JOINT UNDERTAKING

U-AGREE D5.1 Exploratory Research Plan (ERP)

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Abstract

This document serves as the foundation for the evaluation activities within the U-AGREE project. It defines the overall strategy for concept validation and details of the specific steps to be undertaken, including the scope, objectives, and methodologies for validating the risk models and U-space based mitigation barriers developed throughout the project. It also provides an insight into the simulation platform used for the activities.

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U-SPACE AIR AND GROUND RISK MODELS ENHANCEMENT

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1 Executive summary

The purpose of this Exploratory Research Plan (ERP) is to define the objectives, scope, and methodology of the validation activities aimed at assessing the performance of the integrated risk models and U-space based mitigation developed in the U-AGREE project. These models address air, ground, and collision risks in Very Low Level (VLL) airspace and consider the role of U-space services as mitigation barriers.

Two validation exercises are planned, both leveraging Monte-Carlo techniques. The first exercise will assess the initial risk models developed, in which the basic U-space services defined in EU Regulation 2021/664 [5] serve as mitigation barriers. The second exercise will focus on refined risk models and advanced services. Both exercises will be carried out independently on three simulation platforms owned by consortium partners and applied to representative scenarios defined in the project's OSED [7].

The goal of these validation activities is to generate quantitative evidence of how the proposed models and U-space based risk mitigation barriers can enhance safety and support the scalable integration of UAS into European airspace.

The entry and exit maturity levels are respectively TRL0 and TRL2.

2 Introduction

2.1 Purpose of the document

This document outlines the strategy for validating the enhanced U-space risk models and U-space based mitigation measures developed within U-AGREE, detailing the objectives, scope, and methodology of the planned simulation activities. The goal is to assess how these models support U-space operations by addressing critical multidimensional aspects under realistic conditions.

The simulations, that will rely on fast-time approaches and Monte-Carlo techniques, will be executed within high-fidelity U-space simulation platforms developed by consortium partners. These environments replicate real-world operational conditions using detailed datasets and configurable U-space service layers. The reference scenarios chosen for the project [7], illustrated in paragraph 5.1.4, provide the basis for structured, repeatable validation exercises across multiple traffic configurations and levels of service provision.

2.2 Intended readership

This document is intended for a broad community of stakeholders involved in U-space research and development. As a public deliverable, the Exploratory Research Plan offers a consolidated overview of the validation activities conducted within the U-AGREE project and provides useful insights for the validation of risk assessment methodologies in support of safe and scalable UAS integration. Stakeholders and their interests in the validation activities include:

- **Researchers**: Gain access to advanced simulation-based validation methods of the developed risk models to further develop the scientific foundations of U-space safety assessment.
- **Regulatory and standardization bodies**: Obtain robust evidence to support risk-based regulations and guidance material ensuring compliance with safety performance requirements (e.g. Target Level of Safety).
- **Air Navigation Service Providers (ANSPs)**: Understand how validated risk models can be integrated and implemented to enhance safety in U-space operations.
- **U-space Service Providers (USSPs)**: Assess the performance of U-space services as mitigation measures across different traffic environments and evaluate the robustness of the project's risk models, with a specific focus on their contribution to enhancing safety and increasing airspace capacity.
- **UAS Operators**: Understand how they can leverage the risk models developed by U-AGREE, as well as the performance of the mitigation barriers quantified by the project to simplify the process to get the operational approval.

2.3 Background

U-AGREE focuses on identifying and mitigating the potential negative impacts of UAS operations through the use of U-space services. Building upon the established SORA methodology, the project develops enhanced models that incorporate multiple risk factors, including safety, security, privacy, and environmental impacts, for a more comprehensive risk evaluation.

In the first phase, U-space services defined by Regulation (EU) 2021/664 [5] are implemented as mitigation barriers, introduced between accident precursors. The second phase extends the evaluation to more advanced U-space services (U3) outlined in the Concept of Operations (ConOps) developed by the CORUS and CORUS-XUAM projects (specifically, CORUS U-space ConOps Edition 4.0) [8] [9].

Through this two-step approach, U-AGREE aims to establish a robust, forward-looking risk assessment methodology that supports the safe integration of UAS operations and meets evolving regulatory requirements.

2.4 Structure of the document

This document is structured as follows:

- Section 2 outlines the scope of the document, identifies the target audience, introduces the background of the project, and provides a list of acronyms.
- Section 3 establishes the context for the exploratory research activities by defining the research scope and outlining the key research and innovation needs. It also presents the expected performance contributions and indicates the initial and target maturity levels of the solution addressed by the project.
- Section 4 details the exploratory research plan, including the overall approach, involved stakeholders, validation objectives, and underlying assumptions. It also provides a list of validation exercises, their scheduling and platforms, as well as the methodology for data collection and analysis.
- Section 5 is divided into two parts, detailing the first and second validation exercises respectively, both organized according to the same criteria: objectives, scope, scenarios, and assumptions.

2.5 Glossary of terms

Term	Definition	Source of the definition
Deviation threshold	An additional 4D volume around each planned 4D volume for a flight.	[5]
Encounter	An event associated with the presence of an intruder.	[10]
Mid-air Collision	An accident where two aircraft come into contact with each other while both are airborne.	[11]

Near Mid-air Collision	A situation in which two aircraft come within 100 ft vertically and 500 ft horizontally of each other while in flight.	[12]
small Near Mid-air Collision	A situation in which two small UAS come within 30 ft vertically and 100 ft horizontally of each other while in flight.	[10]
Total system Error (TSE)	It is the distance between the true position of the UA and the desired path. It is composed of: • Flight Technical Error (FTE): distance from the estimated position to the intended flight trajectory and it is related to the autopilot's ability to follow that trajectory. • Navigation System Error (NSE): difference between true position and estimated position. It depends on on-board navigation system inaccuracies. • Path Definition Error (PDE): difference between the defined trajectory and the intended flight trajectory at a specific point. It depends typically on the quality of the database of terrain as well as the vertical reference to define the altitude/height along the trajectory.	[13]

Table 1: Glossary of terms

2.6 List of acronyms

Term	Definition
ARA	Airspace Risk Assessment
ATM	Air Traffic Management
CM	Conformance Monitoring
CTA	Control Area
CTR	Control Zone
DAR	Dynamic Airspace Reconfiguration

DES	Digital European Sky
DSD	Digital Sky Demonstrator
DT	Deviation Threshold
EXE	Exercise
FAS	Flight authorisation Service
FAT	Fatality
FTE	Flight Technical Error
GA	Grant agreement
ID	Identifier
KPA	Key performance Area
KPI	Key performance Indicator
MAC	Mid Air Collision
NMAC	Near Mid Air Collision
NSE	Navigation System Error
OSED	Operational Service and Environment Definition
PDE	Path Definition Error
PDRA	Predefined Risk Assessment
PI	Performance Indicator
sNMAC	Small Near Mid Air Collision
SESAR	Single European sky ATM Research
SESAR 3 JU	SESAR 3 Joint Undertaking
SAIL	Specific Assurance and Integrity Level
SITL	Software In The Loop
STS	Standard Scenario
TLS	Target Level of Safety
TS	Traffic Information
TSE	Total System Error

UA	Unmanned Aircraft
UAS	Unmanned Aerial System
UC	Use Case
USSP	U-space Service Provider

Table 2: List of acronyms

3 Context of the exploratory research plan

3.1 Exploratory research plan context

The overarching objective of the U-AGREE exploratory research plan is to validate, at Technology Readiness Level 2, the air, ground, and collision risk models and U-space based mitigation measures developed within the project through dedicated simulations. These models address air, ground, and collision risks in Very Low Level (VLL) airspace and consider the role of U-space services as mitigation barriers.

In the first validation exercise, U-space services defined by Regulation (EU) 2021/664 [5] and the accompanying AMC&GM [6] are implemented as mitigation barriers, introduced between accident precursors:

- Flight Authorization Service, which will act as strategic mitigation barrier.
- Conformance Monitoring Service, which will act as tactical mitigation barrier.
- Traffic Information Service, which will act as tactical mitigation barrier.

For U-space airspaces designated in controlled airspace, the Dynamic Airspace Reconfiguration (DAR) activation process is not simulated within U-AGREE validation activities. The precise mechanisms for DAR activation remain a subject of ongoing research (e.g. within the SESAR ENSURE project) and therefore fall outside the scope of U-AGREE. From the project perspective, when applicable, DAR-related airspace volumes are treated in the same manner as any other dynamic airspace restriction.

Within the scope of validation exercise 1, no DAR-related airspace volumes are considered and included as temporary UAS geographical zones.

Furthermore, when an e-conspicuous manned aircraft not receiving air traffic control instructions enters a U-space airspace, the Traffic Information Service provides information about that aircraft and the responsibility for avoiding collision hazards remains with the UAS operator, in accordance with Regulation (EU) 2021/664 [5]. This concept is further explained in paragraph 5.1.4.2, detailing the avoidance manoeuvres that will be followed by UAS operators.

The second exercise extends the evaluation to more advanced tactical U-space services (U3) outlined in the Concept of Operations (ConOps) proposed by the CORUS and CORUS-XUAM projects (i.e., CORUS U-space ConOps Edition 4.0) [8][9]). Specifically, the Tactical Conflict Prediction and Resolution services will be considered to further mitigate the collision risk in case of encounter between unmanned or between unmanned and manned conspicuous aircraft. The second exercise will also address a Strategic Conflict Resolution Service. In this exercise, DAR-related airspace volumes will be considered and treated as temporary UAS geographical zones during the flight authorisation process.

The specific implementation and use of these advanced U-space services as mitigation barriers within U-AGREE will be detailed in Deliverable D4.2 – Final Barriers Characterisation. Should there be any differences between the U-space services effectively implemented and those described in this ERP, this will be thoroughly explained and justified in the Exploratory Research Report.

Validation exercises will be carried out on three high-fidelity U-space simulation platforms developed by ENGAGE (ENGage srl), Cranfield University (CRA), and Universitat Politècnica de València (UPV). These platforms are capable of reproducing complex UAS traffic scenarios under realistic operational conditions and allow the modelling of both strategic and tactical mitigation measures. The validation will adopt a quantitative simulation methodology based on Monte Carlo techniques, generating and analysing realistic UAS traffic configurations for each scenario selected for the project [7]. The integrated risk models and U-space based mitigation measures developed by U-AGREE will be embedded into each platform to enable a comprehensive performance assessment within representative U-space environments.

To ensure consistency and comparability across simulation runs, a set of simplifying assumptions has been established and is detailed in paragraph 4.4. These assumptions help manage complexity and concentrate the analysis on the impact of U-space mitigation measures.

3.2 Scope

The exploratory research plan defines how the U-AGREE project will validate the integrated risk models and U-space based mitigation barriers developed in the project, to assess the impacts of UAS operations in U-space airspace. These models build upon and extend the SORA methodology by incorporating a wider range of risk dimensions - including safety, security, privacy, and environmental factors - and by explicitly accounting for the mitigating effects of U-space services [5].

The scope of the exploratory research plan covers the design and execution of validation activities aimed at testing the models' applicability, reliability, and operational relevance under realistic conditions. It clearly identifies the validation objectives, assumptions and methodological steps guiding the experiments.

3.3 Key R&I needs

The Exploratory Research Plan (ERP) addresses several key research and innovation (R&I) needs essential for the safe integration of UAS into European airspace, here illustrated.

R&I ID	R&I need/question
R&I- 01	To assess to what extent the deployment of U-space services enhances airspace capacity and security, while maintaining the required level of safety.
R&I- 02	Investigating how variations in operational parameters (e.g. deviation threshold) affect capacity of the U-space airspace, while maintaining the required level of safety.
R&I- 03	Assessing the impact of fauna on both safety and capacity.

Table 3: Key R&I needs

3.4 Estimated performance contributions

Validation activities conducted within the U-AGREE project aim to provide *quantitative* evidence of the performance improvements enabled by the proposed integrated risk models and the application of U-space services as mitigation barriers. These contributions will be evaluated across the following Key

Performance Areas (KPAs), defined in the DES Performance Framework U-space Companion Document [2]:

- **Safety:** Focused on ensuring that the level of safety remains consistent with the Target Level of Safety (TLS) in each scenario, while testing how increase in capacity can be achieved without compromising safety. This excludes broader considerations such as safety culture and management practices.
- **Capacity:** Measured as the maximum number of drone operations that can be safely and efficiently managed within a given U-space airspace over a defined period, while meeting environmental and operational objectives and ensuring that safety levels are not degraded.
- **Security:** Focuses on how U-space services help reduce infringements of sensitive areas and geo-zones, improving operational security within the U-space environment.
- **Environment:** Focused on assessing how mitigation measures act to reduce the environmental impact of UAS operations, limiting potential disturbances to local fauna. The objective is to maintain air risk associated with wildlife presence within acceptable safety levels.

A set of *quantitative* indicators will be assessed for each KPA through simulation-based validation activities. Key performance indicators (KPI) for each KPA are illustrated in the following paragraphs.

3.5 Initial and exit maturity levels

Project/ Proposed SESAR solution(s) ID	Proposed SESAR solution(s) title	Initial maturity level	Exit maturity level	Reused validation material from past R&I Initiatives
0520	Integrated risk models for Unmanned Aerial Systems (UAS) in the U-space	TRL0	TRL2	All validation activities in U-AGREE will be based on newly developed material, tailored specifically to the project's objectives and scenarios.

Table 4: Maturity levels table

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4 Exploratory research plan

4.1 Exploratory research plan approach

Validation activities in UAGREE are organized into two sequential steps, designed to progressively mature and validate the developed risk models:

1. The first validation phase focuses on assessing the initial implementation of the risk models, defining in detail the planned activities and the key performance metrics measured during the activities. This phase provides the evidence required to calibrate and refine both the modelling assumptions and the simulation framework.
2. The second validation phase will address the final risk models, building on the lessons learned during the first validation. Its scope and objectives will be refined based on the results of the first cycle, with any deviations from the initial Exploratory Research Plan formally documented in the dedicated section of the Exploratory Research Report (ERR).

This two-step, iterative approach ensures that insights gained from the first validation are directly used to shape the subsequent phase. In this way, the planned experiments are both necessary and sufficient to achieve the intended maturity progression: the first exercise addresses the baseline U-space deployment and identifies gaps and limitations, while the second explores potential improvements by applying more sophisticated services, thus delivering a comprehensive assessment of safety and capacity performance.

4.2 Stakeholders' expectations and involvement

Stakeholder	Involvement	Why it matters to the stakeholder
U-space Service Providers (USSPs)	No involvement [2]	Results demonstrate the effectiveness of U-space services as mitigation barriers, contributing to enhancing safety and enabling scalable, advanced drone operations.
Common Information Service Providers (CISPs)	No involvement [2]	Validation activities rely on accurate geo-zone information assumed to be provided by CISPs, underlining their foundational role in enabling risk-aware flight planning and regulatory compliance.

[2] This stakeholder is not directly involved in the execution of the validation exercises; however, the results of these activities are of significant relevance to them.

Regulatory Authorities	No involvement [2]	Validations will prove that the developed risk models reliably meet safety standards, supporting regulators in making informed decisions on managing airspace capacity with increasing UAS traffic.
UAS Operators	No involvement [2]	Results illustrate how the proposed risk models and U-space services contribute to safer, more predictable, and potentially more efficient operations, simplifying authorisation processes.
Research Community	The entities involved in the validation activities are representatives of this stakeholder category.	Project outcomes contribute to the advancement of research on UAS traffic management and risk modelling, offering new data and validation methods.
Citizens	No involvement [2]	Risk models developed in the project can enable the deployment of UAS based services: medical and goods delivery, infrastructure inspections, etc.

Table 5: Stakeholders' expectations and involvement

4.3 Validation objectives

This section defines the validation objectives for the Exploratory Research Plan. The overarching objective is to demonstrate that the risk models proposed by the project and the U-space based mitigation barriers implemented can contribute to enhance capacity and security in U-Space environments, without degrading the overall safety. This overarching objective is further broken down into specific objectives.

Objectives are uniquely identified and derived following the rationale:

- At least one objective per addressed KPA (refer to section 3.4 for the list of addressed KPAs).
- Expressed as general statements linking performance expectations with specific operation types and/or environments.
- Each objective is linked to one or more R&I needs.
- Are defined by applying different mitigation measures based on U-space services, in accordance with use cases presented in Deliverable 2.3 – Initial Concept Outline [26].

They are coded OBJ-SOL0520-ERP-00X, being X consecutive numbers.

For each validation objective, success criteria are identified and coded as CRT-SOL0520-TRL2-ERP-00X.00X, where:

- CRT stands for success criteria,
- SOL0520 refers to the project solution identifier,
- TRL2 indicates the TRL addressed by the objective,
- The first three digits (00X) refer to the specific objective,
- The last three digits (00X) represent the sequential numbering of success criteria associated with that objective.

Identifier	Validation Objective	R&I Need
OBJ-SOL0520-ERP-001	Identification of the baseline capacity (N_0).	1, 2
OBJ-SOL0520-ERP-002	Quantification of capacity increment (ΔN_1) because of the introduction of mitigation measures based on Flight Authorization and Traffic Information services.	1, 2
OBJ-SOL0520-ERP-003	Quantification of capacity increment (ΔN_2) because of the introduction of mitigation measures based on Flight Authorization, Traffic Information, and Conformance Monitoring (without pre-alerting) services.	1, 2
OBJ-SOL0520-ERP-004	Quantification of the capacity increment (ΔN_3) because of the introduction of mitigation measures based on Flight Authorization, Traffic Information, and Conformance Monitoring (with pre-alerting) services.	1, 2
OBJ-SOL0520-ERP-005	Quantification of the capacity increment (ΔN_4) because of the introduction of mitigation measures based on adding a Tactical Conflict Prediction and Resolution services.	1, 2
OBJ-SOL0520-ERP-006	Quantification of baseline geographical zone infringements per flight-hour ($\Delta Ninf_0$).	1
OBJ-SOL0520-ERP-007	Quantification of the variation in geographical zone infringements per flight-hour ($\Delta Ninf_1$) due to the implementation of mitigation measures based on Flight Authorization service.	1
OBJ-SOL0520-ERP-008	Quantification of the variation in geographical zone infringements per flight-hour ($\Delta Ninf_2$) due to the implementation of mitigation measures based on Conformance Monitoring service.	1
OBJ-SOL0520-ERP-009	Quantification of the impact of fauna on air risk.	3

[OBJ]

Identifier	OBJ-SOL0520-ERP-001
Objective	Establish the baseline capacity, defined as the maximum number of UAS operations that can be accommodated in the U-space airspace while maintaining the Target Level of Safety (TLS), without the application of any U-space service mitigation.
Title	**Identification of the baseline capacity (N_0)**
Category	Capacity, Safety
Key environment conditions	U-space airspace. Flight conducted in Urban / suburban areas. Type of operations: Inspections, agricultural, medical deliveries.
TRL Phase	2

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	SESAR Solution 0520
<COVERS>	<Enabler>	N/A
<COVERS>	<Sub-Operating Environment>	Scenario 1: The city of Benidorm (non U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 2: The city of Manduria (non U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 3: The Shannon-Limerick Area (APT-small/non U-space sub-OE)

[OBJ Suc]

Identifier	Success Criterion
CRT-SOL0520-TRL2-ERP-001.001	The MAC frequency between UAS shall not exceed 4.35×10^{-5} per flight-hour in Scenario 1.
CRT-SOL0520-TRL2-ERP-001.002	The MAC frequency between UAS and manned aircraft shall not exceed 10^{-7} per flight-hour in Scenario 1.
CRT-SOL0520-TRL2-ERP-001.003	The MAC frequency between UAS shall not exceed $1{,}5 \times 10^{-4}$ per flight-hour in Scenario 2.
CRT-SOL0520-TRL2-ERP-001.004	The MAC frequency between UAS and manned aircraft shall not exceed 10^{-7} per flight-hour in Scenario 2.

CRT-SOL0520-TRL2-ERP-001.005	The MAC frequency between UAS shall not exceed $1{,}7 \times 10^{-2}$ per flight hour in Scenario 3.
CRT-SOL0520-TRL2-ERP-001.006	The MAC frequency between UAS and manned aircraft in uncontrolled airspace shall not exceed 10^{-7} per flight-hour in Scenario 3.
CRT-SOL0520-TRL2-ERP-001.007	The MAC frequency between UAS and manned aircraft in controlled airspace shall not exceed 10^{-9} per flight-hour in Scenario 3.

[OBJ]

Identifier	**OBJ-SOL0520-ERP-002**
Objective	Quantify the capacity increment achievable while maintaining the Target Level of Safety (TLS) when Flight Authorization and Traffic Information services are implemented as mitigation measures.
Title	**Quantification of capacity increment (ΔN_1) because of the introduction of mitigation measures based on Flight Authorization and Traffic Information services.**
Category	Capacity, Safety
Key environment conditions	U-space airspace. Flight conducted in Urban / suburban areas. Type of operations: Inspections, agricultural, medical deliveries.
TRL Phase	2

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	SESAR Solution 0520
<COVERS>	<Enabler>	N/A
<COVERS>	<Sub-Operating Environment>	Scenario 1: The city of Benidorm (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 2: The city of Manduria (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 3: The Shannon-Limerick Area (Airport U-space sub-OE/G class U-space sub-OE)

[OBJ Suc]

Identifier	Success Criterion

CRT-SOL0520-TRL2-ERP-002.001	The maximum number of UAS operations in scenario 1 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.
CRT-SOL0520-TRL2-ERP-002.002	The maximum number of UAS operations in scenario 2 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.
CRT-SOL0520-TRL2-ERP-002.003	The maximum number of UAS operations in scenario 3 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.

[OBJ]

Identifier	**OBJ-SOL0520-ERP-003**
Objective	Quantify the additional capacity increment achievable while maintaining the Target Level of Safety (TLS) when Conformance Monitoring (without pre-alerting) is integrated with Flight Authorization and Traffic Information services.
Title	**Quantification of capacity increment (ΔN_2) because of the introduction of mitigation measures based on Flight Authorization, Traffic Information, and Conformance Monitoring (without pre-alerting) services**
Category	Capacity, Safety
Key environment conditions	U-space airspace. Flight conducted in Urban / suburban areas. Type of operations: Inspections, agricultural, medical deliveries.
TRL Phase	2

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	SESAR Solution 0520
<COVERS>	<Enabler>	N/A
<COVERS>	<Sub-Operating Environment>	Scenario 1: The city of Benidorm (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 2: The city of Manduria (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 3: The Shannon-Limerick Area (Airport U-space sub-OE/G class U-space sub-OE)

[OBJ Suc]

Identifier	Success Criterion

CRT-SOL0520-TRL2-ERP-003.001	The maximum number of UAS operations in scenario 1 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.
CRT-SOL0520-TRL2-ERP-003.002	The maximum number of UAS operations in scenario 2 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.
CRT-SOL0520-TRL2-ERP-003.003	The maximum number of UAS operations in scenario 3 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.

