Final Project Report

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R-WAKE

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Copyright Statement

R-WAKE

WAKE VORTEX SIMULATION AND ANALYSIS TO ENHANCE EN-ROUTE SEPARATION MANAGEMENT IN EUROPE

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Abstract

The R-WAKE project has addressed the SESAR 2020 Exploratory Research program topic of Separation Management and Separation Standards (ER-07-2015), within the area of advanced air traffic services, with the main objective of investigating the risks and hazards of wake vortex encounters in the en-route airspace, and identifying potential enhancements to the current separation schemes in order to allow aircrafts to be more closely spaced while keeping or improving the current safety levels, thus aiming at expected benefits in the safety, airspace capacity, and flight efficiency of the European Air Traffic Management System. To enable the investigation a project main goal is the development of an integrated ATM simulation framework covering the simulation of weather, traffic, wake vortex, wake vortex interaction and prediction, and safety and cost-benefit analysis methods and tools.

The main result achieved is an evidence based proposal of wake separation minima adjustments to improve the current en-route separation schemas that takes into account aircraft category and encounter geometry, referred to as the R-WAKE-1 concept, which, following a positive Exploratory to Industrial Research (ER/IR) maturity assessment gate, has been recommended as a new *operational improvement* SESAR Solution to the SESAR programme ATM Master Plan.

This *R-WAKE Final Project Report* provides a summary of the targeted research objectives and scope, work performed, key achievements, conclusions and recommendations in terms of contribution to the ATM Master Plan, maturity assessment of the achievements, and list of further research needs and next steps identified to continue the development and validation of the proposed concept in the ATM research community.

Table of Contents

List of Figures

List of Tables

1 Executive Summary

1.1 Operational/Technical Context – Air Traffic Management (ATM) needs addressed in the project

The dangers of **wake vortex encounters (WVE) in en-route airspace operations** have been traditionally considered negligible, with a very low probability of a severe wake vortex encounter. However, a few significant accidents have occurred in the recent years, thus showing that the level of risk is actually higher than initially thought, e.g., some wake encounters have been reported as severe up to 25NM behind big generating aircraft.

At the same time, the **SESAR program is looking for increasing sector capacities in en-route sectors** to allocate the high-dense air traffic levels that are expected for the next decades. One way to do that is by **reducing the separation minima between flights** in en-route operations (5NM in horizontal and 1000 feet in vertical is applied today for all aircraft types and conditions) which, due to the technological advances in the navigation and surveillance systems, can be considered over-conservative in some cases for some aircraft categories.

The R-WAKE project aimed at **finding more efficient separation schemes** in which all the aircraft can be protected robustly against the risks of WVEs, thus enhancing **safety**, while protecting them no more than necessary so that new opportunities can be identified to increase **airspace physical capacity**. The mid-air collision hazards were also taken into account in the project, though the primary focus was to establish robust safety boundaries to protect flights against WVE hazards.

In addition, the ATM system is expected to experiment **several changes in the next decades that will cause the increase of both the probability of encounters and their severity.** For instance, the **traffic densities** are expected to be much denser than today in certain areas; the **aircraft mix** is going to be more heterogeneous than today too, with larger aircraft sharing airspace with smaller aircraft; and **new concepts of operations** such as free-routing, or continuous climbing and descending operations for all the flight phases may increase the risks of the WVEs hazards in en-route operations. Therefore, a deep **understanding of the WVE hazards by characterizing and quantifying the risks** is highly needed to **improve the safety and efficiency of current and future operations**.

The methodology and concepts developed in R-WAKE can therefore be considered as **paramount for a short-term revision of the current separation standards** and also **a key enabler of the future SESAR 2020+ ATM system**. Future **Trajectory Based Operations (TBO)** could take full advantage of the enhanced knowledge generated by the R-WAKE project to dynamically adapt the separations to the different atmospheric and flight conditions to enhance the safety, capacity and efficiency of the operations.

1.2 Project objectives and approach

Given this background context, the **R-WAKE** project (**"**Wake Vortex Simulation and analysis to enhance en-route separation management in Europe") has been set with the **overall objective** of investigating the **risks of wake vortex encounter (WVE) hazards in the en-route airspace**, and to identify and assess **potential enhancements to the current separation schemes**, aiming to enable operational improvement steps in air traffic and flight trajectory management. The project addresses the SESAR 2020 Exploratory Research program topic ***ER-07-2015 separation management and separation standards****,* in the area of *advanced air traffic services,* as an **application-oriented research with the purpose to cross the exploratory to industrial (ER/IR) maturity gate.**

The project has therefore addressed the following specific **research question**:

> ***'What separation minima reductions can be applied in specific and clearly defined operational conditions to increase airspace capacity while keeping or enhancing the current safety levels taking into account the risk of en-route WVE hazards?'***

To enable the investigation, the project proposed the development of a fast-time simulation-based architecture for dynamic risk modelling, referred as the **R-WAKE System,** to become a key research tool and concept validation means. The R-WAKE System has been used to simulate and characterize the WVE hazard, available in form of simulation databases and concept study scenarios, and used as evidence body to identify and support the targeted new separation enhancement proposals, referred as the **R-WAKE Concept.**

Following an initial definition phase, the project formulated its **specific project objectives** in agreement with SJU in terms of the following five ***tangible expected outcomes***:

- **O1**: Development of a WVE hazard **severity baseline and tolerability matrix**;
- **O2**: Development of a simulator (the **R-WAKE System**) for testing different separation standards;
- **O3**: A public **database of simulation results** that will provide the evidence to support the proposal of new separation schemes; public access may contribute to future R&I activities;
- **O4**: An **evidence-based proposal** for either maintaining current separation standards or adopting new ones (the **R-WAKE Concept**); and
- **O5**: An **assessment of the feasibility and impact of the concept** on ATM with an initial validation strategy and outline implementation plan.

1.3 Work performed and outcomes

The project faced a complex development applying an iterative approach, doing two full iterations (yearly) to the three project work areas, that is: [1] the **target concept research scoping and study approach,** i.e. defining the target-concept to be assessed, its study scenarios, and the required safety study terms and simulation system, [2] the **research system development,** i.e., the integrated simulation toolset and use methodology, and [3] the **research realization,** i.e., execution of the simulations, data analysis, concept development, safety and robustness analysis, and results assessment.

1.3.1 Research scoping and approach

The **target concept research scoping** has been a major topic addressed in the project, since due to the novelty of the topic it was identified the risk of conducting an application-oriented research not pragmatic enough for the purpose of the ER/IR gate. Following the example of the RECAT programme (minima wake separation optimization in airports TMA/approach), **the R-WAKE Concept** was formulated with a **step-wise approach**, as an evolutionary roadmap of changes **starting by the simplest *"static distance-based category-wise separation" concept***, and planning to move forward towards the overall R-WAKE concept idea defined as "***Dynamic Pair Wise Separation (D-PWS) Management to prevent WVE hazards during En-Route Operations***", which is targeting scenarios in the long-term ATM (SESAR 2020+ target concept).

The concepts being explored (research scoping) have been iteratively focussed and narrowed along the project. Following the **project interim mid-term review scoping advises,** the concept development in the second half of the project was pointed at identifying and assessing a first meaningful step of the R-WAKE Concept, labelled as **R-WAKE-1 Concept,** consisting in the development of a new separation scheme as simplified as possible in order to minimize the impact on current ATM systems and methods, and to facilitate as much as possible the potential short-term implementation of the concept and the its smoothest integration into the current system.

The **research approach** was structured in two incremental steps, aligned with the hazard risk assessment terms, i.e., severity and frequency. The overall research approach is depicted in Figure 1-1. Different simulation models were used at each of the steps. In more detail:

- **Research Step-1,** refers to the study of **upsets and severity levels** for a variety of vortex behaviours, aircraft types, and encountering conditions in the upper flight level. The use of high fidelity **micro-level models** was used to simulate the expected of behaviour/upsets of flights in the presence of a WVE, and an **absolute severity baseline** was developed from the simulation results through a qualitative assessment made by professional pilots and air traffic controllers.
- **Research Step-2,** refers to the study of the **hazard risks** in terms of **frequency or repeatability** of the hazardous events, thus assessing the profile of encounter occurrences per severity level. The absolute severity baseline resulted from step 1 was used to categorize each of the WVE found by their severity. To model the uncertainties and to better account for the potential risks, some **macro-level models** were introduced in the simulations.

Following a similar approach as RECAT, it was found appropriate to divide the assessment of risks (i.e., research step 2) into two additional steps:

- **Research Step 2.1:** focused on the assessment of **Conditioned Individual Risk** (**CIR**), that is, the study of the potential risk level supported by a flight that is forced to have a –simulated– WVE under many different conditions that could potentially occur in the real ATM system, in terms of separation distance, encounter geometry, aircraft condition, and atmospheric condition. This approach led to the characterization of the **Suspected Hazard Areas (SHA)** per each pair of aircraft types.
- **Research Step 2.2**: focused on the risk assessment at system level, that is the study of the frequency profile in different airspace regions arising from simulating different traffic patterns. In this case the encounters are not forced as in Step 2.1, but they emerge as a consequence of the (lack of) effectiveness of the risk mitigation layers in the system. The

system can measure the risk at ECAC level, named **System ECAC-wide Risk** (**SER**), and also the risk in particular airspace regions of the system, called **Segregated Airspace Risk** (**SAR**). The **systemic risk is important to compare the effectiveness of different separation schemes understood as risk mitigation elements of the system**. In particular the new R-wake concept separation schemes (*project safety case* in safety terminology) could be compared against the current schemes (*unit safety case* in safety terms).

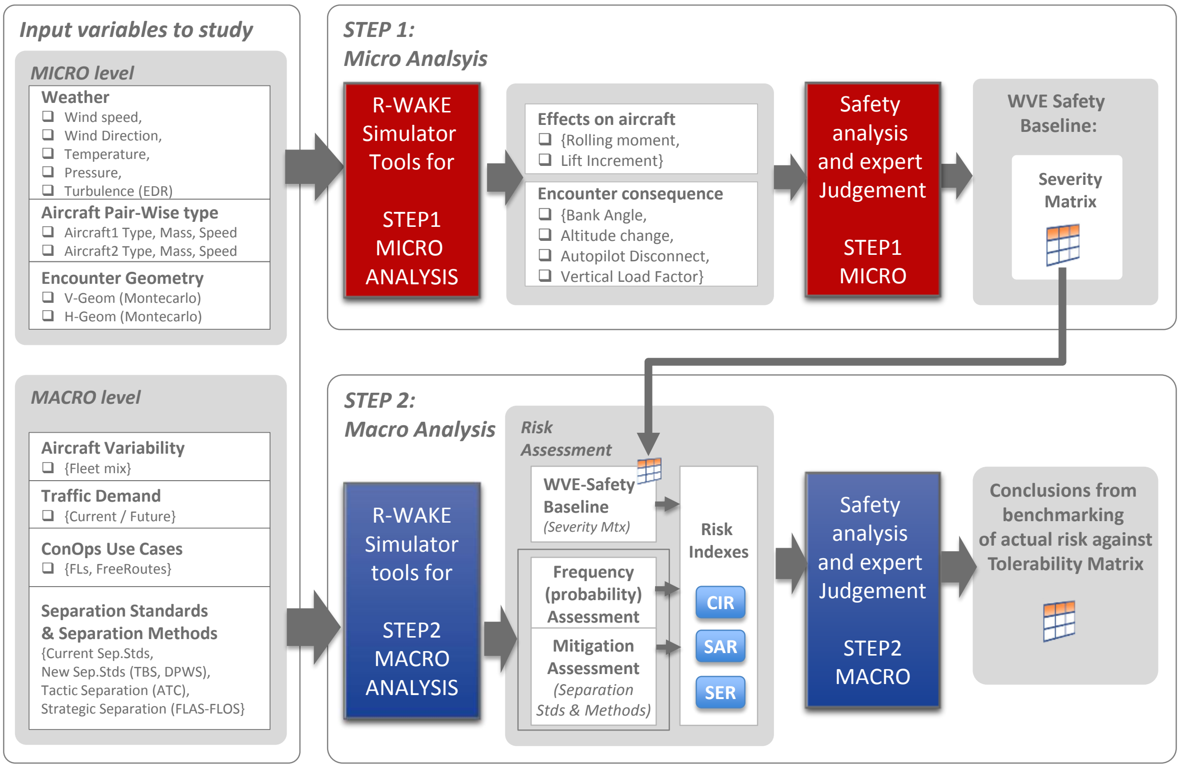


Figure 1-1 R-WAKE Research Approach Steps

The research method was carefully **aligned with the approach developed in the RECAT program**, in order to benefit from the accepted RECAT methodological footprint, an also to facilitate the understanding of the R-WAKE approach in the ATM research community. Both R-WAKE and RECAT share the objective of reducing the *minima wake separation* relying on the advanced assessment of wake vortex hazards for different aircraft types and in specific operating conditions. The En-route context of R-WAKE presented some additional challenges with respect RECAT that deserve to be mentioned, in particular:

- **Higher dimensionality of the encounter geometries and separation options**, as a consequence of the three-dimensional nature of the en-route context. In approach, i.e. in RECAT, the only geometry studied to establish separation was always in-trail, i.e., one flight behind the other, whereas in En-route in can be considered the option to apply space or time separation to either one or both of the aircrafts. In such en-route operating context is much more complex to develop an efficient separation scheme to protect flights of different categories while increasing airspace capacity. Also for the controllers in an en-route dynamic environment is much more challenging to separate traffic if they have to consider different aircraft categories and trajectory geometries, having a complexity factor.

- **Lack of a pre-existing safety baseline reference for minima wake separation En-route.** In the case of RECAT a relative safety criteria could be done due to the pre-existence of ICAO minimum separations specifically designed to protect aircraft against WVE hazards during landing and taking-off operations (distances ranging from 4NM o 8NM depending on the aircraft wake turbulence category). In R-WAKE, due to the lack of a pre-existing separation scheme for en-route that could be considered safe, the development of an absolute risk assessment framework (absolute severity baseline and safety criteria) was required.
- **Different wake vortex behaviours at high altitudes**, due to different atmospheric conditions and lack of ground rebound effects (leading to longer and vertically larger hazard areas); Additional safety distance with respect the current separation standards was identified as necessary in some cases.
- **Different ATM performance improvement drivers** related mainly to the different influence factors of capacity between airports and en-route sectors. In airports the capacity bottleneck is typically the runway, thus reducing the physical separation between aircraft typically leads to an increase of airport capacity and throughput. The limiting factor of airspace throughput for en-route traffic is not always the physical capacity but also the complexity perceived by the controllers and the impact on their workload, which made less trivial how the airspace capacity can actually be increased in en-route airspace. Opportunities to increase flight efficiency were also detected and discussed in R-WAKE.

1.3.2 Research system development

The R-WAKE research system has been architected as a framework of two elements: i) the safety and robustness analysis (SRA) methodology, and ii) the integrated simulation platform (Figure 1-2) The entire framework is fully oriented at the task of providing **quantitative and qualitative evidence to support the development of the safety and business cases**.

The system can generate a body of quantitative evidence by implementing the concept of ***dynamic risk modelling***, widely accepted and used today in the ATM research and practitioner community. This includes the simulation of trajectories, wake vortex encounters and, when necessary, the application of some ATM constraints. The qualitative evidence, including the interpretation of the simulation results, is part of the **R-WAKE safety and robustness analysis (SRA) methodology,** which is **thoroughly aligned with the applicable references** from SESAR and EUROCONTROL, i.e.: the SESAR Safety Reference Material (**SRM**), EUROCONTROL **ESARR4** (Risk Assessment and Mitigation in ATM), and EUROCONTROL **SAM** (Safety Assessment Methodology).

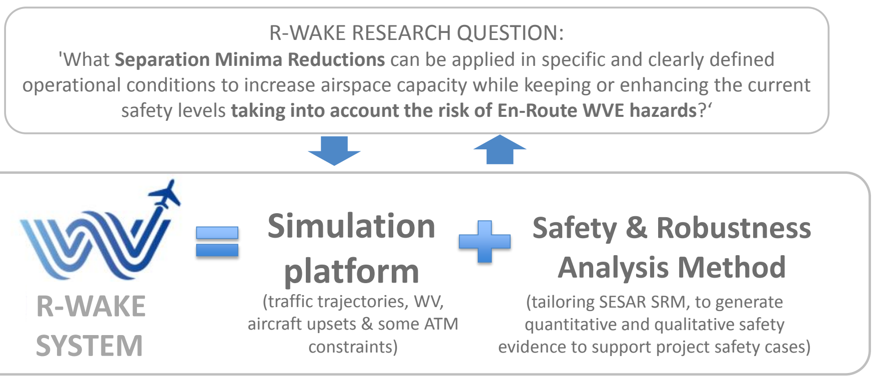


Figure 1-2. R-WAKE System: a framework of safety and robustness analysis method and simulation tools

The R-WAKE system simulation platform includes: 1) a weather simulation (**WXS**) based on historical real met data; 2) an ATM traffic and trajectory simulator (**TRS**), which embeds a high fidelity wake interaction assessment model (**WIAM**) and a wake encounter severity prediction system (**WEPS**); 3) a wake vortex simulator (**WVS**); and 4) a safety and robustness analysis (**SRA**) (including brand-new risk models developed in the project) and methods and tools for a cost-benefit analysis (CBA). Figure 1-3 shows the general architecture.

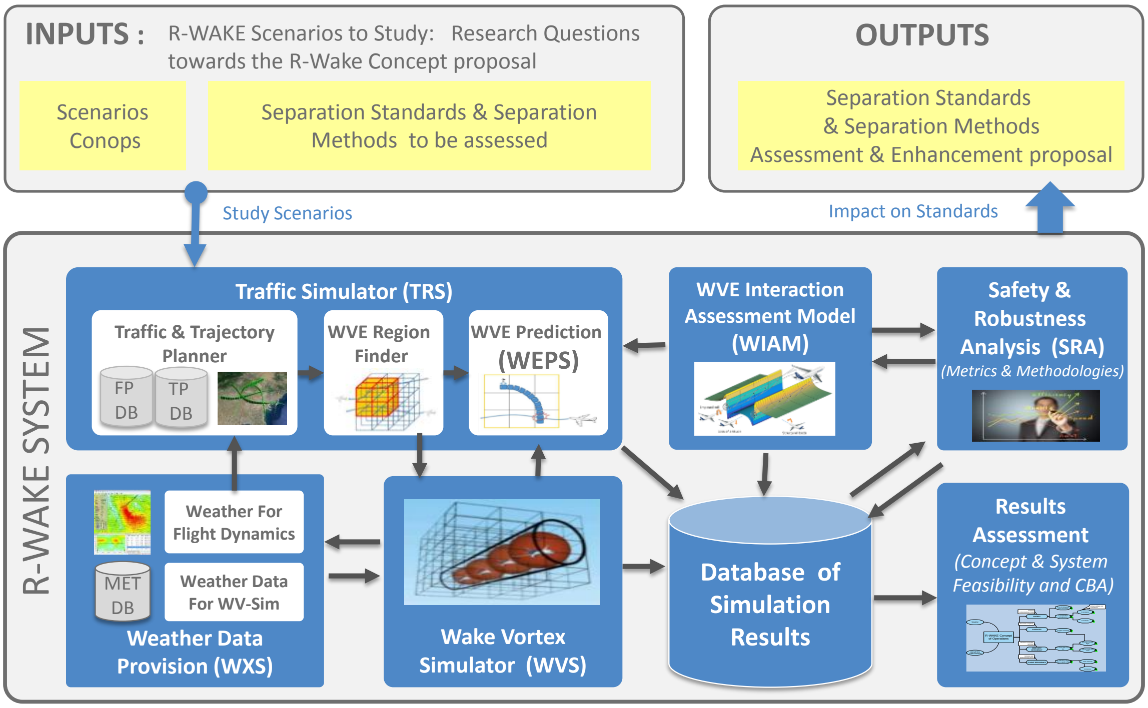


Figure 1-3. R-WAKE System - integrated simulation framework – high level architecture

The R-WAKE simulation platform can be set up in three different configurations, according to three different types of safety studies planned in the research approach:

- **Micro-simulator of upset for the severity baseline study** (referred above as Step 1)**,** based on a new implementation of a *Wake Interaction Assessment Model* (**WIAM**), based on micro modelling of the aircraft wings and 6DoF flight dynamics that react to the air circulation induced by a given wake vortex, thus providing high-fidelity simulations of the consequences of a WVE (upsets). Each WVE simulation case provides 10 seconds of flight data pilot hands free. The scenario can be inspected with an integrated Primary Flight Display (PFD). Such **aircraft upsets can be analysed and categorized according to the severity perceived by the experts** (i.e. pilots and controllers).

- **Macro-simulator of conditioned individual encounters** (Step 2.1)**.** See Figure 1-4. This includes the traffic simulator (TRS) configured to generate specific generator-follower trajectory pairs, the wake vortex simulator (WVS), and the vortex encounter prediction system (WEPS), simulating the upsets suffered by the follower (WIAM), and classifying the severity level according to the severity matrix found in step 1. Such configuration **allows studying the suspected hazard area (SHA)** for a given pair of aircraft under different flight conditions.

