the provision of U-space services, although the approach will be slightly different, because U-AGREE will apply layered Accident Incident Models according to the methodology set out in the EUROCONTROL's Extended Safety Reference Material (E-SRM) [48]. According to that approach, U-AGREE has defined in deliverable D2.3 Initial Concept Outline Safety Criteria, a.k.a. SAC (a proxy of the applicable TLS) for each hazard, as well as different accident precursors related to them. Mitigation barriers will be introduced between accident precursors. Therefore, each mitigation barrier will be characterised by the corresponding Risk Ratio:

$$RR_i = \frac{P(Prec_i|B_i)}{P(Prec_i|\overline{B_i})} \quad \textbf{Eq. 2}$$

where $(Prec_i|B_i)$ is the conditional probability of precursor $Prec_i$ in case the mitigation barrier B_i is applied (i.e., the precursor mitigated probability) and $P(Prec_i|\overline{B_i})$ is the conditional probability of the same precursor in case the mitigation barrier is not applied (i.e., the precursor unmitigated probability).

6.2 Procedure to compute the performance metrics

6.2.1 Monte-Carlo Simulation Overview

The performance metrics are evaluated via Monte-Carlo simulations with different encounter scenarios and environmental data. The synthetic simulation platforms enable to count the number of MACs and compute fatalities per flight hour, with/without each mitigation barrier. The simulation platforms are considered as open-access BlueSky [49] for lightweight Monte-Carlo simulations, and ATM/UTM Research and Development Digital Twin platform (AURD) of Cranfield University for high-fidelity simulation validation. An example screenshot of connecting AURD with ArduPilot is shown in Figure 9.

Figure 9. AURD connected with ArduPilot

An overview of the simulation pipeline is shown in Figure 10. Depending on different traffic patterns, flight plans are generated. Using the strategic/tactical barriers developed from the earlier chapter, the generated U-plans plans, denoted as the reference $r_i(t)$, are modified. The modified reference and the current flight states, denoted as the states $x_i(t)$, are handed over to the traffic and environmental models, which will be the main part of the simulation platform. Each simulation run continues until the MAC occurs, and the number of MAC is counted with more than millions of flight hour. The details of the traffic and environmental models are explained in this chapter.

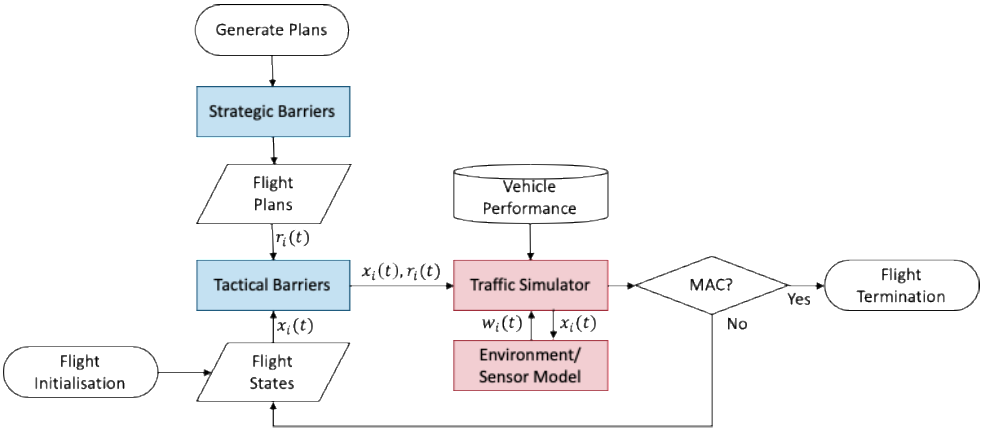

Figure 10. Monte-Carlo simulation overview

6.2.2 Traffic Simulator

The traffic simulation uses approximated kinematic models with velocity and heading rates, limited by the maximum vehicle performance data set such as maximum speed, turn rate, and acceleration. The inputs of the simulator are given as the reference $r_i(t)$ and the current traffic states $x_i(t)$, and the output of the simulator is the updated traffic states $x_i(t)$. Combined with Simulation-In-The-Loop (SITL) noise and disturbance $w_i(t)$ provided by the environmental model, the traffic simulator can further refine vehicle dynamics and enhance fidelity.