[OBJ]

Identifier	**OBJ-SOL0520-ERP-004**
Objective	Quantify the total capacity increment achievable while maintaining the Target Level of Safety (TLS) when all three services, including Conformance Monitoring with pre-alerting, are implemented as mitigation measures.
Title	**Quantification of the capacity increment (ΔN_3) because of the introduction of mitigation measures based on Flight Authorization, Traffic Information, and Conformance Monitoring (with pre-alerting) services.**
Category	Capacity, Safety
Key environment conditions	U-space airspace. Flight conducted in Urban / suburban areas. Type of operations: Inspections, agricultural, medical deliveries.
TRL Phase	2

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	SESAR Solution 0520
<COVERS>	<Enabler>	N/A
<COVERS>	<Sub-Operating Environment>	Scenario 1: The city of Benidorm (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 2: The city of Manduria (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 3: The Shannon-Limerick Area (Airport U-space sub-OE/G class U-space sub-OE)

[OBJ Suc]

Identifier	Success Criterion

CRT-SOL0520-TRL2-ERP-004.001	The maximum number of UAS operations in scenario 1 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.
CRT-SOL0520-TRL2-ERP-004.002	The maximum number of UAS operations in scenario 2 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.
CRT-SOL0520-TRL2-ERP-004.003	The maximum number of UAS operations in scenario 3 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.

[OBJ]

Identifier	**OBJ-SOL0520-ERP-005**
Objective	Quantify the total capacity increment achievable while maintaining the Target Level of Safety (TLS) when Tactical Conflict Prediction and Resolution services are implemented as mitigation measures.
Title	**Quantification of the capacity increment (ΔN_4) because of the introduction of mitigation measures based on adding a Tactical Conflict Prediction and Resolution services.**
Category	Capacity, Safety
Key environment conditions	U-space airspace. Flight conducted in Urban / suburban areas. Type of operations: Inspections, agricultural, medical deliveries.
TRL Phase	2

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	SESAR Solution 0520
<COVERS>	<Enabler>	N/A
<COVERS>	<Sub-Operating Environment>	Scenario 1: The city of Benidorm (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 2: The city of Manduria (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 3: The Shannon-Limerick Area (Airport U-space sub-OE/G class U-space sub-OE)

[OBJ Suc]

Identifier	Success Criterion

CRT-SOL0520-TRL2-ERP-005.001	The maximum number of UAS operations in scenario 1 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.
CRT-SOL0520-TRL2-ERP-005.002	The maximum number of UAS operations in scenario 2 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.
CRT-SOL0520-TRL2-ERP-005.003	The maximum number of UAS operations in scenario 3 increases with respect to the unmitigated baseline, while maintaining the same target level of safety.

[OBJ]

Identifier	**OBJ-SOL0520-ERP-006**
Objective	Quantify the total number of UAS infringements in designated geographical zones without any mitigation measures, establishing the reference level of security for each scenario.
Title	**Quantification of baseline geographical zone infringements per flight-hour ($\Delta Ninf_0$).**
Category	Security
Key environment conditions	U-space airspace. Flight conducted in Urban / suburban areas. Type of operations: Inspections, agricultural, medical deliveries.
TRL Phase	2

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	SESAR Solution 0520
<COVERS>	<Enabler>	N/A
<COVERS>	<Sub-Operating Environment>	Scenario 1: The city of Benidorm (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 2: The city of Manduria (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 3: The Shannon-Limerick Area (Airport U-space sub-OE/G class U-space sub-OE)

[OBJ Suc]

Identifier	Success Criterion

CRT-SOL0520-TRL2-ERP-006.001	The number of UAS infringements of UAS geographical zones shall not exceed TBD[3] per flight hour in scenario 1.
CRT-SOL0520-TRL2-ERP-006.002	The number of UAS infringements of UAS geographical zones shall not exceed TBD[2] per flight hour in scenario 2.
CRT-SOL0520-TRL2-ERP-006.003	The number of UAS infringements of UAS geographical zones shall not exceed TBD[2] per flight hour in scenario 3.

[OBJ]

Identifier	**OBJ-SOL0520-ERP-007**
Objective	Quantify the variation in UAS infringements in geographical zones achieved when applying Flight Authorization service as mitigation measures, while maintaining compliance with the Target Level of Safety (TLS).
Title	**Quantification of the variation in geographical zone infringements per flight-hour ($\Delta Ninf_1$) due to the implementation of mitigation measures based on Flight Authorization service.**
Category	Security
Key environment conditions	U-space airspace. Flight conducted in Urban / suburban areas. Type of operations: Inspections, agricultural, medical deliveries.
TRL Phase	2

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	SESAR Solution 0520
<COVERS>	<Enabler>	N/A
<COVERS>	<Sub-Operating Environment>	Scenario 1: The city of Benidorm (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 2: The city of Manduria (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 3: The Shannon-Limerick Area (Airport U-space sub-OE/G class U-space sub-OE)

[3] The number of UAS infringements of UAS geographical zones for each scenario will be calculated in WP2 and implemented in the Final concept Outline D2.4.

[OBJ Suc]

Identifier	Success Criterion
CRT-SOL0520-TRL2-ERP-007.001	The total number of geographical zones infringements varies compared to the baseline in scenario 1.
CRT-SOL0520-TRL2-ERP-007.002	The total number of geographical zones infringements varies compared to the baseline in scenario 2.
CRT-SOL0520TRL2-ERP-007.003	The total number of geographical zones infringements varies compared to the baseline in scenario 3.

[OBJ]

Identifier	**OBJ-SOL0520-ERP-008**
Objective	Quantify the variation in UAS infringements per flight hour ($\Delta Ninf_2$) in geographical zones achieved when applying Conformance Monitoring service as mitigation measures, while maintaining compliance with the Target Level of Safety (TLS).
Title	**Quantification of the variation in geographical zone infringements per flight-hour ($\Delta Ninf_2$) due to the implementation of mitigation measures based on Conformance Monitoring service.**
Category	Security
Key environment conditions	U-space airspace. Flight conducted in Urban / suburban areas. Type of operations: Inspections, agricultural, medical deliveries.
TRL Phase	2

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	SESAR Solution 0520
<COVERS>	<Enabler>	N/A
<COVERS>	<Sub-Operating Environment>	Scenario 1: The city of Benidorm (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 2: The city of Manduria (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 3: The Shannon-Limerick Area (Airport U-space sub-OE/G class U-space sub-OE)

[OBJ Suc]

Identifier	Success Criterion
CRT-SOL0520-TRL2-ERP-008.001	The total number of geographical zones infringements varies compared to the baseline in scenario 1.
CRT-SOL0520-TRL2-ERP-008.002	The total number of geographical zones infringements varies compared to the baseline in scenario 2.
CRT-SOL0520-TRL2-ERP-008.003	The total number of geographical zones infringements varies compared to the baseline in scenario 3.

[OBJ]

Identifier	**OBJ-SOL0520-ERP-009**
Objective	Quantify the contribution of fauna (birds) to mid-air collision risk and assess mitigation measures to ensure that the Target Level of Safety (TLS) is maintained, while minimizing potential hazardous effects on wildlife.
Title	**Quantification of the impact of fauna on air risk.**
Category	Safety, Environment
Key environment conditions	U-space airspace. Flight conducted in Urban / suburban areas. Type of operations: Inspections, agricultural, medical deliveries.
TRL Phase	2

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	SESAR Solution 0520
<COVERS>	<Enabler>	N/A
<COVERS>	<Sub-Operating Environment>	Scenario 1: The city of Benidorm (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 2: The city of Manduria (G class U-space sub-OE)
<COVERS>	<Sub-Operating Environment>	Scenario 3: The Shannon-Limerick Area (Airport U-space sub-OE/G class U-space sub-OE)

[OBJ Suc]

Identifier	Success Criterion

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CRT-SOL0520-TRL2-ERP-009.001	The TLS defined for scenario 1 is maintained.
CRT-SOL0520-TRL2-ERP-009.002	The TLS defined for scenario 2 is maintained.
CRT-SOL0520-TRL2-ERP-009.003	The TLS defined for scenario 3 is maintained.

Table 6: Complete list of detailed validation objectives and success criteria

To better depict the coverage of validation objectives in validation exercises it is included below a coverage matrix (demonstration objectives versus exercises) that indicates whether each exercise ensures full or partial coverage (if it contributes).

Coverage of validation objectives		
Demonstration Objective	**Exercise #001**	**Exercise #002**
OBJ-SOL0520-ERP-001 Identification of the baseline capacity (N_0).	Fully Covered	Fully Covered
OBJ-SOL0520-ERP-002 Quantification of capacity increment (ΔN_1) because of the introduction of mitigation measures based on Flight Authorization and Traffic Information services.	Fully Covered	Not Covered
OBJ-SOL0520-ERP-003 Quantification of capacity increment (ΔN_2) because of the introduction of mitigation measures based on Flight Authorization, Traffic Information, and Conformance Monitoring (without pre-alerting) services.	Fully Covered	Not Covered
OBJ-SOL0520-ERP-004 Quantification of the capacity increment (ΔN_3) because of the introduction of mitigation measures based on Flight	Fully Covered	Not Covered

Authorization, Traffic Information, and Conformance Monitoring (with pre-alerting) services.		
OBJ-SOL0520-ERP-005 Quantification of the capacity increment (ΔN_4) because of the introduction of mitigation measures based on adding a Tactical Conflict Prediction and Resolution services.	Not Covered	Fully Covered
OBJ-SOL0520-ERP-006 Quantification of baseline geographical zone infringements per flight-hour ($\Delta Ninf_0$).	Not covered	Fully Covered
OBJ-SOL0520-ERP-007 Quantification of the variation in geographical zone infringements per flight-hour ($\Delta Ninf_1$) due to the implementation of mitigation measures based on Flight Authorization service.	Not covered	Fully Covered
OBJ-SOL0520-ERP-008 Quantification of the variation in geographical zone infringements per flight-hour ($\Delta Ninf_2$) due to the implementation of mitigation measures based on Conformance Monitoring service.	Not covered	Fully Covered
OBJ-SOL0520-ERP-009 Quantification of the impact of fauna on air risk.	Not covered	Fully Covered

Table 7: Coverage of validation objectives

For the validation activities, the following types of variables have been identified and defined:

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- **Control variables:** factors kept constant throughout the experiment.
- **Independent variables:** factors that are deliberately changed in the experiment to observe their impact. These variables directly influence dependent variables.
- **Dependent variables:** factors that are measured to assess the effect of changes in independent variables. Their values depend on how independent variables are manipulated.

Variable Type	Variable	Description
Control	Target Level of Safety	It is defined as the threshold below which the harmful effect of a hazard is considered acceptable, representing the level of risk that society deems tolerable; when this threshold is exceeded, mitigation measures must be implemented to bring the risk back to acceptable levels. It is an input for the validation activities, both for air and ground risk.
Control	Encounter distance	It is defined as the threshold value of distance below which the presence of an intruder may result in an encounter. It is an input for the validation activities.
Independent	Deviation threshold (DT)	Additional 4D volume around each planned 4D volume for a flight. They are defined by Member States at the establishment of U-space, guaranteeing safety and capacity. In U-AGREE validation activities, DT will be calculated parametrically, performing Monte-Carlo simulations with different DT values until reaching the value that satisfies the Target Level of Safety. This concept is further explained in Paragraph 5.1.4.

Dependent	Near Mid Air Collision (NMAC)	A situation in which two small UAS come within 30 ft vertically and 100 ft horizontally of each other while in flight.
Dependent	All KPI defined for the ERP.	Please refer to Paragraph 5.1.3.

Table 8: Control, independent and dependent variables

4.4 Validation assumptions

Assumption ID	Assumption title	Assumption description	Justification	Impact Assessment
Assumption 01	Speed variations	Two simulator implementations exist: (1) constant speed, where the UA maintains uniform velocity throughout the flight, and (2) variable speed, where velocity is dynamically adjusted at each tick subject to maximum acceleration and speed constraints. Orthogonally, each implementation may or may not support holding maneuvers, allowing the UA to enter a holding pattern at designated waypoints. All implementations consider avoidance maneuvers based on ICAO Annex II	Limitation of the simulation platform.	May impact realism in energy consumption, conflict dynamics, and time-to-conflict estimation.

		Rules of the Air [18] and account for estimated human performance including maneuver delay and reaction time. This concept is further explained in solution scenarios (paragraph 5.1.4.2).		
Assumption 02	Sequential Flight Authorisation Requests	Flight authorisation requests are submitted one at a time, rather than in batch mode.	Reflects a simplified implementation of the FAS and reduces complexity in managing simultaneous conflicts.	May underestimate system load and overlook performance issues in high-density scenarios or peak submission times.
Assumption 03	U-space services implementation	In solution scenarios, for both exercises listed in this ERP, U-space services are implemented as mitigation barriers. Particularly, the following services are implemented: For exercise 1, TVAL.01.0: • Flight Authorization Service, as strategic mitigation barrier.	Validation activities are focused on validating and quantifying the effect of U-space services as mitigation barriers.	Improvements on capacity and security are expected when mitigation, based on U-space services, are implemented, without affecting safety.

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		• Conformance Monitoring Service, as tactical mitigation barrier. • Traffic Information Service, as tactical mitigation barrier. For exercise 2, TVAL.02.0, Tactical Conflict Prediction and Resolution services are implemented.		
Assumption 04	Operations under non-nominal conditions	Deviations from the approved flight plan due to weather or CNS degradations are considered in the validation activities.	Such conditions reflect realistic operational scenarios and may affect safety and performance outcomes.	Improves realism of results.

Table 9: Validation assumptions overview

4.5 Validation exercises list

The following tables summarize the details of each validation exercise.
[EXE1]

Identifier	TVAL.01.0 TRL1 (FTS) ENGage srl (Italy, SC1, SC2, SC3)
Title	Validation of the initial integrated risk models.
Description	The objective of this first validation exercise is to assess the effectiveness of the initial U-AGREE risk models in predicting and mitigating mid-air collision and ground risks. These models, together with the associated strategic and tactical mitigation barriers, will be

	tested in parallel across the three simulation platforms developed by ENGage srl, UPV, and CRA.
	
	Each simulator will execute the exercise following a common structure consisting of two main steps:
	
	1. **Reference scenarios**: For all the three scenarios chosen for the project, described in paragraph 5.1.4, simulations will be run without the provision of any U-space services. Key Performance Indicators (KPI) will be calculated to establish the baseline risk levels.
	
	2. **Solution scenarios:** The same reference scenarios will then be repeated introducing mitigation barriers:
	
	    1. Flight Authorisation Service (FAS) as a strategic mitigation barrier.
	
	    2. Conformance Monitoring Service (CM) as a tactical mitigation barrier.
	
	    3. Traffic Information Service (TI) as a tactical mitigation barrier.
	
	DAR affected volumes are not considered in this exercise for U-space airspaces designated in controlled airspace.
	
	When an e-conspicuous manned aircraft not receiving air traffic control instructions enters a U-space airspace, the Traffic Information Service provides information about that aircraft and the responsibility for avoiding collision hazards remains with the UAS operator.
	
	Once mitigation barriers are implemented, KPI will be recalculated and compared against the baseline, allowing the derivation of risk ratios that quantify the effectiveness of each barrier. More detailed information about the reference and solution scenarios is provided in paragraph 5.1.4.
	
	For each scenario, simulations will be conducted until reaching a total number of flight hours that are considered statistically significant. In each scenario, UAS are simulated considering the traffic mix defined in deliverable D2.3 [26] and later explained in the document, while manned aircraft data are derived from the analysis of historical ADS-B data (illustrated in paragraph 5.1.7). Results from this process will inform the refinement of the risk models, supporting improvements in safety and enabling more efficient capacity management.

KPA/TA addressed	Safety (SAF), Capacity (CAP)

Addressed expected performance contribution(s)	Improvement in capacity in the three simulated scenarios, without degrading safety levels.
Maturity level	TRL2
Use cases	Validation activities will be conducted in these three scenarios [7]: • S1: The city of Benidorm. • S2: The city of Manduria. • S3: The Shannon-Limerick Area.
Validation technique	Fast time simulations.
Validation platform	Platforms from ENGAGE (ENGage srl), University of Cranfield (CRA) and Universitat Politècnica de València (UPV).
Validation location	Each organization carries out the validation activities at its own premises, which are: • ENGage srl: Santa Maria Capua Vetere (CE), Italy; • UPV: Valencia, Spain; • CRA: Cranfield, England
Start date	01/09/2025
End date	15/12/2025
Validation coordinator	Maurizio Sodano, ENGage srl
Status	Completed
Dependencies	N/A

[EXE Trace]

Linked Element Type	N/A
<SESAR Solution>	SESAR Solution 0520
<Project>	U-AGREE
<Sub-Operating Environment>	Scenario 1: The city of Benidorm (G class U-space sub-OE) Scenario 2: The city of Manduria (G class U-space sub-OE) Scenario 3: The Shannon-Limerick Area (Airport U-space sub-OE/G class U-space sub-OE)
<Validation Objective>	OBJ-SOL0520-ERP-001

	OBJ-SOL0520-ERP-002 OBJ-SOL0520-ERP-003 OBJ-SOL0520-ERP-004

Table 10: Validation exercise #01 layout

[EXE2]

Identifier	TVAL.02.0 TRL2 (FTS) ENGage srl(Italy, SC1, SC2, SC3)
Title	Validation of the final integrated risk models.
Description	The objective of this second validation exercise is to assess the effectiveness of the final U-AGREE risk models in predicting and mitigating risks within U-space operational environments. The risk models developed will be evaluated following a methodology that mirrors the one used in EXE1: 1. **Reference scenarios**: coincide with EXE1 solution scenarios. 2. **Solution scenarios:** The same reference scenarios will then be repeated by introducing tactical mitigation barriers based on the advanced U-space Tactical Conflict Prediction and Resolution Service. The specific implementation and use of this advanced U-space service as mitigation barriers within U-AGREE will be detailed in Deliverable D4.2 – Final Barriers Characterisation. Should there be any differences between the U-space services effectively implemented and those described in this ERP, they will be thoroughly explained and justified in the Exploratory Research Report. In this exercise, DAR affected volumes are considered in the FAS process. Furthermore, when an e-conspicuous manned aircraft not receiving air traffic control instructions enters a U-space airspace, the Traffic Information Service provides information about that aircraft and the responsibility for avoiding collision hazards remains with the UAS operator. For each mitigation barrier, KPI will be recalculated and compared against the reference ones, allowing the derivation of risk ratios that quantify the effectiveness of each barrier. This approach ensures that the impact of each service is assessed separately rather than in combination. For each scenario, simulations will be conducted until reaching a total number of flight hours that are considered statistically significant. In each scenario UAS are simulated considering the traffic mix defined in deliverable D2.3 [26] and later explained in the document, while

	manned aircraft data are derived from the analysis of historical ADS-B data (illustrated in paragraph 5.1.7). The validation will again be conducted parallelly across the three simulation platforms developed by ENGage srl, UPV, and CRA. Results will be used to validate the improved performance of the refined models and U-space based mitigation barriers in enhancing safety and supporting scalable, high-density UAS operations.
KPA/TA addressed	Safety (SAF), Capacity (CAP), Security (SEC), Environment (ENV)
Addressed expected performance contribution(s)	Improvement in capacity and security in the three simulated scenarios, while not affecting safety levels and considering environmental related issues.
Maturity level	TRL2
Use cases	Validation activities will be conducted in these three scenarios [7]: • S1: The city of Benidorm. • S2: The city of Manduria. • S3: The Shannon-Limerick Area.
Validation technique	Fast time simulations.
Validation platform	Platforms from ENGAGE (ENGage srl), University of Cranfield (CRA) and Universitat Politècnica de València (UPV).
Validation location	Each organization carries out the validation activities at its own premises, which are: • ENGage srl: Santa Maria Capua Vetere (CE), Italy; • UPV: Valencia, Spain; • CRA: Cranfield, England.
Start date	12/01/2026
End date	30/04/2026
Validation coordinator	Maurizio Sodano, ENGage srl
Status	Under preparation
Dependencies	

[EXE Trace]

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Linked Element Type	N/A
<SESAR Solution>	SESAR Solution 0520
<Project>	U-AGREE
<Sub-Operating Environment>	Scenario 1: The city of Benidorm (G class U-space sub-OE) Scenario 2: The city of Manduria (G class U-space sub-OE) Scenario 3: The Shannon-Limerick Area (Airport U-space sub-OE/G class U-space sub-OE)
<Validation Objective>	OBJ- SOL0520-ERP-001 OBJ- SOL0520-ERP-005 OBJ- SOL0520-ERP-006 OBJ- SOL0520-ERP-007 OBJ- SOL0520-ERP-008 OBJ- SOL0520-ERP-009

Table 11: Validation exercise #02 layout

4.6 Validation exercises planning

Validation activities included in the scope of this ERP are captured in the STELLAR platform and are associated with two separate validation exercises. The first exercise is scheduled from 01/09/2025 to 15/12/2025, while the second will take place from 12/01/2026 to 30/04/2026. These exercises are further detailed in Chapter 5.

Name	Code	Link to solution	Start date	End date	Status	Space
Category **Validation Exercise** (2)						
Link to solution **0520 - Integrated risk models for Unmanned Aerial Systems...** (2)						
First batch of evaluation activities.	TVAL.01.0	0520 - Integrated risk models for Unmanned Aerial Systems...	01 Sep 25	15 Dec 25	3. Completed	U-AGREE
Second batch of evaluation activities.	TVAL.02.0	0520 - Integrated risk models for Unmanned Aerial Systems...	01 Jan 26	30 Apr 26	1. Under Preparation	U-AGREE

Figure 1: Validation exercises in STELLAR

4.7 Deviations with respect to the SESAR 3 JU project handbook

There are no deviations from the Project Handbook.

However, a modification was made to the ERP template regarding the placement of the paragraph “Validation Exercise Platform / Tool and Validation Technique “, originally in Chapter 5 (dedicated to the validation exercises). Given that the ERP includes two separate validation sub-chapters (one for each validation exercise), and that the same platforms and tools are utilized for both, this paragraph has been extracted from sub-chapters 5.1 and 5.2 and positioned in chapter 4 to avoid redundancy and improve clarity.

4.8 Validation exercise platform / tool and validation technique

4.8.1 Validation exercise platform / tool characteristics

Each validation exercise will be carried out in three different simulators, owned respectively by ENGage srl, Cranfield University, and Universitat Politècnica de València. This multi-platform approach ensures a broader spectrum of testing conditions, as each simulator is characterized by specific strengths in terms of fidelity, functionality, and focus areas. By leveraging these complementary features, the exercises benefit from a richer and more diverse dataset, allowing for a more robust evaluation of procedures and results. In addition, the use of three simulators helps mitigate individual limitations that any single platform might present.