- **Macro-simulator of the ATM systemic traffic scenarios** (Step 2.2)**.** This uses the full integrated system in which the traffic simulator (TRS) reproduces ATM traffic scenarios covering specific airspace sectors or even the full European area (ECAC). This configuration allows **quantifying the risk in the system by assessing the frequencies of each type of WVE (dynamic risk modelling approach).**

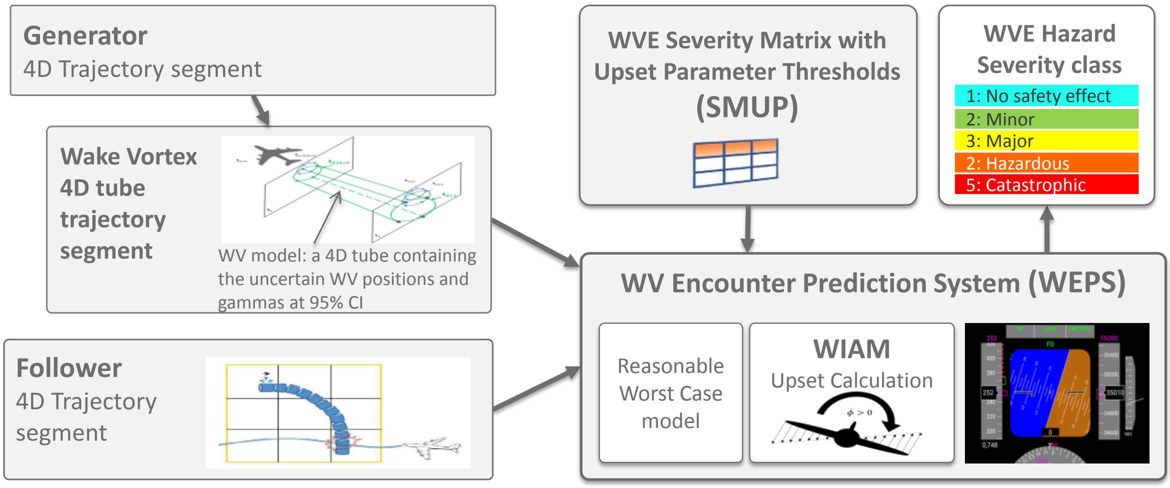


Figure 1-4. R-WAKE system setup to study Conditional Individual Risks (CIR) / Suspected Hazard Areas (SHA)

The <u>**validation of the simulation models and tools**</u> was an important task to ensure the quality and confidence of the research results. It was organised according to three aspects: 1) confidence assessment of the models with reference to calibration data, 2) data appropriateness assessment for the task of safety analysis and experts' judgements, and 3) toolset usability and runtime performance, in order to scope the study of parameters through a design of experiments, which is a highly combinatorial and complex problem. The validation and assessment of the system and models confidence was conducted over three main exercises:

- **Validation exercise of the micro-simulator: WIAM cross-validation against TUBS reference.** The upsets computed with WIAM were thoroughly and satisfactorily cross-checked against those generated with a WIAM baseline tool available at TUBS, which in turn was validated with real flight data in a previous project, i.e. S-WAKE ('Assessment of Wake Vortex Safety'), funded by the European Commission under the FP5 program. The resulting enhanced WIAM implementation represents a kernel component of the R-WAKE simulator system, and a baseline for further extensions (e.g. adding more aircraft models).

- **Validation exercise of the macro-simulator of CIR/SHA: generated CIR/SHA database against EVAIR records.** The CIR/SHA database generated with the macro-simulator (WEPS tool) was cross-checked against 25 real incident records received from the EUROCONTROL Voluntary ATM Incident Reporting (EVAIR) (the 25 set was selected by best data quality from a set of 203 records corresponding to a 4 year period of EVAIR reporting). Despite of finding a large uncertainty in the data due to the low accuracy of the available EVAIR records, in terms of location and upset information, it could be concluded that the simulated CIR/SHA data was congruent with the data in the 25 EVAIR records.

- **Validation exercise of the macro-simulator of ATM airspace/ECAC traffic scenarios (full integrated system): WVE frequency measurement (count) test versus EVAIR records**.
  This exercise reproduced the historical ECAC-wide traffic-trajectories corresponding to a subset of EVAIR records, using the related historical MET data procured from Meteo France for higher scenario fidelity, and assessing the potential findings by the system of the EVAIR historical cases, or other possible VWE cases or false alarms. The approach was tested for one EVAIR record, for which 4 hours of historical trajectories ECAC-wide retrieved from EUROCONTROL (DDR2 files) were simulated. The system reproduced the 6,323 flights available in the historical scenario, detected 20,534 candidate encounters to be within a vortex habitation area of 25NM and 1500 feet, confirmed 997 candidate encounters to be within the computed wake vortex trajectory envelop, and finally 2 of the upset candidates were classified as severity class 2 (minor), and the rest as class 1 (no-effect). The exercise demonstrated the capability of the full R-WAKE simulator to process large traffic scenarios and to count the number of WVE occurrences (frequencies) as a measure of risk, which is considered a proof-of-concept of the R-WAKE system as a tool to perform ATM systemic risk assessments. Due to the low level of detail and accuracy of the flight trajectory and EVAIR historical records, further validation exercises are necessary to complete the validation.

The overall conclusion of the R-WAKE system validation exercises was two-fold:

1. The upset micro simulation (WIAM) and CIR/SHA macro-simulation has reached a **reasonable confidence level** in with respect the concept development **pre-V1 phase**.
2. A **need was identified for collecting and consolidating a larger number of real WVE data** in order to further validate the risk models and increase their confidence level. In particular, real flight measurement data of induced WVEs would be paramount at some stage, as well as a better reporting of the en-route wake incidents, e.g., increasing the resolution and accuracy of some of the descriptor parameters recorded in EVAIR.

1.3.3 Research Realization: simulations, analysis, concept development, and results assessment

The design of experiments aimed at generating the knowledge and evidence required in the project while minimizing the massive combinatorial problem of exploring all the parameters.

The **realization of research step 1** (upset and severity baseline with WIAM tools) produced an upset characterization database with 23.328 scenarios, after combining study parameters of the vortex objects and the encountering aircraft. A representative subset of 12 upset scenarios was selected and assessed by experienced pilots and air traffic controllers, leading to the establishment of the ***R-WAKE absolute severity baseline*** in the form of a ***severity matrix of upset parameter thresholds*** (labelled **SMUP**). With the SMUP any WVE encounter can be classified into 5 severity levels (1-no-safety-effect, 2-minor, 3-major, 4-hazardous, and 5-castastrophic) as a function of the maximum upset generated in the following parameters: 1/ bank roll, 2/ altitude loss, 3/vertical speed change, 4/true airspeed change, and 5/ load factor. The resulting SMUP represents a tangible research outcome of the project, and is also the kernel model integrated in the macro-simulator to classify the WV encounters detected according to their severity (absolute safety criteria).

The **realization of research step 2.1** (CIR/SHA database with TRS-WVS-WEPS tools) simulated 583.632 scenarios and delivered the corresponding database of upsets classified by their severity class. The scenarios considered different aircrafts types, geometries, and atmospheric conditions, and the upsets were calculated within a longitudinal-vertical grid of separation points covering the full wake vortex hazard area. Such CIR database represents a 3D map (4D indeed, since time-based is also considered) of the WVE suspected hazard areas (SHAs) –see Figure 1-5–, which enable the condition-wise identification of currently over-protected cases (opportunities for minima reduction), and the discovery of under-protected cases with respect the current separation standards that may need of a separation minima increase. An outcome data sample is shown in Figure 1-6 with a screenshot of the R-WAKE simulation database CIR/SHA viewer tool. Such tool has been developed and made public to facilitate the exploration and analysis of the Suspected Hazard Areas database. Figure 1-7 shows another way to visualize a SHA, formatted to explore the longitudinal-vertical Minimum Wake Separation (MWS) in a category-wise matrix, and highlighting the opportunities found for separation reduction (green-shadowed cells) or the needs detected for separation increase (red-shadowed cells).

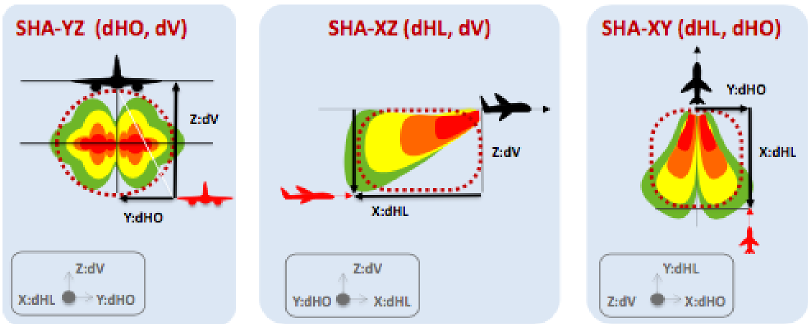


Figure 1-5. Risk Maps of Reasonable Worst Case (RWC) - Suspected Hazard Area (SHA) per Severity Class

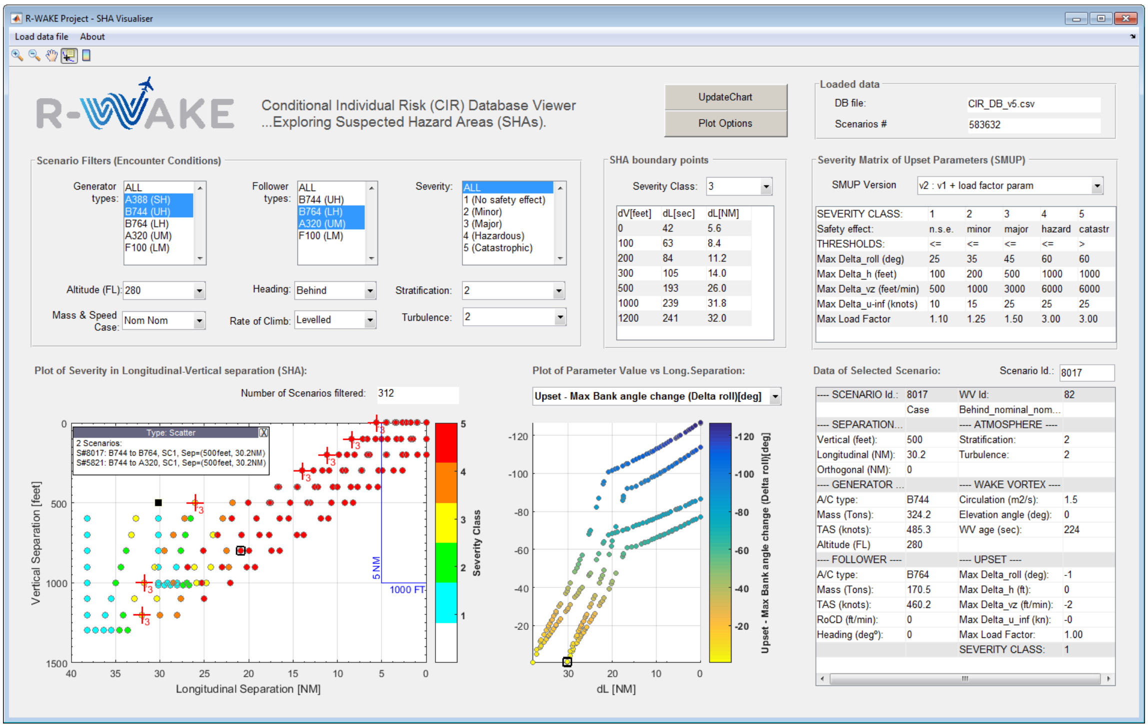


Figure 1-6. R-WAKE simulation results database: CIR/SHA data exploration tool

Simulation database: SHA-1

Green indicates opportunity for reduction

Red indicates need for increase

Relative heading = **Behind**

Protection against: **Severity 3 (Major)**

Some observations:

- **Cat A require in all the cases an increase in longitudinal and vertical distances**
- **Vertical separation below a Cat D or Cat E (Cat RC in R-WAKE-1) could be reduced up to 500 ft**
- **Longitudinal separation behind a Cat C, Cat D or Cat E could be reduced up to 3 NM or less**

R-WAKE MWS – Category-wise Minimum Wake Separation per Altitude

Severity Class	3	Generators conditions		Follower conditions	
Stratification	2	Altitude	FL280	Heading	Behind
Turbulence	2	Mass&Speed	Nominal	RoCD	levelled

GENERATORS

FOLLOWERS	Cat A (SH)			Cat B (UH)			Cat C (LH)			Cat D (UM)			Cat E (LM)		
	VERT	LONG		VERT	LONG		VERT	LONG		VERT	LONG		VERT	LONG	
	feet	sec	NM	feet	sec	NM	feet	sec	NM	feet	sec	NM	feet	sec	NM
Cat B (UH)	0	42	5,6	0	33	4,4	0	21	2,7	0	21	2,5	0	18	1,9
	100	63	8,4	100	53	7,1	100	39	5,0	100	46	5,4	100	49	5,1
	200	84	11,2	200	73	9,8	200	59	7,6	200	95	11,1	200	69	7,2
	300	105	14,0	300	94	12,7	300	100	12,9	300	88	10,3	300	69	7,2
	500	151	20,1	500	162	21,8	500	101	13,0	400	94	11,0	300	69	7,2
	1000	214	28,4	900	180	24,3	600	113	14,6						
	1200	226	30,0												
Cat C (LH)	feet	sec	NM	feet	sec	NM	feet	sec	NM	feet	sec	NM	feet	sec	NM
	0	42	5,6	0	33	4,4	0	21	2,7	0	21	2,5	0	18	1,9
	100	63	8,4	100	53	7,1	100	39	5,0	100	46	5,4	100	49	5,1
	200	84	11,2	200	73	9,8	200	59	7,6	200	95	11,1	200	69	7,2
	300	105	14,0	300	94	12,7	300	100	12,9	300	88	10,3	300	79	8,2
	500	151	20,1	500	162	21,8	500	101	13,0	400	94	11,0	300	79	8,2
	1000	214	28,4	900	180	24,3	600	113	14,6						
	1200	226	30,0												
Cat D (UM)	feet	sec	NM	feet	sec	NM	feet	sec	NM	feet	sec	NM	feet	sec	NM
	0	42	5,6	0	33	4,4	0	21	2,7	0	21	2,5	0	18	1,9
	100	63	8,4	100	53	7,1	100	39	5,0	100	46	5,4	100	49	5,1
	200	84	11,2	200	73	9,8	200	59	7,6	200	95	11,1	200	86	9,0
	300	105	14,0	300	94	12,7	300	122	15,7	300	106	12,4	300	89	9,3
	500	151	20,1	500	193	26,0	500	115	14,8	400	105	12,3	300	89	9,3
	1000	239	31,8	1000	192	25,9	600	123	15,8						
	1200	241	32,0												
Cat E (LM)	feet	sec	NM	feet	sec	NM	feet	sec	NM	feet	sec	NM	feet	sec	NM
	0	42	5,6	0	33	4,4	0	21	2,7	0	21	2,5	0	18	1,9
	100	63	8,4	100	53	7,1	100	39	5,0	100	46	5,4	100	49	5,1
	200	84	11,2	200	73	9,8	200	59	7,6	200	95	11,1	200	86	9,0
	300	105	14,0	300	94	12,7	300	122	15,7	300	106	12,4	300	89	9,3
	500	151	20,1	500	193	26,0	500	115	14,8	400	105	12,3	300	89	9,3
	1000	239	31,8	1000	200	27,0	667	127	16,4						
	1296	253	33,6												

Figure 1-7. R-WAKE Simulation results database: Sample of a SHA table with longitudinal-vertical Minimum Wake Separation (MWS) per category-pairs, highlighting detected over-protections (opportunities for separation reduction (green shadow), and under-protections (needs for separation increase (red shadow).

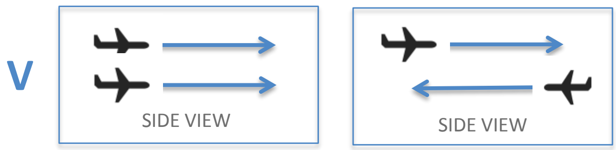
The **R-WAKE-1 concept development** (identification of specific separation schemes improvements) was elaborated on the basis of the generated CIR/SHA database (research step 2.1), looking at the opportunities and needs in the three separation dimensions (longitudinal, vertical, lateral). Four key operational assumptions were considered:

- **Assumption-1**: **Three categories of aircraft are acceptable** by controllers to determine the minimum wake separation to apply in en-route. The number of R-WAKE categories (referred CAT-Rx) initially proposed is based on the existing ones defined by ICAO for TMA/approach:
  - **CAT-RA** (corresponding to ICAO super heavy, or RECAT CAT-A, e.g. A380);
  - **CAT-RB** (corresponding to ICAO heavies, or RECAT CAT-B and C, e.g. B744, B764)
  - **CAT-RC** (corresponding to ICAO medium & lights, RECAT CAT-D and E, e.g. A320)
- **Assumption-2**: Minimum wake separations (**MWS**) can co-exist with surveillance minimum radar separation (**MRS**), and the controllers will apply the most conservative at any moment;
- **Assumption-3** En-route **navigation accuracy** is **RNP-1** for horizontal (1NM), and **50 feet (150m) in vertical** at cruise flight levels and for the 95% of the flight time.
- **Assumption-4**: Minimum radar separation (**MRS**) can be set to **3NM** for horizontal and **500 feet** for vertical (current ICAO MRS is 5NM and 1000 feet).

The resulting **R-WAKE-1 concept developed** consists in four new static separation schemes and two new dynamic wind dependent separation schemes, labelled as *En-Route Minimum Wake Separation, RMWS,* designed to provide the required safety protection and looking for airspace capacity increases. The schemes are:

- **RMWS-1**: Static MWS-lateral-orthogonal for followers in parallel tracks for any generator
- **RMWS-2**: Static MWS-vertical for all followers in any relative headings per generator category.
- **RMWS**-3: Static MWS-longitudinal for followers levelled in-trail or crossing behind per generators category
- **RMWS-4**: Static MWS-longitudinal for follower climbing/descending behind or crossing in FL below a generator's trajectory (and not separated vertically) per Generators (RA, RB, RC)
- **RMWS-5**: Dynamic Wind-Dependent MWS-lateral-orthogonal for parallel tracks
- **RMWS-6**: Dynamic Wind-Dependent MWS-combined-vertical-lateral-orthogonal in parallel tracks

To illustrate what the schemes are specifically, Figure 1-8 shows the proposed adjustment by the RMWS-2 scheme (vertical).



Generator	Vertical MWS required for the follower	Change relative to the current standard
CAT RA	1500 feet	+500 feet
CAT RB	1000 feet	0 feet
CAT RC	500 feet	-500 feet

Figure 1-8. R-WAKE RMWS-2 : Static MWS Vertical in all horizontal geometries

The proposed R-WAKE-1 concept schemes are complemented with a set of **application ideas (operational strategies)** that aim to illustrate how the expected benefits in airspace capacity and safety could potentially materialize. The applications are:

- **APP-1**: Lateral Separation reduction for parallel tracks
- **APP-2**: Vertical separation reductions to increase vertical physical airspace capacity
- **APP-3**: Longitudinal separation reduction for in-trail traffic at the same flight level as the generator aircraft
- **APP-4**: Combination of vertical separation reduction and lateral separation to compress the traffic vertically
- **APP-5**: Increase safety during climbing/descending operations with traffic crossing below
- **APP-6**: Cooperative subliminal offsets based on ADS-B
- **APP-7**: Wake encounter risk advisory service;

An initial **Cost Benefit Analysis** of the R-WAKE-1 concept and potential applications concluded that R-WAKE-1 separation schemes could result, if implemented, in a good balance between: a) increased safety and potential reduced capacity under some conditions (in which currents standards do not protect the flights enough), and b) increased capacity and unchanged safety under other conditions.

1.4 Summary of key achievements, conclusions and lessons learnt

The project closure and concept maturity assessment meeting with SJU took place on the 19th of March 2018. It was focused on the presented R-WAKE-1 concept proposal and concluded that **the project has fully achieved and delivered its five targeted tangible expected outcomes**:

1. A **WVE hazard absolute severity baseline**, defined as a matrix of five upset parameters thresholds per severity class, developed with contributions of experienced pilots and air traffic controllers.
2. An **ATM traffic simulator that includes high-fidelity WVE dynamic risk models**, referred as the ***R-WAKE system***, and consisting of an integrated framework of methods and tools that support the safety and robustness assessment of new separation schemes.
3. A **public database of simulation results**, which constitutes an evidence body to support the new separation scheme proposed in the project. The database contains the upset and severity class computed for a large number of encounter scenarios, including different aircrafts types, geometries, separation distances and atmospheric conditions. The database is complemented with a tool to visualise and analyse the 3D/4D map of the WVE suspected hazard areas (SHA). The public access to the database and the SHA visualizer tool can support other future R&I activities.
4. An **evidence-based proposal** to improve the current en-route separation scheme, referred as the **R-WAKE-1 concept**, which consists of **six new separation schemes** designed to enhance safety against WVE hazards and to increase airspace capacity. Flight efficiency could potentially be also optimised under certain conditions.
5. An **assessment of the feasibility and impact of the proposed concept on ATM,** including an initial validation strategy and outlining an implementation plan. The assessment concluded that there is enough justification for **proposing R-WAKE-1 as a new SESAR Solution** in the ATM Master Plan pipeline. A roadmap of incremental evolutions (stepped-approach) has been also identified towards a long term R-WAKE concept for optimising en-route separation minima provision in future SESAR ATM 2020+.

The **Maturity Assessment** of the proposed R-WAKE-1 concept against the pre-V1 ER/IR gate was performed in close collaboration with the SJU. It was concluded that all the assessment criteria are satisfied (fully or partially-non-blocking), and therefore the concept can be considered at TRL-2 level, and **ready for transition into industrial research** and development phase. A maturity assessment against the V1-IR gate criteria was also performed afterwards (internal project view) showing several partial achievement criteria, and providing the specific identification of research activities needed to reach the V1/TRL-3 level. Overall, in terms of the SESAR pipeline methodology (E-OCVM), it was concluded that the concept can be considered at “V1-ongoing” level.

Derived from the assumptions and limitations identified in the approach, a comprehensive list of **further research needs** (next steps) is provided to move forward the development and validation of both, the **R-WAKE system** (simulation models and safety and robustness analysis method), and the **R-WAKE-1 concept** (safety and robustness analysis (safety case) and business case requirements, and concept operational assumptions).