The traffic simulator has two main modes:

- **Waypoint-based autopilot:** Aircraft trajectories are decomposed into segments aligned with waypoints within a defined geographical scope. Aircraft are controlled using a set of guidance instructions that manage heading, speed, and altitude to follow the flight plan. Lateral navigation provides horizontal flight guidance and steering angle, and vertical navigation commands are adjusted for aircraft's vertical profile to meet altitude constraints at specific waypoints such as arrival times.

- **Human response:** Upon receiving a conformance alert, the flight operator shall assess the type of alert and perform a manoeuvre to return to the flight plan. Flight operators' response time to the conformance monitoring is modelled stochastically based on the literature.

6.2.2.1 Human response modelling

The response timeline of the UAS operator can be subdivided as: surveillance, separation, communication, responding, and manoeuvring [50]. The time required for each step is not fixed and hence the statistical information is leveraged to model as Gaussian distributions. As there are numerous sources causing each stage of the latency, it is reasonable to assume the Gaussian distribution as a whole, due to the central limit theorem.

Surveillance time is the time for detection of non-conformance provided by airspace management providers, such as U-Space Service Providers (USSPs). For ADS-B transmitters, the total latency cannot exceed 2 seconds [51], and remote identification methods have more various latency but can be also conservatively set as 2 seconds [52].

Separation time include the time for the human operator to react and execute appropriate actions. The experimental data [53] shows the reaction time of air traffic control as mean value of 4.6 seconds with the standard deviation of 4.1 seconds, and the separation execution time of in average 2.3 seconds with the standard deviation of 2.7 seconds. Considering both reaction time and execution time, the separation time is modelled with the mean value of 6.9 seconds and the standard deviation of 4.9 seconds.

Communication time is the time required for the aircraft to receive collision avoidance manoeuvres either from the USSPs or pilots, and hence is modelled only where the aircraft is not conducting self-separation. The experimental data [54] shows the communication and pilot's responding time as the mean value of 2.76 seconds with the standard deviation of 1.18 seconds. Manoeuvring time depends on the manoeuvre instructed by the USSPs and on the performance of the involved UAS and it is hard to model by means of probability distributions; therefore, this term will be numerically modelled and assess in the Monte Carlo experiments.

The distribution of the each of the time delays are summarised in Figure 11. Summing the probability distributions, we can obtain the mean and standard deviation of the response time, as μ_{RT} and σ_{RT}, respectively.

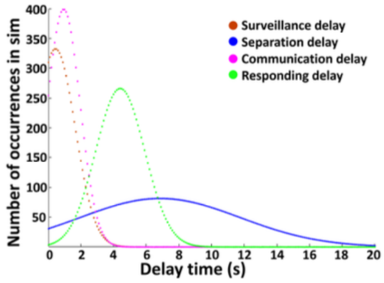

Figure 11. Response time modelling

6.2.3 Environment/Sensor Model

ArduPilot with virtual Pixhawk flight controller is used as SITL to provide noise and disturbance due to hazards. Two main hazard models are included: sensor error and wind impact, and the details of the source of hazards are explained in this section.

The resultant example noise and disturbance are shown in Figure 12. The impact of sensor error and wind is realised in the trajectory deviation, speed profile, heading angle, and other attitude angle errors. These data will be re-generated with respect to the scenarios defined in WP2.