4.8.1.1 ENGage srl simulation platform: *Pegasus*

PEGASUS is a cloud-based simulation platform developed by ENGage srl to support the validation of the U-space risk models developed within the project. The platform enables the creation and execution of UAS operational scenarios with a variable number of missions distributed over a defined geographic area. Users can configure mission profiles, import 3D environmental data (including obstacles from open-sources such as OpenStreetMap [14] or by uploading a GeoJSON file), import no-fly zone information from the USSP and define geospatial constraints relevant to U-space operations.

PEGASUS allows for the computation of both near mid-air collision and ground risk metrics, applying basic U-space services as mitigation barriers, as defined by project objectives, including ADS-B data of manned aircraft for the scenarios chosen for the project. The platform supports the quantitative evaluation of risk throughout the mission lifecycle, enabling scenario-based performance assessments.

Key Components:

- **Mission Generation:** this feature allows users to create missions. They can select a UA or eVTOL for the simulation from the existing database or, if the vehicle is not yet available on the platform, upload a new one by providing relevant details, including:

  - Model.
  - Manufacturer.
  - Configuration Type.
  - Performance specifications: maximum and cruise speed, maximum height, characteristic dimension, take-off mass, payload, endurance, range.
  - Propulsion Type.

  Once the preferred vehicle is selected, the user can define the mission’s flight plan either by uploading a JSON route file containing a predefined series of waypoints or by manually drawing them. In both cases, the following steps must be taken to create a new mission:

  - Upload a JSON obstacle file containing obstacles information for the target flight area (optional),

  – Set route parameters such as flight height and mean speed,
  – Define path priority, *low*, *medium* and *high,* needed for conflict resolution,
  – Configure simulation options by enabling or disabling the following parameters:
    - Avoid Obstacles: when enabled, the trajectory is generated to avoid physical obstacles,
    - Avoid No-Fly Zones: when enabled, the trajectory is generated to avoid restricted airspace zones,
    - Avoid Other Drones: when enabled, the trajectory is generated to avoid other drones,
    - Visible Path: when enabled, the calculated path is visible to other drones.

  The platform provides as output the 4D trajectory computed on the basis of all the input parameters defined by the user, considering also the Flight Technical Errors defined in EUROCAE, ED-301 Guidelines for the use of Multi-GNSS solutions for UAS Specific Category-low risk operations SAIL I & II document [13].

- **User and Fleet Management Layer:** The system supports multiple users, each with distinct permissions and roles. It also provides fleet management capabilities, allowing authorized users to add, remove, and modify vehicles (UAs and eVTOLs) within the fleet.
- **Probabilistic track generation:** Starting from the 4D trajectory defined in the previous step, random tracks are defined.
- **Risk Analysis Module:** the platform performs NMAC Detection. It calculates the number of Near Mid-Air Collisions (NMAC), both between UAS, and UAS and manned aircraft, if data are available. By calculating the distance between the UAS and all other vehicles in the shared airspace for a certain time, a check is performed: if the distance is less than
  - 100 ft vertically and 500 ft horizontally for aircraft,
  - 30 ft vertically and 100 ft horizontally for small UAS,

  an NMAC is defined.
- **Implementation of U-space services:**
  - **Strategic - Flight authorisation Service:** the platform simulates the flight authorisation service by exploiting the Medium-Term Conflict Detection (MTCD) algorithm. MTCD is an established tool in air traffic management (ATM) planning, typically operating with a conflict detection horizon of up to 20 minutes. Its core functionalities include both the identification of potential trajectory conflicts and, where applicable, the provision of conflict resolution advisories to support trajectory adjustments. For each pair of vehicles, at a frequency of one second, the tool calculates their relative distance and compares it against a predefined threshold, derived from the total system error and

the allowable deviation margin. If the distance falls below this threshold, the algorithm identifies a potential conflict: this means that the projected trajectories overlap and therefore cannot be authorized.

- **Tactical – Conformance Monitoring Service:** for each trajectory, the platform continuously calculates the distance between the planned trajectory and the actual vehicle position. When this distance becomes smaller than half the Total System Error (TSE), the system issues a *preliminary alert* to the pilot, indicating that the vehicle is exiting the safety corridor. To simulate the pilot's correction maneuver, the system implements a trajectory tracking algorithm with noise, which models the vehicle's attempt to return to the planned trajectory while accounting for sensor noise and control inaccuracies. If, instead, the vehicle continues to deviate from the initial trajectory (so, the distance between the planned trajectory and the actual vehicle position is higher than $\frac{Total\ System\ Error}{2} + Deviation\ Threshold$), a non-conformance alert is provided to the pilot. At this stage, another corrective maneuver is simulated. Should this maneuver fail, and the deviation persist, the situation may escalate to a Near Mid-Air Collision (NMAC) risk *if other vehicles are operating nearby*.

- **Tactical – Traffic Information Service:** information of other vehicles in the shared airspace are provided to the vehicle through the whole flight to increase situational awareness.

- **Tactical – Conflict Prediction Service:** allows the predictive detection of NMAC with surrounding vehicles.

- **Tactical – Conflict Resolution Service:** together with the conflict prediction provides suggestion to the UAS operator or commands to autonomous flight control system onboard.

- **Post-Flight Data Access**: enables review of simulation outputs, including risk indicators and mission-level metrics for further analysis.

4.8.1.2 UPV simulation platform

The simulator that the UPV will use to carry out the validation exercises comprises different tools designed to assess U-space environments. These tools can calculate the frequency of near-mid-air collisions and therefore compute related risk metrics. Additionally, UPV's platform also contains a tool designed to create the UAS trajectories in terms of waypoints and can use those waypoints to generate realistic trajectories.

The tools described in this section will conduct experiments for the validation exercise of the initial mitigation barriers identified in U-AGREE, as further refinement and definition will be needed once the advanced mitigation barriers models are defined.

Each tool is designed for the different barriers integrated in the U-AGREE project, as will be explained in this section. Figure 2 provides an overview of the architecture of the simulator.

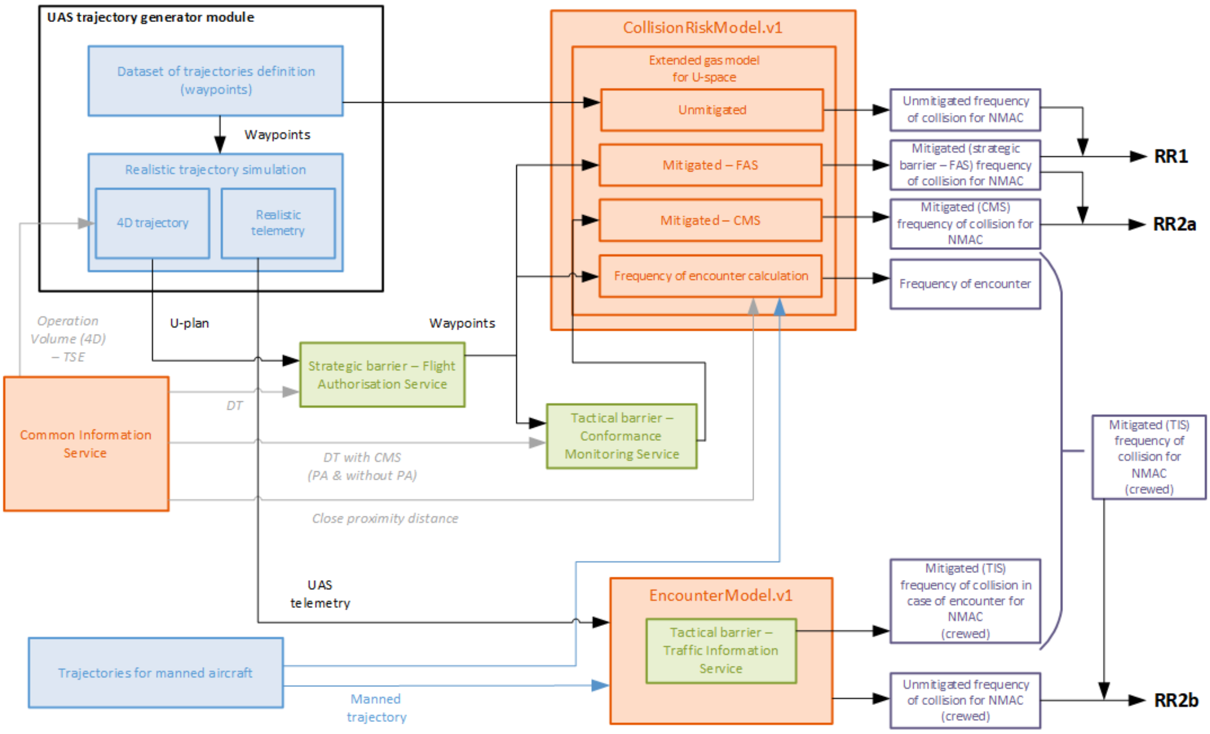

Figure 2: UPV simulator diagram

Unmitigated calculation

For the calculation of the frequency, the tool utilizes the random waypoints generated by the trajectory generator module from the UPV and constructs the trajectories with a GPS error model structure that simulates errors based on actual sensor behaviour. This approach improves upon the Random Walk model by providing a more accurate simulation of UAS positioning uncertainty.

The tool calculates the frequency of near mid-air collisions in terms of flight hours ($\lambda_{UAS_{NMAC}}$) by implementing an extended version of the Endoh's gas model applicable to U-space operations. To extend the model to cope with the diversity in UAS performance, size and missions, UAS operating within any given volume of airspace are categorized into M distinct classes, each characterized by specific attributes, i.e., aircraft in category i are represented by a cylinder of diameter g_i and height h_i, centred at the nominal aircraft position. We assume that UAS do not execute vertical displacements or collision avoidance maneuvers. We also assume that there are N_i aircraft in each class such that $N = \sum_{i=1}^{M} N_i$, being N the total number of UAS flying within the volume.

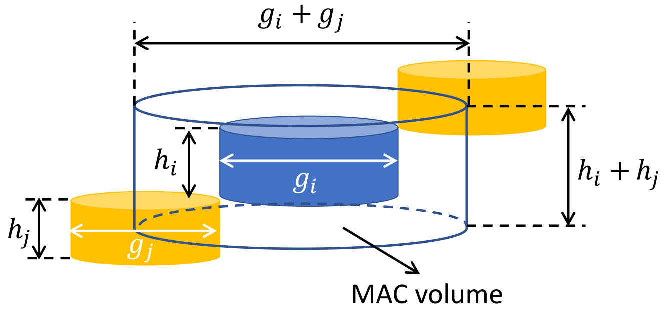

Figure 3: MAC volume between UAS of category i with UAS of category j.

Figure 3 represents a collision detected by the tool between one UAS of category i (represented by the blue cylinder) and UAS of category j (represented by orange cylinders). A collision between UAS of category i and j occurs when they overlap in both horizontal and vertical dimensions, forming a MAC volume around them. Following the same approach, the NMAC volume will be defined as a cylinder around the UAS. For small UAS (with a maximum wingspan of 25 ft), NMAC is 50 ft radius, 30 ft height [12] for larger aircraft (General Aviation – GA – or UAM/AAM aircraft), the NMAC dimensions are 500 ft radius, 200 ft height [10].

As discussed in deliverable D3.3 [15], the unmitigated collision frequency (per flight-hour) $\lambda^0_{UAS_{NMAC}}$ and the number of simultaneous operations are related by a scenario-dependent parameter, i.e.:

$$\lambda^0_{UAS_{NMAC}}(N) = (N-1) \cdot P_{NMAC}$$

Therefore, we determine the **scenario-dependent parameter P_{NMAC}** given a determined size and traffic mix for each scenario by simulating operations flying realistic trajectories representative of the expected missions in the specific scenario over a large period of time and counting the number of NMAC events. Since NMAC are rare events, to get statistically relevant results the simulator applies a brute-force approach (i.e., running the simulation for around 100,000 hours).

This parameter will be calculated not only for the unmitigated case but for the mitigated barrier of the Flight Authorisation Service and the barrier of Conformance Monitoring Service, as it computes the collision risk, and will serve as the basis to compute the **frequency of NMAC**, either between specific pairs of aircraft (e.g., manned vs unmanned) or overall figures of NMAC involving all classes of aircraft operating in the airspace volume.

Strategic barrier – Flight Authorisation Service

The **Flight Authorisation Service (FAS)** receives the U-plan and processes it on a *first-come, first-serve* basis. Upon receiving the request, the deviation threshold is applied to the 4D trajectory and the new 4D trajectory is used for the detection of conflicts, i.e., volume overlapping.

In order to support the detection of conflicts between different USSPs, UPV developed a new service, Search For Overlap Service (SFOS), inspired by the Discovery and Synchronization Service (DSS) described in the F3548-21 Standard Specification for UAS Traffic Management (UTM) UAS Service Supplier (USS) Interoperability, the American Society for Test and Materials (ASTM) [16]. This new service is a centralized one that receives the information from different USSPs and discretizes the U-space airspace in cells. The service identifies the cells that the U-plan occupies and detects whether the identified cells are occupied by previously approved U-plans or not. This approach supports a multi-

USSP environment [17]. The Flight Authorisation Service sends the U-plan to this centralized service and retrieves the IDs of the volumes whose cells are occupied by previously approved authorizations.

If an overlap between the U-plan and a previously approved authorisation is detected, the request is set withdrawn as Reg. 664 [5] indicates that the flight must be free of any intersection with a previously approved authorisation request.

The tool also checks with the Common Information Service whether the 4D trajectory with the deviation threshold applied is free of intersection with a geographical zone that has any restrictions on flying (e.g., prohibited geo-zone).

Once the U-plan is accepted, the information from the flight will be shared with the tool that calculates the frequency of collision for NMAC and will obtain the **strategic mitigated frequency of collision for NMAC** ($\lambda^{FAS}{}_{UAS_{NMAC}}$).

Tactical barrier – Conformance Monitoring Service

Once an aircraft is in flight, the **Conformance Monitoring Service** (**CMS**) checks whether it remains within the defined safety margins around its theoretical trajectory. The simulator implements a real-time Conformance Monitoring Service that models flight deviations and pilot responses, including potential human and technical failures. The service injects the trajectory waypoints and the deviation threshold values corresponding to the case where conformance monitoring exists, with and without pre-alert.

The system uses the integrityStatus variable to track the conformance state of each aircraft. The key states and transitions are described below:

- State 0: Nominal Flight: The aircraft is within its safety corridor, defined by half of the Total System Error (TSE). Its actual position is updated considering any error model, which simulates small deviations, in addition to its normal advance based on speed and heading.

- States 1 and 3: TSE Corridor Excursion (4D trajectory):

    - If the aircraft's distance from its original trajectory exceeds half of TSE, a deviation is flagged.
    - The system simulates pilot notification. There is a probability (pfailureTSE) that this alert may fail.
    - If the alert is successful (integrityStatus = 1): A timer (integrityLossTime) is started, and a pilot response delay (pilotDelay) is generated based on its statistical distribution. The pilot will act after this delay.
    - If the alert fails (integrityStatus = 3): The aircraft continues to deviate without intervention.

- State 2: Return to Trajectory (Post-TSE):

    - Once the integrityLossTime exceeds the pilotDelay, the state changes to 2.
    - The system uses a correction angle to steer the aircraft back to its original trajectory. The direction of the correction depends on which side of the trajectory the aircraft is on.

- The aircraft returns to State 0 once it reaches its original trajectory again.

- States 4, 5, and 7: Protection Buffer/Deviation threshold (Pbuffer) Breach: If an aircraft in State 3 (missed TSE alert) continues to deviate and its distance exceeds the sum of TSE_h/2 + Pbuffer, it enters a more critical condition.

- State 4: A waiting timer (timeOutPbuffer) is activated before a second, more urgent alert is sent.

  - After this time, a new alert is attempted, which again has a probability of failure (pfailurePbuffer).
  - If the alert is successful (integrityStatus = 5): Like State 1, a delay is set for the pilot's action.
  - If the alert fails (integrityStatus = 7): The aircraft continues flying without heading correction.

- State 6: Return to Trajectory (Post-Pbuffer): This is functionally identical to State 2. Once the pilot acts (after the pilotDelay), the state changes to 6, and the aircraft begins the correction manoeuvre to return to its planned route.

- State 7: All alerts have been lost and the drone flights erratically.

By modelling the behaviour of the drone and pilot, the trajectory of the drone will be simulated, and the **mitigated frequency of collision with CMS for NMAC** ($\lambda^{CMS}{}_{UAS_{NMAC}}$) will be calculated with the extended gas model presented before.

Tactical barrier – Traffic Information Service

The Traffic Information Service (TIS) acts as a mitigation barrier designed to avoid conflicts between manned and unmanned aircraft. Within the simulator, the evaluation of TIS effectiveness is structured into three main computational steps:

1. Frequency of encounter.
2. Unmitigated collision frequency.
3. Mitigated collision frequency with TIS as tactical barrier.

The first step involves calculating the **frequency of encounters** using the extended gas model. Instead of using the NMAC distances, this model applies the encounter distance (also known as close proximity in regulation 664).

Once the frequency of encounter is calculated, the encounter model will compute the **unmitigated frequency of collision** without the mitigation barrier of the Traffic Information Service between manned and unmanned. This calculation is based on detecting when an encounter occurs (i.e. when a UAS is in the proximity of manned aircraft). The encounter model used was developed by EUROCONTROL and the detection of the conflict is purely geometric, based on the distance between involved aircraft, calculated from their positions contained in the corresponding NRID reports. The encounter model generates pairs of random realistic trajectories and simulates them to detect whether they lead to an NMAC or not and applies a Monte Carlo approach with a large number of trials (in the order of 10,000) to get statistically sound results.

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The **mitigated frequency of collision with TIS in case of encounter** is calculated following a similar approach. In this case, the simulator applies a conflict resolution mechanism based on the flight rules defined in ICAO Annex 2 [18] and obtains the frequency of collision using the approach explained before. The most critical factor in this resolution process is the accurate modelling of human behaviour when an encounter occurs (AMCs to regulation 664 explicitly banned the provision of any support by the U-space to help the UAS operator to avoid the potential collision).

With these frequencies, the calculation of the **mitigated with TIS frequency of collision for NMAC between unmanned and crewed** is obtained.

Trajectory generation

The trajectory generation tool is composed of two main modules. The first one is designed to generate random waypoints for each trajectory. This module takes into consideration UAS limitations such as the turn rate from one waypoint to another and the size of the U-space airspace. It can also include the density of operations related to the population density map of the scenario.

For the first batch, the trajectories will be computed without considering the population density map and will define a dataset of trajectories defined by their waypoints. Later on, in the second batch of simulations, these parameters will be considered to compute the trajectories. The waypoints obtained with this tool will be used to create the 4D trajectories, bearing in mind the traffic mix of each scenario.

The second module of the trajectory generation utilizes these waypoints and generates realistic trajectories using the software-in-the-loop PX4 [19]. From this realistic trajectory, the 4D trajectory is constructed as a set of 4D volumes for each segment of the trajectory, as presented in Figure 4. Flight geometry represents the 4D trajectory of the UAS and the protection volume represents the deviation threshold added to the 4D trajectory.

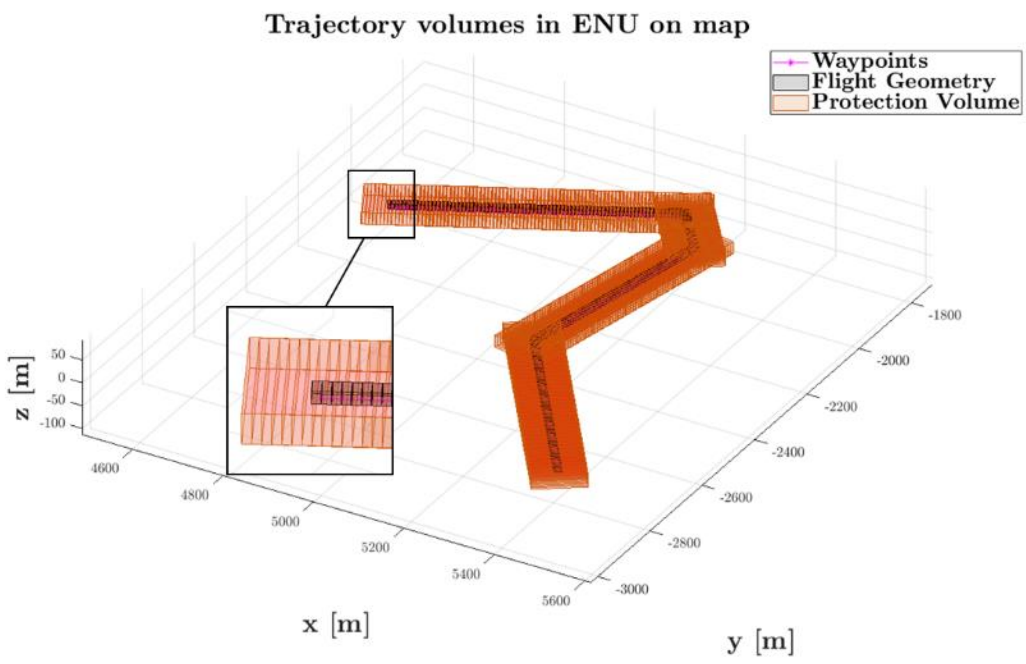

Figure 4: 4D trajectory & deviation threshold/protection volume generated by UPV's tool [17]

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4.8.1.3 CRA simulation platform: BlueSky and AURD

Cranfield University will perform simulations in open-access traffic simulator BlueSky [20] for lightweight Monte-Carlo simulations, and ATM/UTM Research and Development Digital Twin platform (AURD) of Cranfield University for high-fidelity simulation validation. The architecture of AURD platform is shown in Figure 5.