The main R&D activities to progress on the **R-WAKE system development and validation** are:

- To perform **large data collection campaigns** with real aircraft flight data, to enable further assessment and validation of models.
- To address the validation data limitations found in the **historical traffic trajectory files**, for more accurate post-operations analyses and to assess the WVE risk in airspace sectors (e.g. using real radar data trajectories).
- Complete the coverage of **aircraft models in the micro-simulator**, including turbo-prop models or RPAS (drone) among the models.
- Validate further the absolute severity baseline (**SMUP matrix**), with more expert panels, and more extensive exploration of upsets for the complete aircraft fleet models.
- Perform **weather parameters statistical analysis**, **and sensitivity analysis** on wake vortex behaviour, knowing that WV is very sensitive to atmospheric conditions;
- Complete the validation of the wake-vortex-simulator models and predictions for **all weather conditions**, and in particular in relation to the tropopause;
- Develop further the **R-WAKE system platform 'as a service'**, including high-performance computing, to enable the simulation of larger design of experiments (exploration of larger combinatorial of study parameters, including uncertainty and sensitivity analysis).

The main R&D activities to progress on **the R-WAKE-1 concept development and validation** are:

- Further development and validation of the **separation schemes** with users; an holistic approach of the safety case should include success and failure (integrity) aspects;
- Perform the **ATM-system risk assessment** of hazardous events (SAR and SER) of current system (unit safety case) and with the proposed separation schemes (project safety case);
- Perform the **ATM-System performance impact assessment** with macro simulations, providing quantitative measures/evidences of capacity and efficiency improvement, in order to complete the business-case (cost-benefit-analysis).
- Determine and specify the system requirements for new **ATC decision support tools**, e.g. the WVE risk advisory service, embedding the knowledge of the WVE hazard and risk mitigation recommendations, and runtime wind/weather data.
- The main R&D point regarding R-WAKE-1 Concept **operational assumptions** validation is related to the vertical navigation errors and altimetry, and the potential evolution of the RVSM (Reduced Vertical Separation Minima) concept.

<u>**Linking with the SESAR programme**</u>

The new **R-WAKE-1 SESAR Solution** is defined as a candidate *Operational Improvement Step* named:

> ***'Optimised En-Route separation minima resulting from static Distance-Based Geometry-Based Category-Wise assessment of WVE hazards***',

which includes associated candidate *Enablers:* of type ***Standard*** (the separation schemes as such), of type ***Procedures*** (to manage the new separation schemes), and of type ***Systems*** (introduction of ATC tools to support the assessment, application, monitoring and management of the new schemes).

The **R-WAKE-1 SESAR solution can be developed in phases** according to the different and specific possible applications of the new R-WAKE-1 separation schemes. It must be remarked that the suggested seven applications (APP-x) are just ideas that require further research, development and validation, and they have been elaborated in this project with the only purpose of fostering discussion among experts and a deeper understanding about how the R-WAKE-1 separation schemes and their potential applications could improve safety, capacity and efficiency in en-route airspaces.

Among the suggested applications it is also worthy to highlight the **APP-7: *WVE risk advisory service*.** It is indeed not an application of the new separation schemes proposal, but it responds to the idea that a new ATM decision support tool can be developed in a short term to provide ATC controllers with an early warning of potential WVE encounters in the on-going traffic situation. This can support the identification by ATC of the most appropriate risk mitigation instruction to be applied, and could facilitate the application of the EASA recommendations published in the Safety Information Bulletin SIB-2017-10. This WVE-related ATM service tool could act as a R-WAKE-1 precursor system, thus paving the way towards subsequent WAKE-1 Concept applications development.

The R-WAKE system could evolve as well to become a **SESAR Technological Solution (Enabler)** in order to assist opportunities like: a) offline post-operations and safety assessments for sectors or for the entire ECAC; b) simulation-based WEPS integrated in the avionics to support the identification of WVE hazards on-board and even to enable cooperative subliminal offsets with ADS-B (APP-6); and c) as an enabler of the WVE risk advisory service (APP-7) mentioned above.

In terms of **potential cooperation and relationship with ongoing SESAR projects**, the opportunities to further develop R-WAKE concept and research system can be related mainly to the SESAR 2020 project PJ10 Advanced Air Traffic Services – Separation management for En-route and TMA - PROSA, Controller Tools and Team Organization for the Provision of Separation in Air Traffic Management. It is also relevant to highlight the relation with SESAR 2020 PJ02 (High Performance Airport-TMA Operations, in particular Pj.02-01 on RECAT evolution), in terms of relevant available research ATM community resources. This illustrated in Figure 1-9.

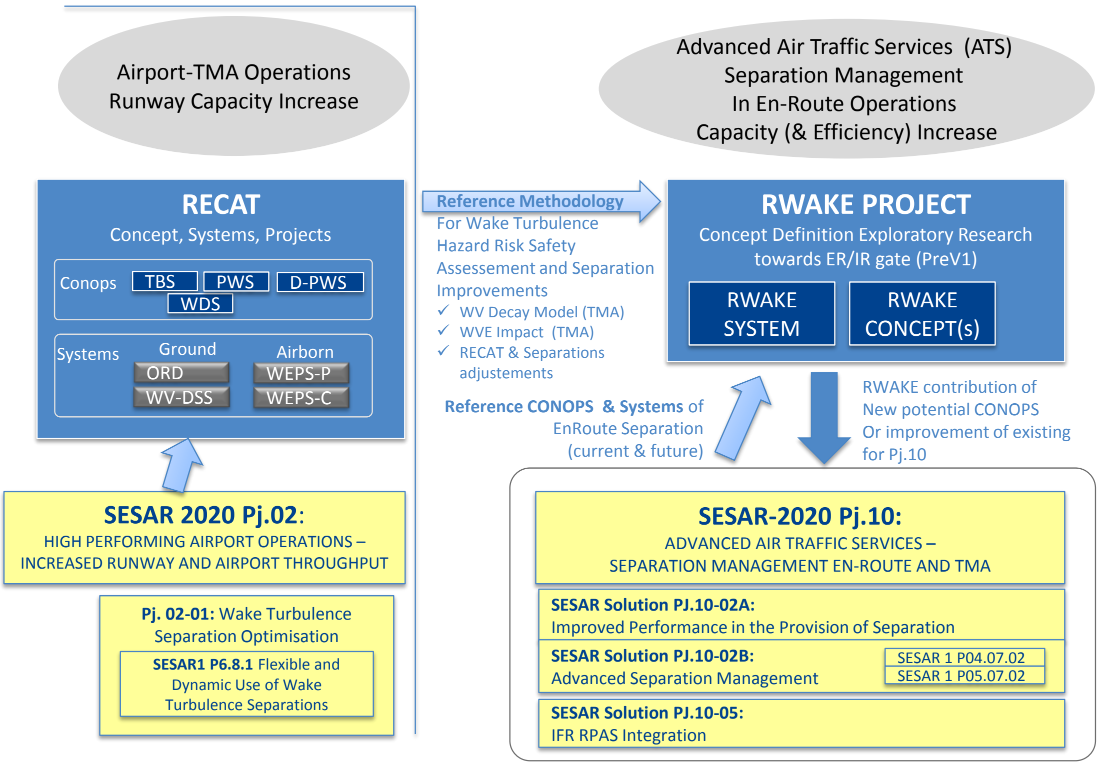


Figure 1-9. SESAR Programmatic Context

More information available at the project web site: http://www.rwake-sesar2020.eu/

2 Project Overview

2.1 Operational/Technical Context

As they pass through the air, aircrafts generate strong rotating air turbulence with vortices in the wingtips, which can last for several minutes and therefore can be encountered at considerable distances from the generating aircrafts, until their circulation strength decays and the turbulence disappears. These wake vortex turbulences can be hazardous to other aircrafts if encountered too near and in a bad combination of several factors, being a possible cause of discomfort, incidents, or even accidents. The main protection mechanism to avoid that hazard is to maintain a minima separation to the generating aircrafts that takes into account the wake vortex hazards.

Wake vortex encounter (WVE) hazards have been deeply studied in approach and landing operations in airport terminal area since they are a main limiting factors in airport capacity (runway throughput). Many efforts have been made to optimize the ways of re-categorizing aircraft according to their wake turbulence characteristic (RECAT), and new procedures such as Time Based Separations (TBS) have been designed considering wake vortex behaviour and duration, in order to enable air traffic control and flights to be more precise with the synchronization of the landing traffic.

However, very few projects have tried to investigate WVE at typical cruise altitudes, and therefore there is little knowledge about the actual level of protection provided by current separation standards with regards en-route WVE hazards, with most of the background research based in simulation since data collection at high altitudes (above FL200) is a difficult task.

In general terms, looking at the current ATM system, it is suspected that the current separation minima standard applied today in En-route (5NM in horizontal and 1000 feet in vertical for all aircraft types and conditions) is over-conservative for some cases and some aircraft categories, while not enough in other cases (e.g., WVE occurrences have been reported up to 25NM behind big generating aircrafts).

2.2 Project Scope and Objectives

The R-WAKE project overall objective is **to investigate the wake vortex encounter (WVE) hazard in the en-route airspace**, and to identify and **assess potential enhancements to the current separation schemes**, aiming to enable operational improvements steps in traffic and trajectory management, in current and future ATM scenarios, with expected benefits in the performance areas of safety, airspace capacity, and flight efficiency of the European ATM system. The project is framed as an application-oriented exploratory research according to the given SESAR ATM Research Methodology (European Operational Concept and Validation Methodology, E-OCVM), thus aiming to present a feasible operational concept proposal at the final **exploratory to industrial maturity assessment gate** (pre-V1 ER/IR criteria), to be contributed to the SESAR ATM Master Plan.

To enable the investigation, the project proposed first the development of an ATM simulation and analysis framework, referred as **R-WAKE System**, and following that, the realization of the due study scenario simulations and analysis in order to build the required body of evidence, targeting the development and test of the new separation rules and concept, referred to as **R-WAKE Concept.**

The project objectives were refined during the first project period as nominal part of task WP2 (Concept Definition) and set in agreement with SJU in terms of the following five **tangible expected outcomes**:

- **O1**: Development of a WVE hazard **severity baseline and tolerability matrix**;
- **O2**: Development of a simulator (the **R-WAKE System**) for testing different separation standards;
- **O3**: A public **database of simulation results** that will provide the evidence to support the proposal of new separation schemes; public access may contribute to future R&I activities;
- **O4**: An **evidence-based proposal** for either maintaining current separation standards or adopting new ones (the **R-WAKE Concept**); and
- **O5**: An **assessment of the feasibility and impact of the concept** on ATM with an initial validation strategy and outline implementation plan.

2.3 Work performed

The project work-plan was structured in 6 work-packages: WP1 “Management”, WP2 “Concept Definition”, WP3 “System Design”, WP4 “System Development”, and WP5 “Integrated Simulations”. Table 2-1 summarises the focus per WP and the planned (and produced) deliverables.

Activity:		Output Deliverable
WP1	**Management**	D1.1 Project Management Plan Report D1.2 Final Project Report
WP2	**Concept Definition**: intended concept, study scenarios, specification of simulator system and validation plan.	D2.1 System Specification Report D2.2 System Validation Plan Report D2.3 Scenarios Definition Report
WP3	**System Design**: detailed definition simulators components and safety & robustness methods.	D3.1 System Design Report
WP4	**System Development:** development, integration and validation of the system, planning for two major iterations (releases).	D4.1 System Release 1 (DEMO) D4.2 System Release 2 (DEMO) D4.3 System Validation Report
WP5	**Simulation and Analysis**: simulation activities and the correspondent safety & robustness analysis, and finally, performing the assessment and cost-benefit analysis of the proposed concept.	D5.1 Simulation Results Database and Concept Development (REPORT & DEMO); D5.2 Safety & Robustness Analysis Report D5.3 Results Assessment Report
WP6	**Dissemination**, addressing the dissemination and planning the exploitation of results.	D6.1 Dissemination Report

Table 2-1 Performed activities and deliverables

It must be remarked that the project faced a complex development in an iterative way, doing two full yearly iterations to the three main project work areas, that is:

- **Research target concept scoping and study approach** (linked to WP2), defining the target-concept to be assessed, its study scenarios, the required safety study terms and simulation system),
- **Research system development** (linked to WP3 and WP4), about integrated simulation toolset and use methodology, and
- **Research realization** (linked to WP5), execution of the simulations, data analysis, concept development, and results assessment.

Complexity of the work is due to the topic novelty, and also due to the closely coupled nature of the three work areas, having in one hand that the hazard and target concept to be explored acts as source of system development requirements (e.g. in terms of simulation models and scenario implementations), and on the other hand having that the system development baseline and project resources limitation conditions the addressable concepts to be explored.

Figure 2-1 depicts the map of deliverables and underlying work-flow.

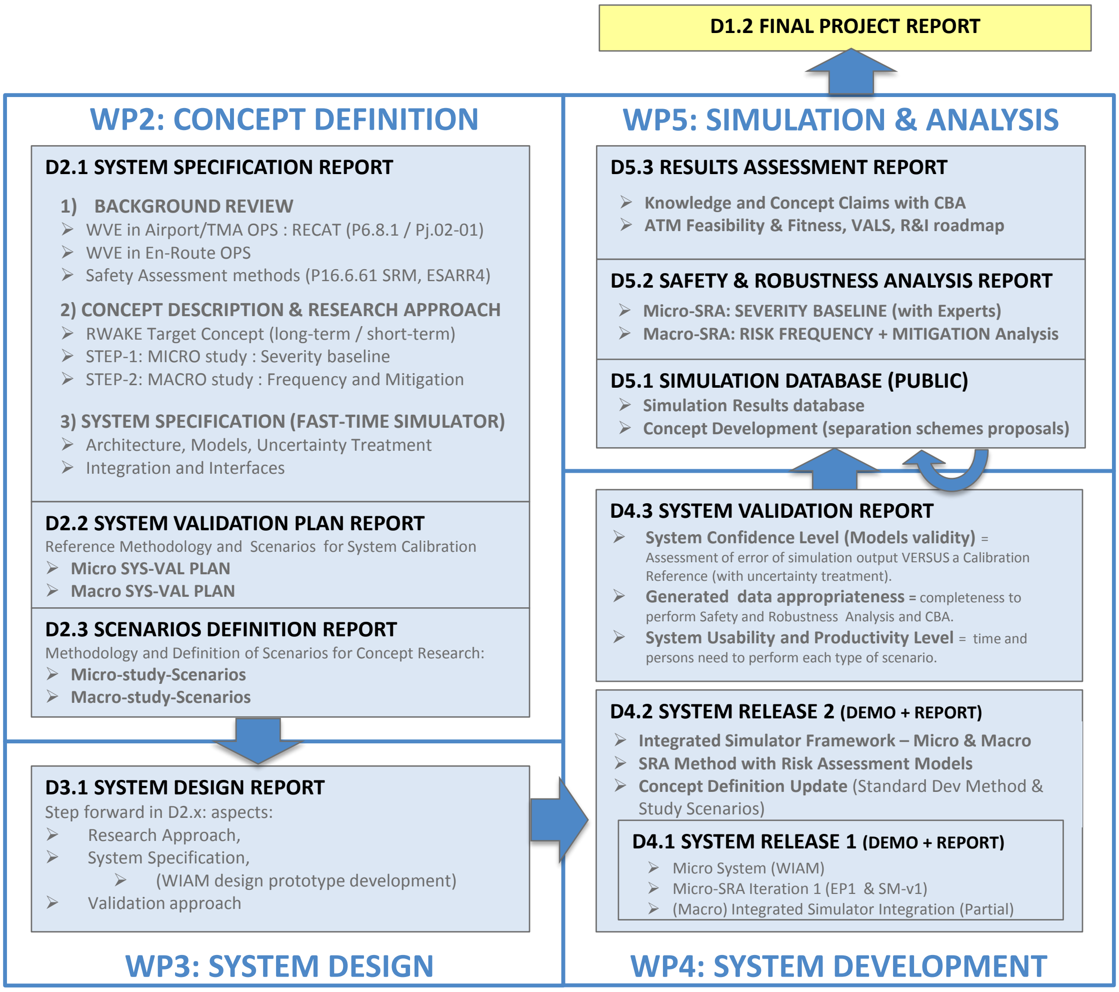


Figure 2-1. Project Deliverables and work flow

The work has been implemented by the **R-WAKE Consortium,** established by six complementary **partners** bringing deep background on the ATM addressed problem and phenomena, and relevant simulation tools background:

- **GTD Information Systems**, a Spanish engineering company with a business unit dedicated to the development and exploitation of a weather awareness solution to the airlines market, is the project coordinator, and provider of the weather simulation modules;
- **University Polytechnic of Catalonia (UPC)**, project technical coordinator, and provider of the traffic simulation including the wake encounter prediction system;
- **TUBS**, provider of the wake vortex simulation modules and expertise.
- **DEEP BLUE**, as Safety & Robustness analysis expert;
- **A-SYS**, as Cost Benefit Analysis expert, bringing the ATM Performance and Implement-ability perspective, for the Research & Innovation and ROI analysis of the potential outcomes; and
- **M3SB**, as Wake Vortex and ATM Expert.

Follows a brief description of the work performed in each work-package per work area.

2.3.1 WP2 Concept Definition

The WP2 Concept Definition produced the planned deliverables reports: *D2.1 Concept Definition, D2.2 System Validation Plan,* and *D2.3 Scenarios Definition Document*. A main result in this step was the structuration of the research approach and system in two steps (as shown in Figure 1-1):

- *Research Step 1: Micro-level modelling study*, to identify the Safety case baseline, that is, the **WV encounter severity** level that is acceptable for the en-route wake encounters, for a representative set of vertical and horizontal encounter geometries, weather conditions, and aircraft involved.
- *Research Step 2: Macro-level modelling study* for a EU-wide area (ECAC) and different traffic patterns, to perform the **hazard risk assessment** in terms of encounter frequency per severity level (using the safety baseline from step 1), for current separation standards and for new R-wake separation standards and methods in different CONOPS, and to assess the ATM Performance potential impact on the KPA/KPIs of Safety, Capacity, Efficiency, and Environment

Another main result of WP2 was the project objectives scoping around the five *tangible expected project outcomes*, as summarize in previous point 2.2.

2.3.2 WP3 System Design

The WP3 System Design activity produced *D3.1 System Design report*, as a continuation of the WP2 baseline, elaborating further details and maturity on the research approach and simulator system components, providing a baseline to start the system development (WP4). Aspects elaborated and included in D3.1 report were:

- Structure and operation concept of the Simulation Database, to become a public deliverable that will contain the simulation and analysis performed in the project;
- R-Wake System Framework integration approach, workflow operational protocol, and specification of file-formats for data exchange (XML-schemas);
- Wake Vortex Simulation requirements and data interfaces;

- Further definition of the safety analysis approach;
- Further definition of the simulation uncertainties framework, and update of the registry of assumptions and limitations.

A critical task of WP3 was the proof of concept prototype of the Wake Interaction Assessment Model micro-simulator, being the kernel of the whole research approach and system, and added to the initial integrated simulator architecture concept.

2.3.3 WP4 System Development

The **WP4 System Development** was the central task in the project, organised in two incremental iterations (system releases), each one with a set of system validation exercises involved:

- System Release 1 (deliverable D4.1), achieved by the end of 2nd period,
- System Release 2 (deliverable D4.2), achieved by the end of 3rd Project Period.
- System Validation (deliverable D4.3), refocused as a final outcome of WP5 in order to include all lessons learnt along WP5 system usage.

System Release 1 (deliverable D4.1) was centred on developing the brand new micro-simulation tool WIAM, enabling an early iteration of the micro-level study of upsets and severity baseline, including a first Expert Panel. Release 1 also addressed the development of most of simulator components and integration framework. This iteration was a key input for mid-term-review.

System Release 2 (deliverable D4.2) constitutes the final **project tangible outcome #2**, i.e., the R-WAKE System intended to support the research approach addressed as central task of WP5 (Simulation and Analysis), and beyond. The R-WAKE system has been architected as a framework of two elements: i) the safety and robustness analysis (SRA) methodology, and ii) the integrated simulation platform (Figure 1-2).

The work for System Release 2 started with an ***update of the research focus and approach*** taking into account mid-term review considerations, in particular the short-term target concept with minimal impact on the current ATM methods (***R-WAKE-1***), and with a more detailed analysis of useful similitudes and key differences of R-WAKE versus RECAT, which resulted in a ***R-WAKE concept development reference method*** elaborated as an extension of the RECAT method.

The ***safety and robustness analysis (SRA) method*** was further elaborated by tailoring the background references of ESARR4, SRM, SAM, SAME, E-OCVM, and Safety Case Development Methodology, and by elaborating the **quantitative risk assessment models** (Risk Models in short), also aligned with RECAT risk models background. This risk modelling update determined the evolution of the research approach into the three-fold research schema:

- **Research Step-1:** (micro) simulation and analysis of the upset and absolute severity baseline, leading to the **Severity Matrix of Upset Parameter Threshold (SMUP);**
- **Research Step-2.1**: (macro) simulation and analysis of the **Conditioned Individual Risk (CIR),** probabilistic model approach, leading to the elaboration of the Pairwise-Risk-Map of Reasonable Worst Case Severity Baseline, and the elaboration of **Simplified Hazard Areas (SHA) by Severity Class**. This outcome is considered the main body of risk-assessment evidence to support concept development claims in R-WAKE-1.
- **Research Step-2.2**: (macro) simulation and analysis of the **System Risk (SER and SAR),** following a frequency analysis approach (occurrences count), and leading to concept under test complete risk assessment, Unit Safety Case and Project Safety Case;

The **R-WAKE system simulation platform** was fully integrated including: 1) a weather simulation (**WXS**) based on historical real met data; 2) an ATM traffic and trajectory simulator (**TRS**), which embeds the high fidelity wake interaction assessment model (**WIAM**) and a wake encounter severity prediction system (**WEPS**); 3) a wake vortex simulator (**WVS**); and 4) the safety and robustness analysis (**SRA**) (including the brand-new risk models developed in the project) and methods and tools for a cost-benefit analysis (CBA). The R-WAKE simulation platform was tailored into three configurations, one for each of the three safety studies in the research approach:

- Micro-simulator of upset for the severity baseline study (WIAM) (research step 1)
- Macro-simulator of conditioned individual encounters (CIR-WEPS) (research step 2.1)
- Macro-simulator of the ATM systemic traffic scenarios (full simulator) (research step 2.2)

The **System Validation** (reported in **deliverable D4.3)** addressed three system aspects: 1) Confidence assessment of the models with reference calibration data, 2) Data appropriateness assessment for safety analysis and experts' judgements task, and 3) Toolset usability and runtime performance, in order to scope the study of parameters through a design of experiments, which is a highly combinatorial and complex problem. The validation activities were expanded to WP5 in order to include all the lessons learn along WP5 usage.