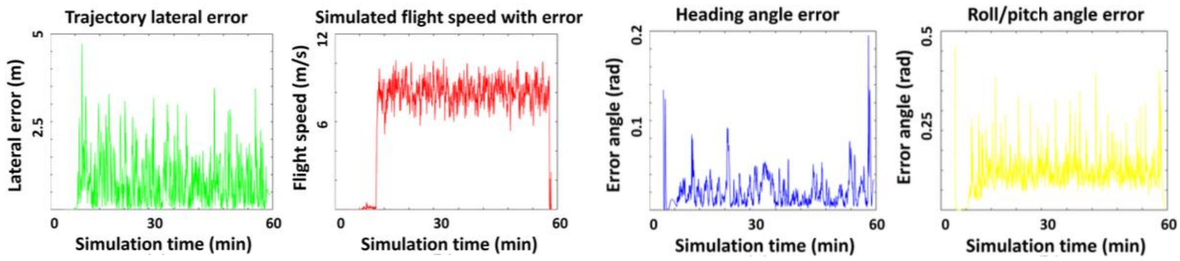

Figure 12. Noise and disturbance modelling

6.2.3.1 Sensor error

ArduPilot [55] enables to simulate various sensor noise characteristics and disturbances to better reflect real-world conditions. The following types of sensor noise are considered as hazards:

- IMU (Gyro and Accelerometer) Noise
    - Noise can be added to IMU measurements in simulation, though the default configuration may have minimal or no noise unless explicitly set by the user.
    - The noise characteristics (such as standard deviation or bias) can be adjusted in the simulation parameters, though the exact location to modify these may depend on the simulation backend (e.g., Gazebo plugin files or SITL parameters).
    - ArduPilot provides software filtering mechanisms (lowpass and notch filters) to manage and analyse the effects of noise and vibration, allowing users to observe how noise at specific frequencies (e.g., motor harmonics) impacts sensor readings and control performance.

- GPS Noise

- "Fake GPS" simulation is supported, but the level and nature of the noise or inaccuracies simulated by default may be limited. Custom noise models would require additional coding or configuration.
- Users can potentially introduce position and velocity noise to GPS data, but this is not always enabled by default in the simulation.

- Compass (Magnetometer) Noise
  - The simulation can include compass data, but explicit noise modelling for the compass in SITL is less documented. The fusion of compass and IMU data for yaw computation is handled within the attitude estimation modules.

- Proximity and Rangefinder Sensors
  - Noise in proximity sensor data can be simulated, and noisy readings are stored as "obstacles" in the autopilot's onboard data

6.2.3.2 Wind impact

ArduPilot [55] enables to simulate various wind types and their impact on the aircraft, allowing simulating real-world hazards from environments. The following types of wind impact are considered as hazards:

- Wind Speed and Direction:
  - Users can set specific wind speeds and directions using simulation parameters. For example, you can configure the wind to blow from any compass heading at any speed (e.g., from the south at 10 m/s). This allows for testing vehicle performance against headwinds, tailwinds, and crosswinds.

- Wind Turbulence:
  - The simulation supports the addition of wind turbulence, enabling users to assess how the vehicle responds to gusty or unstable wind conditions. This is crucial for evaluating stability and control algorithms under real-world, variable wind scenarios.

- Dynamic Wind Shifts:
  - The simulator can introduce random wind shifts, simulating the effect of changing wind conditions over time. This helps test the robustness of navigation and control systems, especially for autonomous missions.

- Barometer and Sensor Effects:
  - Wind can cause barometric pressure errors, especially if the autopilot is exposed to airflow. ArduPilot includes compensation mechanisms in simulation to account for wind-induced barometer interference, which can affect altitude estimation and control.

7 References

7.1 Applicable documents

This deliverable complies with the requirements set out in the following documents:

Project and programme management

[1] 101167187 U-AGREE Grant Agreement

[2] SESAR 3 JU Project Handbook – Programme Execution Framework, 11 April 2022, Ed. 1.0

7.2 Reference documents

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Appendix A Operational Diagrams

This annex includes four NOV-5 diagrams that visually represent the operational processes associated with the final version of U-AGREE risk mitigation framework. These diagrams are aligned with the regulatory and technical context described in the deliverable and are intended to enhance understanding of the strategic and tactical barriers by illustrating key workflows and interactions between U-space stakeholders.

The operational views have been developed in ORBUS, pursuing the alignment of U-AGREE outcomes at program level. Therefore, when drawing the project operational views, U-AGREE has reused material that other SESAR projects had previously created, including the business function 'CISP Operations'. This function is described as: 'It performs all the activities related to the provision of Common Information for U-space. It is also responsible, if applicable, of the exchange of information of ATM and U-space'. Hence, despite using the same acronym as Reg. 664 uses to refer to the designated single Comon Information Service Provider (CISP), the operational views included in this Appendix apply to any particular implementation of the Common Information Services at service or system levels.