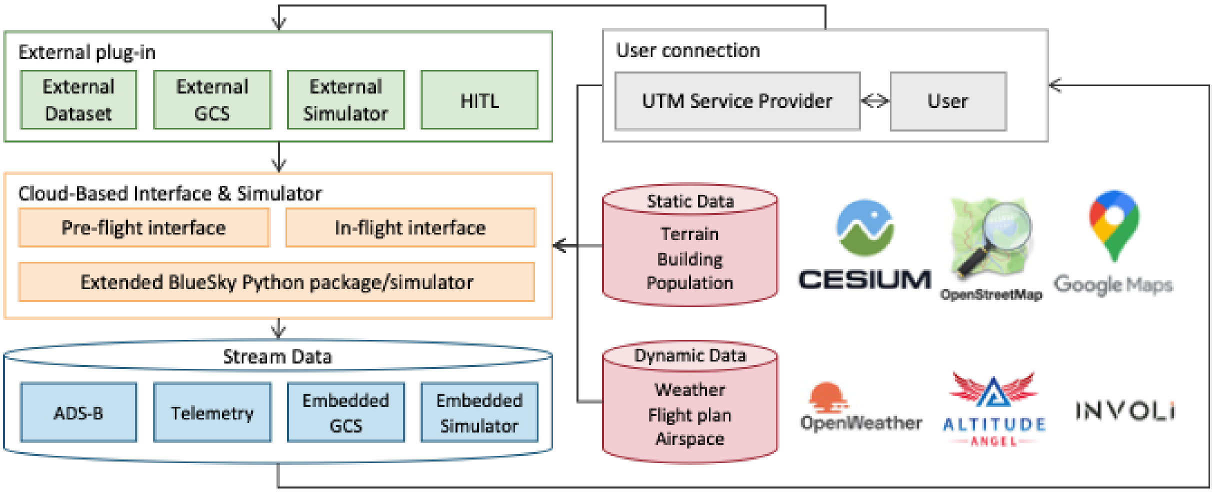

Figure 5: AURD connected with ArduPilot

The traffic simulator uses approximate kinematic models with velocity and heading rates, limited by the maximum vehicle performance data set such as maximum speed, turn rate, and acceleration. Combined with Simulation-In-The-Loop (SITL) noise and disturbance provided by the environment 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 and other constraints for those 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 maneuver to return to the flight plan. Flight operators’ response time to the conformance monitoring is modelled stochastically.

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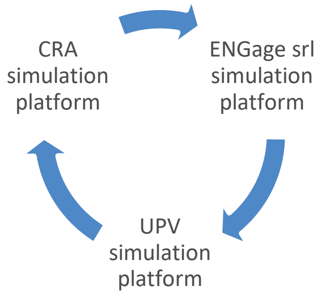

Figure 6: Exercise #01 and #02 validation infrastructure

4.8.2 Validation exercise technique

Simulations are executed using a fast-time technique without human-in-the-loop, to analyse system behaviour under controlled and repeatable conditions. To obtain relevant data from simulations, Monte Carlo trials are conducted.

5 Validation exercises

5.1 Validation exercise 001 plan

5.1.1 Validation exercise description and scope

The first set of validation activities in U-AGREE aims to assess, through simulation, the concept of the *initial* air, ground and collision risk models developed in the previous work packages of the project. The focus for this initial validation exercise is specifically on risk elements that can be mitigated through U-space basic service provision— namely, the strategic Flight Authorisation Service and the tactical Conformance Monitoring and Traffic Information Services, that will be extensively illustrated in paragraph 5.1.4.2.

This first exercise will focus on safety and capacity key performance areas (KPA) and will exploit Monte-Carlo simulations to derive key performance indicators (KPI) related to the abovementioned KPA. The exercise will focus on the three scenarios chosen for the project [7], defined in paragraph 5.1.4. In these, a range of traffic densities, operations, and mitigation strategies will be simulated using fast-time simulation techniques. All inputs data and analysis needed for the exercise are illustrated in paragraph 5.1.8.

Simulations will be conducted in parallel using three U-space platforms developed by: ENGAGE, Cranfield University, and Universitat Politècnica de València. These simulators include models of strategic and tactical mitigation barriers adapted to U-AGREE’s requirements. They also feature extensive environmental datasets, including 3D terrain and building profiles, ground and aeronautical hazard maps, and surveillance inputs (ADS-B data). Each simulator will feature the capability to define and execute realistic UAS trajectories based on high-fidelity vehicle models.

The applicable Technology Readiness Level (TRL) for these initial activities is 2.

This first exercise will contribute to the achievement of the following objectives:

- OBJ-SOL0520-ERP-001: Identification of the baseline capacity (N_0).
- OBJ-SOL0520-ERP-002: Quantification of capacity increment (ΔN_1) because of the introduction of mitigation measures based on Flight Authorization and Traffic Information services.
- OBJ-SOL0520-ERP-003: Quantification of capacity increment (ΔN_2) because of the introduction of mitigation measures based on Flight Authorization, Traffic Information, and Conformance Monitoring (without pre-alerting) services.
- OBJ-SOL0520-ERP-004: Quantification of the capacity increment (ΔN_3) because of the introduction of mitigation measures based on Flight Authorization, Traffic Information, and Conformance Monitoring (with pre-alerting) services.

Within the scope of validation exercise 1, no DAR-related airspace volumes are considered.

Furthermore, when an e-conspicuous manned aircraft not receiving air traffic control instructions enters a U-space airspace, the Traffic Information Service provides information about that aircraft and the responsibility for avoiding collision hazards remains with the UAS operator, in accordance with

Regulation (EU) 2021/664 [5]. This concept is further explained in paragraph 5.1.4.2, detailing the avoidance manoeuvres that will be followed by UAS operators.

5.1.2 Stakeholder's expectations and benefit mechanisms addressed by the exercise

Stakeholder	Involvement	Why it matters to the stakeholder
U-space Service Providers (USSPs)	No involvement	Validations will prove how U-space services play a key role as strategic and tactical mitigation barriers by effectively reducing operational risks and maximizing airspace usage, confirming their ability to manage growing UAS traffic while ensuring compliance with safety requirements.
Regulatory Authorities	No involvement	Validations will prove that the developed risk models reliably meet safety standards, supporting regulators in making informed decisions on managing airspace capacity with increasing UAS traffic.
UAS Operators	No involvement	Results illustrate how the proposed risk models and U-space services contribute to safer, more predictable, and potentially more efficient operations.
Research Community	The entities involved in the validation activities are representatives of this stakeholder category.	Project outcomes contribute to the advancement of research on UAS traffic management and risk modelling, offering new data and validation methods.
Citizens	No involvement	Risk models developed in the project can enable the deployment of UAS based services: medical and goods delivery, infrastructure inspections, etc.

Table 12: Stakeholders' expectations

5.1.3 Validation objectives

The following table provides the validation objectives and the success criteria defined for the first validation exercise of U-AGREE.

SESAR solution validation objective	SESAR solution success criteria	Coverage and comments on the coverage of SESAR solution validation objective in exercise #01	Exercise validation objective	Exercise success criteria
OBJ-SOL0520-ERP-001 Identification of the baseline capacity (N_0).	CRT-SOL0520-TRL2-ERP-001.001, same as paragraph 4.3.	Fully covered	No changes to the SESAR solution validation objective	No changes to the SESAR solution validation success criteria
	CRT-SOL0520-TRL2-ERP-001.002, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-001.003, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-001.004, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-001.005, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-001.006, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-001.007, same as paragraph 4.3.			
OBJ-SOL0520-ERP-002 Quantification of capacity	CRT-SOL0520-TRL2-ERP-002.001, same as paragraph 4.3.	Fully covered	No changes to the SESAR solution	No changes to the SESAR solution

increment (ΔN_1) because of the introduction of mitigation measures based on Flight Authorization and Traffic Information services.	CRT-SOL0520-TRL2-ERP-002.002, same as paragraph 4.3. CRT-SOL0520-TRL2-ERP-002.003, same as paragraph 4.3.		validation objective	validation success criteria
OBJ-SOL0520-ERP-003 Quantification of capacity increment (ΔN_2) because of the introduction of mitigation measures based on Flight Authorization, Traffic Information, and Conformance Monitoring (without pre-alerting) services.	CRT-SOL0520-TRL2-ERP-003.001, same as paragraph 4.3. CRT-SOL0520-TRL2-ERP-003.002, same as paragraph 4.3. CRT-SOL0520-TRL2-ERP-003.003, same as paragraph 4.3.	Fully covered	No changes to the SESAR solution validation objective	No changes to the SESAR solution validation success criteria
OBJ-SOL0520-ERP-004 Quantification of the capacity increment (ΔN_3) because of the introduction of mitigation measures based on Flight Authorization, Traffic Information, and Conformance Monitoring (with	CRT-SOL0520-TRL2-ERP-004.001, same as paragraph 4.3. CRT-SOL0520-TRL2-ERP-004.002, same as paragraph 4.3. CRT-SOL0520-TRL2-ERP-004.003, same as paragraph 4.3.	Fully covered	No changes to the SESAR solution validation objective	No changes to the SESAR solution validation success criteria

pre-alerting) services.				

Table 13: Validation objectives addressed in validation exercise #01

An extensive study was conducted to identify the most suitable performance indicators for these validation activities. It was concluded that the best set of indicators is taken from D3.1, Demonstrations Reference Indicators, of U-ELCOME project [21], with minor adjustments to ensure their feasibility for the U-AGREE project. Other KPI are inspired by the DES Performance Framework U-space Companion Document [2]. These KPIs have been adopted to enable effective quantitative measurement of the expected outcomes and the fulfilment of the success criteria.

The following table presents the Key Performance Indicators (KPIs) calculated in the first validation exercise. As done for the exercise objectives, each KPI is identified by the code U-AGREE-KPI-XX, where:

- U-AGREE refers to the project identifier,
- KPI-XX identifies the performance indicators, with the two digits (XX) that represent the sequential numbering of performance indicators.

This coding scheme ensures clear traceability between KPIs and their corresponding exercise objectives, facilitating validation and performance assessment.

KPA	KPI	Related validation objective	Reference document
Safety	U-AGREE-KPI-01 **Number of NMAC/FH:** This metric counts the number of events where a UAS and a manned aircraft breach the predefined minimum separation distance per flight hour. This also applies to UAS-UAS. The procedure for calculating NMACs in each simulator is described in Paragraph 4.8.	OBJ-SOL0520-ERP-001 OBJ-SOL0520-ERP-002 OBJ-SOL0520-ERP-003 OBJ-SOL0520-ERP-004	Derived from the PI “Number of close UAS and manned aircrafts”, D3.1, Demonstrations Reference Indicators, of U-ELCOME project. [21]
	U-AGREE-KPI-02 **Number of non-conformance events/FH:**		Derived from the PI “Number and ratio of conformance alerts: Number of

	Number of non-conformance events solved with the support of the conformance monitoring service, per flight hour.	OBJ-SOL0520-ERP-003 OBJ-SOL0520-ERP-004	conformance alerts made for each flight to assess the reliability of the conformance monitoring service " [21] and adapted to U-AGREE needs.
Capacity	U-AGREE-KPI-03 **Area drone density:** The maximum number of drone operations which can be accommodated in an area per unit of time, coherently with the TLS desired.	OBJ-SOL0520-ERP-001 OBJ-SOL0520-ERP-002 OBJ-SOL0520-ERP-003 OBJ-SOL0520-ERP-004	New proposed PI, inspired by U.CAP1: "U-space maximum number of drones: The maximum number of drone operations which can be accommodated in a U-space per unit of time.", DES Performance Framework U-space Companion Document [2]. The PI has been adapted to U-AGREE needs. Particularly, "U-space" has been substituted with "area", to consider the exercise 1 reference scenario, in which U-space is not present. Furthermore, in U-AGREE validation activities, the calculated drone density for a given area is coherent with the TLS

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			expected for that area.
	U-AGREE-KPI-04 **Average number of authorised U-plans:** Average number of authorised U-plans within a U-space volume over a period of time.	OBJ-SOL0520-ERP-002 OBJ-SOL0520-ERP-003 OBJ-SOL0520-ERP-004	PI derived from D3.1, Demonstrations Reference Indicators, of U-ELCOME project [21].
	U-AGREE-KPI-05 **Maximum number of authorised U-plans:** Peak number of authorised simultaneous UAS operations within a U-space volume over a period of time.	OBJ-SOL0520-ERP-002 OBJ-SOL0520-ERP-003 OBJ-SOL0520-ERP-004	PI derived from D3.1, Demonstrations Reference Indicators, of U-ELCOME project [21].

Table 14: Performance indicators addressed in validation exercise #01

Furthermore, as detailed in paragraph 5.1.4.2, U-space services act as mitigation barriers within the exercise. These barriers are introduced between accident precursors and their effectiveness in reducing risk is assessed through the calculation of risk ratios [22]:

$$RR_i = \frac{P(Prec_i|B_i)}{P(Prec_i|\overline{B_i})} \qquad \textbf{Eq. 1}$$

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).

5.1.4 Validation scenarios

The scenarios in which exercises will be conducted are [7]:

S1 The city of Benidorm, in Spain, in which Urban U-space operations in uncontrolled airspace have been executed. This area is representative of a densely populated urban area in uncontrolled airspace (class G) and different test flights have been conducted therein in the context of the DSD project U-ELCOME [23]. Both flights below and above the VLL will be considered. When UAS operations take place below the VLL, the ground risk prevails over the air risk. However, when UAS operations take place above VLL, relevant air risk might arise due to the proximity of the nearby Alicante airport, which has a relevant level of traffic.

S2 The city of Manduria, in South of Italy, in which medical transport operations from suburban to urban areas have been conducted in the context of the European Project CORUS-XUAM [24]. This area is representative of a mixed urban-suburban area, and it lies beneath the Zone 3 of Grottaglie CTR, starting at 1,500 ft AMSL and classified as airspace class D. Operations were conducted to transport medical goods with a fixed-wing UA from the Taranto Grottaglie airport to a small private airfield for general aviation, ultralight aircraft, and flight training activities, called AeroTre Airfiled. From this location, the package was split in smaller ones, and one package was onboarded on a multirotor, that performed BVLOS last mile delivery to “Marianna Giannuzzi” hospital, located in Manduria city-center.

S3 The Shannon-Limerick Area, in which U-space BVLOS operations in low-density peri-urban and rural areas within Class-C were conducted as part of the Irish DSD project ÉALÚ–AER [25]. The Shannon–Limerick area is representative of a suburban and sparsely populated rural areas. Part of the Shannon – Limerick location lies within the ATZ of the Shannon international airport (ranging from ground to 5,000 ft AMSL), classified as controlled class C airspace. The rest of the area is uncontrolled class G airspace up to 5,000 ft AMSL, where the Shannon CTA (class C controlled airspace) starts.

Figure 7: Benidorm – U-space operations in uncontrolled airspace scenario over urban areas.

Figure 8: Manduria – U-space operations in uncontrolled airspace over mixed urban and suburban areas.

Figure 9: Shannon–Limerick area - U-space operations in sparsely populated suburban and rural areas within controlled (class-C) and uncontrolled (class G) airspace.

As stated in the Initial Concept Outline D2.3 [26], U-AGREE has developed a risk-based classification of non-segregated traffic operations in U-space airspace, since the risk of an operation depends on the traffic mix present in a given airspace, as demonstrated in WP3. This classification includes open category operations (A1, A2, A3) with increasing risk levels; specific category operations, either under standard scenarios (STS), pre-defined risk assessments (PDRA), or assessed via SORA resulting in SAIL I–VI; certified category operations of type #2 (excluding UAM); and manned VFR flights, including UAM type #3, HEMS, law enforcement, and general aviation.

U-AGREE has identified, based on this risk-based classification, an expected traffic mix for each of these scenarios, distinguishing between operations below VLL and above VLL. The following tables describe the identified traffic mix:

Traffic class	Type	Contribution to the traffic mix [%]		
		Benidorm	Manduria	Shannon - Limerick
Open A1	Multirotor	25.51	2.91	0.00
	Fixed-wing	5.10	0.00	0.00
Open A2	Multirotor	10.20	4.85	4.85
	Fixed-wing	5.10	0.00	4.85
Open A3	Multirotor	10.20	24.23	4.85
	Fixed-wing	5.10	0.00	4.85

PDRA/STS	Multirotor	15.31	19.39	24.23
	Fixed-wing	5.10	0.00	24.23
Specific SAIL I-II	Multirotor	5.10	33.93	9.69
	Fixed-wing	5.10	0.00	9.69
Specific SAIL III-IV	Multirotor	0.00	0.00	6.79
	Fixed-wing	0.00	0.00	2.91
Specific SAIL IV-V	Multirotor	0.00	0.00	0.00
	Fixed-wing	0.00	0.00	0.00
Certified type #2	-	5.10	11.63	0.00
Manned VFR – below VLL	-	3.06	3.06	3.06

Table 15: Projected traffic mix in the identified scenarios (up to VLL)

Traffic class	Type	Contribution to the traffic mix [%]		
		Benidorm	Manduria	Shannon - Limerick
Open A1	Multirotor	25.00	2.85	0.00
	Fixed-wing	5.00	0.00	0.00
Open A2	Multirotor	10.00	4.75	4.75
	Fixed-wing	5.00	0.00	4.75
Open A3	Multirotor	10.00	23.75	4.75
	Fixed-wing	5.00	0.00	4.75
PDRA/STS	Multirotor	15.00	19.00	23.75
	Fixed-wing	5.00	0.00	23.75
Specific SAIL I-II	Multirotor	5.00	33.25	9.50
	Fixed-wing	5.00	0.00	9.50
Specific SAIL III-IV	Multirotor	0.00	0.00	6.65
	Fixed-wing	0.00	0.00	2.85
Specific SAIL IV-V	Multirotor	0.00	0.00	0.00
	Fixed-wing	0.00	0.00	0.00
Certified type #2	-	5.00	11.40	0.00

Manned VFR – below VLL	-	3.00	3.00	3.00
Manned VFR – above VLL	-	2.00	2.00	2.00

Table 16: projected traffic mix in the identified scenarios (above VLL)

5.1.4.1 Reference scenarios

For the reference scenarios, it is assumed that no U-space services are provided within the three scenarios described above. In this configuration, UAS operate freely alongside manned aircraft, without supervision or conflict detection and resolution.

A dataset of flight plans, defined in terms of waypoints and entry times (refer to paragraph 5.1.7 for further information) has been defined for each scenario, starting from the data set of expected operations [26]. From this dataset, each simulator randomly selects a number of flight plans and generates 4D trajectories based on them. Random variations—such as slight adjustments to entry times or trajectory excursions—are applied to reproduce realistic variability in traffic patterns. Excursions are introduced according to the most conservative approach depending on the operational category:

- Open Category A1[4], A2, A3: 1 excursion per 100 flights (10^{-2})
- PDRA/STS and Specific SAIL I to III: 1 excursion per 1,000 flights (10^{-3})
- Specific SAIL IV to V, Certified Type #2, and Manned VFR below VLL: 1 excursion per 10,000 flights (10^{-4}).

During each trial, manned aircraft are also included. Their number is derived from the analysis of historical ADSB data, which provides the typical peak traffic levels for each scenario. This ensures that the interaction between manned and unmanned traffic reflects realistic conditions for the scenario being assessed (methodology for extraction of ADS-B data is illustrated in paragraph 5.1.7). The combined manned and unmanned traffic is then simulated repeatedly until the cumulative simulated flight time reaches a value considered statistically significant for evaluation. The total number of flight hours required for meaningful statistical results cannot be precisely defined in advance, as it depends on the variability observed during initial runs. For planning purposes, a broad range between 10,000 and 100,000 cumulative flight hours is considered. This entire process constitutes one Monte Carlo simulation trial.

Throughout each trial, key performance indicators (KPIs) are continuously calculated to define the baseline performance metrics. To ensure statistical robustness, the Monte Carlo process is repeated multiple times, each time applying different randomized variations of the same flight plans. The typical range considered is 100 to 1,000 independent trials.

[4] A1 UA with a maximum take-off mass, including payload, of less than 250 g and a maximum operating speed of less than 19 m/s are not covered by IR (EU) 2021/664 [5]. Thus, do not require U-space services.

5.1.4.2 Solution scenarios

The solution scenarios enhance the reference ones by introducing basic U-space services acting as mitigation barriers. The services considered are in line with the IR (EU) 2021/664 [5] and the acceptable AMC/GM to the IR (EU) 2021/664 [6], and additional safety measures will also be considered, such as the preliminary infringement alert defined in Solution scenario 2.

The same trajectories used in reference scenarios are re-executed, now under the influence of the proposed mitigation mechanisms. The same key performance indicators are computed to allow direct comparison. Risk ratios, evaluated via Monte-Carlo simulations, are then derived to quantify the effectiveness of the mitigation strategies.

In D2.3, Initial Concept Outline [26], it is illustrated the U-AGREE accident-incident model describing how U-space services are used as mitigation barriers between accident precursors to prevent MACs. Here services are described from an operational point of view.

First, the implementation of each U-space service in the consortium's simulation platforms is described. Then, these services are combined to build the solution scenarios, ensuring alignment with the validation objectives defined for this exercise.

Flight Authorization Service

Flight Authorisation Service serves as strategic mitigation barrier within the U-space framework. It consists of the submission, by the UAS operator to the USSP, of a flight authorisation request, that describes the flight trajectory as a series of one or more 4D volumes expressed in height (base, ceiling), longitudinal and lateral limits, and duration (entry and exit times).

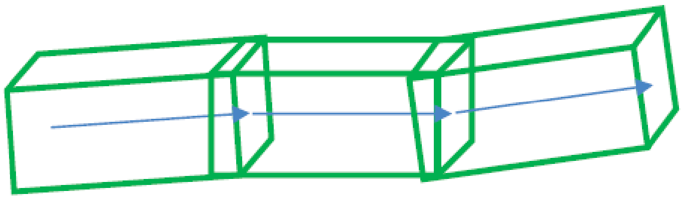

Figure 10: Linear 4D trajectories [7]

Each dimension includes the uncertainties of the flight, e.g. earliest possible entry, latest possible exit [5]. In U-AGREE validation activities the flight authorization service will be implemented following these steps:

- The UAS operator requests the authorisation of the U-plan.
- The USSP checks if:
    1. the submitted trajectory does not conflict with a prohibited (no-fly) geographical zone,
    2. the trajectory in question is free of intersections in space and time with any other notified UAS flight authorisation within the same U-space airspace. The conflict detection is performed considering the planned 4D trajectories of the flights with the deviation thresholds added. These deviation thresholds are defined as *the maximum acceptable deviation from the intended UAS flight path* [5]. They define an additional 4D

volume around each planned 4D volume for a flight and their dimension is defined by Member States, when performing the ARA, to balance the needs of safety with the efficient use of the airspace, and are refined over time, for the U-space airspace under consideration, based on the observed usage of the U-space airspace, the performance (and conformance) of the UAS flights in the airspace, and other factors. In U-AGREE validation activities, deviation thresholds are parametrically evaluated for each scenario. The objective is to identify the dimension of the deviation threshold that satisfies the Target Level of Safety for the airspace under consideration, while preserving adequate capacity. It is expected that the acceptable level of safety may be achieved by having UAS flight authorisation for 4D trajectories that do not intersect and contain their flights for 95 % of the time.

- If all these checks have a positive result, flight authorisation is granted to the UAS operator that requested it, and flight activation occurs immediately after. On the contrary, the USSP:
    - can simply reject the U-plan submitted, guaranteeing that safety is addressed in the U-space,
    - may apply a strategic deconfliction mechanism, proposing to the UAS operator an alternative deconflicted trajectory to be flown or a delay in take-off time, guaranteeing safety and increasing capacity in U-space. The ultimate decision to accept this suggestion rests with the UAS operator.