The validation and assessment of the system and models confidence was based on two main references: i) **WIAM model reference at TUBS**, and ii) a set of **EVAIR records** (EUROCONTROL Voluntary ATM Incident Reporting), using 25 records selected by best data quality from a set of 203 records received specific on Wake Turbulence incidents corresponding to a 4 year period. Three validation exercises were conducted:

- Validation exercise 1: micro-simulator WIAM cross-validation against TUBS reference.
- Validation exercise 2: macro-simulator CIR/SHA database cross check against EVAIR records.
- Validation exercise 3: full integrated macro-simulator for ECAC-wide traffic scenarios and WVE frequency measurement (count) test versus EVAIR records.

The most important validation exercise has been the **cross-validation of WIAM** tool against the legacy WIAM available at TUBS, which was validated with real flight data. Its origin comes from the European commission funded project S-WAKE (Assessment of Wake Vortex Safety, Contract No. G4RD-CT-1999-00099), in which wake vortex encounter flight trials were conducted. TUBS operated a Dornier Do 128-6 aircraft equipped with four five-hole probes for the flight trials. Measurements of wake vortices generated by DLR's VFW614 ATTAS were conducted, providing data about vortex strength, velocity profile and aircraft reaction. The WIAM software of TUBS was cross-validated with this flight test data.

Concerning other aircraft types modelled in the WIAM software, basic public available data is used to model the aircraft. Missing data like flight mechanic derivatives and mass distributions are estimated. In the R-WAKE project, TUBS and UPC used the same data sets of modelled aircraft. The software code and the underlying physical algorithms have been developed independently and cross-validated during the R-WAKE project, such that it can be assumed that remaining uncertainties are not due to the developed UPC WIAM tool, but rather to missing, manufacturer proprietary data for the simulated aircraft.

2.3.4 WP5 Integrated Simulations and Analysis

WP5 activity was structured in three main subtasks, each one associated to a key deliverable report:

- T5.1 Scenario simulations → D5.1 Simulations Results Database and Concept Development;
- T5.2 Safety and Robustness Analysis → D5.2 Safety & Robustness Analysis Report;
- T5.3 Result Assessment and cost benefit analysis → D5.3 Results Assessment;

Task 5.1 (deliverable D5.1) addressed the generation of simulations results database and the target concept development. Main outcomes of this task are:

- **Realization of step 1 simulation database:** (**study of scenarios upset and severity** baseline with WIAM tools) produced an upset characterization database with 23.328 scenarios, after combining study parameters of the vortex objects and the encountering aircraft. A representative subset of 12 upset scenarios was selected and assessed by experienced pilots and air traffic controllers, leading to the establishment of the ***R-WAKE absolute severity baseline*** in the form of a ***severity matrix of upset parameter thresholds*** (labelled **SMUP**). With the SMUP any WVE can encounter be classified into 5 severity levels (1-no-safety-effect, 2-minor, 3-major, 4-hazardous, and 5-castastrophic) as a function of the maximum upset generated in the following parameters: 1/ bank roll, 2/ altitude loss, 3/vertical speed change, 4/true airspeed change, and 5/ load factor. The resulting SMUP represents the research tangible outcome O1 of the project, and is also the kernel model integrated in the macro-simulator to classify the WV encounters detected according to their severity (absolute safety criteria).
- **Realization of research step 2.1** (**CIR/SHA simulation database with TRS-WVS-WEPS tools**): simulated 583.632 scenarios and delivered a database of upsets classified by their severity class. The scenarios considered different aircrafts types, geometries, and atmospheric conditions, and the upsets were calculated within a longitudinal-vertical grid of separation points covering the full wake vortex hazard area. Such CIR database represents a 3D map (4D indeed, since time-based is also considered) of the WVE suspected hazard areas (SHAs) –see Figure 1-5–, which enable the condition-wise identification of currently over-protected cases (opportunities for minima reduction), and the discovery of under-protected cases with respect the current separation standards that may need of a separation minima increase. An outcome data sample is shown in Figure 1-6 with a screenshot of the R-WAKE simulation database CIR/SHA viewer tool. Such tool has been developed and made public to facilitate the exploration and analysis of the Suspected Hazard Areas database. Figure 1-7 shows another way to visualize a SHA, formatted to explore the longitudinal-vertical Minimum Wake Separation (MWS) in a category-wise matrix, and highlighting the opportunities found for separation reduction (green-shadowed cells) or the needs detected for separation increase (red-shadowed cells).
- **Development of the CIR/SHA Visualizer tool**. To facilitate the access and analysis to the CIR-WEPS database and the knowledge generated, a user-friendly application has been developed that allow the easy visualisation of the SHAs for different aircraft types, in different geometries and under different weather and flight conditions. The tool has been released together with the database, which will be publicly available for its use by other ATM researchers and practitioners.

Both the database and the SHA visualizer constitute the **tangible project outcome #3**.

- **R-WAKE-1 Concept development**. With the SHAs as the fundamental quantitative evidence from the 'safety success approach' perspective, a proposal of 6 different separation scheme enhancements has been developed. The enhancements aim at increasing safety, capacity and efficiency in the en-route operations, and they constitute the major targeted achievement regarding the development of the R-WAKE-1 concept, i.e. **project outcome #4**. This evidence-based proposal has been complemented with a preliminary qualitative integrity assessment ('safety failure approach') that has been documented in D5.2.

  Summary of R-WAKE-1 concept developed is provided in Appendix B.

Task 5.2 Safety and Robustness Analysis (D5.2 deliverable report) provided the achievements:

- The elaboration of an Accident-Incident Model (**AIM**) for Wake-induced risk in the En-route Operating Environment, in accordance with the SESAR Safety Reference Material;
- The derivation and improvement of the **Absolute Severity Baseline** (represented as the Severity Matrix of Upset Parameters), which has been developed with the point of view of pilots and ATCOs, and constitutes the **project outcome #1** (preliminary delivered in WP-4 and now refined)**;** and,
- The preliminary identification of **Safety Criteria**.
- A preliminary qualitative integrity assessment of the R-WAKE-1 concept (**'safety failure approach'**), through the presentation and discussion of the 6 separation scheme enhancements to active ATCOs. Recommendations for concept refinement were also gathered (reduced version included here in Appendix C).

Task 5.3 Results Assessment (D5.3 deliverable report) constitutes **the project outcome #5,** providing the following achievements:

- A **summary of the project results and of the performance analysis**, including the research objectives and scope, in terms of research questions and targeted study scenarios, and an assessment of the research approach and tools.
- An **assessment of the concept** under investigation in terms of Operations, ATM System, Performance, Validation and Transition topics;
- A **SESAR conformity analysis,** including the identification of new SESAR Solutions, Operational Improvements and Enablers, the impact on the European ATM Architecture and the link with other SESAR projects and Solutions;
- A complete **Maturity Assessment** following the SESAR guidelines and focused on the SESAR **ER-IR Gate criteria**.
- **Recommendations** for changes to future ATM, according to the **ATM needs identified and preliminary quantified** based on the evidence generated during the research and validation exercises.
- The identification of future **research needs and validation strategies** for further develop the concept in the context of a SESAR Solution development life cycle**.**

2.3.5 WP6 Dissemination

The R-WAKE WP6 dissemination and exploitation activities addressed three elements: Public website, Publications, and Dissemination to SESAR.

The **project public website** was established in September 2016, based on WordPress© as Content Management System. Its purpose is to present the R-WAKE project to the public and to provide the main project outcomes. It is up-to-date URL is: http://www.rwake-sesar2020.eu/

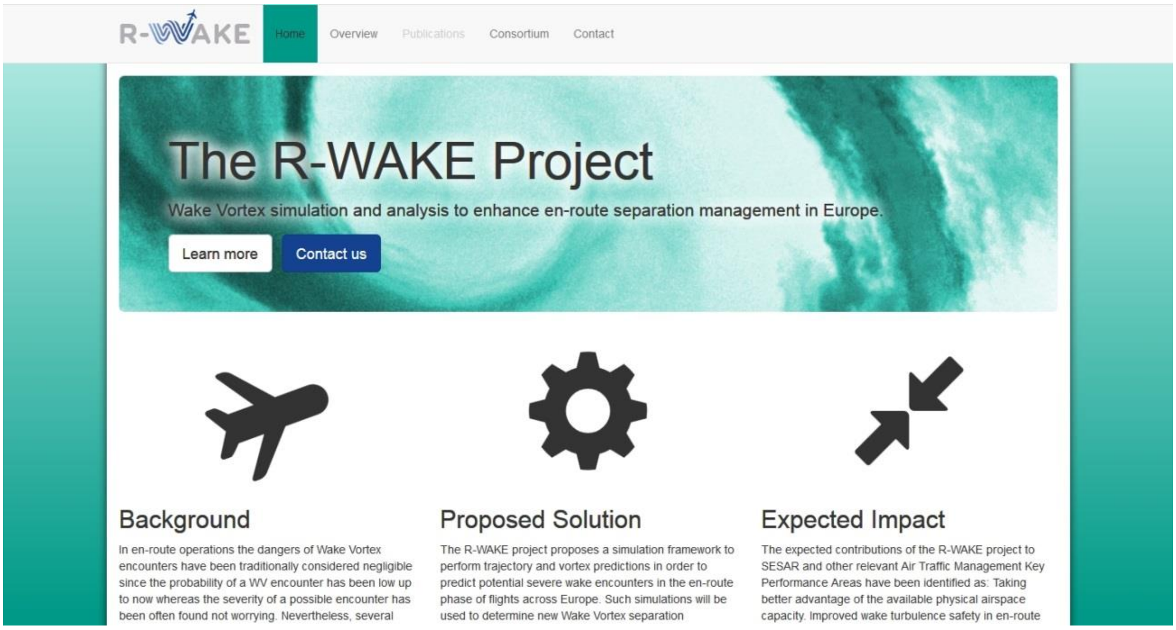


Figure 2-2. R-WAKE public website main page (desktop view)

Publications:

- SESAR Innovation Days 2016 — Project poster submitted and presented. *Ruiz, S. et al.; R-WAKE project: Wake Vortex Simulation and Analysis to Enhance En-Route Separation Management*. A paper was also submitted but rejected. It was an early project method description without experimental results:
- SESAR Innovation Days 2017 — Paper submitted and presented: *Melgosa, M. et al.; A Novel Framework to Assess the Wake Vortex Hazards Risk Supported by Aircraft in En-Route Operations*.

Dissemination to WakeNet-USA was planned in the project, via membership of TUBS, but finally possible due to changes in schedule in WakeNet-USA. Details:

- WakeNet-USA-2017-Spring — Participation cancelled by consortium decision due to lack of results maturity

- WakeNet-USA-2017-Autumm — Meeting postponed to February 2018 due to FAA's short term budgetary uncertainties. February 2018 meeting postponed until further notice due to uncertainties in US appropriation bill signature. Slot for R-WAKE project and results presentation reserved and confirmed
- WakeNet-USA-2018-Spring — No official date published, yet.

Dissemination to SESAR related communities:

- 28th November 2017, Madrid — **Busto & Ruiz, Presentation to Pj.10 PROSA Project Management Board Meeting, held in Madrid, 28/11/2018**. Comprehensive introduction to R-WAKE (with advanced preliminary results), in a 1.5 hours slot.
- 6th February 2018, Brussels — **Presentation to the SESAR Scientific Committee.** Busto, J. et al., R-WAKE SESAR 2020 Exploratory Research Project - Project Presentation to SESAR Scientific Committee meeting
- 29th March 2018, Paris — **R-WAKE presentation by UPC at the EUROCAE WG 75 (ACAS/TCAS) meeting in Paris, 29th March 2018.** UPC, as member of the Working Group 75 of the EUROCAE, which together with the RTCA (the US counterpart) is tasked to develop new standards for ACAS (airborne collision avoidance systems), was given a 1,5hours slot to present R-WAKE. Key conclusions from the attendees: i) The wake vortex phenomena must not be ignored when the separation minima is defined; ii) Nowadays, the separation minima may sometimes be over-conservative while in some situations may not protect the flights enough; iii) Future research is needed for analyzing the frequency of the severe wake vortex encounters in the ATM system;

2.4 Key Project Results

The project closure meeting and maturity assessment ER/IR gate was performed on 29th of March, within the original project time frame (month 24), concluding that the project did fully achieved to deliver its five targeted tangible expected outcomes:

1. A **WVE hazard absolute severity baseline**, defined as a matrix of five upset parameters thresholds per severity class, developed with contributions of experienced pilots and air traffic controllers.

2. An **ATM traffic simulator that includes high-fidelity WVE dynamic risk models**, referred as the ***R-WAKE system***, and consisting of an integrated framework of methods and tools that support the safety and robustness assessment of new separation schemes.
   Summary of R-WAKE simulator system is provided in Appendix A.

3. A **public database of simulation results**, which constitutes an evidence body to support the new separation scheme proposed in the project. The database contains the upset and severity class computed for a large number of encounter scenarios, including different aircrafts types, geometries, separation distances and atmospheric conditions. The database is complemented with a tool to visualise and analyse the 3D/4D map of the WVE suspected hazard areas (SHA). The public access to the database and the SHA visualizer tool can support other future R&I activities.

4. An **evidence-based proposal** to improve the current en-route separation scheme, referred as the **R-WAKE-1 concept**, which consists of **six new separation schemes** designed to enhance safety against WVE hazards and to increase airspace capacity. Flight efficiency could potentially be also optimised under certain conditions. The schemes are complemented with a set of six application operational strategies.
   Summary of the proposed R-WAKE-1 concept is provided in Appendix B.

5. An **assessment of the feasibility and impact of the proposed concept on ATM,** including an initial validation strategy and outlining an implementation plan. The assessment concluded that there is enough justification for **proposing R-WAKE-1 as a new SESAR Solution** in the ATM Master Plan pipeline. A roadmap of incremental evolutions (stepped-approach) has been also identified towards a long term R-WAKE concept for optimising en-route separation minima provision in future SESAR ATM 2020+.

   The proposed SESAR solution is defined as a candidate *Operational Improvement Step* named ***'Optimised En-Route separation minima resulting from static Distance-Based Geometry-Based Category-Wise assessment of WVE hazards***', which includes associated candidate *Enablers* of type ***Standard*** (the separation schemes as such), of type ***Procedures*** (to manage the new separation schemes), and of type ***Systems*** (introduction of ATC tools to support the assessment, application, monitoring and management of the new schemes).

   The maturity assessment concluded that the R-WAKE-1 concept with its supporting material has maturity level of "Pre-V1 non-blocking" and "V1-ongoing".
   The ER/IR maturity assessment of the R-WAKE-1 Concept is provided in point 3.2
   The IR V1 maturity assessment of the R-WAKE-1 Concept is provided in Appendix E.

2.5 Technical Deliverables

Ref.	*Title*	*Type*	*Dissemination*	*Delivery date*

D1.2	**Final report**	**Report**	**Public**	**15/03/2018**
The R-WAKE Final Project Report provides a summary of the targeted research objectives and scope, work performed, key achievements, conclusions and recommendations in terms of contribution to the ATM Master Plan, maturity assessment of the achievements, and list of further research needs and next steps identified to continue the development and validation of the proposed concept in the ATM research community.				
D2.1	**System Specification**	**Report**	**CO**	**13/10/2016**
D2.1 is the head document of the project technical work, providing three main elements: first, a background and state of the art review of the overall addressed problem; second, the preliminary definition of the targeted *R-WAKE concept* and its *research approach,* structured in the two steps of micro-scale and macro-scale modelling; and third, the *R-WAKE system specification*, which is the fast-time simulation tool concept validation technique -research enabler-. The system specification is defined in the form of a functional simulation workflow with detailed identification of inputs and output variables between each simulation components, and the related parameters for uncertainty treatment and sensitivity analysis. Significant refinements and incremental updates of the contents of D2.1 are provided in subsequent reports D3.1, D4.2, and D5.1, D5.2, reflecting the progressive maturity of the research design, system design, and system validation.				
D2.2	**System Validation Plan**	**Report**	**CO**	**13/10/2016**
This report provides the methodology and definition of test cases, test procedures and expected results to validate that the R-WAKE system simulator meets the *System Specification* (Deliverable 2.1), and also to validate that is functionally and operationally ready to perform the R-WAKE concept study, i.e., simulation of different scenarios and analysis. The validation level achieved by the R-Wake System is a key confidence indicator of the achievable maturity of research result claims to be presented after completion of WP5.				
D2.3	**Scenario Definition Document**	**Report**	**CO**	**13/10/2016**
D2.3 elaborates further the research approach and questions presented in D2.1 with a methodology and definition of scenarios to be studied for each research area (micro and macro). The report starts from the research approach introduced in D2.1 and elaborates further the micro and macro study steps, describing in detail their purpose, methodology, and variations of input parameters to be explored. D2.3 represents the work-plan for WP5 simulation and analysis. D5.1 provides the final complete description of study scenario performed.				
D3.1	**R-Wake System Design Document**	**Report**	**CO**	**01/03/2017**
Resulting from the WP3 design activities, as a continuation of the WP2 baseline, this report provides an incremental iteration of the three layers of design: i) research methodology design, ii) simulation system design, and iii) simulation system validation plan design. The report sets the baseline to start the system development activities in WP4.				
D4.1	**R-Wake System 1st Release**	**Demo & Report**	**CO**	**19/04/2017**
This report covers the first iteration of system development and validation performed within WP4, providing details on the early results in three main topics: 1) the implementation status of the				

software tool for the micro-analysis of en-route wake vortex encounters (WIAM) and the level of confidence of its outputs; 2) the execution of the safety assessment that included the 1st Expert Panel with pilots, to define a preliminary version of the Severity Matrix (the first tangible outcome of the project); and 3) the implementation status of the complete simulation framework for the macro-analysis of the project.				
D4.2	**R-Wake System 2nd Release**	**Demo & Report**	**CO**	**09/10/2017**
This deliverable report describes the final system resulting from WP4 (System Development), intended to support the research to be addressed as central task of WP5 (Simulation and Analysis). The report includes: • A comprehensive update of the research objectives, scope and approach incorporating the recommendations at the mid-term review of the project, • Further elaboration of the safety and robustness method and models, consistently aligned with the background references of ESARR4, SRM, SAM, SAME, E-OCVM, and Safety Case Development Methodology, • Description of a more mature implementation of the required quantitative risk assessment models of the WVE hazard (CIR, SAR, SER). • A reference methodology for the development of separation improvement concepts aligned with RECAT methodology, with deep discussion of useful similarities and key challenging differences. • The simulator system framework description with validation test cases performed.				
D4.3	**System Validation Report**	**Report**	**CO**	**01/02/2017**
This deliverable report contains a summary of the methodology and tests conducted to assess the confidence of the models used in the R-WAKE System, as well as about the data generated by the system. Validation results indicate that the models used are congruent with the literature background and historical records available, and that the level of confidence achieved in the project is considered valid for V0 maturity and even for higher levels of maturity. However, further validation against real wake vortex data measurements in en-route phase of flight is needed for further validation and refinement of the models and of the research results and conclusions.				
D5.1	**Simulation Result Database**	**Demo & Report**	**Public**	**06/03/2018**
Deliverable D5.1 has public dissemination level, and includes three elements, a report, a database, and a database exploration supporting tool. The report contains two main parts: D5.1-Part1 provides the description of the meaning and purpose of the database generated using the R-WAKE System simulations tools and used in the WV-Encounters Hazard Study. This part together with the associated package of database files containing the simulation results constitutes the third expected tangible outcome of the project (O3): "Database of simulation results that will provide enough evidence to propose new Separation Schemes for further R&I activities". D5.1-Part2 provides the discussion and elaboration of a set of proposals for Separation Scheme improvements in En-Route operations, based on the body of evidence available in the generated simulation data. That is, the R-WAKE Concept Development. This part represents the central subject for the Safety and Robustness Analysis project tasks 5.2, reported in deliverable D5.2. D5.1-Part2 together with D5.2 constitutes the fourth expected tangible outcome of the project (O4): "Evidence-based proposal for either maintaining current Separation Standards or adopting new ones".				

The database contents and viewer tool are provided "AS IS", with no liability by the R-WAKE consortium partners due to the simulation models validation limitations and possible inaccuracies in the resulting data as described in the D5.1 report.				
D5.2	**Safety and Robustness Analysis Report**	**Report**	**CO**	**06/03/2018**
Deliverable 5.2 'Safety and Robustness Analysis' 1st Edition covers the preliminary identification of hazards in the scope defined by R-WAKE, followed by the identification of the impacted Safety Services. A notable advancement in the SRA is the refinement of the Severity Matrix with Upset parameter Threshold (SMUT) with the integration of the ATC point of view. The initial, adapted FAA Severity Matrix contains also the ATC perspective now. A summary of the second Expert Panel is also detailed in this document. Finally, the elaboration of a new AIM model paves the road to the initial development of Safety Criteria, also present in this deliverable. Deliverable 5.2 'Safety and Robustness Analysis' 2nd Edition covers the preliminary identification of hazards in the scope defined by R-WAKE, followed by the identification of the impacted Safety Services. A notable advancement in the SRA is the refinement of the Severity Matrix with Upset Parameter Threshold (SMUP) with the integration of the ATC point of view. The initial, adapted FAA Severity Matrix contains also the ATC perspective now. A summary of the second Expert Panel is also detailed in this document, as well as the results of the ATC focus group conducted in Padova. Finally, the elaboration of a new AIM model paves the road to the initial development of Safety Criteria, also present in this deliverable.				
D5.3	**Assessment Report**	**Report**	**CO**	**12/03/2018**
This report provide a summary of project results and of the performance analysis, with an emphasis on SESAR conformity and, where relevant, recommendations for changes to future ATM. Its central objective is to provide an evidence-based proposal based on the SESAR ER-IR Gate criteria for either maintaining current separation-standards, or adopting new potential separation improvements as defined by the R-WAKE Concept(s). The report includes an assessment of the research objectives and scope, in terms of research questions and targeted study scenarios, and an assessment of the research approach and tools.				
D6.1	**Report on communication and dissemination**	**Report**	**Public**	**06/03/2018**
Deliverable **D6.1** provides a summary of project dissemination activities. The report includes an overview on the R-WAKE project website, papers and dissemination to SESAR and other project relevant projects.				