Figure 13. Strategic Barrier – U-plan acceptance operational diagram

NOV-5 - Final Strategic Barrier. Acceptance of the request

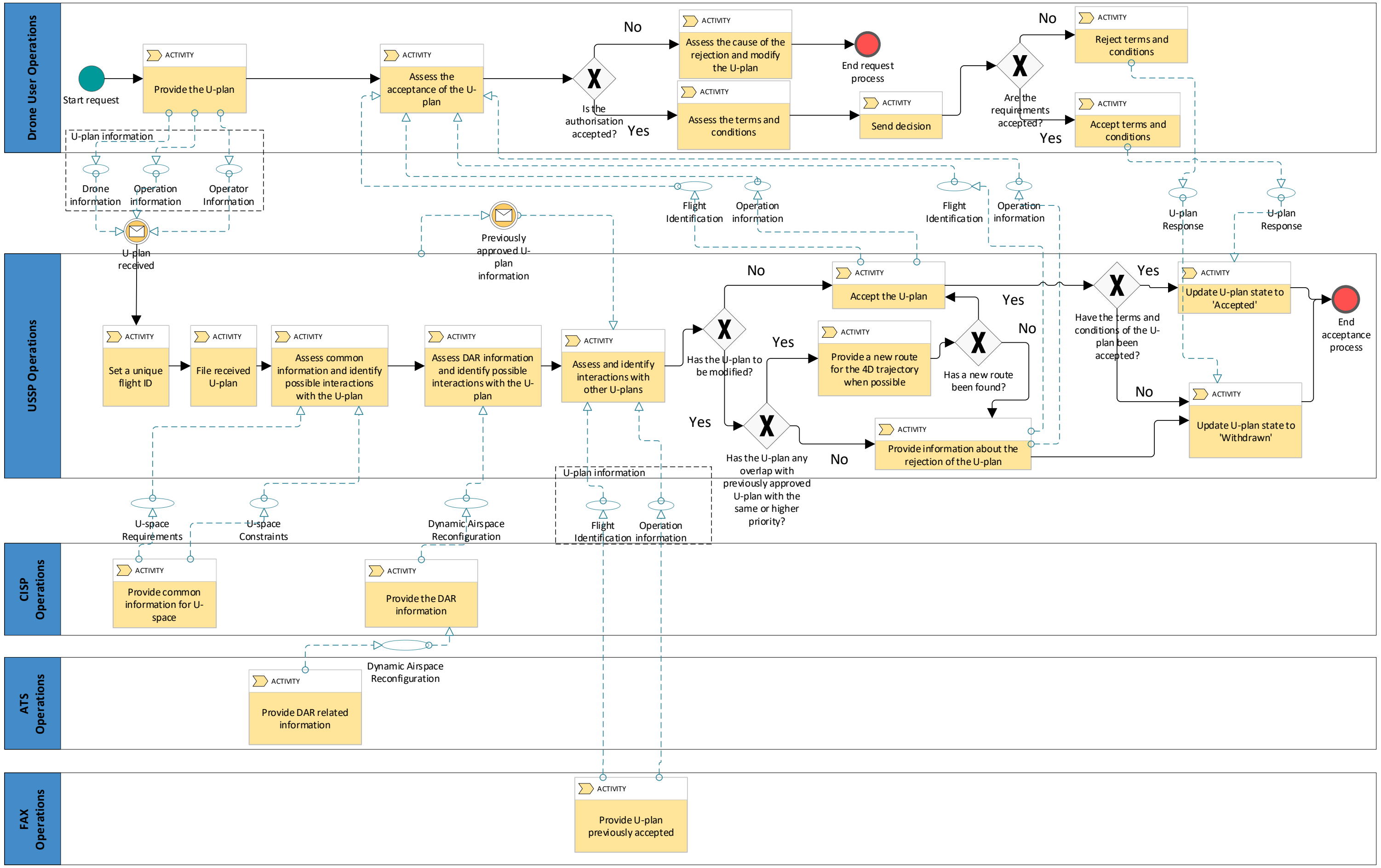

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Figure 14. Strategic Barrier – U-plan activation operational diagram