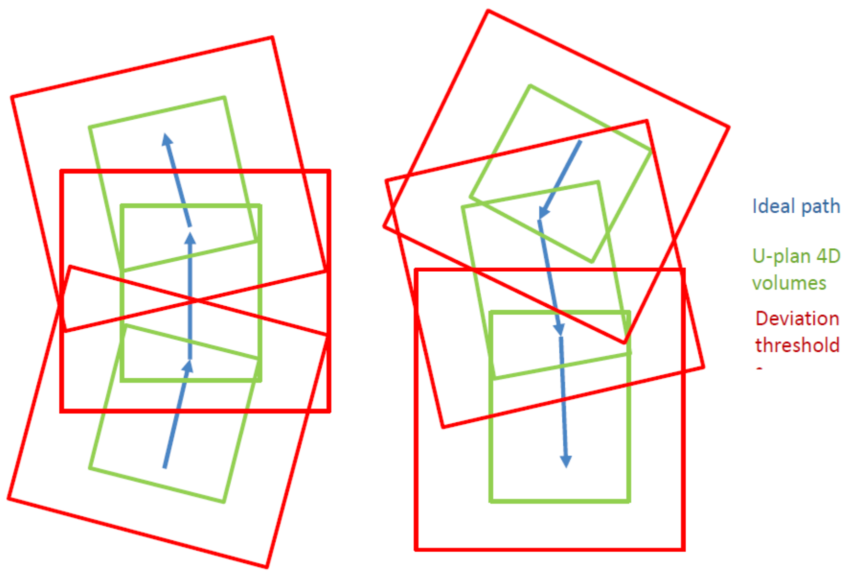

Figure 11: 2D diagram illustrating Deviation Thresholds for two non-conflicting U-plans [7]

In U-AGREE first validation exercise, the Flight Authorisation Service is assessed without the conflict resolution mechanism, where conflicting U-plans are directly rejected.

Authorized U-plans are used to calculate the strategic mitigated frequency of collision ($\lambda^{FAS}{}_{UAS_{NMAC}}$), necessary for risk ratios calculations, and all the KPI defined in Table 14.

Conformance Monitoring Service

Conformance Monitoring Service serves as tactical mitigation barrier within the U-space framework. It is provided as soon as the flight is activated, and it allows the early identification of non-conformance behaviour of the UAS in terms of deviations between its actual trajectory and the approved U-plan. This enables timely corrective actions by the operator. Two types of alerts are simulated:

- Preliminary alert, *optional*. It is provided by the USSP when the UAS flight approaches the boundaries of the authorized 4D volume, to raise awareness of the UAS operator about the potential for infringement and non-conformance.
- Non-conformance alert, *mandatory*. It is provided by the USSP when the UAS is outside the authorized 4D volume, including the deviation thresholds, for more than 5 % of the time as validated over time. To ensure the safety of operations through the timely reaction of UAS operators, the USSP should alert UAS operators within 5 seconds, for 99 % of the time, when a non-conformance is detected.

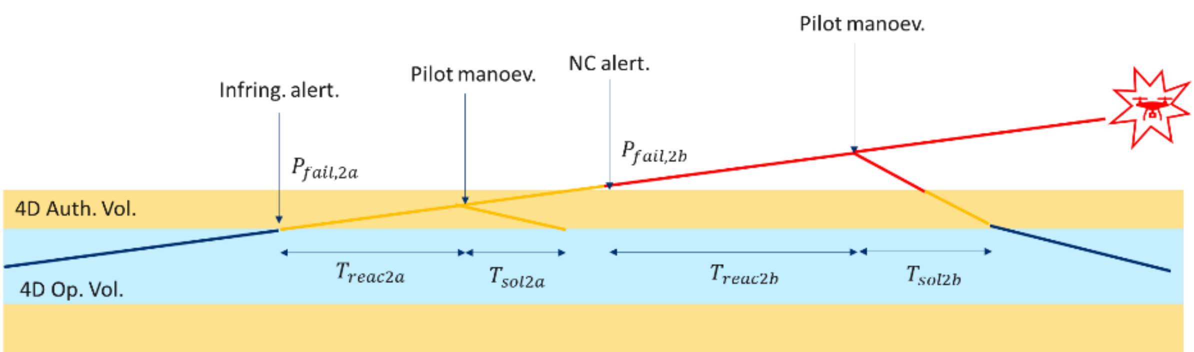

Figure 12: Conformance Monitoring Alert Overview [22]

In U-AGREE validation activities, two operational scenarios are analysed: one with only the non-conformance alert implemented, and another that also includes the preliminary alert. This comparison aims to assess how the presence of a preliminary alert influences pilot behaviour. A high-fidelity representation of pilot behaviour is achieved through a Human Response Model, detailed in Paragraph 5.1.8.1. KPI, defined in Paragraph 5.1.3, are calculated.

Traffic Information Service

Traffic Information Service serves as tactical mitigation barrier. It aims to enhance awareness by providing UAS operators with timely and relevant information about other conspicuous traffic that may be in *proximity* to the position or intended route of the UAS flight; generally, where there could be some risk of collision with the UAS in question. Its provision starts as soon as the flight is activated, and it supports the UAS operator to modify its trajectory to prevent the conflict from escalating into an imminent collision.

Traffic information for vehicles inside the defined surveillance volume (as defined in GM2 Article 11(1)) is assumed to be available to the UAS operator, and any delays in detection, communication, or presentation are inherently considered within the Human Response modelling. This model, illustrated in Deliverable D4.1 [22], and presented in section 5.1.8, accounts for surveillance, separation, communication, responding, and manoeuvring time.

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Traffic information data include position, timestamp, speed, and heading and will be simulated according to traffic patterns that U-AGREE consortium agreed are characteristics of each scenario.

Manned aircraft data, collected by Collins in the representative scenarios (refer to section 5.1.8), are utilized to understand if a potential conflict arises with unmanned traffic.

This information is used by encounter detection algorithms to identify potential proximity[5] events (*encounters*) between the UAS under test and nearby traffic. The estimation process follows two main steps:

1. **Encounter frequency estimation** – The first step is to estimate how often proximity events occur between the UAS under test and surrounding traffic. This is done using the EUROCONTROL *encounter model*, which is based on a purely geometric conflict detection principle: an encounter is registered whenever the relative distance between two aircraft falls within the *encounter thresholds* (also referred to as *close proximity* in Regulation 664 [5]). These thresholds are:

   - UAS–UAS: 1 km lateral, 100 m vertical

   - UAS–manned: 2 NM lateral, 150 m vertical.

   The output of this step is the encounter frequency, i.e., the expected number of proximity events involving the UAS.

- **Unmitigated collision frequency** – In the second step, the set of detected encounters is evaluated to determine how many evolve into near mid-air collisions (NMACs) when no tactical mitigation (i.e., without the Traffic Information Service) is applied. This calculation provides the unmitigated collision frequency, which represents the baseline level of risk before introducing any barrier. In this step (i.e., without the Traffic Information Service), it is considered that UAS operators are not aware of the traffic in proximity and the encounter geometry, if any, even for VLOS operations. Therefore, no avoidance maneuvers are considered.

2. **Mitigated collision frequency** – The final step estimates the reduction of collision risk when the Traffic Information Service (TIS) is available. The simulation is conducted under the assumption that avoidance maneuvers are executed as soon as the encounter is detected allowing the calculation of the mitigated NMAC frequency.

   Current European regulation [5] does not prescribe specific pilot behaviour when traffic information is provided, and the AMCs to Regulation 664 explicitly forbid U-space from providing direct collision-avoidance support, U-AGREE introduces assumptions on priority rules applied by the operator:

[5] For the definition of *proximity,* U-AGREE will refer to the EUROCONTROL *encounter model.*

- If there is a potential conflict with a manned aircraft, the manned aircraft has priority and the UAS operator performs a correction manoeuvre to avoid the conflict;
- If there is a potential conflict with a UAS, the UAS operators apply avoidance manoeuvres. No change of speed or hold position are considered. Instead, the project decided to implement an adapted version of the *Rules of Air*, defined in ICAO ANNEX II [18], originally defined for manned aircraft:
  - *Approaching head-on:* When two aircraft are approaching head-on or approximately so and there is danger of collision, each shall alter its heading to the right.
  - *Converging*: When two aircraft are converging at approximately the same level, the aircraft that has the other on its right shall give way.
  - *Overtaking:* An overtaking aircraft is an aircraft that approaches another from the rear on a line forming an angle of less than 70 degrees with the plane of symmetry of the latter […]. An aircraft that is being overtaken has the right-of-way and the overtaking aircraft, whether climbing, descending or in horizontal flight, shall keep out of the way of the other aircraft by altering its heading to the right, and no subsequent change in the relative positions of the two aircraft shall absolve the overtaking aircraft from this obligation until it is entirely past and clear.

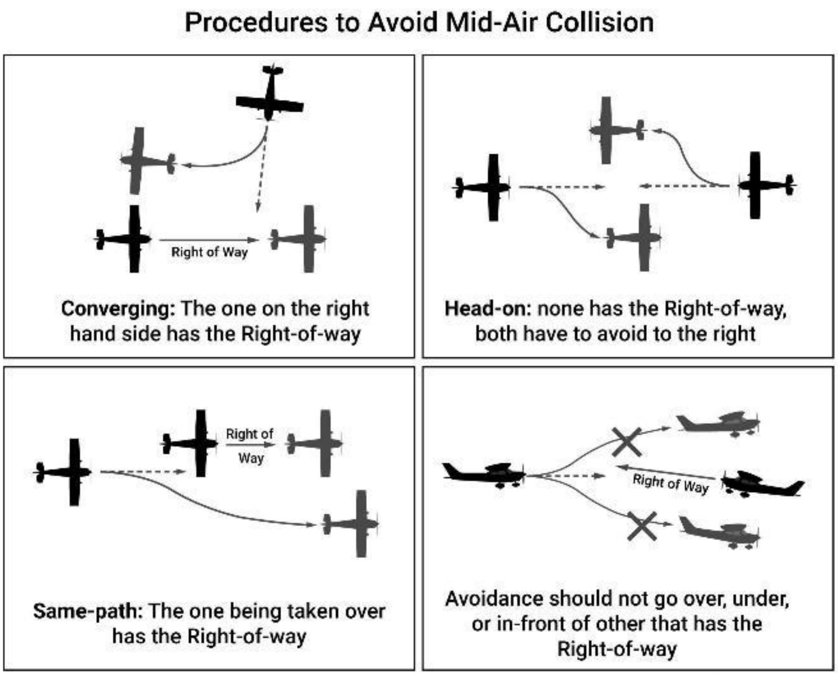

Figure 13: Rules of Air

To realistically represent possible operator reactions, we assume that, when the operator receives traffic information, only a certain percentage of operators correctly interpret the information, recognize the conflict, and apply right-of-way rules to resolve it. Furthermore, it could also happen that avoidance manoeuvres are not effective enough. This probabilistic approach accounts for realistic variability in human performance, including cases where the operator may fail to perceive the information, misinterpret it, or be unaware of the applicable rules of the air. This variability in human behaviour is the most critical factor in determining the mitigated collision frequency, i.e., the residual risk after the Traffic Information Service is applied.

In order to comply with validation objectives, the scenarios presented will be combined to get:

- **Solution scenario 1**: Flight Authorization Service and Traffic Information Service are implemented.
- **Solution scenario 2**: Flight Authorization, Traffic Information, and Conformance Monitoring (without pre-alerting) services.
- **Solution scenario 3**: Flight Authorization, Traffic Information, and Conformance Monitoring (with pre-alerting) services.

To better illustrate how the reference and solution scenarios are executed, Figure 14 presents the methodology adopted for this validation exercise.

The same procedure will be carried out in parallel with the three simulation platforms selected for U-AGREE (ENGage srl, UPV, and CRA simulators).

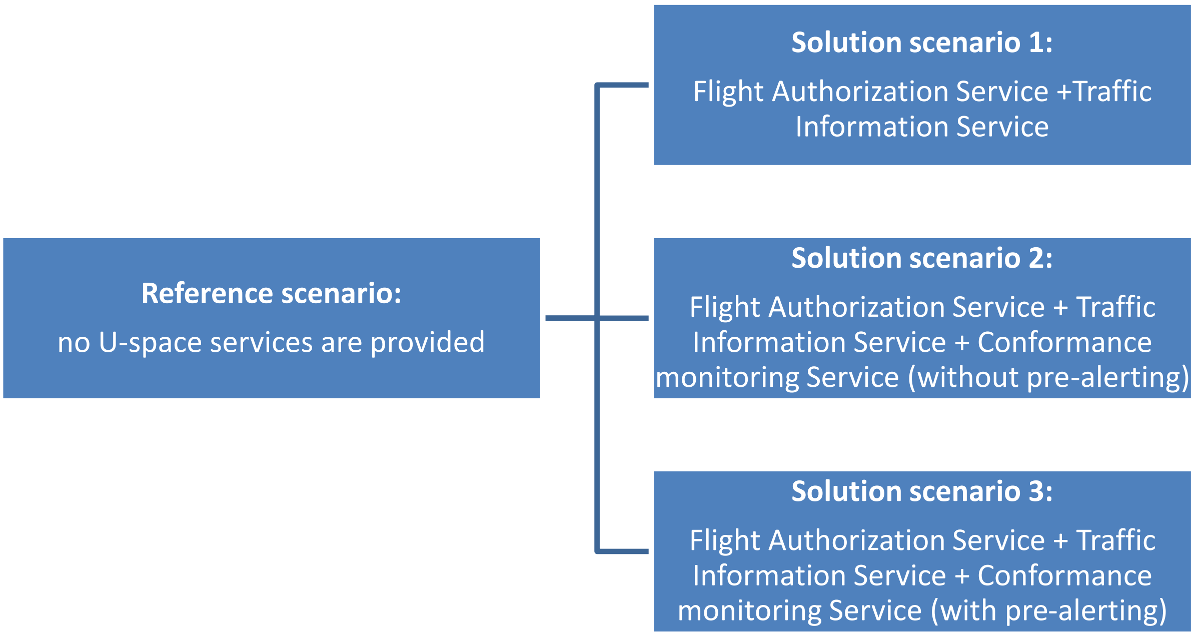

Figure 14: Reference and Solution scenarios for EXE1

5.1.5 Exercise validation assumptions

Adding to the assumptions defined in paragraph 4.4, the following assumption is valid for exercise 1:

Assumption ID	Assumption title	Assumption description	Justification	Impact Assessment
Assumption 05	Dynamic Airspace Reconfiguration affected volumes	DAR affected volumes are not considered in U-AGREE exercise 1.	The implementation of DAR is beyond the scope of the exercise.	The absence of DAR may limit the representativeness of highly dynamic or demand-driven U-space environments.

5.1.6 Limitations and impact on the level of significance

The significance and scalability of the validation results are influenced by several factors related to the design, execution, and assumptions of experimental activities. In particular, the following elements play a critical role in determining the reliability, sensitivity, and validity of the outcomes:

- **Reliability**: This depends on the fidelity and proper calibration of the simulation platforms, as well as the accuracy and representativeness of input data.
- **Sensitivity**: The capacity of the risk models to capture variations in key operational parameters—such as traffic density—has been explored to a limited extent, due to the predefined nature of the scenarios and constraints on the number of simulations performed.
- **Validity**: Results are strengthened through cross-validation across the three independently developed simulation platforms (illustrated in paragraph 4.8), and by the progressive refinement of the risk models between the two validation batches.
- **Scope limitations**: The current validation campaign does not yet account for extreme or degraded service conditions, which may influence the robustness and reliability of the proposed risk mitigation strategies under operational stress.

These factors must be considered when interpreting the outcomes of the validation activities, particularly when assessing their applicability to real-world U-space environments or their extrapolation to broader operational contexts.

5.1.7 Validation exercise platform / tool and validation technique

Validation exercise platforms are outlined in section 4.8.

5.1.8 Data collection and analysis

5.1.8.1 Data and data collection methods

To ensure relevant and comprehensive results from validation activities, numerous inputs are gathered from validation contributors. These inputs include the following:

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- **4D Trajectories**, A dataset of trajectories in the three scenarios of interest are simulated using PX4 autopilot as Software-in-the-Loop (SIL), in terms of waypoints and entry times. To get representative results, UAS trajectories are created applying specific traffic patterns representative of the actual foreseen UAS operations in the scenarios (e.g. medical delivery, critical infrastructure inspections, agricultural purposes), as illustrated in D2.3 Initial Concept Outline [26]. From these trajectories, 4D trajectories are created by adding the deviation thresholds, as defined by regulation. The number of trajectories must be sufficiently large to obtain statistically sound results.
- **Total System Error (TSE)**, defined as deviation of an aircraft's actual position from its desired flight path, both horizontal and vertical [13]. It is composed of:
  - Flight Technical Error (FTE): distance from the estimated position to the intended flight trajectory and it is related to the autopilot’s ability to follow that trajectory.
  - Navigation System Error (NSE): difference between true position and estimated position. It depends on on-board navigation system inaccuracies.
  - Path Definition Error (PDE): difference between the defined trajectory and the intended flight trajectory at a specific point. It depends typically on the quality of the database of terrain as well as the vertical reference to define the altitude/height along the trajectory.
- **Population density maps**, necessary to understand the risks posed to the ground by mid-air collisions between UAS or between UAS and manned aircraft, are retrieved from the open data source Copernicus Global Human Settlement Layer [27].
- **ADS-B data on manned aircraft** Data for the three scenarios is collected from FlightAware to perform air-risk calculations. For each scenario, a geospatial polygon has been defined to delimit the area of interest where UAS operations are simulated. The data, summarized in Table 17, are collected over a one-year period (2024) to capture seasonal variability. Before analysis, the dataset is filtered by altitude, excluding:
  - Manned aircraft operating above 5000 ft AMSL for S1 (The city of Benidorm), given the vicinity of the Alicante airport and the related CTR.
  - Manned aircraft operating above 1,500 ft AMSL for S2 (The city of Manduria), as this altitude marks the beginning of Zone 3 of the Grottaglie CTR, which is classified as Class D controlled airspace.
  - Manned aircraft operating above 5000 ft AMSL for S3 (The Shannon-Limerick Area), where the Shannon CTA (class C controlled airspace) starts.

  After filtering, the remaining traffic is grouped per hour to facilitate further processing.

  Peak traffic data, corresponding to the highest traffic levels observed (typically in summer), are then used for validation activities to test the risk models under the most demanding conditions. In validation activities, the number of simulated manned aircraft is set to the maximum traffic level recorded for each of the three scenarios.

Summary	Field Name	Description
Flight Identifier	Ident	Callsign identifying the flight. Typically, ICAO airline code plus

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		IATA/ticketing flight number, or the aircraft registration.
Latitude	Lat	In decimal degrees, rounded to 5 decimal points
Longitude	Lon	In decimal degrees, rounded to 5 decimal points
Altitude	Alt	Altitude ASL
Report Time	Clock	POSIX epoch format.
Heading	Heading	In decimal degrees

Table 17: ADS-B data from FlightAware

- **Building (sheltering) data** are extracted from open data sources: OpenStreetMap [14] and Copernicus Data [27] offering detailed spatial information on infrastructure relevant for ground risk assessment.
- **Human response modelling** is necessary to simulate the basic U-space services of Conformance Monitoring and Traffic Information one, which serve as mitigation barrier in the first validation exercise. The human response modelling, illustrated in deliverable D4.1 [22], can be subdivided as: surveillance, separation, communication, responding, and manoeuvring. 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 [29], and remote identification methods have more various latency but can be also conservatively set as 2 seconds [30].
  - Separation time includes the time for the human operator to react and execute appropriate actions. The experimental data [31] 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 it is modelled only where the aircraft is not conducting self-separation. The experimental data [32] shows the communication and pilot’s responding time as the mean value of 2.76 seconds with the standard deviation of 1.18 seconds.

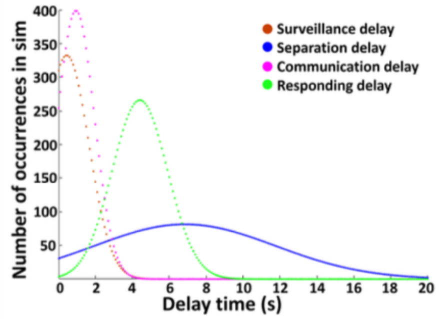

Figure 15: Response time modelling

Summing the probability distributions, we can obtain the mean and standard deviation of the response time, as μ_{RT} and σ_{RT}, respectively.

- **Target level of safety (TLS)** is defined at project level. It is defined as the threshold below which the harmful effect of a hazard is considered acceptable, representing the level of risk that society deems tolerable; when this threshold is exceeded, mitigation measures must be implemented to bring the risk back to acceptable levels. The defined values are:
  - $TLS_{MAC_{ground}} = 10^{-7}$ FAT-FH
  - $TLS_{air,uncontrolled} = 10^{-7}$ MAC/F-H
  - $TLS_{air,controlled} = 10^{-9}$ MAC/F-H.

During simulations KPIs will be collected through Monte-Carlo trials across a range of flight plans, ADS-B data from manned aircraft, and scenarios involving noise and operational disturbances. For each simulated scenario, the mean and standard deviation of the KPIs will be calculated and visualized using box plots to highlight distribution characteristics, including variability and outliers.

Among the defined KPIs, throughput will be directly derived from the simulation outputs, while risk ratios will require post-processing, following the methodology described in paragraph 5.1.3.

5.1.8.2 Analysis methods

To assess how system performance varies with key parameters—such as deviation threshold, human response time, and airspace density—statistical analyses will focus on the trends in the mean and standard deviation of the KPIs across these variables. This approach supports the investigation of whether specific parameter combinations enable the system to meet predefined safety and performance criteria. An example box plot to show the parametric relationship to risk ratio and throughput is shown in Figure 16.

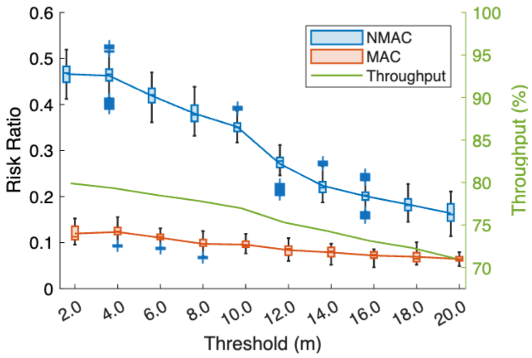

Figure 16: Example Box Plot

The results will further be analysed using multi-dimensional visualisation, by plotting mean values of the KPIs in hyperplanes. This will illustrate the trade-offs between competing objectives, particularly between safety (e.g., low risk ratios) and operational efficiency (e.g., high throughput). This will also enable multi-objective optimisation using Pareto front analysis, helping to identify parameter sets that offer the best balance of performance across different metrics.

5.1.9 Exercise planning and management

5.1.9.1 Activities

The activities foreseen for each exercise include preparatory, execution, and post-execution phase.