Table 2-2 Project technical deliverables produced

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

The assessment concluded that there is enough justification provided for proposing the elaborated **R-WAKE-1 Concept as a new Operational Improvement (OI) step SESAR Solution** in the ATM Master Plan pipeline, together with a roadmap of stepped incremental evolutions towards a long term **overall R-WAKE concept** aimed at optimising en-route separation minima provision in future SESAR ATM 2020+.

3.1.1 The R-WAKE-1 Concept as a new SESAR Solution

The proposed **candidate SESAR Solution** covering the **R-WAKE-1 concept** is phrased in a similar way as the reference SESAR 2020 project Pj.02-01 "Wake Turbulence Optimization" of Airport/TMA context, namely:

> *"PJ.xx-xx En-Route Wake Turbulence Separation Optimization, which aims to optimize separation minima for En-Route operations based on improved knowledge of wake turbulence to enhance safety, airspace capacity and flight efficiency. It focuses on the development of:*
>
> - *wake separation schemes based on weather, static aircraft characteristics and encountering geometries;*
> - *airspace organisation schemes to exploit the benefits of the wake separation schemes;*
> - *separation delivery and management support tools for ATCOs;*
> - *wake risk investigation, prediction, monitoring and awareness functions (ground and airborne)."*

The proposed SESAR Solution can be defined as:

- A candidate Operational Improvement Step "**Optimised En-Route separation minima resulting from static Distance-Based Geometry-Based Category-Wise assessment of WVE hazards**";

  With associated candidate Enablers:

  - [of type Procedure] "**ATC En-route separation procedures to manage static Distance-Based Geometry-Based Category-Wise assessment of WVE hazards** "; and,
  - [of type Standard] **"Static Distance-Based Geometry-Dependent Category Wise Separation Schemes to prevent WVE hazards in En-Route Operations"**
  - [of type System] "**Introduction of ATC tools for the assessment, application, monitoring and management of static separation schemes arising from WVE hazards in En-Route Operations**"

Depending on the further development of the proposed R-WAKE-1 concept separation schemes and applications in future research, it may be appropriate to divide the proposed Operational Improvement and related Enablers into phases, which could be organised according to the proposed specific schema operational applications, for example:

An Operational Improvement Step group relating to **APP-1, Offset Reduction in parallel tracks** would be:

- An Operational Improvement Step "**[CM-xxx-A] Offset reduction in parallel tracks resulting from static Distance-Based Geometry-Based Category-Wise assessment of WVE hazards";** With associated Enablers:
  - [of type Procedure] "[PRO-xxx] ATC En-route separation procedures to manage offset reduction in parallel tracks resulting from static Distance-Based Geometry-Based Category-Wise assessment of WVE hazards"; and,
  - [of type Standard] "[REG-xxx] Static Distance-Based Geometry-Dependent Category Wise Separation Scheme for offset reduction in parallel tracks to prevent WVE hazards in En-Route Operations"
  - [of type System] "[ER-APP-xxx] Introduction of ATC tools for the assessment, application, monitoring and management of static offset reduction in parallel track separation schemes arising from WVE hazards in En-Route Operations"

An Operational Improvement Step group relating to **APP-2 Vertical separation reductions to increase vertical physical capacity**; would be:

- An Operational Improvement Step **"[CM-xxx-B] Vertical separation reductions resulting from static Distance-Based Geometry-Based Category-Wise assessment of WVE hazards";** with associated Enablers:
  - [of type Procedure] "[PRO-xxx] ATC En-route separation procedures to manage Vertical separation reductions resulting from static Distance-Based Geometry-Based Category-Wise assessment of WVE hazards"; and,
  - [of type Standard] "[REG-xxx] Static Distance-Based Geometry-Dependent Category Wise Separation Scheme for Vertical separation reductions to prevent WVE hazards in En-Route Operations"
  - [of type System] "[ER-APP-xxx] Introduction of ATC tools for the assessment, application, monitoring and management of static Vertical separation reduction schemes arising from WVE hazards in En-Route Operations"

3.1.2 Overall R-WAKE Concept evolution and development roadmap

The proposed R-WAKE-1 Concept assumes the current ATM CONOPS context, that is, to current airspace design/organisation, current traffic patterns and volumes, and as much as possible the current operation procedures and systems. Whereas the **overall R-WAKE Concept** considers the **target SESAR Concept of Operations Context**, based on flight trajectory management, i.e., the 4D Trajectory Based Operations (TBO) concept, where the different stakeholders can optimise "business and mission trajectories" through common 4D trajectory information, user defined priorities and precise definition of ATM constraints.

In the context of SESAR2020+/TBO Concept of Operations, the development and implementation of new separation schemes and tools to mitigate En-Route WVE hazards will lead to safer operations and could also enable Free Route and continuous operations to be applied along the entire European airspace, therefore allowing the Airspace Users to plan their optimal/prefered flight trajectories. SESAR envisages the coexistence of 'tactical' and 'strategic' conflict management methods, therefore, trajectory amendments to avoid WVE hazards might be primarily applied through, for example, imposing new ATM constraints to either the encountering or the generator aircraft during the negotiation of the 4D trajectories, or even to both (i.e., cooperative conflict resolution). This process would be enabled by accurate automated trajectory and WV predictions with longer look-ahead times.

Therefore, further development of the overall R-WAKE concept beyond the R-WAKE-1 first step will need to address various aspects of the SESAR Concept of Operations, for example: Free Routes; Future traffic patterns and volumes; and Strategic 4D Trajectory de-confliction of WVE hazards.

Overall R-WAKE Concept Development Roadmap

It is not possible to be definitive about how the overall R-WAKE concept may be incrementally developed in the future as this will be dependent on further progress in the development and implementation of the R-WAKE-1 Concept first step; however, it is pragmatic to assume that:

- Further development and implementation of the R-WAKE-1 Concept could result in the identification of additional opportunities for separation scheme adjustments taking into account, for example,
    - Refinement of generating/encountering aircraft pair categories
    - Refinement of separation schemes
    - Additional geometries of encounter in the investigated En-Route sub-operating environment
    - Additional En-Route sub-operating environments
- the application of the R-WAKE concept to SESAR Concept of Operations will need to coincide with the development of Dynamic Pair-Wise Separation (D-PWS) management i.e. real-time adjustment of separation considering the specific characteristics of the generating and encountering aircraft. An initial step could be the introduction of a Distance-Based D-PWS followed by a Combined Distance/Time based D-PWS;
- initial development and deployment would focus on target airspace organisation and management and associated future traffic patterns and volumes building on associated changes to ATC procedures;
- strategic de-confliction could be a subsequent enhancement of the D-PWS as it would have been applied to target airspace organisation and future traffic patterns/volumes.

This suggests candidate initial evolution steps of the overall R-WAKE concept, as follows (incremental element is highlighted with underline):

- **R-WAKE-1**: Static Distance-Based Geometry-Dependent Category-Wise Separation Schemes to prevent WVE hazards during En-Route Operations

- **R-WAKE-2**: Wind-dependent Static Distance-Based Geometry-Dependent Category-Wise Separation Schemes to prevent WVE hazards during En-Route Operations

- **R-WAKE-3**: Wind-dependent Static Distance-Based Geometry-Dependent Pair-Wise Separation Schemes to prevent WVE hazards during En-Route Operations

The concept then could evolve further into dynamic pair-wise time-based management in the 4D Trajectory environment as follows:

- **R-WAKE-4:** Weather-dependent Dynamic Distance-Based Pair-Wise Separation (D-PWS) Management to prevent WVE hazards in the En-route Trajectory Based Operations environment
- **R-WAKE-5**: Weather-dependent Dynamic Combined Distance/Time-Based Pair-Wise Separation (D-PWS) Management to prevent WVE hazards in the En-route Trajectory Based Operations environment
- **R-WAKE-6**: Strategic 4D Trajectory Deconfliction of WVE hazards in trajectory negotiation.

3.1.3 Operating Environments

The R-WAKE Concept is specifically aimed at the En-Route Operating Environment, for which the ATM Master Plan identifies three sub-Operating Environments (sub-OEs): Low Complexity, Medium Complexity and High Complexity. There are no formal definitions of these sub-OEs as they are based on a variety of interacting factors such as traffic volume, spatial-geometry of the sector, number and structure of routes (e.g. crossing vs. parallel), ATCO workload etc.

As initially presented in D4.2, System Release 2 Report, and updated in D5.1 Simulation Results Database, the R-WAKE-1 Concept could provide capacity and flight efficiency benefits to the three En-Route sub-OEs subject to balancing the potential adverse effects on ATCO workload in the more complex ones (i.e. those with greater traffic volume and/or crossing routes). The scope of the Project Case scenarios, however, was guided by the SJU to focus on En-Route airspace with long parallel route structures on the basis that the perceived flight efficiency gains for crossing geometries would be minimal.

It is considered, therefore, that the specific **R-WAKE-1 scenarios** being considered by the project relate to the **Low and Medium Complexity En-Route sub-OEs**. It may be appropriate to consider the application of R-WAKE to the High Complexity En-Route sub-OE in the subsequent evolution, development and definition of the concept.

3.1.4 Relations with existing SESAR 2020 activities

It is noted that the **current version of the European ATM Master Plan**[1] does not have SESAR Solutions that specifically addresses WVE separations in En-Route airspace, however there are two main related on-going elements (illustrated in Figure 1-9):

- The **SESAR 2020 project PJ10 PROSA "Controller Tools and Team Organization for the Provision of Separation in Air Traffic Management"**,

[1] An **analysis of the working ATM Master Plan data** ("Dataset 17b Draft") revealed 23 OI Steps dealing with wake vortices of which, 21 relate specifically to arrival and departure management at airports/TMAs and 2 to systems for exchanging wake vortex related data such as meteorological.

PROSA has the objective of providing air traffic controllers with more automated tools, aiming to improve current conflict detection, and supporting the air traffic controller with resolution advisory and monitoring of flight trajectory, and new ways of working together, taking into account developments such as drones.
Thus, PROSA is considered by R-WAKE as the main context to integrate and use R-WAKE Concept R&D outcomes.

- The **SESAR 2020 project PJ.02-01 Wake Turbulence Separation Optimization** (RECAT related):
  Pj.01-10 has the objective of optimizing wake turbulence separation minima for arrivals and departures to enhance airport runway throughput. It focuses wake separations reductions based on weather and static aircraft characteristics; separation delivery support tool for ATCOs; wake risk monitoring and awareness functions (ground and airborne); and wake vortex decay enhancing devices.
  Therefore, Pj.02-01 represents the main methodological reference background of R-WAKE.

3.1.5 Long Term Research topics R-WAKE related

Although not specifically required in addressing the ER-IR Gate Criteria for the R-WAKE-1 concept, a number of longer term potential research topics have been identified during the conduct of the R-Wake project, related to the overall R-WAKE concept evolution, or related to other SESAR concepts where R-WAKE can be relevant. In summary:

- **[LTR-1]** Support for advanced altitude rules for allocating Flight Levels, such as continuous linear function of magnetic course;
- **[LTR-2]** Advanced En-Route traffic planning and management to optimise capacity and flight efficiency, such as a capacity/efficiency optimiser tool;
- **[LTR-3**] Parallel track and horizontal regular lattice arrangement of airspace supported by APP-4, Combination of vertical separation reduction and lateral offset to compress traffic vertically
- **[LTR-4]** Avionics: on-board Wave Encounter Prediction System (WEPS). This has been identified as a possible future Enabler for the application of the separation scheme RMWS-6 Wind dependent Combined Vertical and Lateral/Orthogonal (dV & dO) in parallel tracks.
- **[LTR-5]** Application of R-WAKE-1 distance-based separation schemes to the traffic patterns that incorporate future traffic demand and/or ECAC-wide Free Routes Area and/or Continuous Cruise Climbs;
- **[LTR-6]** Investigation of Time-based and Dynamic pairwise separation mitigation methods in En-Route airspace considering WVEs in both current and future traffic patterns.

3.2 Maturity Assessment

Table 3-1 below shows **the ER/IR gate criteria assessment** summary applied to the R-WAKE-1 concept proposed as a new SESAR Solution (as described in previous points), which includes the outcome made by SJU experts in the maturity assessment closeout meeting. A**ll the ER/IR criteria have been considered achieved fully or partially non-blocking,** and it is concluded that the **R-WAKE-1 concept** presented **as a new SESAR Solution is at the "V1-ongoing" maturity level (near TRL-2), and ready to pass from exploratory to industrial research phase**. The recommended R&D next steps and validation strategy for that transition to IR are summarised in point 4.3.

The **IR V1 gate criteria** was also assessed after the closeout meeting, reflecting only the project view, providing the identification of specific R&D needs and activities required to meet the V1 maturity level, i.e., further completing TRA.ER.1 criteria (see Appendix E).

Criteria ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
OPS.ER.1	Has a potential new idea or concept been identified that employs a new scientific fact/principle?	Achieved	Previously detailed in D2.1 System Specification, updated in D4.2 System Release 2, finalised in D5.1, Simulation Results Database and summarised in D5.3 Assessment Report, Section 3.1.
OPS.ER.2	Have the basic scientific principles underpinning the idea/concept been identified?	Achieved	Previously detailed in D2.1 System Specification and D3.1 System Design and summarised in D5.3 Assessment Report Section 3.1.2
OPS.ER.3	Does the analysis of the "state of the art" show that the new concept / idea / technology fills a need?	Achieved	Previously detailed in D2.1, System Specification and D3.1 System Design, updated in D4.2 System Release 2, reported in D5.1 Simulation Results Database and summarised in D5.3 Assessment Report Section 3.1
OPS.ER.4	Has the new concept or technology been described with sufficient detail? Does it describe a potentially useful new capability for the ATM system?	Achieved	Detailed in D5.1 Simulation Results Database and summarised in D5.3 Assessment Report Section 3.1.
OPS.ER.5	Are the relevant stakeholders and their expectations identified?	Partial - Non Blocking	No formal stakeholder analysis performed, discussed in D5.3 Assessment Report, Section 3.1.6; expected to be updated in further research following further concept development

OPS.ER.6	Are there potential (sub)operating environments identified where, if deployed, the concept would bring performance benefits?	Partial - Non Blocking	Discussed in D5.3 Assessment Report, Section 3.3.2; expected to be updated in further research following further concept development
SYS.ER.1	Has the potential impact of the concept/idea on the target architecture been identified and described?	Partial - Non Blocking	Initial analysis is presented in D5.3 Assessment Report, Section 4.1.2
SYS.ER.2	Have automation needs e.g. tools required to support the concept/idea been identified and described?	Partial - Non Blocking	Initial analysis in D5.3 Assessment Report, Section 4.2 identifies the need to update ATC ATCO tools to support application of the R-WAKE-1 concept
SYS.ER.3	Have initial functional requirements been documented?	Not Applicable	Out of scope for project
PER.ER.1	Has a feasibility study been performed to confirm the potential feasibility and usefulness of the new concept / idea / Technology being identified?	Partial - Non Blocking	Limited to an expert judgement ATCO focus group detailed in D5.2 Safety & Robustness Analysis and summarised in D5.3 Assessment Report, Section 5.1
PER.ER.2	Is there a documented analysis and description of the benefit and costs mechanisms and associated Influence Factors?	Partial - Non Blocking	Qualitative benefits are initially identified in D5.1 Simulation Results Database, analysis and benefit mechanisms are identified in D5.3 Assessment Report, Section 5.2. Costs have not been analysed due to immaturity of concept.
PER.ER.3	Has an initial cost / benefit assessment been produced?	Partial - Non Blocking	Qualitative and limited quantitative assessment of benefits are described in D5.3 Assessment Report, Section 5.2. Costs have not been analysed due to immaturity of concept
PER.ER.4	Have the conceptual safety benefits and risks been identified?	Partial - Non Blocking	Accident-Incident Model, Severity Matrix and Safety Criteria have been developed as detailed in D5.2 Safety & Robustness Analysis and summarised in D5.3, Assessment Report, Section 5.3.

PER.ER.5	Have the conceptual security risks and benefits been identified?	Not Applicable	Out of scope for project
PER.ER.6	Have the conceptual environmental impacts been identified?	Not Applicable	Out of scope for project
PER.ER.7	Have the conceptual Human Performance aspects been identified?	Partial - Non Blocking	No formal Human Factors study conducted, however HF issues identified as part of Safety Assessment Expert Panels as detailed in D5.2 Safety & Robustness Analysis and summarised in D5.3 Assessment Report Sections 5.1 and 5.6.
VAL.ER.1	Are the relevant R&D needs identified and documented? Note: R&D needs state major questions and open issues to be addressed during the development, verification and validation of a SESAR Solution. They justify the need to continue research on a given SESAR Solution once Exploratory Research activities have been completed, and the definition of validation exercises and validation objectives in following maturity phases.	Achieved	Summarised in D5.3 Assessment Report, Section 6.3.1
TRA.ER.1	Are there recommendations proposed for completing V1 (TRL-2)?	Partial - Non Blocking	An outline roadmap of recommended R&D and validation activities is provided in D5.3 Assessment Report, Section 6.3.2

Table 3-1 Summary of the ER/IR criteria achievement for R-WAKE-1 concept. Complete description in D5.3 report.

4 Conclusion and Lessons Learned

4.1 Conclusions

The R-WAKE project has clearly identified and preliminary quantified with enough level of confidence the **need and opportunity in the ATM system for enhancing the current separation minima schemes provisioned in en-route operations** taking into account the generated knowledge on Wake Vortex hazard assessment applying a high-fidelity simulation based approach. The **project tangible outcomes** include:

- An **ATM simulator that includes high-fidelity WVE dynamic risk models**, referred as *R-WAKE System*, tailored to support the project research approach.
- A **WVE hazard severity baseline**, defined as a matrix of upset parameters thresholds per severity class, developed and assessed with contributions of experienced pilots and air traffic controllers.
- A **public database of simulation results** which represents the suspected hazard areas (SHA) maps that constitute an evidence body to support new separation scheme proposals. The public access to the database and the companion SHA visualizer tool (deliverable D5.1) can support future R&I activities for different research groups, subject to a disclaimer related to the validation limitations reported (as detailed in the corresponding D5.1 report).
- The **R-WAKE-1 Concept** proposal, which consists of **six new separation schemes** designed to increase safety against WVE hazards and also airspace capacity, looking at the minimum wake separation in the three dimensions: lateral, vertical, longitudinal, and also combined lateral-vertical, and wind-dependent dynamic separations. The schemes are complemented with a set of six application operational strategies.
- And **a feasibility and impact assessment of the concept**, concluding that there is enough justification for proposing R-WAKE-1 Concept as the basis for **a new SESAR Solution** in the ATM Master Plan pipeline, as a first step in a roadmap of identified incremental evolutions towards a long term overall R-WAKE concept for optimising en-route separation minima provision in the future SESAR 2020+ ATM system.

The SESAR Fit recommendation is to include in the SESAR ATM Master Plan pipeline two elements:

- A candidate ***SESAR Solution covering the R-WAKE-1 concept*** (as summarised in 3.1.1 and Appendix B) defined as an ***Operational Improvement (OI) Step*** with associated ***Enablers*** of type Procedure, Standard, and System. The OI Steps and associated Enablers may grouped in phases according to the different specific Operational Applications and operating environment of the R-WAKE-1 separation schemes.
- A candidate ***overall R-WAKE concept development roadmap*** (as summarised in point 3.1.2), which currently envisages a step-wise evolution of six concepts, R-WAKE-1 to R-WAKE-6, aiming R-WAKE-1 to fit first in the shorter-term current ATM operation context.

The proposed R-WAKE-1 Concept has been assessed in the **maturity assessment ER/IR gate as "*partial non-blocking" and "IR-V1 ongoing"***. The R-WAKE-1 concept, expressed as a set of separation schemes applied to certain operating situations, requires further development prior to industrialisation. There are a number of significant outstanding questions regarding the proposed schemes and their applications; however sufficient progress has been made for the potential significant benefit in terms of safety and airspace capacity to recommend progressing with its development. In order to develop the concept some further enhancements and validation of the R-WAKE System integrated simulation framework would be required, mainly related to improvement of models validation by means of further generation and consolidation of **validation reference real flight data**.

As shortest-term opportunity, among the suggested applications it is also worthy to highlight the proposal of a ***WVE risk advisory service*** (**APP-7).** It is indeed not an application of the new separation schemes proposal, but it responds to the idea that a new ATM decision support tool can be developed in a short term to provide ATC controllers with an early warning of potential WVE encounters in the on-going traffic situation. This can support the identification by ATC of the most appropriate risk mitigation instruction to be applied, and could facilitate the application of the EASA recommendations published in the Safety Information Bulletin SIB-2017-10. This WVE-related ATM service tool could act as an R-WAKE-1 precursor system, thus paving the way towards subsequent WAKE-1 Concept applications development.

In addition of the R-WAKE-1 Concept as an Operational Improvement step, the **R-WAKE system could** evolve as well to **become a SESAR Technological Solution (Enabler)** in order to assist opportunities like: a) offline post-operations and safety assessments for sectors or for the entire ECAC; b) simulation-based WEPS integrated in the avionics to support the identification of WVE hazards on-board and even to enable cooperative subliminal offsets with ADS-B (APP-6); and c) as an enabler of the WVE risk advisory service (APP-7) mentioned above.