NOV-5 - Final Strategic Barrier. Activation of the request with Conformance Monitoring Service

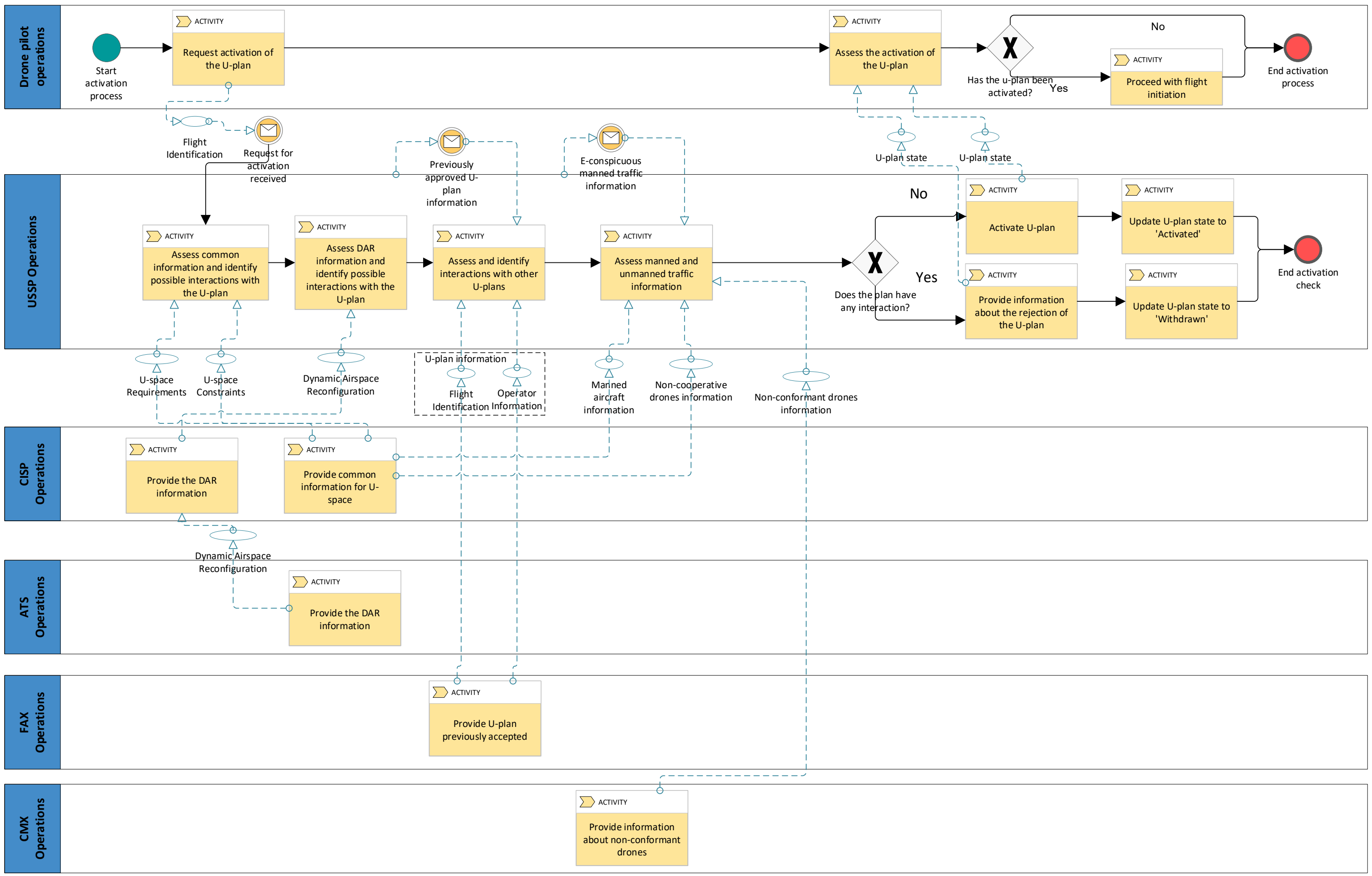

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Figure 15. Tactic Barrier – Conformance Monitoring