5.1.9.1.1 Preparatory activities

The preparatory phase is critical to ensure the successful execution of the validation exercises. The main tasks are as follows:

- **High-level definition of the validation exercise**, including the steps to be undertaken to implement the air and ground risk models and get statistically relevant results.
- **Scenario preparation**, including:
  - Definition of physical and airspace environments.
  - Identification of representative UAS operations in the defined scenarios.
  - Collection of manned aviation activity in the scenarios, using ADS-B data from FlightAware, conducted by Collins.
- **Simulator preparation**, to configure the platforms and implement mitigation barriers, based on basic U-space services.
- **Data collection plan**, defining KPI and parameters to be captured during execution.

5.1.9.1.2 Execution activities

The execution phase consists of:

- Simulation of **unmitigated collision frequencies** to establish a risk baseline.

- Simulation of **mitigated collision frequencies**, applying strategic mitigation (e.g., Flight Authorisation Service), tactical mitigation (e.g., Traffic Information, Conformance Monitoring).
- Data collection in accordance with the plan defined during the preparatory phase.

5.1.9.1.3 Post-execution activities

In the post-execution phase, the results of the simulations are analysed to assess the validation objectives:

- Analysis of the KPIs collected and calculation of the risk ratios in all the scenarios.
- Comparative assessment of unmitigated vs. mitigated risks in the scenarios to quantify the impact of the deployed U-space services.
- Consolidation of outcomes to support performance evaluation.

5.1.9.2 Roles and responsibilities in the exercise

Partner	Role	Responsibilities
CRIDA	Scenario Coordinator	• Coordinate scenarios definition • Define physical and airspace environments • Identify UAS operations in each scenario
ENGage srl	Simulator Owner	• Perform scenario implementation • Configure mitigation strategies • Execute simulations
CRA	Simulator Owner & Data Analyst	• Perform scenario implementation • Configure mitigation strategies • Execute simulations • Lead data analysis post-execution
UPV	Simulator Owner	• Generate trajectories, in terms of waypoints, for the three scenarios • Perform scenario implementation • Configure mitigation strategies • Execute simulations
COLLINS	Data Provider	• Provide ADS-B data using FlightAware

Table 18: Roles and responsibilities in the exercises

5.1.9.3 Time planning

5.1.9.3.1 ENGage srl simulator: Pegasus

Activity	September 2025				October 2025				November 2025			December 2025	
	Week				Week				Week			Week	
	1	2	3	4	1	2	3	4	1	2	3	1	2
Simulator preparation													
Reference scenarios simulations (all scenarios)													
Solution scenario 1 simulations (all scenarios)													
Solution scenario 2 simulations (all scenarios)													
Solution scenario 3 simulations (all scenarios)													
Parameter Analysis													

Table 19: Detailed exercise #01 time planning - ENGage srl

5.1.9.3.2 UPV simulator

Activity	September 2025				October 2025				November 2025			December 2025	
	Week				Week				Week			Week	
	1	2	3	4	1	2	3	4	1	2	3	1	2
Simulator preparation													
Reference scenarios simulations (all scenarios)													

Solution scenario 1 simulations (all scenarios)													
Solution scenario 2 simulations (all scenarios)													
Solution scenario 3 simulations (all scenarios)													
Parameter Analysis													

Table 20: Detailed exercise #01 time planning - UPV

5.1.9.3.3 CRA simulator: BlueSky and AURD

Activity	September 2025				October 2025				November 2025			December 2025	
	Week				Week				Week			Week	
	1	2	3	4	1	2	3	4	1	2	3	1	2
Simulator preparation													
Reference scenarios simulations (all scenarios)													
Solution scenario 1 simulations (all scenarios)													
Solution scenario 2 simulations (all scenarios)													
Solution scenario 3 simulations (all scenarios)													

Parameter Analysis													

Table 21: Detailed exercise #01 time planning - CRA

5.1.9.4 Identified risks and mitigation actions

Risks identified for the exercise are:

Risk	Risk ID	Impact (1-low, 2-medium, 3-high)	Likelihood (1-low, 2-medium, 3-high)	Criticality (calculated based on likelihood and impact)	Mitigation actions
Unavailability of data for the scenarios	3722	3 - High	2 - Medium	6.00	Anticipate data related tasks and activities to secure the required datasets ahead of the validation schedule.
Failure of one simulator to implement the Flight Authorisation Service	3723	3 - High	1 - Low	3.00	Ensure redundancy by having multiple simulators capable of covering the missing functionality if needed.
Failure of one simulator to implement the Conformance Monitoring Service	3724	3 - High	1 - Low	3.00	Ensure redundancy by having multiple simulators capable of covering the missing functionality if needed.
Failure of one simulator to implement the Traffic Information Service	3725	3 - High	1 - Low	3.00	Ensure redundancy by having multiple simulators capable of covering the missing functionality if needed.

Table 22: Exercise #01 risks and mitigation actions

5.2 Validation exercise 002 plan

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5.2.1 Validation exercise description and scope

The second set of validation activities in U-AGREE aims to evaluate, through simulations, the final air, ground, and collision risk models developed during the project. This second validation phase focuses on risk elements mitigated through advanced U-space service provision and builds upon the lessons learned from the initial validation cycle. In particular, the Tactical Conflict Prediction and Resolution service will be implemented as mitigation barriers in the solution scenarios, together with a Strategic Conflict Resolution Service. The detailed implementation and use of these services within U-AGREE will be defined in Deliverable D4.2 Final Barriers Characterisation. Should any differences arise between the service implementations adopted in the validation activities and the description provided in this ERP, these will be fully described and justified in the Exploratory Research Report (ERR).

This exercise addresses four key performance areas (KPA): safety, capacity, security, and environment and Monte-Carlo trials are used to obtain relevant KPIs defined accordingly. The exercise considers the same three scenarios of exercise 1, testing a range of traffic densities, operational conditions, and mitigation strategies, using fast time simulation techniques.

As for exercise 1, simulations are conducted parallelly on the three U- space platforms developed by ENGAGE, Cranfield University, and Universitat Politècnica de València.

The applicable Technology Readiness Level (TRL) for this second validation phase is 2.

This second exercise will contribute to the achievement of the following objectives:

- OBJ-SOL0520-ERP-001: Identification of the baseline capacity (N_0).
- OBJ-SOL0520-ERP-005: Quantification of the capacity increment (ΔN_4) because of the introduction of mitigation measures based on adding a Tactical Conflict Prediction and Resolution services.
- OBJ-SOL0520-ERP-006: Quantification of baseline geographical zone infringements per flight-hour ($\Delta Ninf_0$).
- OBJ-SOL0520-ERP-007: Quantification of the variation in geographical zone infringements per flight-hour ($\Delta Ninf_1$) due to the implementation of mitigation measures based on Flight Authorization service.
- OBJ-SOL0520-ERP-008: Quantification of the variation in geographical zone infringements per flight-hour ($\Delta Ninf_2$) due to the implementation of mitigation measures based on Conformance Monitoring service.
- OBJ-SOL0520-ERP-009: Quantification of the impact of fauna on air risk.

In this exercise, airspace volumes affected by DAR are considered during the flight authorization process as prohibited geographical zones.

Furthermore, when an e-conspicuous manned aircraft not receiving air traffic control instructions enters a U-space airspace, the Traffic Information Service provides information about that aircraft and the responsibility for avoiding collision hazards remains with the UAS operator, in accordance with Regulation (EU) 2021/664 [5]. This concept is further explained in paragraph 5.1.4.2, detailing the avoidance manoeuvres that will be followed by UAS operators.

In this second validation exercise, temporary UAS geo zones are defined to address Key Performance Areas (KPA) related to security and environment. To ensure comparable results, the same geo zones are applied across all simulators within each scenario. Results are normalized by flight hours to ensure comparability. The discussion on how these geo zones are defined is still ongoing at the time of writing this document; full details will be provided in the Exploratory Research Report (ERR).

5.2.2 Stakeholder's expectations and benefit mechanisms addressed by the exercise

Stakeholder	Involvement	Why it matters to the stakeholder
U-space Service Providers (USSPs)	No involvement	Validations will prove how advanced U-space services will contribute to enhance safety and capacity in U-space environments.
Regulatory Authorities	No involvement	Validations will prove that the final risk models reliably meet safety standards, supporting regulators in making informed decisions on managing airspace capacity with increasing UAS traffic.
UAS Operators	No involvement	Results illustrate how the proposed risk models and U-space services contribute to safer, more predictable, and potentially more efficient operations.
Research Community	The entities involved in the validation activities are representatives of this stakeholder category.	Project outcomes contribute to the advancement of research on UAS traffic management and risk modelling, offering new data and validation methods.
Citizens	No involvement	Risk models developed in the project can enable the deployment of UAS based services: medical and goods delivery, infrastructure inspections, etc.
Common Information Service Providers (CISPs)	No involvement	Validation activities rely on accurate geo-zone information assumed to be provided by CISPs, underlining their foundational role in enabling risk-aware flight planning and regulatory compliance.

Table 23: Stakeholders' expectations

5.2.3 Validation objectives

The following table provides the validation objectives and the success criteria defined for the second validation exercise of U-AGREE.

SESAR solution validation objective	SESAR solution success criteria	Coverage and comments on the coverage of SESAR solution validation objective in exercise #01	Exercise validation objective	Exercise success criteria
OBJ-SOL0520-ERP-001 Identification of the baseline capacity (N_0).	CRT-SOL0520-TRL2-ERP-001.001, same as paragraph 4.3.	Fully covered	No changes to the SESAR solution validation objective	No changes to the SESAR solution validation success criteria
	CRT-SOL0520-TRL2-ERP-001.002, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-001.003, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-001.004, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-001.005, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-001.006, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-001.007, same as paragraph 4.3.			

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OBJ-SOL0520-ERP-005 Quantification of the capacity increment (ΔN_4) because of the introduction of mitigation measures based on adding a Tactical Conflict Prediction and Resolution services.	CRT-SOL0520-TRL2-ERP-005.001, same as paragraph 4.3.	Fully covered	No changes to the SESAR solution validation objective	No changes to the SESAR solution validation success criteria
	CRT-SOL0520-TRL2-ERP-005.002, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-005.003, same as paragraph 4.3.			
OBJ-SOL0520-ERP-006 Quantification of baseline geographical zone infringements per flight-hour ($\Delta Ninf_0$).	CRT-SOL0520-TRL2-ERP-006.001, same as paragraph 4.3.	Fully covered	No changes to the SESAR solution validation objective	No changes to the SESAR solution validation success criteria
	CRT-SOL0520-TRL2-ERP-006.002, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-006.003, same as paragraph 4.3.			
OBJ-SOL0520-ERP-007 Quantification of the variation in geographical zone infringements per flight-hour ($\Delta Ninf_1$) due to the implementation of mitigation measures based on Flight	CRT-SOL0520-TRL2-ERP-007.001, same as paragraph 4.3.	Fully covered	No changes to the SESAR solution validation objective	No changes to the SESAR solution validation success criteria
	CRT-SOL0520-TRL2-ERP-007.002, same as paragraph 4.3.			
	CRT-SOL0520-TRL2-ERP-007.003, same as paragraph 4.3.			

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Authorization service.				
OBJ-SOL0520-ERP-008 Quantification of the variation in geographical zone infringements per flight-hour ($\Delta Ninf_2$) due to the implementation of mitigation measures based on Conformance Monitoring service.	CRT-SOL0520-TRL2-ERP-008.001, same as paragraph 4.3. CRT-SOL0520-TRL2-ERP-008.002, same as paragraph 4.3. CRT-SOL0520-TRL2-ERP-008.003, same as paragraph 4.3.	Fully covered	No changes to the SESAR solution validation objective	No changes to the SESAR solution validation success criteria
OBJ-SOL0520-ERP-009 Quantification of the impact of fauna on air risk.	CRT-SOL0520-TRL2-ERP-009.001, same as paragraph 4.3. CRT-SOL0520-TRL2-ERP-009.002, same as paragraph 4.3. CRT-SOL0520-TRL2-ERP-009.003, same as paragraph 4.3.	Fully covered	No changes to the SESAR solution validation objective	No changes to the SESAR solution validation success criteria

Table 24: Validation objectives addressed in validation exercise #02

The following table presents the performance indicators used for the second validation exercise. As in the previous case, risk ratios are calculated to assess the effectiveness of the mitigation barriers.

KPA	KPI	Related Validation Objective	Reference document
	U-AGREE-KPI-01 **Number of NMAC/FH:**	OBJ-SOL0520-ERP-001 OBJ-SOL0520-ERP-005	Derived from the PI "Number of close UAS and manned

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Safety	This metric counts the number of events where a UAS and a manned aircraft breach the predefined minimum separation distance per flight hour. This also applies to UAS-UAS. The procedure for calculating NMACs in each simulator is described in Paragraph 4.8.		aircrafts", D3.1, Demonstrations Reference Indicators, of U-ELCOME project. [21]
	U-AGREE-KPI-02 **Number of non-conformance events/FH:** Number of non-conformance events solved with the support of the conformance monitoring service per flight hour.	OBJ-SOL0520-ERP-008	Derived from the PI "Number and ratio of conformance alerts: Number of conformance alerts made for each flight to assess the reliability of the conformance monitoring service " [21] and adapted to U-AGREE needs.
Capacity	U-AGREE-KPI-03 **Area drone density:** The maximum number of drone operations which can be accommodated in an area per unit of time, coherently with the TLS desired.	OBJ-SOL0520-ERP-001 OBJ-SOL0520-ERP-005	New proposed PI, inspired by U.CAP1: "U-space maximum number of drones: The maximum number of drone operations which can be accommodated in a U-space per unit of time.", DES Performance Framework U-space Companion Document [2].

			The PI has been adapted to U-AGREE needs. Particularly, "U-space" has been substituted with "area", to consider the exercise 1 reference scenario, in which U-space is not present. Furthermore, in U-AGREE validation activities, the calculated drone density for a given area is coherent with the TLS expected for that area.
	U-AGREE-KPI-04 **Average number of authorised U-plans:** Average number of authorised U-plans within a U-space volume over a period of time.	OBJ-SOL0520-ERP-001 OBJ-SOL0520-ERP-005	PI derived from D3.1, Demonstrations Reference Indicators, of U-ELCOME project [21].
	U-AGREE-KPI-05 **Maximum number of authorised U-plans:** Peak number of authorised simultaneous UAS operations within a U-space volume over a period of time.	OBJ-SOL0520-ERP-001 OBJ-SOL0520-ERP-005	PI derived from D3.1, Demonstrations Reference Indicators, of U-ELCOME project [21].
Security **Environment**	U-AGREE-KPI-06 **Number of geozones infringement/FH:** Number of UAS geographical zones	OBJ-SOL0520-ERP-006 OBJ-SOL0520-ERP-007 OBJ-SOL0520-ERP-008	New proposed PI.

	infringements per flight hour.	OBJ-SOL0520-ERP-009	

Table 25: Performance indicators addressed in validation exercise #02

5.2.4 Validation scenarios

The scenarios identified for the exercise are the same as in exercise 1, illustrated in paragraph 5.1.4.

5.2.4.1 Reference scenarios

Since the second exercise builds upon the results of the first one, the baseline scenarios coincide with the solution scenarios of the first exercise, defined in paragraph 5.1.4, in which basic U-space services are provided.

5.2.4.2 Solution scenarios

In the solution scenario, advanced U-space services defined in the CORUS XUAM project [7] are implemented as mitigation barriers. Compared to the first validation exercise, these services provide a more mature and comprehensive set of operational capabilities. The calculation of risk ratios and KPIs follows the same methodology previously adopted, ensuring consistency across assessment phases and enabling direct comparison of results.

In the second U-AGREE validation exercise, the Flight Authorisation Service is implemented together with the conflict resolution mechanism. In this configuration, when conflicting U-plans are detected, alternative deconflicted trajectories are proposed to UAS operators. This setup enables the assessment of how the conflict resolution function contributes to enhancing U-space capacity while ensuring compliance with the Target Level of Safety (TLS). Volumes affected by DAR are considered in the FAS process.

In accordance with validation objective OBJ-SOL0520-ERP-009, wildlife activity is also considered. Geographical zones are defined in areas of intense bird activity and integrated into the Flight Authorisation process. This approach allows maintaining the required safety levels within U-space while addressing environmental performance through the protection of wildlife from potential disturbances caused by UAS operations.

Furthermore, in the solution scenario the Tactical Conflict Prediction and Resolution service acts as key mitigation barrier. It operates in real time to prevent loss of separation and potential NMAC between cooperative UASs in U-space. This function requires continuous, high-fidelity knowledge of aircraft positions within the relevant airspace volume, with frequent updates and quantified accuracy. It interfaces with the Traffic Information Service and—where available—uses intent data from U-plans to improve prediction accuracy. Conflicts are predicted by analysing the current motion parameters of each aircraft and extrapolating their future trajectories. Since both position and velocity data are affected by measurement and modelling uncertainties, the predicted aircraft location is not treated as a single point but rather as a safety volume around the estimated position. The smallest protection layer is the NMAC volume, representing the critical distance at which a near mid-air collision is considered to occur. Surrounding this are three progressively larger protection volumes, each associated with specific alert thresholds and mitigation actions [33]:

- The Collision Avoidance threshold, which triggers immediate onboard collision-avoidance manoeuvres.

- The Separation threshold is safeguarded by tactical conflict detection and resolution services to prevent loss of separation.
- The Tactical Conflict threshold (outermost volume), where the tactical conflict prediction service first detects and addresses potential conflicts.

This layered approach comes from the separation event hierarchy defined in BUBBLES [34]:

- Tactical conflicts are triggered when the tactical conflict prediction detects that the projected trajectories will be closer than a given threshold (i.e., a loss of separation minima) and the time to the loss of separation is smaller than a predefined time (i.e., look-ahead time), which is defined so that the tactical conflict resolution service can avoid the loss of separation with a given probability described in terms of a specific risk ratio. Performance-based tactical conflict thresholds can be defined considering the look-ahead time, the aircraft performance and the applicable CNS and weather conditions. Therefore, a tactical conflict will be triggered when the volumes defined by the tactical conflict thresholds of the involved aircraft overlap, as illustrated in Figure 17.
- Loss of separation corresponds to breaching the separation threshold. Performance-based separation thresholds (or minima) are defined considering the time needed by the tactical conflict resolution service to avoid an imminent collision or a near mid-air collision (depending on whether collision avoidance systems are considered or not) in case of a separation loss, with a given probability expressed in terms of a specific risk ratio.
- Imminent collisions arise when the collision-avoidance threshold is penetrated. The imminent collision threshold is defined, as in the previous cases, from the time needed by the airborne collision avoidance system to avoid the occurrence of an NMAC event in case an imminent collision event happens. Although collision avoidance systems are not U-space services, SORA considers the use of these systems to mitigate air risk

Triggered by prediction alerts, the conflict resolution component issues advisories or mandatory instructions to modify aircraft speed, altitude, or heading to resolve the conflict. Timely and reliable dissemination of these instructions to the UAS pilot or autonomous flight control system is essential.

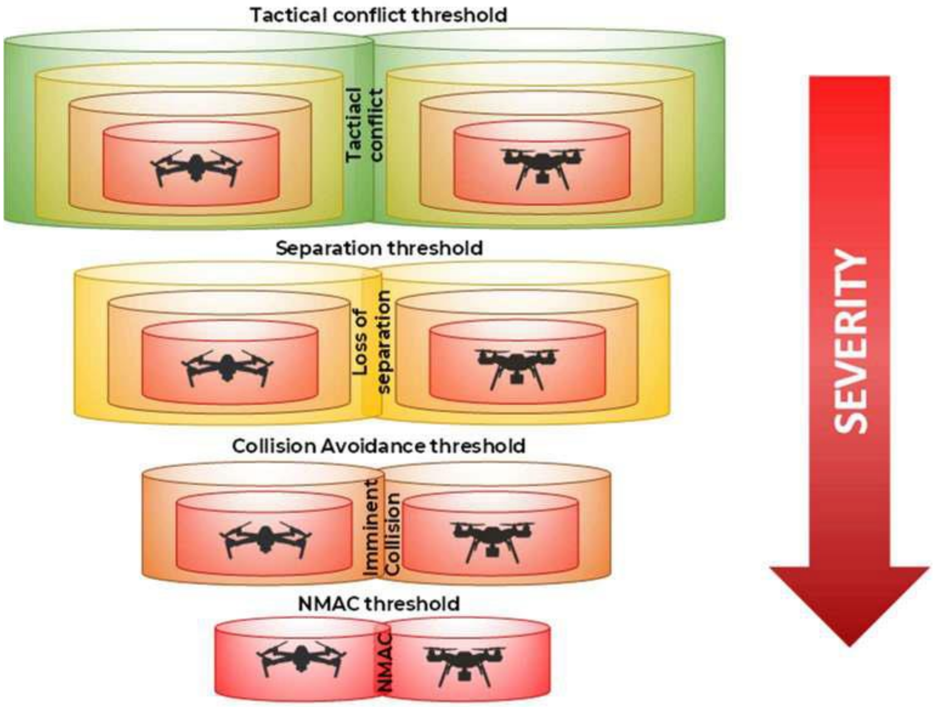

Figure 17: Safety volumes for Tactical Conflict Prediction [7]

The same solution scenario will be carried out in parallel with the three simulation platforms selected for U-AGREE (ENGage srl, UPV, and CRA simulators).

Discussions on the implementation of the Tactical Conflict Prediction and Resolution service are ongoing at the time of writing this document. In particular, the suitability of simulating a single or multiple USSPs, and the implications of this choice on communication and coordination delays, are being evaluated. Details on the approach adopted in the simulations, alongside any differences between what is described in the ERP and what is implemented, will be provided in the Exploratory Research Report (ERR).

5.2.5 Exercise validation assumptions

All validation assumptions are defined in paragraph 4.4.

5.2.6 Limitations and impact on the level of significance

The considerations regarding limitations and their impact on the level of significance are identical to those described for Exercise 1 (see Section 5.1.6). Therefore, no additional elements are introduced for this second exercise.

5.2.7 Validation exercise platform / tool and validation technique

Validation exercise platforms are outlined in section 4.8.

5.2.8 Data collection and analysis

5.2.8.1 Data and data collection methods

Inputs and outputs for the second exercise are identical to Exercise 1 (see section 5.1.8.1).

The only difference stands for manned aircraft ADS-B data: in this second exercise, seasonal data are considered. The exercise considers seasonal variations in risk calculation. The goal is to assess average risk levels and how these contrast with the peak risk.

5.2.8.2 Analysis methods

The analysis conducted on outputs for the second exercise is identical to Exercise 1 (see section 5.1.8.2).

5.2.9 Exercise planning and management

5.2.9.1 Activities

The activities carried out in this second exercise closely mirror those performed in the first (see section 5.1.9.1).

5.2.9.2 Roles and responsibilities in the exercise

This second exercise involves the same participants as the first one, with the same responsibilities (see section 5.1.9.2).