Regarding **Stakeholder Expectations,** although a formal stakeholder analysis has not been performed, it is possible to identify that the R-WAKE concept is relevant to most of the ATM stakeholders: **Regulatory** (for the formulation of modified separation schemes for En-Route airspace that maintain or improve current safety levels); **ANSPs** (for the changes to separation services provided resulting in increased En-Route airspace capacity and a reduction in the number of WVE related safety incidents; **Airspace Users** (for the changes to separation procedures resulting in the opportunity to plan and operate more efficient routes); **Network Manager** (changed separation schemes resulting in the opportunity to modify the design of En-Route airspace enabling greater capacity and offering Airspace Users more efficient routes), and **Aeronautics Industry** (possible introduction of new controller tools and avionics, possible exploitation of WVE data and improved accuracy (e.g. MET) in AC-to-AC and AC-to-Ground data exchange).

4.2 Technical Lessons Learned

The R-WAKE project has allowed R-WAKE Consortium partners to develop further their complementary expertise and background in developing a complex safety-oriented operational concept research, which has required an iterative approach on three closely coupled work areas: 1) definition of research scope and research approach, 2) research system simulation and methods development and validation, and 3) research realization involving large number of scenario simulations (with high combinatorial of study parameters), data analysis involving safety and domain experts, concept development, and assessment.

A main cornerstone in the project approach is the development and validation of the Aircraft **Wake Interaction Assessment Model (WIAM)** that enables high-fidelity micro-simulation of wake encounter upsets, and the development of the hazard **absolute severity baseline.** The limited real life data that has been available to validate this core micro-simulation models represents a main limiting factor in the results.

The developed WIAM was thoroughly and satisfactorily cross-checked against a WIAM baseline tool available at TUBS, which in turn was validated with real test flight data in a previous project, i.e. S-WAKE ('Assessment of Wake Vortex Safety'), funded by the European Commission under the FP5 program. In S-WAKE wake vortex encounter flight trials were conducted operating a Dornier Do 128-6 aircraft equipped with four five-hole probes for the flight trials, and measurements of wake vortices generated by DLR's VFW614 ATTAS, providing data about vortex strength, velocity profile and aircraft reaction. The WIAM software of TUBS was cross-validated with this flight test data. Concerning other aircraft types modelled in the R-WAKE WIAM software, they are based on public available data used to model the aircraft, and missing data like flight mechanic derivatives and mass distributions are estimated. The resulting enhanced WIAM implementation represents a kernel component of the R-WAKE simulator system, and a baseline for further extensions, e.g. adding more aircraft models, and adding real flight reference data for validation.

4.3 Recommendations for future R&D activities (next steps)

A comprehensive list of <u>**further research needs**</u> (next steps) has been derived from the assumptions and limitations in the performed approach, in order to move forward the development and validation of both, 1st) the **R-WAKE system** (simulation models and safety and robustness analysis method required to support R-WAKE concept development), and 2nd) the **R-WAKE-1 concept** (safety and robustness analysis (safety case) and business case requirements, and concept operational assumptions validation). The full description of the identified R&D activities is provided in deliverable D5.3 (labelled as FRN), and slightly reduced version is included in this document in Appendix D. Here follows a synthesis:

The main R&D activities to progress on the **R-WAKE system development and validation** are:

- To perform **large data collection campaigns** with real aircraft flight data, to enable further assessment and validation of models.
- To address the validation data accuracy limitations found in the **historical traffic trajectory files** needed for post-operations analyses and to assess the WVE risk in airspace sectors (e.g. by using real radar data trajectories). Once addressed further research can be conducted with large traffic scenarios of days or weeks (rather than the performed with few hours), assessing post-ops risks of historic cases and patterns as highlighted by the EASA Safety Information Bulletin (SIB) 10-2017;
- Complete the coverage of **aircraft models in the micro-simulator**, including turbo-prop models or RPAS (drone) among the models.
- Validate further the absolute severity baseline (**SMUP matrix**), with more expert panels, and more extensive exploration of upsets for the complete aircraft fleet models.
- Perform **weather parameters statistical analysis, and sensitivity analysis** on wake vortex behaviour, knowing that WV is very sensitive to atmospheric conditions;

- Complete the validation of the **wake-vortex-simulator models and predictions for all weather conditions**, and in particular in relation to the tropopause;
- Develop further the **R-WAKE system platform 'as a service'**, including high-performance computing, to enable the simulation of larger design of experiments, in two aspects: exploration of larger combinatorial of study parameters, including uncertainty and sensitivity analysis, and simulation of large macro scenarios of days and weeks instead of hours.

The main R&D needs to progress **the R-WAKE-1 concept development** and validation are:

- Further development and validation of the **separation schemes** with users; an holistic approach of the safety case should include success and failure (integrity) aspects;
- Perform the **ATM-system risk assessment** of hazardous events (SAR and SER) of current system (unit safety case) and with the proposed separation schemes (project safety case);
- Perform the **ATM-System performance impact assessment** with macro simulations, providing quantitative measures/evidences of capacity and efficiency improvement, in order to complete the business-case (cost-benefit-analysis).
- Determine and specify the system requirements for new **ATC decision support tools**, e.g. the WVE risk advisory service, embedding the knowledge of the WVE hazard and risk mitigation recommendations, and runtime wind/weather data.
- The main R&D point regarding R-WAKE-1 Concept **operational assumptions** validation is related to the vertical navigation errors and altimetry, and the potential evolution of the RVSM (Reduced Vertical Separation Minima) concept.

Based in the future research needs identified (see Appendix D), a 2-step **Validation Roadmap** approach is proposed for the **R-WAKE-1 Transition to Industrial Research:**

- **Step A:** Complete the development and validation of R-WAKE System as an integrated simulation framework to develop the R-WAKE-1 concept, and then complete the R-WAKE-1 concept analysis of the proposed separation schemes and applications for near-term implementation, this step would address:
  - For the R-WAKE System, the FRN-1, 2, 4, 5, 7, 11, 14;
  - For the R-WAKE-1 concept analysis, the FRN-9, 10, 17, 18, 19;
- **Step B**: on the basis of a more mature concept defined after Step A, to conduct a set of validation activities in accordance with the E-OCVM case based approach:
  - Develop the R-WAKE-1 V2 Business Case (addressing FRN-13)
  - Develop the R-WAKE-1 V2 Unit Safety Case and Project Safety Case (addressing FRN-3, 6 ,8, 16)
  - Develop the R-WAKE-1 Environment Case
  - Develop the R-WAKE-1 Human Factors Case
  - Develop the R-WAKE-1 Standards and Regulatory Case

4.4 Cooperation

In terms of **potential cooperation and relationship with ongoing SESAR projects**, the opportunities to further develop R-WAKE concept and research system can be related mainly to

- The SESAR 2020 project ***PJ10 Advanced Air Traffic Services – Separation management for En-route and TMA - PROSA, Controller Tools and Team Organization for the Provision of Separation in Air Traffic Management***.

Finally, it is worth highlighting the following other projects or groups as relevant for the R-WAKE research progress and cooperation:

- The **SESAR 2020 PJ02 (High Performance Airport-TMA Operations, in particular Pj.02-01 on RECAT evolution)**, in terms of relevant available research ATM community resources.
- The joint **RTCA/EUROCAE Working Group WG-75** on Traffic Alert and Collision Avoidance Systems (TCAS and ASAS), in order to harmonize the R-WAKE mid-air WV-encounter risk models with the mid-air collision risk modeling, and the possible cooperation with regulation and standardization.
- The **EUROCAE WG-68 on Altimetry** in order to progress on the validation of operational assumptions related vertical navigation accuracy, and Reduced Vertical Separation Minima, RVSM.

5 References

[1]. D2.1 R-WAKE System Specification Ed2

[2]. D2.2 R-WAKE System Validation Plan Ed2

[3]. D2.3 R-WAKE Scenarios Definition Ed2

[4]. D3.1 R-WAKE System Design Ed2

[5]. D4.2 R-WAKE System Release 2 Report Ed1

[6]. D4.3 R-WAKE System Validation Report Ed1

[7]. D5.1 Simulation Results Database Ed1

[8]. D5.2 Safety and Robustness Analysis Ed2

[9]. D5.3 Results Assessment Report

[10]. European ATM Portal (www.eATMportal.eu) Working: Master Plan DS17b Draft/EATMA V9.1

Appendix A R-WAKE System - software toolbox summary

A.1 System Architecture

The **R-WAKE System Integrated Simulator Framework**, presented in D4.2 System Release 2 report, consists of the following main components (Figure 5-1):

- **WIAM**: WVE Interaction Assessment Model
- **TRS**: Traffic Simulator, which consists of:
  - **TRS.TP**: Traffic and Trajectory Planner & Simulation
  - **TRS.WERF**: Wake Encounter Region Finder
  - **TRS.WEPS**: Wake Encounter Prediction & Severity Assessment
- **WXS**: Weather Simulator
- **WVS**: Wake Vortex Simulator
- **FWM**: Framework Workflow Manager and Shared Folder for on-line distributed Integrated Simulation

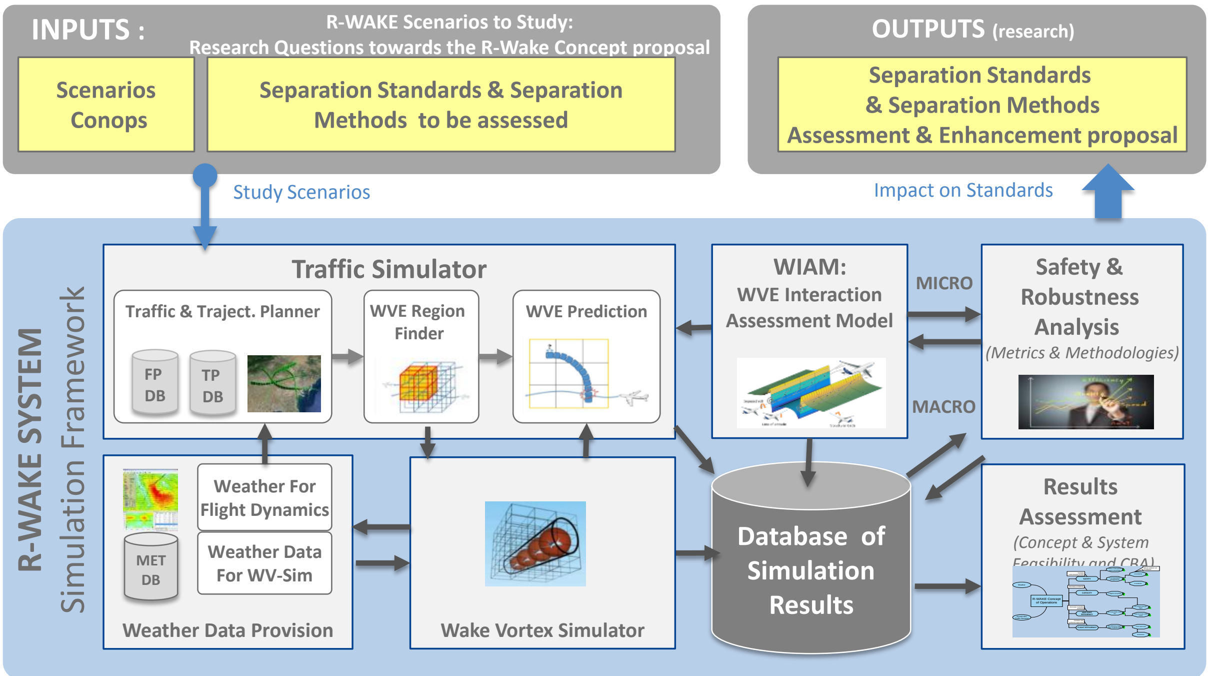


Figure 5-1. R-WAKE System - integrated simulation framework – high level architecture

The macro SAR/SER study was not performed due to lack to schedule, but the full macro system was validated using a reduce scenarios of 4 hours of real historic traffic covering the full ECAC.

A.2 System Usage: the Research steps / workflow

R-WAKE system is presented as a tool to generate the evidence body to answer whether the current separation standards for en-route can be maintained or not, and if there is margin to reduce them. It supports the execution of simulation exercises; some are oriented to characterize the WVE hazards, and some to quantify the level of systemic risk in the ATM, with the current standards (Unit Safety Case) and with the new proposed standards (Project Safety Case). Table 5-1 below summarizes the research simulation tasks and its purpose for the safety analysis task. Figure 5-2 depicts the 5 study areas of the research approach.

Simulation Task	Purpose for Safety Analysis task
[Step-1] Micro-Upset Micro simulations with WIAM for the analysis of the Upset and Severity Baseline development	To assess the severity of different types of upsets that aircraft may potentially experiment during a WVE, and generate an **absolute safety baseline** (**severity matrix**)
[Step-2.1] Macro-CIR Macro simulations with WEPS of conditioned individual pairwise encounters for the analysis of CIR.	To assess the **risk supported by a follower aircraft** given that certain event conditions are true (i.e., the Conditioned Individual Risk, **CIR,** for each aircraft pair, geometry at a given V and H separation distance applied). To find opportunities for separation reduction between aircraft pairs, while maintaining or improving current safety levels.
[Step-2.2] Macro-SAR/SER Macro simulations with the full integrated simulator of regional traffic for the analysis of systemic risk.	To find the **systemic risk** at sector and ECAC level, two risk terms are addressed: *System ECAC-wide Risk* (SER), and the *Segregated Airspace Risk* (SAR). To find opportunities to group the aircraft in different categories of a new separation standard that potentially increases the capacity and efficiency, while maintaining or improving current safety levels.

Table 5-1 Overview of the proposed set of simulation and analysis tasks (scope of Task 5.1 and Task 5.2)

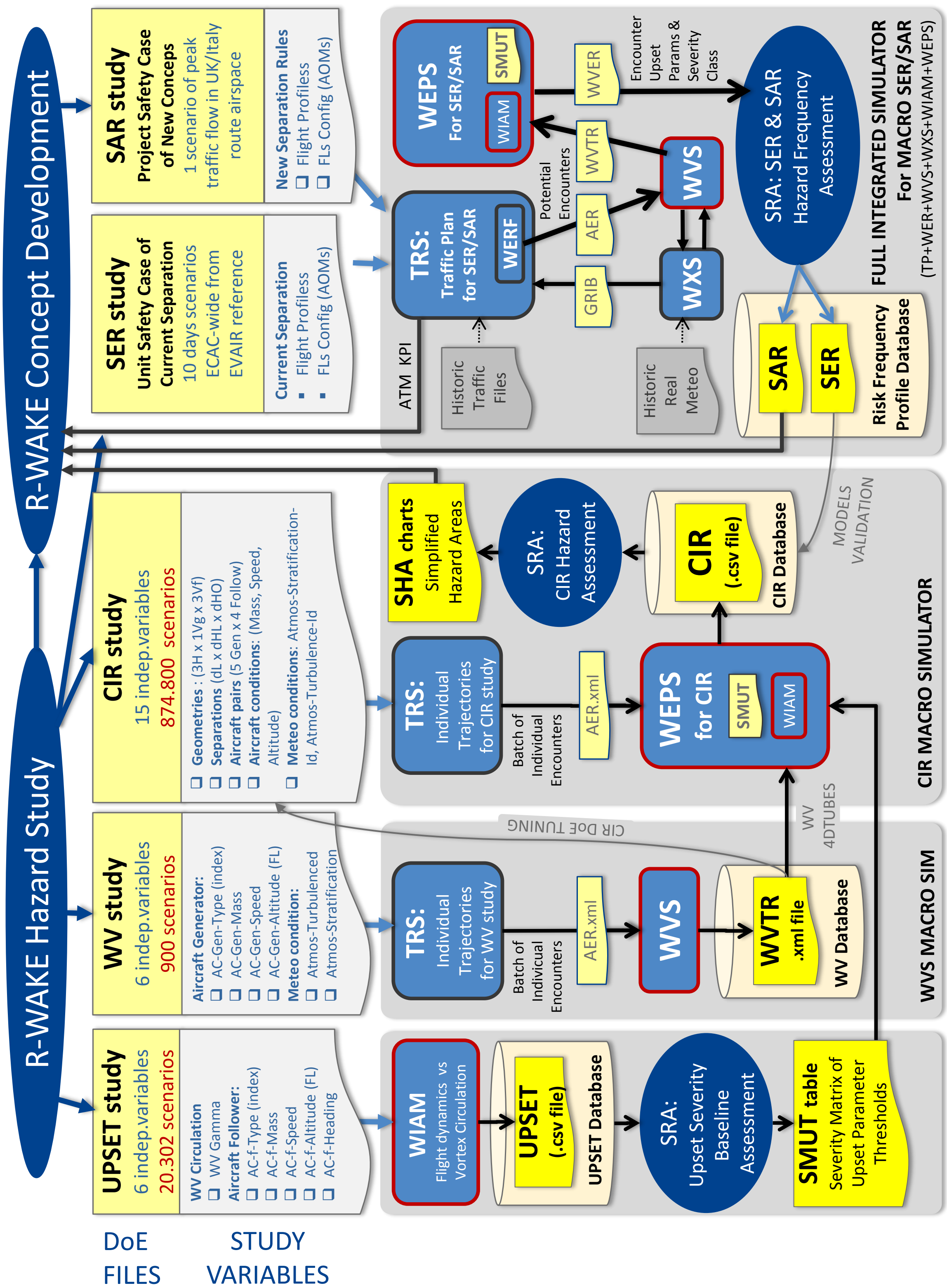


Figure 5-2. Components and tools of the R-WAKE System that is required for each area of study

A.3 Toolbox components

The following table provides summary of the **integrated components**.

Component	Components description and status update	Availability format
WIAM	**Wake Interaction Assessment Model (WIAM):** WIAM computes En-Route 3D WVE flight dynamics**.** WIAM provides the following variables describing the upset: bank angle, altitude change, rate of climb, change of airspeed and load factor.	MATLAB standalone with parallel computing cluster behind, by UPC, available internally.
	WIAM Output Data Charting: Scripts that support the Safety Analysis assessing worst case encounter patterns, by clustering based on upset magnitude large sets of simulations performed by WIAM.	MATLAB standalone by UPC, available internally.
	WIAM PFD display. A realistic avionics Primary Flight Display (PFD) implementation for pilots to see the dynamic behaviour of the upset computed by WIAM.	Standalone tool by UPC, available internally.
TRS-TP	**Trajectory and Traffic Planner (TP).** There are two independent variant versions of TRS.TP, each one oriented to the Task 5.1 research steps of i) step 2.1 study of conditioned individual risk, aka, macro-CIR, and ii) step 2.2 study of systemic risk, aka, macro SAR/SER. **TRS-TP for macro-CIR**: this module delivers pairs of trajectories following a CIR DoE: design of experiments of synthetic pair of conditioned individual encounters. See D5.1 section 3.1 and 3.2 (Research Step 2.1). **TRS-TP for macro-SER/SAR**: this module is the initial concept of traffic planner oriented to perform ECAC or Airspace Sector studies of systemic risk, i.e., frequency assessment. TRS.TP for SER/SAR has to mode of operation: 'historic traffic play', and 'synthetic trajectories generation'. TRS.TP for SER/SAR for 'historic traffic play' reproduces the trajectories from traffic files from Eurocontrol DDR2 files. This mode of use has been applied in the EVAIR validation exercise (see D4.3). TRS.TP for SER/SAR for 'synthetic trajectories generation' produced trajectories files based on traffic patterns, using the ATC separation module (aka, Conflict Resolution) developed for the 1st release. Once all trajectories of an input configuration file are generated, all aircraft pairs infringing a given and configurable minimum separation criterion are detected (WERF1 function), and then the trajectory of one of	**Online server by UPC**, with a parallel computing cluster behind, usable through R-WAKE FWM data exchange protocols.

	the aircraft is locally modified in order to achieve the separation minima. This is the Conflict Resolution (CR) function.	
TRS-WERF	<u>Wake Vortex Encounter Region Finder</u> **(WERF)** has been split in two parts: one inside TRS.TP (aka WERF-1), and the other inside TRS.WEPS (aka WERF-2). WERF-1 function inside TRS.TP-for-SAR/SER provides a conservative detection based on WV habitation area parameters, like 5NM in horizontal or 1000 feet in vertical. It represents the function of Conflict Detection of the TRS.TP that activates the WV simulator and the WEPS function. WERF-2: it a part inside the TRS.WEPS-for-SAR/SER that uses the WV geometry provided by WVS (WVER file 4D tube data) to confirm that the candidate encounter is within the WV-trajectory envelop, and activates the upset computation with the WIAM module, and the severity classification with the Severity Matrix with Upset Parameter Thresholds (SMUP).	Embedded in TRS.TP and TRS.WEPS
TRS-WEPS	<u>Wake Vortex Encounter Prediction System</u>**.** This component embeds the following key parts: [1] WERF-2 coupled with WIAM input calculation module: first, WERF-2 is a geometry-based confirmation of the candidate encounter provided by TRS.TP/WER-1 (based bounding box habitation area), using the WV-trajectory envelope computed by WVS. Then the vortex circulation to be used by WIAM is computed, embedding Reasonable Worst Case assumptions (parameters) (further described in D5.1 report). [2] WIAM tool, it automatically process all potential wake vortex encounters detected by the RF using the WV-object information provided by the WVS and a given severity matrix.	**<u>Online server by UPC</u>**, usable with R-WAKE FWM protocols
WVS	<u>Wake Vortex Simulator</u> **(WVS) Server:** Additional wake vortex models has been implemented, and internally, adapted core to usage multiple wake vortex prediction models. Interfaces to WEPS and WXS have been improved. A handling software was developed to request the weather data based on a given trajectory (AER file). The handling software is parsing the weather reply (WDR file) to the WVS. The WVS is calculating the wake vortex behaviour and providing the output to the Wake Vortex trajectory file (WVTR file).	**<u>Online server by TUBS</u>**, usable with R-WAKE FWM protocols.
WXS	<u>WXS - Weather Database</u> is ready, and specific data product are loaded for 10 specific days selected from EVAIR set having	Accessible through the WXS Server

	known WV-turbulence occurrences, to support system validation, and can be also for scenarios research.	
	WXS - Weather Server Engine and service (system interface protocols). The WXS is available on-line according to the R-WAKE framework operation protocol based on the XML file-based weather data query and response (WDQ and WDR).	**Online server by GTD**, usable with R-WAKE FWM protocol
	WXS.HMI: Weather Simulation Planning - User Interface. It is available internally as a desktop tool to explore and analyse weather data contents.	C++ Standalone by GTD available internally.
FWM	**FWM-MNG: Framework manager - User Interface Application**	Java standalone available from GTD.
	FWM.SCM: Simulator Framework manager – Simulation Component Manager: java application to be deployed in each service oriented simulation components (TRS.TP, TRS.WEPS, WVS, and WXS), enabling fully integrated simulations workflow at the command of the FWM.MNG application.	Java standalone, available from GTD.
	FWM.SDB: The **Simulation Data Base** is the online File System Database available via internet Cloudsync protocol (driver freely available from Synology site).	**Online server by GTD**.
SRA-Method	**SRA Method and Risk Models**, The SRA as general method and risk models are described in detail in section D4.2 section 4, and further developed in D5.2.	D4.2 and D5.2
SRA-SMUP	**SMUP: Severity Matrix with Upset Parameter Thresholds.** It is the main outcome of the micro-analysis and a configuration input for the TRS.WEPS. The matrix can be object of revision and study.	Developed during Expert Panel 1
SRA CIR-SHA Viewer tool	**CIR-SHA Viewer tool**. MATLAB tool developed by GTD to explore the Conditioned Individual Risk (CIR) simulation results database, and chart the Suspected Hazard Area (SHA).	MATLAB standalone distributed with the CIR DB in deliverable D5.1 (public).
SRA-AIM	**SRA. AIM models. En-route WVE Accident Incident Models**	In D5.2 Safety & Robustness Report.