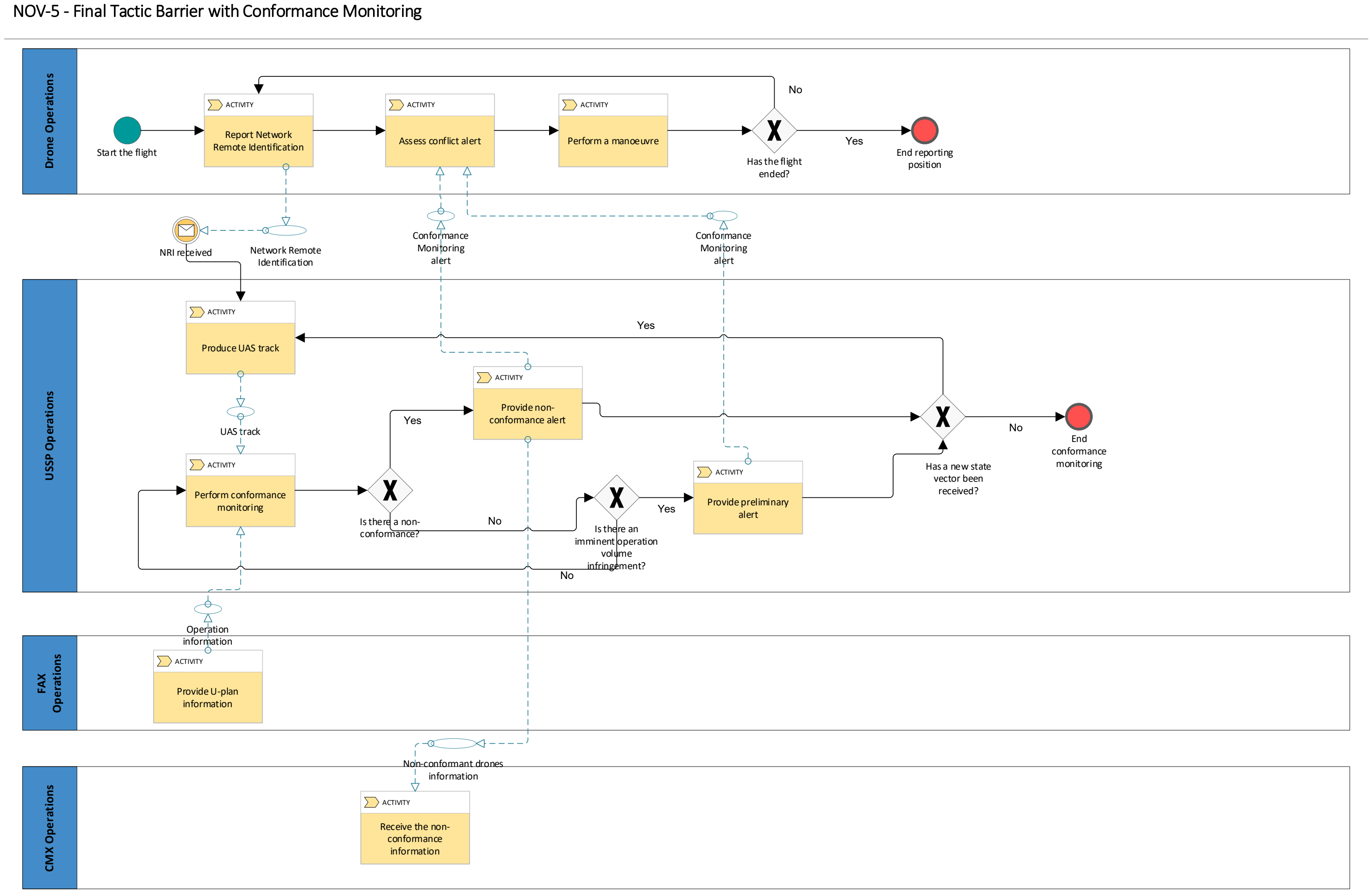
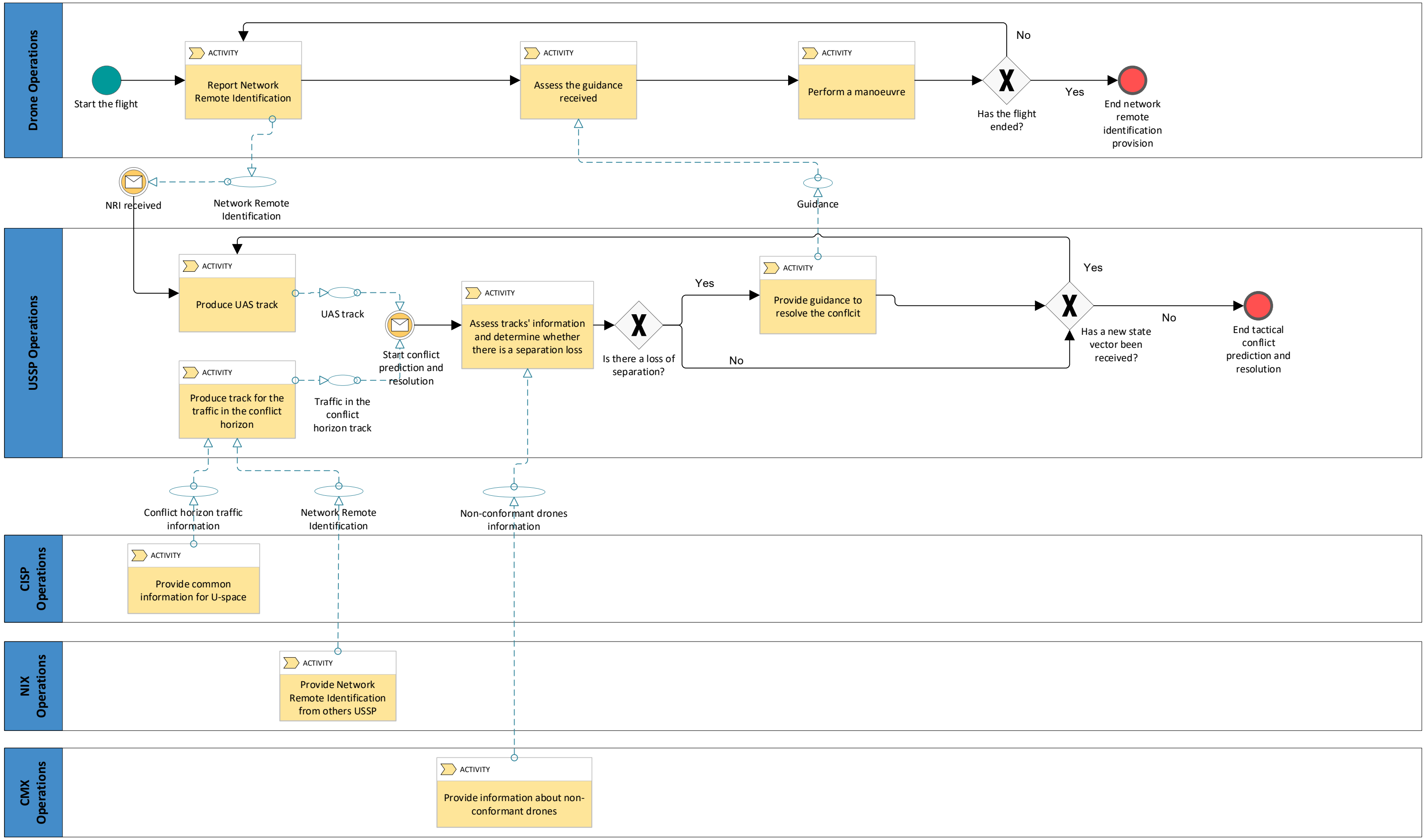


Figure 16. Tactic Barrier – Tactical Conflict Prediction and Resolution

NOV-5 - Final Tactic Barrier. Tactical Conflict Prediction and Resolution



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