5.2.9.3 Time planning

5.2.9.3.1 ENGage srl simulator: Pegasus

Activity	January 2026				February 2026				March 2026				April 2026			
	Week				Week				Week				Week			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Solution scenario 4 simulations (all scenarios)																
Solution scenario 5 simulations (all scenarios)																
Parameter Analysis																

Table 26: Detailed exercise #02 time planning - ENGage srl

5.2.9.3.2 UPV simulator

Activity	January 2026				February 2026				March 2026				April 2026			
	Week				Week				Week				Week			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Solution scenario 4 simulations (all scenarios)																
Solution scenario 5 simulations (all scenarios)																
Parameter Analysis																

Table 27: Detailed exercise #02 time planning - UPV

5.2.9.3.3 CRA simulator: BlueSky and AURD

Activity	January 2026				February 2026				March 2026				April 2026			
	Week				Week				Week				Week			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Solution scenario 4 simulations (all scenarios)																
Solution scenario 5 simulations (all scenarios)																
Parameter Analysis																

Table 28: Detailed exercise #02 time planning - CRA

5.2.9.4 Identified risks and mitigation actions

Risk	Risk ID	Impact (1-low, 2-medium, 3-high)	Likelihood (1-low, 2-medium, 3-high)	Criticality (calculated based on likelihood and impact)	Mitigation actions
Failure of one simulator to implement Strategic Deconfliction	3726	3 - High	1 - Low	3.00	Ensure redundancy by having multiple simulators capable of covering the missing functionality if needed.
Failure of one simulator to implement Conflict Detection	3727	3 - High	1 - Low	3.00	Ensure redundancy by having multiple simulators capable of covering the missing functionality if needed.
Failure of one simulator to implement the advanced U-space Services.	3728	3 - High	1 - Low	3.00	Ensure redundancy by having multiple simulators capable of covering the missing functionality if needed.

Table 29: Exercise #02 risks and mitigation actions

6 References

6.1 Applicable documents

Content development

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Performance management

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Project and programme management

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Appendix A Safety Assessment Plan and preliminary results

A.1 Methodological approach and scope

U-AGREE will apply EUROCONTROL's E-SRM methodology [35] to the three use cases identified in deliverable D2.3 Initial concept outline [26]. Figure 18 illustrates the three phases that this methodology consists of:

- **Definition phase:** the first set of Safety Criteria (defined in terms of proxies related to mitigation of hazards inherent to aviation) are determined also at that stage from a preliminary safety impact assessment of the change.
- **Specification phase:** the safety specification is derived to meet the safety criteria, and the risk analysis is conducted at this stage. Safety criteria could be refined, and additional safety criteria could be identified in terms of proxies related to operational hazards following the hazard identification and analysis (HAZID).
- **Design phase:** the design phase is relative to the high-level design. The safety assessment and related assurance process will derive safety requirements covering both success and failure aspects to meet the safety specification.

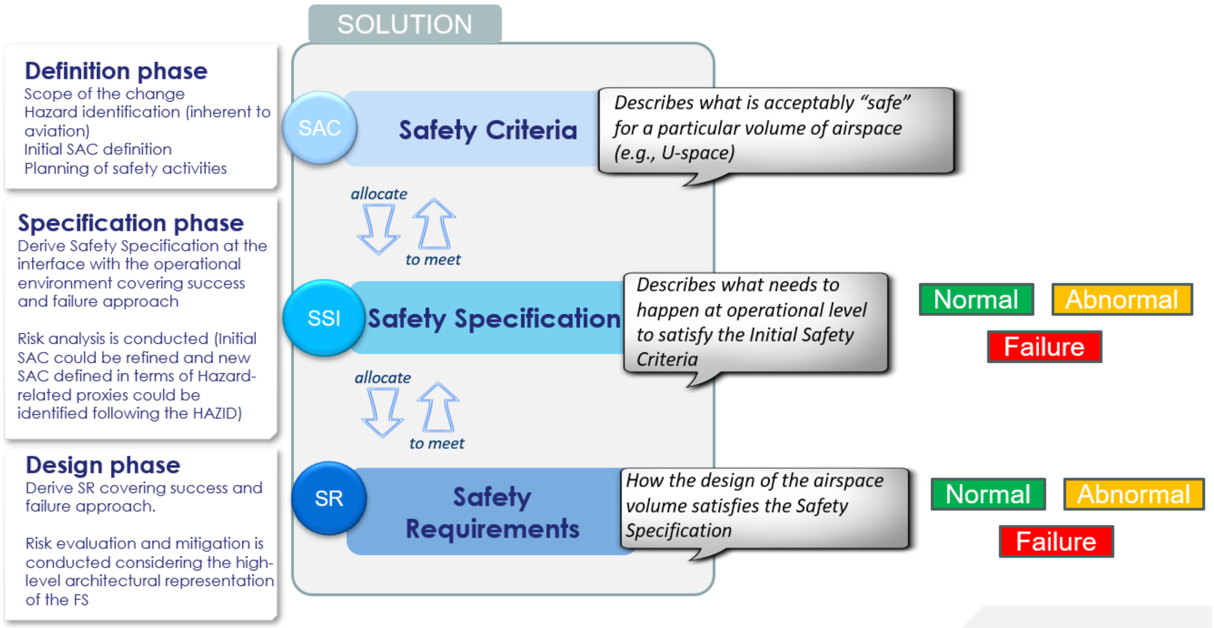

Figure 18. E-SRM method process for the safety assessment in ARA [35]

The E-SRM addresses the impact on safety of any change to the functional system that supports aviation operations. The U-AGREE initial concept outline set out in this document concerns the roll out of U-space services in accordance with Reg. 664. Therefore, the change to the functional system assessed hereinafter consists of the deployment of the bundle of U-space services laid down by that regulation in a scenario where such services were not previously available.

The safety assessment will encompass a broader approach considering safety from two perspectives:

- **First**, the impact on safety of the change to the functional system is assessed under the assumption that it operates as intended. This assessment considers existing hazards inherent to aviation that are affected by the change. *Operating as intended* means functioning under normal or abnormal environmental conditions, but without any failures of the functional system. The objective is to demonstrate that the concept is intrinsically safe in the absence of failures.
- **Second**, the impact on safety of the change to the functional system is assessed under a failure-based approach—that is, by considering any relevant malfunction of the modified functional system. This assessment should address both the new hazards introduced by the change and the existing hazards that may be influenced or exacerbated by it.

The E-SRM approach bases the safety assessment process on Integrated Risk (Accident-Incident) Models, which are composed of mitigation barriers and accident precursors. The ones that have been developed so far by EUROCONTROL in the context of the ARA cover the following:

- MAC (Mid-Air Collision) in U-space airspace within controlled airspace (both manned a/c vs UAS and UAS vs UAS).
- MAC (Mid-Air Collision) in U-space airspace within uncontrolled airspace (both manned a/c vs UAS and UAS vs UAS).
- UAS infringement to controlled airspace from U-space airspace.
- UAS infringement to uncontrolled airspace from U-space airspace.

A.2 Definition phase

According to the procedure detailed in [35] and sketched in Figure 18, the E-SRM definition phase consists of:

1. Scoping for the change.
2. Identifying the hazards inherent to aviation.
3. Defining initial Safety Criteria (SAC).
4. Planning of safety activities.

The next paragraphs describe how the first three steps have been addressed by U-AGREE. Given the expected project maturity, the last step is deemed unnecessary and has been skipped.

A.2.1 Step #1: Scoping the change

UAS operations are conducted without the provision of U-space services. The change consists of the roll out of the U-space services described in Reg. 664. According to the E-SRM, the ARA requires a full safety assessment, covering all the stages shown in Figure 18. However, considering that U-AGREE is indeed a SESAR U-space research project, the extent to which the E-ESRM needs to be implemented depends on the expected maturity of such solution. Being an Exploratory Research project targeting a TRL2, **U-AGREE will limit the safety assessment to the definition and specification phases.**

A.2.2 Step #2: Identifying the hazards inherent to aviation.

U-AGREE carried out the hazard identification process (HAZID) in two stages:

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1. A brainstorming process with the stakeholders gathered in the 1st U-AGREE stakeholders' workshop hosted by EUROCONTROL in Brussels on January 30th led to a first list of hazards identified in the different scenarios discussed in the meeting, compiled in Table 30 - Table 32.
2. A technical meeting of the U-AGREE team hosted by EUROCONTROL in Paris on April 11th, 2025, in which the research team assessed the hazards identified in the stakeholders' workshop and expressed them in the way hazards are described by the ICAO in the Global ATM Operational Concept (GATMOC) [36]. The resulting hazards are listed in Table 33.

Hazard ID	Description
0.1.1	High population density
0.1.2	Presence of critical infrastructure
0.1.3	Manned aviation entry into uncontrolled airspace
0.1.4	Diversity of UAS operations
0.1.5	Urban infrastructure interference (wit CNS)

Table 30: Hazards inherent to aviation identified by U-AGREE in scenario 1 (Benidorm)

Hazard ID	Description
0.2.1	High population density
0.2.2	Presence of critical or restricted areas
0.2.3	CNS limitations
0.2.4	Weather and environmental factors
0.2.5	Interaction with manned aviation

Table 31: Hazards inherent to aviation identified by U-AGREE in scenario 2 (Manduria)

Hazard ID	Description
0.3.1	Presence of critical infrastructure
0.3.2	Weather conditions
0.3.3	Presence of SID sand STARs
0.3.4	MAC with manned aviation activity
0.3.5	CNS infrastructure

Table 32: Hazards inherent to aviation identified by U-AGREE in scenario 3 (Shannon-Limerick)

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Hazard ID	Description
HAZ01	UAS crash into the ground due to a loss of control
HAZ02	UAS crash into the ground due to a MAC
HAZ03	MAC between a UAS and a manned aircraft in uncontrolled airspace
HAZ04	MAC between a UAS and a manned aircraft in controlled airspace
HAZ05	UAS infringement of a UAS geographical zone

Table 33: Hazards inherent to aviation identified by U-AGREE according to the GATMOC

HAZ01 and HAZ02 address the hazard posed by UAS operations to people on the ground, as well as to critical infrastructures. HAZ03 and HAZ04 represent the hazard UAS posed to manned aircraft. HAZ05 covers a broad range of hazards, since UAS geographical zones can be defined by a number of reasons (safety, security, environment and/or privacy).

Since U-AGREE focuses on risks that can be mitigated by means of the provision of U-space services, HAZ01 falls out of the project's scope. In the case of the specific category, this hazard is managed by means of SORA assessments in the specific category, whereas for certified operations the risk is mitigated through the certification process. This risk is considered negligible for operations in the open category. The risk posed by HAZ02 to HAZ05 can be effectively mitigated by using U-space serviced with a given level of performance, as will be discussed later in this document. The way of characterizing the risk posed by HAZ05 is still a matter of research and will not be addressed in this document. The outcomes of the ongoing research on this topic will be integrated into the final risk model (v2) and reported in U-AGREE deliverable D2.4 (Final concept outline).

Notice that there are some hazards related to weather, environment and CNS conditions that were identified during the HAZID brainstorming in the stakeholders' workshop and are listed in Table 30-Table 32, but have no associated hazard in Table 33. The reason for that is because the research team considered in the technical meeting where the conclusions of the workshop were discussed that those hazards were closer to abnormal conditions than to hazards inherent to the aviation. Therefore, based on this assessment, the following initial abnormal conditions were identified:

Ab. cond. ID	Description
ABN01	Adverse weather conditions affect the capability of the UAS to fly the intended trajectory.
ABN02	Adverse communication conditions affect the capability of the remote pilot to control the UAS
ABN03	Adverse GNSS conditions affect the capability of the remote pilot to control the UAS
ABN04	A manned aircraft in state of emergency enters the U-space airspace.

Table 34: Initial abnormal conditions identified by U-AGREE form the outcomes of the stakeholders' workshop

A.2.3 Step #3: Initial Safety Criteria (SAC) definition

U-AGREE defined SAC for each of the hazards listed in Table 33 in the technical meeting held in Paris on the 11th April, 2025.

U-AGREE team proposed those SAC based on the applicable Target Levels of Safety (TLS), which have been used in aviation over decades to express what is agreed as 'acceptably safe'. In the case of UAS, there are several TLS that are already in use in the framework of SORA, addressing both the air risk and the ground risk.

For the air risk, SORA considers two different TLS, depending on whether operations take place in controlled or uncontrolled airspace. In uncontrolled airspace, the air risk $TLS_{air,uc}$ is 10^{-7} MAC/F-H, while for operations in controlled airspace the $TLS_{air,c}$ is set to 10^{-9} MAC/F-H. U-AGREE adopted these TLS as the applicable SAC for HAZ03 and HAZ04, respectively.

For ground risk, the TLS considered by SORA is 10^{-6} FAT/F-H. Ground risk TLS is expressed in different units than air risk TLS because UAS crashing into the ground do not always provoke fatalities, whereas MAC between UAS and manned aircraft are generally modelled as catastrophic events, under the conservative assumption that all occupants of the manned aircraft perish. Moreover, the severity of a UAS ground impact depends on the characteristics of both the involved aircraft (size and speed) and those of the area in which the crash occurs (population density and obstacles' sheltering). An accurate estimation of the number of fatalities per flight hour is, of course, possible. However, such approach would lead to performance requirements specific for each type of MAC involving UAS that would be impractical. Therefore, U-AGREE will derive SAC for HAZ02 in terms of flight-hours applying the ground risk model set out in U-AGREE deliverable D3.2:

$$\lambda_{MAC_{ground}}^{max} = \frac{TLS_{MAC_{ground}}}{\overline{FAT}_{MAC_{ground}}} \qquad \text{Eq. A1}$$

where:

- $\overline{FAT}_{MAC_{ground}}$ is the average expected number of fatalities caused on the ground by any MAC event within that airspace volume.
- $TLS_{MAC_{ground}}$ is the target level of safety for mid-air collisions considering the ground risk. The U-AGREE team has adopted a $TLS_{MAC_{ground}} = 10^{-7}$ FAT-FH, based on the SORA TLS of 10^{-6} FAT/F-H and the discussions with JARUS in the stakeholders' workshop.

$\overline{FAT}_{MAC_{ground}}$ needs to be computed in any scenario where the U-AGREE ground risk model is applied [37]:

$$\overline{FAT}_{MAC_{ground}} = 2\sum_{i=1}^{M} P_i \overline{N}_{FAT_i} \qquad \text{Eq. A2}$$

where P_i represents the contribution of each class to the traffic mix in the corresponding scenario, and $\overline{N}_{FAT_i}$ is the average number of fatalities when a UAS of a given class (namely, class i) crashes into the ground after a MAC. This figure depends on UAS kinetic energy (represented by their critical area, $A_{c_{i,n}}$, computed using the method outlined in Annex F of SORA 2.5 [38]), the population density in the location of the crash ($D_{pop,n}$) and the sheltering effect of buildings and obstacles ($SE_{i,n}$):

The average number of fatalities of a given class of UAS characterised by its size and kinetic energy (i.e., its mass and speed) is computed as:

$$\overline{N}_{FAT_i} = \frac{1}{N_i}\sum_{n=1}^{N_i} D_{pop,n}A_{c_{i,n}} + SE_{i,n} \qquad \text{Eq. A3}$$

The average in Eq. A3 is computed by simulation. A total number of N_i flights representative of class i UAS operations in the specific scenario are simulated using PX4 autopilot as Software-in-the-Loop (SIL) [39] and, at a random position along the trajectory the UAS is assumed to crash into the ground following a ballistic trajectory. To get representative results, UAS trajectories are created applying specific traffic patterns representative of the actual UAS operations in the operational area (e.g., uniformly distributed traffic according to the population density, flights taking off from logistic hubs, corridors joining specific locations such as hospitals or a combination thereof). It is important to note that the number of trajectories must be sufficiently large to obtain statistically sound results.

Finally, with regards HAZ05, there is research work still ongoing, and no definitive conclusion has been reached on the relevance and feasibility of defining a single SAC for this hazard. The conclusions of this work will be reported in the final version of the U-AGREE concept outline.

Table 35 summarises the SACs defined by U-AGREE instantiated in the U-AGREE scenarios that are representative of the relevant sub-operating environments identified by the research team based on the outcomes of the 1st stakeholders' workshop. SACs for HAZ02 have been estimated applying the initial U-AGREE ground risk model outlined in Eqs. 1-3 to these scenarios using data on population density and obstacles gathered by the U-AGREE team from [27]. *This initial assessment does not account for temporal variations of the ground risk (either daily, weekly or seasonal)*. For details on the implementation of the ground risk model, refer to U-AGREE deliverable D3.2 [40].

Scenario	Assoc. HAZ	SAC_ID	Description
1	HAZ02	102	The number of MAC between UAS shall not exceed $4{,}35 \times 10^{-5}$ per flight hour
	HAZ03	103	The number of MAC between UAS and manned aircraft shall not exceed 10^{-7} per flight hour
	HAZ05	105	The number of UAS infringements of UAS geographical zones shall not exceed TBD per flight hour
2	HAZ02	202	The number of MAC between UAS shall not exceed $1{,}5 \times 10^{-4}$ per flight hour
	HAZ03	203	The number of MAC between UAS and manned aircraft shall not exceed 10^{-7} per flight hour
	HAZ05	205	The number of UAS infringements of UAS geographical zones shall not exceed TBD per flight hour
3	HAZ02	302	The number of MAC between UAS shall not exceed $1{,}7 \times 10^{-2}$ per flight hour
	HAZ03	303	The number of MAC between UAS and manned aircraft in uncontrolled airspace shall not exceed 10^{-7} per flight hour

	HAZ04	304	The number of MAC between UAS and manned aircraft in controlled airspace shall not exceed 10^{-9}per flight hour
	HAZ05	305	The number of UAS infringements of UAS geographical zones shall not exceed TBD per flight hour

Table 35: Initial SAC identified by U-AGREE for the relevant hazard in each scenario

A.3 Safey specification

A.3.1 Identification of operational services.

Whenever the projected demand exceeds the baseline or the maximum peak number of simultaneous operations as defined in Annex B, mitigation measures need to be put in place to accommodate it without jeopardising safety. U-AGREE focuses on the mitigation of the risk by means of the provision of U-space services described in Reg. 664.

Reg. 664 designates U-space services as essential enablers for the safe, secure, and efficient integration of UAS into the airspace, particularly in areas with high traffic density or complex operations. Among the services defined in the regulation, U-AGREE identified those relevant to mitigate the risk (i.e., those that can have a safety impact, according to [35]) in D4.1 [22].

- **Flight Authorisation Service – FAS –**, identified as the strategic barrier, ensures that each UAS flight is accepted and activated after performing a detection of conflict between constraints and requirements of the U-space and, with previously approved U-plans.
- **Conformance Monitoring Service – CMS – (optional)**, one of the tactical barriers, alerts the remote pilot in case the flight deviates from its intended trajectory during flight.
- **Network Identification Service – NIS –**, responsible for the exchange of Network Identification reports containing UAS state (position and velocity) and identification data among USSPs.
- **Traffic Information Service – TIS –**, the other tactical barrier, provide alerts to the remote pilot about traffic in close proximity, to help the remote pilot avoid a possible conflict between the UAS and other aircraft (manned or unmanned) in close proximity.

Given that some U-space services will be required only in case they are necessary to achieve the TLS established by the Competent Authorities, and considering that pre-alerting about imminent excursions out of the authorised 4D volume is an optional feature of the CMS, this use case unfolds in three different operational scenarios:

- No CMS
- CMS w/o pre-alerting function.
- CMS with pre-alerting function.

The paragraphs below list the safety specification items (SSI) identified for each of operational scenarios applying the specification phase defined in the E-SRM. SSIs in Table 36-Table 38 have been defined considering the mitigation barriers' models described in U-AGREE deliverable D4.1 [22] and taking into consideration the following assumptions:

A1. Mitigations not based on the provision of U-space services are considered out of the scope of the assessment.
A2. The simplified barriers' models set out in deliverable D4.1 are considered herein, namely:

- Flight activation comes immediately after the flight authorisation, i.e., the continuous check of events that might cause the update or withdrawal of approved flight authorisation requests is out of scope.
- Flight authorisations are no updated or withdrawn either by the initiative of the FAS or because of a UAS operator request.
- The deactivation of the U-space airspace because of a dynamic airspace reconfiguration (DAR) is considered as an airspace constraint (i.e., a UAS geographical zone where UAS flights are not allowed). The transient state in which the DAR is implemented is considered out of the scope of the project.

A3. Flight authorisation requests are processed on a first come, first served base (i.e., no fairness rules or priority policies are applied).

A4. The traffic pattern is considered fixed regardless of the day of the week or the season. Weekly/seasonal fluctuations will be addressed in the final risk model.

A5. Temporal variations of both the ground risk and the air risk are considered out of the scope of risk model v1.

A6. Providence has been assumed equal to 10% (i.e., 10% of MAC end up in a MAC), as a conservative approach, according to [37].

Assumptions A1-A3 are inherent to the limits in time and resources imposed by the nature of the project (fundamental research and outreach). Assumptions A4 and A5 are due to the specific scope of the initial version of the risk model (v1) and will be reviewed in the final risk model. Assumption A6 is a general 1, coming from [41], and will be kept throughout the project lifespan.

SSIs addressing abnormal conditions in Table 34 have not been developed yet and have been identified as a future research item, as well as SSIs in faulty conditions. Safety requirements associated to these SSIs will be developed upon the results of the validation exercises that U-AGREE will run in October-November 2025 and will be integrated into deliverable D5.2.

A.3.2 Safety Specification Items for the Flight Authorisation and the Traffic Information Services

This section addresses the mandatory U-space services identified as mitigation barriers in the U-AGREE deliverable D4.1: **Flight Authorisation Service** and **Traffic Information Service**. Table 36 presents the SSI identified for these services under normal conditions in the identified scenarios. Note that the list in Table 36 is not exhaustive and has been developed considering the assumptions enumerated in section A3.1.

SSI ID	Safety specification item (SSI) *(functionality and performance)*	Related SAC ID	Use case ID & ops activity/ service ID
SSI 001a	The drone operator shall be able to provide the U-plan to the FAS.	SAC#XX	UC-102(a)
	The FAS shall be able to receive the U-plan information for approval from the drone operator.		