Table 5-2 R-WAKE System – Integrated Platform components summary

Appendix B R-WAKE-1 Concept summary

The **R-WAKE-1 Operational Concept Description (OCD)** is enunciated as:

> **R-WAKE-1: "Aircraft Category and Geometry-Wise Wake Separation Minima improvement for En-Route Separation Provision Advanced Services"**.

Having the purpose of: i) improving wake turbulence safety in En-Route operations; and, ii) improving airspace capacity and potentially enhance flight efficiency, whilst maintaining the same or improved level of safety.

The specific R-WAKE-1 concept proposal consists of a set of **six new separation schemes that have been identified by** looking at the simulation-based minimum wake separation in the three dimensions lateral, vertical, longitudinal, and also in combined lateral-vertical, and wind-dependent dynamic separations. The schemes are referred as en-Route Minimum Wake Separation (RMWS). They are summarized in the following table.

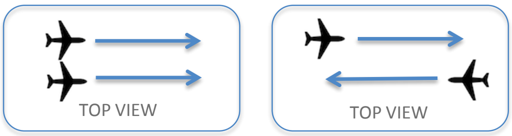
RMWS-#	Dynamic Type	Separation dimensions	Geometry-wise condition	Aircraft Category wise
RMWS-1	Static	Lateral-Orthogonal (dO)	Follower in Parallel tracks	Same for ALL
RMWS-2	Static	Vertical (dV)	Follower in all horizontal geometries	Per Generators RA,RB,RC
RMWS-3	Static	Longitudinal (dL)	Follower behind/in-trail flying levelled	Per Generators RA,RB,RC
RMWS-4	Static	Longitudinal (dL)	Follower behind generators climbing/descending Or Follower crossing below the generators trajectory	Per Generators RA,RB,RC
RMWS-5	Wind-dependent	Lateral-Orthogonal (dO)	Follower in Parallel track	Same for ALL
RMWS-6	Wind-dependent	Combined Vertical and Lateral-Orthogonal (dV+dO)	Follower in Parallel tracks	Same for ALL

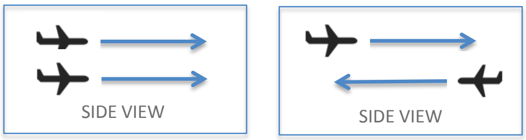
Table 5-3 Summary of the six R-WAKE-1 Separation Schemes

For each separation scheme a table is presented in deliverable D5.1, detailing the operating conditions (the relative geometry conditions), the separation scheme proposed for such operating conditions, and the expected impact on safety, capacity and flight efficiency. A robustness analysis is also recorded regarding the sensitivity of the proposed separations to the navigation uncertainties and atmospheric conditions.

B.1 The R-WAKE-1 concept separation schemes

The following points provide a reduced description of the schemes proposals.

<table>
<tr><th>RMWS-1</th><th>Static MWS lateral-orthogonal for followers in parallel tracks</th></tr>
<tr><td>Applicable Geometry</td><td>For followers <u>flying in parallel tracks</u>,
H 
</td></tr>
<tr><td>Separation adjustments proposal</td><td>MWS in lateral-orthogonal common for all generators:
<table>
<tr><th>Generator</th><th>Lateral MWS for the follower</th><th>Change relative to current standard</th></tr>
<tr><td>ALL</td><td>3 NM</td><td>-2 NM</td></tr>
</table></td></tr>
<tr><td>Performance impact expected</td><td>➢ <u>Increase airspace capacity,</u> due to reduced separation</td></tr>
</table>

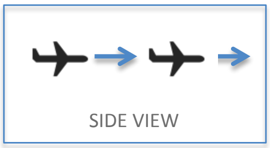
<table>
<tr><th>RMWS-2</th><th>Static MWS vertical in all horizontal geometries</th></tr>
<tr><td>Applicable Geometry</td><td>For followers <u>flying at any heading</u> (any horizontal geometries),
V 
</td></tr>
<tr><td>Separation adjustment proposal</td><td>MWS in <u>vertical</u> per generator category:
<table>
<tr><th>Generator</th><th>Vertical MWS for the follower</th><th>Change relative to current standard</th></tr>
<tr><td>CAT RA</td><td>1500 FT</td><td>+500 FT</td></tr>
<tr><td>CAT RB</td><td>1000 FT</td><td>0 FT</td></tr>
<tr><td>CAT RC</td><td>500 FT</td><td>-500 FT</td></tr>
</table></td></tr>
<tr><td>Performance impact expected</td><td>➢ <u>Increase safety,</u> due to the extra separation distance required after Category RA
➢ <u>Increase airspace capacity,</u> due to the reduction potential for flights below Category RC
➢ <u>Increase flight efficiency,</u> due to the greater number of FLs available which shall increase the likeliness for each flight to fly closer to its optimal altitude</td></tr>
</table>

RMWS-3 MWS static longitudinal for levelled followers in-trail or crossing behind

Applicable Geometry

For followers <u>flying levelled at any heading</u> (any horizontal geometries),

V



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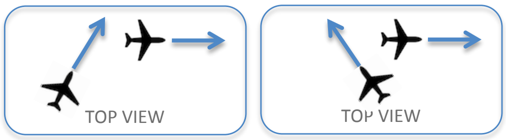


Separation adjustments proposal

A proposed <u>longitudinal MWS</u> per generators category:

Generator	Longitudinal MWS for the follower	Change relative to current standard
CAT RA	45 s / 6 NM (35 s/ 5 NM if Cat A)	N/A / +1 NM (N/A / 0 NM)
CAT RB	35 s / 5 NM	N/A / 0 NM
CAT RC	25 s / 3 NM	N/A / -2 NM

Performance impact expected

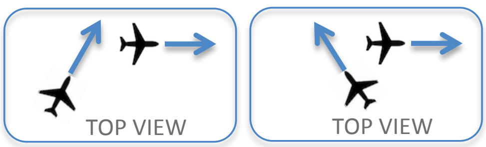
- <u>Increase safety,</u> due to the extra separation required after Category RA
- <u>Increase airspace capacity,</u> due to the reduction potential for flights behind Category RC

RMWS-4 MWS static longitudinal for aircraft climbing or descending behind or crossing in FL below a generator's trajectory (and not separated vertically)

Applicable Geometry

For followers <u>climbing or descending behind or crossing in FL below</u> a generator's trajectory (and not separated vertically),

H



V

Separation adjustments proposal

MWS in longitudinal per generators category:

Generator	Longitudinal MWS for the follower	Change relative to current standard
CAT RA	240 s / 32 NM	N/A
CAT RB	200 s / 27 NM	N/A
CAT RC	120 s / 13 NM	N/A

Note on exception: if the generator is Cat RC and the follower is in crossing/diagonal geometry, then the separation can be 70 s / 7 NM for F100 and MRS for all the others.

Note on maturity and further elaboration: The geometries considered in RWWS-4 are particularly sensitive to the aircraft/category variation and geometry variation. As a consequence, the design criterion of considering just the generator to determine the separation might require a revisit, perhaps introducing 3x3 generator-follower category wise matrix scheme with more precise separations**.** This would enable extra capacity gain at the expense of increased complexity/difficulty for the ATCO, but such aspect could be mitigated with support tools. The following tables are the separations proposed as needed to per category and different geometries in this potential evolution.

HEADING BEHIND		Generator		
		CAT RA	**CAT RB**	**CAT RC**
Followers	**CAT RA**	¿?	¿?	¿?
	CAT RB	30	22	11
	CAT RC	32	27	13
HEADING DIAGONAL		Generator		
		CAT RA	**CAT RB**	**CAT RC**
Followers	**CAT RA**	¿?	¿?	¿?
	CAT RB	25	20	MRS
	CAT RC	29	22	MRS
HEADING CROSSING		Generator		
		CAT RA	**CAT RB**	**CAT RC**
Followers	**CAT RA**	¿?	¿?	¿?
	CAT RB	22	13	MRS
	CAT RC	28	20	MRS

Performance impact expected

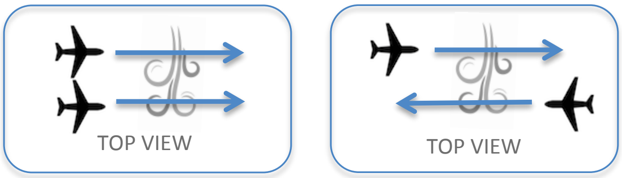
- Increase safety, due to new consideration of the hazardous vortex trail and the protection with new safety distances, compared to the lack of special separation standard today to protect against the traffic climbing or descending or crossing in a flight level below.

RMWS-5 MWS lateral-orthogonal for parallel tracks wind-dependent

Applicable Geometry

For followers flying in parallel tracks with cross-winds,

H



Separation adjustments proposal

MWS in lateral-orthogonal wind dependent:

Lateral MWS (upwind)	Max crossed wind component tolerated	Change relative to the current standard
3 NM	45 Kts	-2 NM
4 NM	60 Kts	-1 NM
5 NM	75 Kts	0 NM
X NM	15X Kts	+ (X-5) NM

Exception to nominal wind-dependent offsets (dO): If the generator is **CAT RC**, then the distances could be **reduced to the half** (due to the lower duration of their WV generated).

Performance impact expected

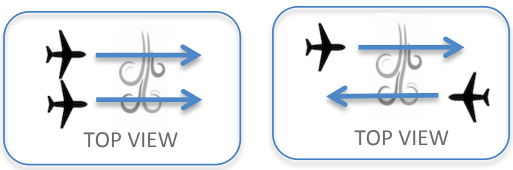
- For winds faster than 75 kts the new scheme shall **increase safety**
- For winds slower than 60 kts the new scheme shall **increase capacity**

RMWS-6 MWS combined vertical and lateral-orthogonal in parallel tracks wind-dependent

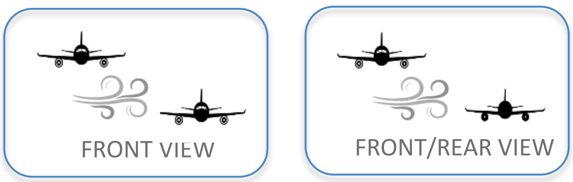
Applicable Geometry

For followers flying in parallel tracks with cross-winds,

H



V+H



<table>
<tr>
<td>Separation adjustments proposal</td>
<td>MWS in combined vertical and lateral-orthogonal wind dependent:
<table>
<tr><th>Minimum lateral separation (upwind)</th><th>Max crossed wind component tolerated</th><th>Change relative to the current standard</th></tr>
<tr><td>1 NM
(only if dV >= 500ft)*</td><td>15 Kts</td><td>N/A</td></tr>
<tr><td>2 NM
(only if dV >= 500ft)*</td><td>30 Kts</td><td>N/A</td></tr>
</table>
</td>
</tr>
<tr>
<td>Performance impact expected</td>
<td>

<u>Increase Safety</u>, due to combined vertical-lateral separations considering crossed winds, in-line with what been recently recommended by ICAO and EASA to increase safety;
<u>Increase Airspace capacity and fuel efficiency</u>, due to the introduction of new procedures with combined separations to protect aircraft flying 500 ft or 1000 ft below a Cat RA or 500 ft below a Cat B, (in contrast with the extra vertical separation required for such categories).

</td>
</tr>
</table>

B.2 Potential Applications of the proposed separation schemes

This section summarises the identified set of potential applications of the R-WAKE-1 proposed separation schemes improvements, intended to materialize the expected performance benefits of airspace capacity and flight efficiency.

DISCLAIMER NOTE: It should be noted that all the potential applications proposed here require further research, development and validation, and due to their current low level of maturity sometimes are presented together with strong assumptions and simplifications. Therefore, **these potential applications should be seen as exploratory ideas and illustrative examples** that aim at fostering discussion and deeper understanding among experts around the R-WAKE-1 separation schemes potential application to improve the safety, capacity and efficiency performances in the en-route separation provision.

APP-1: Lateral Separation Reduction for parallel tracks

According to the ICAO Annex 11, two route segments are considered parallel when: a) they have about the same orientation, i.e., the angular difference does not exceed 10 degrees; b) they are not intersecting, i.e., another form of separation must exist at a defined distance from the intersection; and c) traffic on each route is independent of traffic on the other route, i.e., it does not lead to restrictions on the other route. Such definition could be extended to refer to **'parallel tracks'**, therefore **including the cases in which free-route is implemented**, since SESAR is moving the ATM towards **free-route trajectory-based operations**.

Improvements in the Performance Based Navigation (PBN) capabilities (see assumption A-3) may allow an increase of horizontal capacity: **traffic flying in parallel tracks could be separated by 3 NM** (see assumption A-4), which represents a robust separation against collision risk of 6 sigma with respect to the navigational standard error, and it might be still acceptable for ATC controllability (e.g., traffic not scattered, i.e., not too close, in the radar screen).

In the R-WAKE project it has been explored if such 3 NM separation can be also considered safe from the point of view of **WVE hazards**, and some **wind-dependent separation minima schemes** have been proposed to increase the robustness of the separations to crosswind components.

Figure 4 shows that even **if the current route structures are preserved (i.e., not a free-route environment), the capacity could be still increased**, for instance by adding some extra lanes within a same route corridor (e.g., three or four). A configuration with three lanes in the route would leave a conservative distance of 6 NM with respect to the limits of the air route. This might be convenient in the presence of protected areas in the vicinity of the upper air route borders or in case that extra separation is preferred with respect to other routes (e.g., if the neighbour route is set for traffic with opposite direction). **A potential practical application today could be in long route segments (e.g., 300 NM) with dense traffic.**

The use of parallel lanes, since they allow overcomes between flights, may also facilitate the **traffic delivery (sequencing and merging) at the coordination points of the sectors that feed TMAs** and airports, thus opening the door to a **more advanced flight sequencing of the AMAN systems**, and potentially **optimising in turn the use of available airport capacities**.

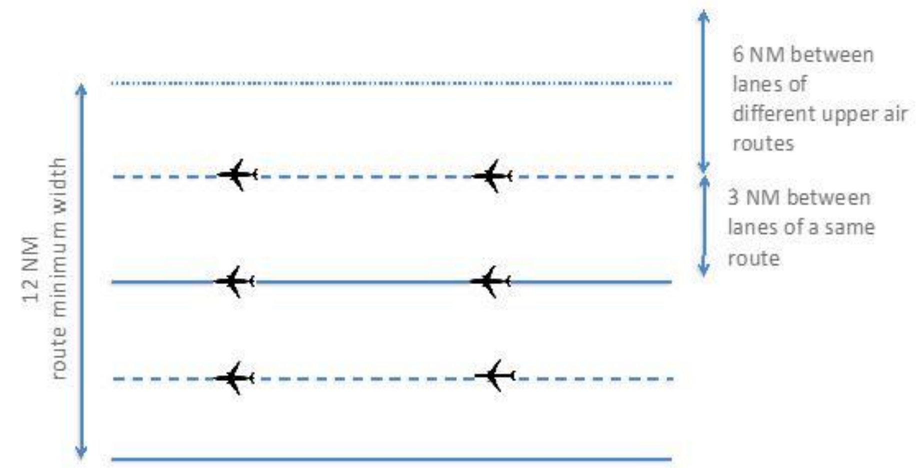


Figure 5-3 R-WAKE Horizontal Separation Minima concept. 3 NM of separation in parallel tracks

APP-2: Vertical separation reductions to increase vertical physical airspace capacity

Today the **traffic is strategically de-conflicted by the design of airspace and procedures** that organise the traffic into virtual airspace discrete layers, a.k.a., **flight levels (FLs).** Controllers usually allocate aircraft to flight levels in accordance with a flight level allocation rule. For example, a **semi-circular rule** might require that aircraft whose track is between 000º to 179º should cruise at odd flight levels, while aircraft proceeding with course between 180º and 359º should cruise at even flight levels. Such rule prevents aircraft moving in roughly opposite directions from occupying the same level, and therefore such design of ATM contributes to reduce considerably the complexity and workload of ATC, thus reaching a fairly good trade-off between safety, capacity and flight efficiency.

Figure 5-4(left and right) shows how the en-route capacity could be increased in the last decades by reducing the **conventional vertical separation minima (CVSM)** among flights and introducing the concept of **Reduced Vertical Separation Minima (VRSM),** fully adopted in the ECAC since 2005. With RVSM the flight level allocation scheme (FLAS) changed between FL290 and FL410 and the flight levels usable for the RVSM-capable flights were distanced from 2000 ft (CVSM) to 1000 ft (VRSM).

It must be noted that, while the introduction of RSVM doubled the physical capacity available, from 6 to 12 flight levels; however, **the actual net capacity increase, was estimated by EUROCONTROL in about a 20% with the same number of ATC resources**, which can be considered an important positive achievement. The operational capacity was not doubled because most flights want to use the upper flight levels, and therefore the traffic complexity and volume in some upper layers still represent an important bottleneck of the en-route airspace. Extra capacity can be obtained in some cases where **due to a greater number of flight levels more sectors can be opened** in the vertical domain. In terms of safety, **risks have been preserved under tolerable levels**, since no increase in the number of mid-air collisions has been evidenced after the implementation of RVSM.

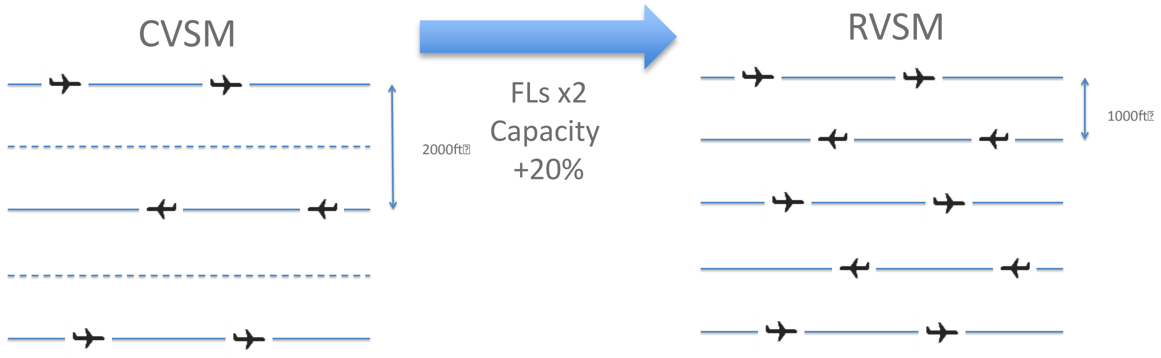


Figure 5-4 Conventional (left) and reduced (right) vertical separation minima concepts

In R-WAKE, the possibility of **reducing the vertical separation up to 500 ft for some flights**, or enabled with the introduction of **combined vertical and lateral separation**, has been proposed aiming at **increasing the physical capacity** in the vertical domain, with similar logic than the RVSM concept.

Risk of collision is expected to remain under controlled levels, since it is assumed in the project that vertical navigation precision will be enhanced in the future (as well as the horizontal). Note that even for today cruise operations the risk of collision in the case of introducing a minimum vertical separation of 500 ft might be considered acceptable for en-route cruise phase of flights, taking into consideration the minimum required performance standardised for navigational vertical deviations of RVSM-capable aircraft.

In particular, **EASA** standardised the following for **Airborne Navigation Specifications** that are relevant to the R-WAKE-1 concept:

- **RVSM system performance**: the automatic altitude control system controls the altitude within **±20 m (65 ft)** about the selected altitude, when the aircraft is operated in straight and level flight under non- turbulent non-gust conditions.
- **Altimetry system accuracy**:
  - At the point of the flight envelope where the mean ASE (ASEmean) reaches its largest absolute value that value does not exceed **25 m (80 ft);**
  - At the point of the flight envelope where the absolute mean ASE plus three standard deviations of ASE (ASE3SD) reaches its largest absolute value, the absolute value does not exceed **60 m (200 ft).**

On the other hand, **ICAO doc 9574 (RVSM Implementation Manual)**, states that in studies conducted previous to the RVSM implementation, most common vertical errors were found within an **envelope of +/- 50 ft**, and only from time to time (relatively infrequently) **some errors were found up to 300 ft.** These numbers have been confirmed by EUROCONTROL experts in navigation systems based on analysis of historical correlated radar trajectories of ECAC traffic. Same ICAO document states that certified **automated height-keeping systems** should be capable of maintaining the aircraft in **+/- 40 ft the 95% of the time (2 sigma)** when flying level-off.