SSI ID	Safety specification item (SSI) *(functionality and performance)*	Related SAC ID	Use case ID & ops activity/ service ID
	The FAS shall be able to assign a unique flight ID to the U-plan received.		
	The FAS shall be able to file the information from the received U-plan.		
	The CIS/CISP shall be able to provide to the USSP with the information from U-space (requirements and constraints).		
	The FAS shall be able to receive the information provided by the CIS/CISP.		
	The FAS shall be able to assess the information received by the CIS/CISP and identify possible interactions with the U-plan being processed.		
	The Flight Authorisation Exchange Service (FAXS) shall be able to provide the USSP with the flight identification and operation information from previously approved U-plans from other USSP.		
	The FAS shall be able to receive the U-plans information from the FAXS from other USSPs.		
	The FAS shall be able to assess the U-plans received by the FAXS and the ones approved by themselves and identify possible interactions with the U-plan that is being processed.		
	The FAS shall be able to send the drone operator the information about the acceptance or the withdrawal of the U-plan.		
	The drone operator shall be able to assess the acceptance or the withdrawal of the U-plan.		
	In case the U-plan is accepted, the drone operator shall accept the terms and conditions to confirm the acceptance of the request.		
	In case the drone operator accepts the terms and conditions of the acceptance of the request, the FAS shall be able to update the state of the U-plan to accepted.		

SSI ID	Safety specification item (SSI) *(functionality and performance)*	Related SAC ID	Use case ID & ops activity/ service ID
	In case the U-plan has been withdrawal, the FAS shall be able to update the state of the U-plan to withdrawn.		
	In case the drone operator rejects the terms and conditions of the request, the FAS shall be able to update the status of the U-plan to withdrawn.		
	The drone operator shall be able to request the FAS the activation of the accepted U-plan before starting the flight.		
	The FAS shall be able to receive the request for activation of the accepted U-plan from the drone operator before starting the flight.		
	The CIS/CISP shall provide information to the FAS on traffic of manned aircraft and non-cooperative drones.		
	The FAS shall be able to receive information from the CISP about the traffic of manned aircraft and non-cooperative drones.		
	The FAS shall be able to assess the manned and unmanned traffic information in close proximity to the UAS and identify possible interactions with the U-plan that has requested activation.		
	The FAS shall be able to send the drone operator information about the activation or the withdrawal of the U-plan.		
	The drone operator shall be able to receive notification about the activation of the flight.		
	In case the flight is activated, the drone operator shall be able to initiate the flight.		
	Once in flight, the drone operator shall be able to report the position of the UAS to the NIS.		
	The NIS shall be able to receive the position of the UAS during flight.		
	The CIS/CISP shall be able to provide information about the aircraft in close proximity.		

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SSI ID	Safety specification item (SSI) *(functionality and performance)*	Related SAC ID	Use case ID & ops activity/ service ID
	The TIS shall receive information during flight about the aircraft in close proximity from the CIS/CISP.		
	The Network Identification Exchange Service (NIXS) shall be able to provide the information to the NIS about UAS in close proximity to the UAS.		
	The NIS shall be able to receive the information from the NIXS about UAS in close proximity.		
	The TIS shall be able to provide the traffic information to the UAS operator.		
	The UAS operator shall be able to receive the traffic information from the TIS.		
	The UAS operator shall be able to perform a manoeuvre to avoid any conflict with traffic information in close proximity.		

Table 36. Safety specification items for UC-102(a) considering normal conditions

A.3.3 Safety Specification Items for the Conformace Monitoring Service without pre-alterting capability

This section addresses the CMS when it does not feature the capability of detecting imminent infringements of the authorised 4D trajectory, which is optional according to [6]. Table 37 presents the specific SSI identified for the CMS under normal conditions in the identified scenarios, while SSIs in Table 36 still apply to the other services. Note that the list in Table 37 is neither an exhaustive list and has been developed considering the assumptions enumerated in section A3.1.

SSI ID	Safety specification item (SSI) *(functionality and performance)*	Related SAC ID	Use case ID & ops activity/ service ID
SSI 00Xa	The CMS shall be able to receive the U-plan information (protection volumes) to check whether there is non-conformance.	SAC#XX	UC-102(b)
	The CMS shall be able to detect whether there is a non-conformant of the UAS predicted trajectory and the U-plan information (perform conformance monitoring).		

SSI ID	Safety specification item (SSI) *(functionality and performance)*	Related SAC ID	Use case ID & ops activity/ service ID
	The CMS shall be able to provide the non-conformance information to the Conformance Monitoring Exchange Service (CMXS).		
	The CMSP shall be able to alert the UAS operator of the non-conformance.		
	The UAS operator shall be able to receive the alert about the non-conformance.		
	The UAS operator shall be able to perform a manoeuvre after receiving the non-conformance alert.		
	The CMXS shall be able to provide the information to the USSP about non-conformant UAS.		
	The CMS shall be able to receive information about non-conformant UAS from the CMX.		

Table 37. Safety specification items specific for UC-102(b) considering normal conditions

A.3.4 Safety Specification Items for the Conformace Monitoring Service without pre-alterting capability

This section CMS, including the optional capability of pre-alerting when of the authorised 4D trajectory. Table 38 presents the specific SSI identified for the CMS under normal conditions in the identified scenarios for this use case, while SSIs in Table 36 and Table 37 still apply to the other services as well as to the pre-alerting capability of the CMS. Note that the list in Table 38 is neither an exhaustive list and has been developed considering the assumptions enumerated in section A3.1.

SSI ID	Safety specification item (SSI) *(functionality and performance)*	Related SAC ID	Use case ID & ops activity/ service ID
SSI 00Xa	The CMS shall be able to detect an imminent operation volume infringement while performing the conformance monitoring.	SAC#XX	UC-102(c)
	The CMS shall be able to provide a pre-alerting to the UAS operator about the imminent operation volume infringement.		

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SSI ID	Safety specification item (SSI) *(functionality and performance)*	Related SAC ID	Use case ID & ops activity/ service ID
	The UAS operator shall be able to receive the pre-alert about the imminent operation volume infringement from the USSP.		
	The UAS operator shall be able to perform a manoeuvre to avoid the imminent operation volume infringement.		

Table 38. Safety specification items specific for UC-102(c) considering normal conditions

Appendix B Risk-based estimation of the airspace capacity

B.1 Initial (unmitigated) capacity estimation

The initial SAC previously defined shall be assessed in the operational conditions in the corresponding operational aera to determine whether they are acceptably safe per se. This preliminary assessment will focus on two key performance areas (KPA), namely, safety and capacity. Other KPAs will be addressed in the safety specification phase.

Safety is driven by the SACs defined in Table 35, and capacity is intrinsically interwound with safety since capacity will be given by the number of simultaneous UAS operations that are compatible with the SACs. The baseline capacity (driven by the unmitigated risk) can be improved if appropriate mitigations (in the case of U-AGREE, the provision of U-space services) are put in place. It is relevant to point out here that SACs in Table 35 are stated in absolute terms. This is necessary because they will be used in this initial risk assessment. Once the baseline capacity is identified, SACs shall be reviewed and updated and formulated in a relative way.

The initial risk assessment describe hereinafter is based on the collision risk model described in U-AGREE deliverable D3.3 and on the initial SAC listed in Table 35. The assessment is conducted in each of the operational areas that are representative of each sub-operating environment. Since there are two applicable SAC, there will be two different baseline capacity valued, being the most restrictive the one that must be applied. The following paragraphs detail how these capacity bounds are estimated.

B.1.1 Ground-risk-driven baseline capacity

As demonstrated in U-AGREE deliverable D3.3, there is a linear dependency of the unmitigated collision frequency λ^0_{MAC}, expressed in terms of flight hours, and the number of possible pairs of aircraft in the airspace $(N-1)$, i.e.:

$$\lambda^0_{MAC}(N) = (N-1)\cdot P'_{MAC} \qquad \text{Eq. B1}$$

where P'_{MAC} is a purely scenario-dependent parameter, i.e.:

$$P'_{MAC} = f\left(A, H, M, N_i, g_i, h_i, E'\left[v_{i,j}\right], TSE_{H,i}, TSE_{V,i}\right) \qquad \text{Eq. B2}$$

where:

- M is the number of aircraft classes in the airspace,
- N_i is the number of class i aircraft operating in the airspace per unit of time,
- g_i is the horizontal dimension of class i aircraft,
- h_i is the vertical dimension of class i aircraft,
- A is the area of the surface projected by the UTM airspace on the Earth's ellipsoid,
- H is the height of the UTM airspace (assumed constant),
- $E'\left[v_{i,j}\right]$ is the expected value of the random variable $v_{i,j}$ representing the relative velocity between class i and j UAS, computed among all possible UAS pairs.
- $TSE_{H,i}, TSE_{V,i}$ are the total system error of aircraft class i, i.e., the difference between the intended trajectory and the trajectory actually flown, both on the horizontal plane (H) and in height (V).

Figure 19 illustrates the decomposition of the total system error into three errors contributing components (subindex X represents either H or V) [13]:

$$TSE_{X,i} = 1.2 \times \left(PDE_{X,i} + NSE_{X,i} + FTE_{X,i}\right) \quad \text{Eq. B3}$$

Where:

- $PDE_{X,i}$ is the path definition error, which represents the 95% containment bound of the error between the intended trajectory and the trajectory defined in the aircraft navigation system (e.g., the autopilot). This error mainly depends on the quality of the cartography used by the UAS operator and human errors in the path definition.
- $FTE_{X,i}$ is the flight technical error, which represents the 95% containment bound of the error between the position of the UA and the one on the trajectory defined in the navigation system, and represents the ability of the navigation system/remote pilot to follow the intended trajectory. This error is influenced by weather conditions (especially wind) and the quality of the navigation system or the pilot's skills.
- $NSE_{X,i}$ is the navigation system error, which represents the 95% containment bound of the error between the position estimated by the onboard positioning system and the actual aircraft position. This error is mainly driven by the GNSS position error but can be also affected by the performance of the communication link between the ground control station (GCS) and the unmanned aircraft (UA).

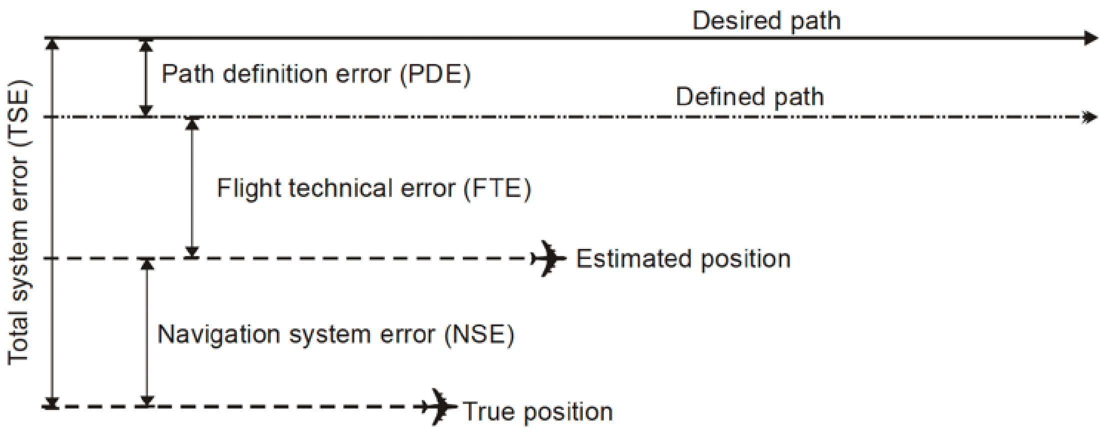

Figure 19. Decomposition of the Total System Error into its contributing components (from [42]).

Since $FTE_{X,i}$ and $NSE_{X,i}$ depend on weather and on GNSS/COM errors, respectively, they emerge as the natural way to account for the initial abnormal conditions defined in Table 34.

Type	PDE_H (m)	FTE_H (m)	NSE_H (m)	PDE_H (m)	FTE_H (m)	NSE_H (m)
Multirotor	0.75	7.05	1.87	4	1.45	3.16
Fixed wing	0.75	4.79	1.87	4	0.17	3.16

Table 39: Nominal values of PDE, FTE and NSE according to [13]

Assuming a constant demand equal to the peak one, the baseline capacity due to the ground risk posed by MACs can then be computed from Eq. B1 as:

$$N_{base}^{ground} = \text{floor}\left(\frac{\lambda_{MAC}^{max}}{P'_{MAC}}\right) + 1 \qquad \text{Eq. B4}$$

where λ_{MAC}^{max} is given by Eq. 1.

Table 40 and Table 41 summarise the baseline capacity computed using Eq. B1 in the operational areas identified by U-AGREE in the light of the SACX02, assuming the traffic mix detailed in Table 15 and Table 16: projected traffic mix in the identified scenarios (above VLL) and considering the TSE the nominal conditions defined in Table 39. However, Since N_{base}^{ground} depends on P'_{MAC}, which is computed in the three scenarios defined by U-AGREE, as part of the validation exercises done in October and November 2025, like Table 40 and Table 41 will also be completed once this parameter is obtained, and the results will be reported in U-AGREE deliverable D5.2.

Scenario	N_{base}^{ground}
1	TBD
2	TBD
3	TBD

Table 40. Baseline capacity in the U-AGREE operational areas representing the different scenarios considering ground risk (U-space designated up to VLL)

Scenario	N_{base}^{ground}
1	TBD
2	TBD
3	TBD

Table 41. Baseline capacity in the U-AGREE operational areas representing the different scenarios considering ground risk (U-space extended above VLL)

Results in Table 40 and Table 41 will be obtained assuming that the number of simultaneous flights remains constant over time. This assumption is acceptable from the safety point of view, but is unrealistic and rather conservative, and can lead to overdemanding requirements.

Assuming the demand fluctuations throughout the day as reported by the project [43], the normalised demand shown in Table 42 can be computed as $\overline{N}_i = N_i/N_p$, where N_i is the number of simultaneous operations during the $i-th$ hour of the day ($1 \leq i \leq 24$) and N_p is the number of simultaneous flights during the peak hour. Both values are assumed to be constant.

ToD	N_i/N_p	ToD	N_i/N_p	ToD	N_i/N_p
00:00-01:00	0.07	08:00-09:00	0.38	16:00-17:00	0.99
01:00-02:00	0.03	09:00-10:00	0.55	17:00-18:00	0.95
02:00-03:00	0.02	10:00-11:00	0.77	18:00-19:00	0.87

03:00-04:00	0.02	11:00-12:00	0.83	19:00-20:00	0.77
04:00-05:00	0.03	12:00-13:00	0.79	20:00-21:00	0.57
05:00-06:00	0.08	13:00-14:00	0.79	21:00-22:00	0.36
06:00-07:00	0.15	14:00-15:00	0.93	22:00-23:00	0.19
07:00-08:00	0.22	15:00-16:00	1.00	23:00-24:00	0.11

Table 42. Normalised daily demand per hour (from [43])

Applying the procedure outlined in the Annex F to the BUBBLES deliverable D2.1 [37], the contribution of the operating aircraft during one single hour to the collision risk is given by:

$$R_i = N_i(N_i - 1) \quad \text{Eq. B5}$$

Introducing the definition of the normalised demand ($\overline{N}_i = N_i/N_p$) into Eq. 8 leads to

$$R_i = N_p\overline{N}_i\left(N_p\overline{N}_i - 1\right) \quad \text{Eq. B6}$$

Next, the contribution of the variation of the traffic during the day on the overall collision risk, $\bar{R}$, is computed as the average of this risk, apportioned among all aircraft operating throughout the day:

$$\bar{R} = \frac{\sum_{i=1}^{24} R_i}{\sum_{i=1}^{24} N_i} = \frac{\sum_{i=1}^{24} \overline{N}_i\left(N_p\overline{N}_i - 1\right)}{\sum_{i=1}^{24} \overline{N}_i} \quad \text{Eq. B7}$$

Finally, $\overline{N}_{eq}$ is defined as the equivalent number of simultaneously operating aircraft associated with the level of risk $\bar{R}$:

$$\overline{N}_{eq} = 1 + \bar{R} \quad \text{Eq. B8}$$

Assuming that the traffic mix remains stable throughout the day, the parameter $\overline{N}_{eq}$ is related to the unmitigated collision frequency as:

$$\lambda_{MAC}^{0}(N) = \left(\overline{N}_{eq} - 1\right) \cdot P'_{MAC} \quad \text{Eq. B9}$$

where the parameter P'_{MAC} is the same as in Eq. 4. Equating Eq. 12 to the maximum allowable collision frequencies $\lambda_{MAC_{ground}}^{max}$ specified in Table 35, and taking into consideration Eqs. B8 and B912, yields:

$$\lambda_{MAC_{ground}}^{max} = \bar{R} \cdot P'_{MAC} = \frac{\sum_{i=1}^{24} \overline{N}_i\left(N_p^{max}\overline{N}_i - 1\right)}{\sum_{i=1}^{24} \overline{N}_i} \cdot P'_{MAC} \quad \text{Eq. B10}$$

where N_p^{max} is the maximum number of simultaneous operations during the peak hour, which can be obtained from Eq.B10 as:

$$N_{p_{ground}}^{max} = \frac{\lambda_{MAC_{ground}}^{max} \sum_{i=1}^{24} \overline{N}_i + \sum_{i=1}^{24} \overline{N}_i \, P'_{MAC}}{P'_{MAC} \sum_{i=1}^{24} \overline{N}_i^2} \quad \text{Eq. B11}$$

Note that the peak flights' number in Eq. B11 depends simultaneously on the scenario characteristics (including the traffic mix), represented by P'_{MAC} and on the temporal distribution of the demand, given by $\{\overline{N}_i\}$, as specified in Table 42, as well as on the ground risk specific of the scenario, expressed as $\lambda_{MAC_{ground}}^{max}$.

Since $N_{p_{ground}}^{max}$ also depends on P'_{MAC}, as N_{base}^{ground}, Table 43 and Table 44 will be completed once this parameter is obtained, like Table 40 and Table 41, and the results will be reported in U-AGREE deliverable D5.2.

Scenario	$N_{p_{ground}}^{max}$
1	TBD
2	TBD
3	TBD

Table 43. Peak number of simultaneous flights in the U-AGREE operational areas representing the different scenarios considering ground risk (U-space designated up to VLL)

Scenario	N_{p}^{max}
1	TBD
2	TBD
3	TBD

Table 44. Peak number of simultaneous flights in the U-AGREE operational areas representing the different scenarios considering ground risk (U-space extended above VLL)

B.1.2 Air-risk-driven baseline capacity

The collision risk model described in U-AGREE deliverable D3.3 enables the computation of the collision frequency between specific classes of UAS. The air risk is driven by the number of collisions per time unit between manned and unmanned aircraft. The results reported in the U-AGREE deliverable D3.3 show that the unmitigated frequency of MACs involving manned aircraft linearly depends on the number of possible pairs manned-unmanned:

$$\lambda_{MAC}^{0}(N) = (N-1) \cdot P''_{MAC} \qquad \text{Eq. B12}$$

where P''_{MAC} is a scenario-dependent parameter similar to P'_{MAC}. Therefore, the baseline capacity due to the air risk is given by:

$$N_{base}^{air,uc} = \text{floor}\left(\frac{TLS_{air,uc}}{P''_{MAC}}\right) + 1 \qquad \text{Eq. B13-a}$$

$$N_{base}^{air,c} = \text{floor}\left(\frac{TLS_{air,c}}{P''_{MAC}}\right) + 1 \qquad \text{Eq. B13-b}$$

depending on whether the airspace is controlled or uncontrolled. In operating environments that comprise both controlled and uncontrolled airspace (like the Shannon-Limerick operational area considered by U-AGREE), the more conservative figure shall be applied.

P''_{MAC} will be also computed in the three relevant scenarios detailed in section 5.1.4 within the validation exercises that U-AGREE will run in September and October 2025. Hence, Table 45 and Table 46 will be completed once those results are obtained. These results will be compiled in U-AGREE deliverable D5.2. In this case, the team will estimate the manned traffic from FlightAware data provided by the U-AGREE partner COLLINS.

Scenario	$N_{base}^{air,uc}$	$N_{base}^{air,c}$
1	TBD	NA
2	TBD	TBD
3	TBD	NA

Table 45. Baseline capacity in the U-AGREE operational areas representing the different scenarios considering air risk (U-space designated up to the VLL)

Scenario	$N_{base}^{air,uc}$	$N_{base}^{air,c}$
1	TBD	NA
2	TBD	TBD
3	TBD	NA

Table 46. Baseline capacity in the U-AGREE operational areas representing the different scenarios considering air risk (U-space extended above the VLL)

As in the case of the ground risk, Eqs. B-13 assumes a constant number of simultaneous flights throughout the day. If the demand fluctuation is taken into consideration in a similar way as it has been outlined for the ground risk, the following expressions bounding the peak number of simultaneous operations in controlled and uncontrolled air space due to the air risk can be derived:

$$N_{p_{air,uc}}^{max} = \frac{TLS_{air,uc}\ \sum_{i=1}^{24} \bar{N}_i + \sum_{i=1}^{24} \bar{N}_i\, P''_{MAC}}{P''_{MAC} \sum_{i=1}^{24}\ \bar{N}_i^2} \qquad \text{Eq. B14-a}$$

$$N_{p_{air,c}}^{max} = \frac{TLS_{air,c}\ \sum_{i=1}^{24} \bar{N}_i + \sum_{i=1}^{24} \bar{N}_i\, P''_{MAC}}{P''_{MAC} \sum_{i=1}^{24}\ \bar{N}_i^2} \qquad \text{Eq. B14-b}$$

Applying Eqs. B14 to the three scenarios defined by U-AGREE that instantiate the relevant sub-operating environments identified by the project, allows for calculating the figures in Table 47 and Table 48, both in the case the U-space is designated up to the VLL or when it is extended above that limit. As in the case of Table 40 and Table 41, and Table 43-Table 46, Table 47 and Table 48 will be completed once P''_{MAC} is obtained in the validation exercises. These results will be reported in U-AGREE deliverable D5.2.

Scenario	$N_{p_{air,uc}}^{max}$	$N_{p_{air,c}}^{max}$
1	TBD	NA
2	TBD	TBD
3	TBD	NA

Table 47. Peak number of simultaneous flights in the U-AGREE operational areas representing the different scenarios considering ground risk (U-space designated up to VLL)

Scenario	$N_{p_{air,uc}}^{max}$	$N_{p_{air,c}}^{max}$
1	TBD	NA
2	TBD	TBD
3	TBD	NA

Table 48. Peak number of simultaneous flights in the U-AGREE operational areas representing the different scenarios considering ground risk (U-space extended above VLL)

B.1.3 Overall baseline capacity

The final baseline capacity (in the case of constant demand) will be identified as:

$$N_{base} = \min\left(N_{base}^{ground}, N_{base}^{air,uc}, N_{base}^{air,c}\right) \quad \text{Eq. B15}$$

while the maximum peak number of simultaneous operations in the case of variable demand will be:

$$N_p^{max} = \min\left(N_{p_{air,uc}}^{max}, N_{p_{air,uc}}^{max}, N_{p_{air,c}}^{max}\right) \quad \text{Eq. B16}$$

Whenever the projected demand exceeds the baseline capacity given by Eq. B15 or the maximum peak number of simultaneous operations given by Eq. B16, mitigation measures need to be put in place to accommodate it without jeopardising safety. U-AGREE focuses on the mitigation of the risk by means of the provision of U-space services described in Reg. 664.