The R-WAKE-1 vertical separation proposals can also contribute to **enhance the flight efficiency** of the operations, since the availability of a greater number of flight levels generates more opportunities for the airspace users to operate their flights closer to their optimal altitudes.

Note that in practice the vertical separation scheme proposed in R-WAKE might suppose **limited change for ATC** compared to their current way of operating, possibly just adding constraints to the cleared flight levels (CFLs) that the controller can issue. In some airspaces and for some procedures, the phraseology of ATC already includes the usage of FLs referred with multiples of 5. Therefore, the use of 500 ft between flight levels may introduce **little impact on the phraseology of current ATC** and pilot procedures, since the FLs are today referred with 3 digits, representing the highest weight digits of the total barometric altitude in hundreds of feet, e.g., FL210 = 21,000 ft. Therefore, in the new R-WAKE concept of operations references to flight levels such as for instance FL215 (21,500 ft) or FL215 (21,500 ft) could be cleared by the ATC and followed by the pilot as a navigation reference. The **coordination between sectors or airways that may have different FLAS** has to further discussed, but it is expected that the procedures can be **similar to the ones used in the cases in which traffic is transferred from non-RVSM to RVSM airspace.**

Of particular interest is the case in which **two flights move in opposite directions, the follower being one FL below the generator (this is typically a worst case of WVE).** Clearly, for some cases (generator belongs to Cat A or Cat B) the separation of 500 ft is not enough and two options are available depending on the application environment and/or on the preferences of the ATCo in charge. One option is to increase vertical distance up to 1000 ft (Cat B generator) or 1500 ft (Cat A generator), and the other option is to apply a **combined separation by adding a lateral separation (e.g., 1 NM) in addition to the vertical separation**. In the presence of wind the upset should be applied upwind or large enough to provide a robust separation.

APP-3: Longitudinal separation reduction for in-trail traffic at the same flight level as the generator aircraft

Reducing the longitudinal separation might be interesting also in some practical cases, specially for flights flying **one behind the other** (see Figure 5-5), since **it may contribute to increase notably the throughput at sectors**. This could have an especial positive impact in the traffic sequences delivered from one sector to a TMA to feed one or more airports.

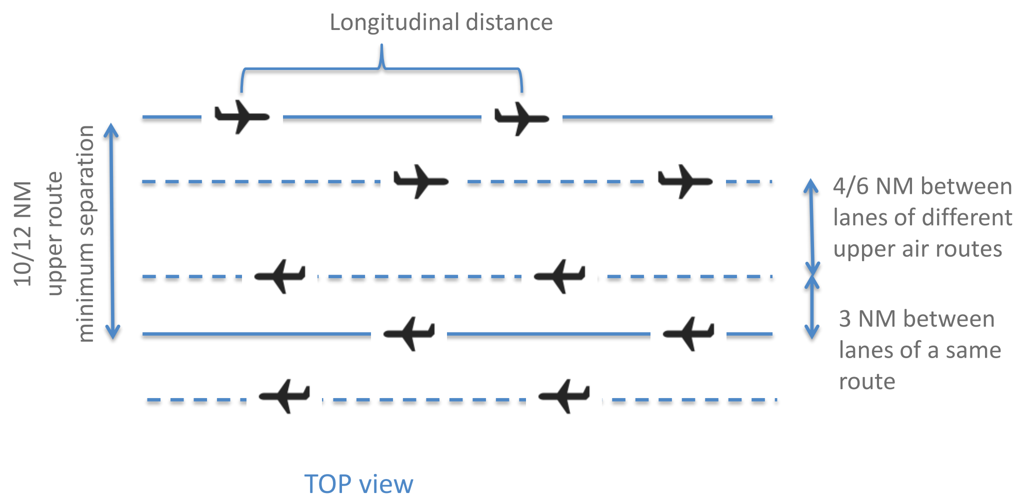


Figure 5-5 R-WAKE Longitudinal Separation reduction for in-trail traffic at the same FL

APP-4: Combination of vertical separation reduction and lateral separation to compress the traffic vertically

The EASA Bulletin recently proposed to apply **combined separations to protect traffic flying on the same track** and below an A380 or similar, typically going in opposite directions, in order to mitigate the risk of severe WVE. Such mitigation mechanism can also be used if the traffic is separated 500 ft instead of 1000 ft. Therefore, in some particular traffic environments, for instance in **high-density flows of parallel traffics** (unidirectional or bidirectional), the flights could be separated 500 ft (same for every flight, irrespective to the categories of the generator or the follower) while their tracks could be offset by e.g. 1-3 NM depending on the flight level allocated. See Figure 5-6. Wind strength and direction must be taken into account to ensure the effectiveness of the protection.

Note that the compression of traffic vertically **could increase notably the capacity and flight efficiency performances**. On the other hand, the offset techniques **can only be applied to parallel traffic**, which limits its utilisation to some controlled environments.

A good environment to introduce these ideas could be on one of the **major traffic flows in Europe** in which the traffic demand is **highly dense at some periods,** and where generating **additional capacity and flight efficiency** shall bring more noticeable benefits. A particularly interesting high-density flow is the one existing between **South of France / North Italy and London**.

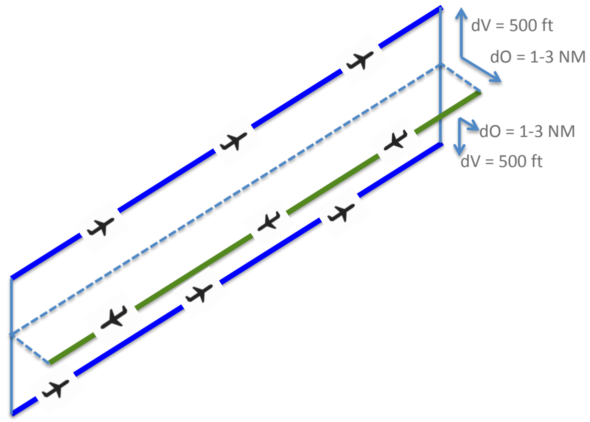


Figure 5-6 Combined separations for vertical traffic compression

APP-5: Increase safety during climbing/descending operations with traffic crossing below

One of the contributions of R-WAKE has been bringing an increased awareness of the WVE hazards that today are not sufficiently mitigated with the current separation standards applied. **Hazardous or even catastrophic accidents can be drastically mitigated if a better separation provision is developed by ATC**: first, by identifying the 4D no-go regions corresponding to the pre-specified boundaries of the suspected hazards areas of the wake vortices; and second, deciding how to amend the trajectories to avoid the hazards. The important of **such awareness would be much more significant if traffics were separated by 500 ft vertically** instead of 1000 ft. In any case, while the WV is not dissipated after a generator has generated, the controllers should avoid the rest of the traffic entering such region, yet by **providing vertical, lateral of longitudinal separations, as proposed in R-WAKE-1 concept**, depending on the specific needs of the traffic and sector situations.

APP-6: Cooperative subliminal offsets based on ADS-B

Traffic awareness in cockpit has been drastically enhanced in the last decade with the introduction of ADS-B (OUT and IN) technologies on board. Advanced safety net and self-separation systems based on ADS-B are envisioned for the future SESAR 2020 ATM. Taking advantage of such technological roadmap, a new operational improvement could be introduced in which:

- Aircraft could be equipped with **on-board WVE preventing systems** (with ADS-B technological basis);
- Aircraft over a same track could apply **subliminal off-sets (e.g., 100 m or less)** in the direction of the wind for the generator and upwind for the follower;

These offsets would possibly be **not perceived by ATCOs (subliminal) but would reduce significantly the risk of WVE** (also valid with today's separation standard).

This potential application can be understood as the **continental equivalent of the oceanic SLOP** that is operational today, where no ATCO clearance is required for the offset, but instead of offsetting by 1 or 2 miles aircraft would offset by 100m (enough to reduce the hazard risks, and not too much to require ATCO's attention).

Note that the concept of lateral offset is not used here as a strictly limited to a fixed route reference, but it is understood as a lateral shift with regards a certain track followed by the aircraft; thus the **lateral/parallel shift could be applied with regards to a free-route or a 4D trajectory assigned to a flight and not necessarily to a fixed route.** Further research is needed to determine whether some kind of offset-like concept may be useful when either the leader or the follower are not following a route.

APP-7: Increased wake encounter risk advisory service

The APP-7 idea would be a ground tool that would advise ATCOs when there is increased risk of wake encounters (pairwise or in a whole area), similarly –and indeed complementary– to a Short Term Conflict Alert system (STCA).

If pairwise, ATCOs would inform the follower, or in case datalink is enabled, a warning could be uplinked automatically without direct ATCO involvement. For increased risk in one area, maybe ATCOs could be advised to increase separation minima whenever possible.

Note that the target R-WAKE concept is to implement a whole new separation scheme, but the project team estimates that development and implementation of this interim concept to address the increased safety concerns about potential wake encounters in en-route would require a shorter lifecycle and already provide safety benefits, and that the work in the development of the interim concept would also support the development of the target concept.

Appendix C Feasibility assessment: feedback from ATC Controllers Experts Panel

A preliminary qualitative integrity assessment of the R-WAKE-1 concept (**'safety failure approach'**), through the presentation and discussion of the 6 separation scheme enhancements to active ATCOs. Recommendations for concept refinement were also gathered, in order to complete the definition of how the proposed R-WAKE-1 separation schemes would be applied operationally (this was reflected in the research needs identified: FRN#17, 18, and 19).

The conclusions obtained are reported in in D5.2 Safety and Robustness Analysis, and consolidated in D5.3 Results Assessment (chapter 5), as part of the concept performance assessment conformant to the ER/IR criteria, addressing the key question: '*Have the results of the research validated the investigated Concept in terms of feasibility, implementability, safety and cost-benefits?*

Table below recalls here the concept feasibility expert judgement comments about the R-WAKE-1 concept elements (schemes and suggested applications).

R-WAKE-1 Concept Element	ATCO Feedback	Feasibility
Separation Schemes: RMWS-1: Static Lateral-Orthogonal (dO) for followers in parallel tracks and RMWS-3: Static Longitudinal (dL) for levelled followers in-trail or crossing behind	Actions on horizontal plane easier than vertical because 2D displays. Not against differentiating lateral from longitudinal – requires change because only work with one horizontal separation now. Need clear differentiation of when to apply lateral and when to apply longitudinal if 3NM proposal is not always applicable (e.g. if the longitudinal constraint is 7NM). If both lateral and longitudinal need to be taken into account then a tool would be required.	Feasible subject to clear rules being provided with supporting tools.

R-WAKE-1 Concept Element	ATCO Feedback	Feasibility
Separation Scheme: RMWS-2: Static Vertical (dV) in all horizontal geometries	If aircraft considered in pairs then not considered an issue. If considering more aircraft then only manageable if allowed to apply the same separation, i.e. ***not*** a mixture of 500ft, 1000ft and 1500ft because this would be a significant increase in workload. Additional coordination between sectors will be required where separation minima exceed the standard altitude spacing resulting in reduced capacity. More sensible to maintain universal 1000ft and move to 1500ft if following a Cat RA or 500ft if following a Cat RC. Need a tool to advise moving to 500ft and safety net to highlight need to move to 1500ft.	Partially feasible, requires further investigation of the impact on: - ATCO Workload when multiple separations are required - Sector coordination and the potential adverse effect on capacity
Separation Scheme: RMWS-4: Static Longitudinal (dL) for aircraft climbing/descending behind or crossing in FL below a generator's trajectory (and not separated vertically)	Adverse effect on sector capacity arising from the required separations following category RA and RB aircraft compared with current standards applied to typical sector dimensions. If necessary to apply 13 NM or 17 NM separations when climbing descending to levelled flight with a 3 NM separation then the reduction in capacity is too abrupt and difficult to manage.	Significant feasibility issues, requiring further assessment of: - Adverse effect on sector capacity - Management of different separations when moving from levelled flight to climbing/descending.
Separation scheme: RMWS-5: Wind-Dependent Lateral-Orthogonal (dO) for parallel tracks	Strongly criticized. Even if a tool providing cross-wind data were available the variability of wind conditions would result in that data becoming outdated quickly resulting in excessive ATCO workload to apply the necessary separation adjustments.	Not feasible under ATCO control – considered too challenging

R-WAKE-1 Concept Element	ATCO Feedback	Feasibility
Application: APP-1 Offset reduction in parallel tracks	Interest shown in the proposed application; clear indication required of how configurations could be achieved when transiting to/from levelled flight when climbing/descending.	Feasible subject to resolution of the issue of the apparent incompatibility between levelled flight separations and those applied to climbing/descending
Application: APP-2: Vertical separation reductions to increase vertical physical capacity	Not seen as an issue. Noted that new potential rules concerning flight level allocation should be consistent with rules concerning separation minima, i.e. problematic to have FLs organised by 500 ft when three different separation minima are to be applied. This results in increased workload for ATCOs due to the amount of tactical vectoring instructions required. Additional coordination between sectors will be required where separation minima exceed the standard altitude spacing resulting in reduced capacity.	Partially feasible, subject to further investigation on possible adverse impact on ATCO workload through increased tactical vectoring instructions and sector coordination
Application: APP-6 Cooperative subliminal offsets based on ADS-B	Potential improvement on today's situation where there is no prescription for ATCO to instruct pilots on WVE avoidance.	Feasible; subject to concept application development and tool specification

Table 5-4 R-WAKE-1 Schemes Feasibility assessment : feedback from ATC Controllers Panel

D5.2, Safety and Robustness Assessment, also notes that the ATCOs were not supportive of the idea of allocating lighter categories of aircraft to higher flight levels in order to maximise the capacity impact of the proposed separation schemes. Specifically, they were critical of its operational applicability, because:

- Lighter aircraft are more likely used for short/medium haul flights and would need to climb/descend through many FLs in limited timeframe, thereby increasing complexity of traffic and ATCO workload
- The benefit of increased fuel efficiency at higher FLs is much greater for heavier aircraft, therefore requiring these to fly at lower FLs is likely to have an adverse effect on overall flight efficiency (and consequently environmental) key performance areas and a very low acceptability with aircraft operators.

Appendix D Further R&D needs description

This point includes the list of Further Research Needs (FRN) identified arising from maturity limitations in the four main aspects of the project approach towards its objectives:

- Arising from the **R-WAKE Simulation Framework;** scope, limitations, assumptions and activities not completed, including Safety and Robustness Analysis methodology, in order to support the **R-WAKE-1 Concept** further development.
- Arising from the **R-WAKE-1 Concept assessment**; maturity of definition, the scope, limitations, assumptions and achievements of the validation activities performed;
- Arising from the **Assessment Key questions**; coverage in terms of the questions not addressed or partially addressed by the project;
- Arising from the **ER-IR Gate Criteria**; coverage in terms of the criteria not addressed or partially addressed by the project;

D.1 Arising from the R-WAKE System Simulation Framework

FRN#	Description	Limitation addressed
FRN-1	***Complete the coverage of aircraft models in the micro-simulator*** Currently only one aircraft model per RECAT category has been simulated (i.e., generators: A388, B744, B764, A320, F100, and followers: B744, B764, A320, F100). It is of particular interest to include turbo-prop models for future R&D activities.	R-WAKE system: aircraft micro models completeness and accuracy.
FRN-2	***Weather conditions statistics (climatology view) and wake vortex model results sensitivity analysis, e.g. especially with temperature gradients (stratification) phenomena.*** Weather-dependent separations would be highly advisable to reach a good trade-off between safety and capacity. This is due to the fact that wake vortex behavior and duration are very sensitive to the changing temperature gradients (stratification).	R-WAKE system: Models maturity: uncertainty in weather phenomena statistics. **(linked with FRN-7)**
FRN-3	***Robustness Analysis of separation schemes proposals especially for all weather conditions.*** For instance, **the atmospheric cases of Stratification=1 (i.e., Buoyancy frequency N* = 0) have been not considered** to establish the new separation schemes, since the area of uncertainty is too large while the probability of such atmospheric	R-WAKE system: Models maturity: Weather and WV models uncertainty impact on separation schemes.

FRN#	Description	Limitation addressed
	conditions is very low. It must be pointed out that the unfeasibility of applying a static separation scheme that protects against all the weather conditions (also the rate ones) is well-known by the experts in the field and accepted due to the large capacity losses that the static/non-weather-dependent separation schemes would require in contrast with the unlikeliness of such atmospheric conditions.	
FRN-4	***Vertical navigational errors statistical study and results sensitivity analysis*** The vertical and longitudinal separation schemes proposed for levelled aircraft are **very sensitive to vertical navigational errors**. In addition, such separation schemes are applied to the most risky geometries, e.g., traffic flying in-trail (like in RECAT) or below, in the same or opposite direction and not separated vertically. **In En-Route, it is much more likely than in airports (RECAT) that a follower can be below the generator** (even when two flights try to navigate in the same FL). Therefore a **robust protection should be applied**. In R-WAKE-1, advanced navigational aircraft capabilities have been considered (total vertical error contained in +/- 50 ft), however further research could be done with today's navigation system performances. Considering vertical navigational errors for both generator and follower flights, **a reasonable total error between 100 and 200 ft should be considered for today's RVSM-certified navigation systems.** In most cases, the consideration of vertical navigation uncertainties **requires considerable separation buffers (from 1 NM up to 7 NM, added to the best case**, i.e., the separation of the dV=0).	R-WAKE Concept: Operational assumption#3 validation : RNP-1 capability in ATM
FRN-5	***Severity Matrix of Upset Parameter Threshold further validation and refinement, e.g., Load Factor impact in Crossing/Diagonal scenarios.*** The **severity matrix with upset parameters and thresholds** was developed as an absolute safety reference with the help of two expert panels. The upset parameters that were found relevant to determine the severity of an encounter were: a) the rolling angle; b) the altitude change; c) the maximum altitude change speed; and d) the airspeed change. However, after analysing the simulation results for the **crossing/diagonal scenarios**, it has been concluded that the **maximum Load Factor must be also a parameter considered to determine the separation needed. Further validation with experts must be conducted** to refine the severity scale associated to the load factor variability.	R-WAKE system: Absolute Severity Baseline validation maturity **(linked with FRN-14)**

FRN#	Description	Limitation addressed
FRN-6	***Robustness and Integrity assessment by ATCOs.*** Acceptability of the separation schemes by ATCOs has been addressed only partially, and with the main purpose of receiving an early feedback of the potential acceptability and to identify areas of improvement for the concept development (this is a common E-OCVM validation exercised to be conducted for concept that still are at low level of maturity).	R-WAKE-1 Concept: Robustness and Integrity Assessment maturity
FRN-7	***All weather condition wake vortex predictions*** Available wake vortex prediction models that have reached a certain level of maturity for application in assessing current and new separation standards do not cover all possible weather conditions or combinations. The models applied in the R-WAKE project do not consider instabilities like e.g. Crow-Instability in certain meteorological conditions, thus in rare cases the prediction leads to a longer wake vortex lifetime and is thus conservative for certain meteorological conditions. Additionally, wake vortex decay and transport has only been modelled for neutral and stable stratified atmosphere due to a lack of available wake vortex modelling for instable atmospheres temperature stratification.	R-WAKE System: WVS models completeness **(linked with FRN-2 and FRN-11)**
FRN-8	***Refinement of Separation Schemes and Applications through macro-simulations to assess impact on risk.*** To demonstrate the viability of the R-WAKE-1 Concept it will be necessary to determine its effect on the risk of WVE in terms of frequency of occurrence and severity. This will enable Absolute Safety Criteria to be defined. The R-WAKE simulation framework would be used to update the proposed schemes and their application(s) based on: i) a current baseline measurement of WVE risk using current traffic volumes and mix, current ATC procedures and standards (i.e. the Unit Safety Case), and ii) the effect on WVE risk through application of the proposed R-WAKE-1 separation schemes based on current and future traffic volumes and mix (i.e. the Project Safety Case).	R-WAKE-1 concept: Lack of concept systemic simulations, and Absolute Safety Criteria definition. Lack of quantitative hazard occurrence frequency measurements. **(linked with FRN-13)**
FRN-14	***Refine Severity Matrix for combination of upset parameters*** Currently the severity matrix is applied considering only one of the upset parameters, i.e. if roll angle is between 25° and 30° the severity is classed as Minor (2) without consideration of the other parameters. If all the parameter thresholds for Minor (2) were met (i.e. roll angle is between 25° and 30° and altitude between 100 and 500 ft and vertical speed change was between 500 and	Absolute Severity Baseline validation maturity **(linked with FRN-5)**

FRN#	Description	Limitation addressed
	1000 ft/sec and airspeed change between 10 and 15kn) then overall the severity may be classified higher (e.g. Major (3)). Further investigation is required to assess whether this is the case.	
FRN-15	***Refine Dynamic Risk Models*** Currently the risk models are restricted in scope and should be further developed, for example to integrate with the Accident Incident Models (AIM) for Safety Risk Management and include new models to assess the risk in sectors or the ECAC airspace.	Dynamic Risk Model maturity
FRN-16	***Enhance Safety and Robustness Analysis (SRA) Approach*** Currently the SRA, although fully aligned with the methodologies and requirements of ESSAR4, SAME and SESAR SRM, is restricted by the relative immaturity of the concept under investigation. Further analysis is required including: conducting further Systems, Human Factors and Procedures analyses; generating evidence and safety requirements as the concept increases maturity; and, adopting a wider systemic approach to include AIMs analysis.	Restricted SRA achievements

D.2 Arising from the R-WAKE-1 Concept Definition and Validation

FRN#	Description	Limitation addressed
FRN-9	***Validate the Minimum Radar Separation of 3NM*** [Relevant for proposed separation scheme **RMWS-1** Static Lateral-Orthogonal (dO) for followers in parallel tracks] A minimum radar separation of MRS = 3 NM has been assumed as robust enough in an operating environment in which RPN-1 navigation capabilities are assumed for all the aircraft. This assumption needs to be tested.	R-WAKE-1 separation schemes and application feasibility and use issues
FRN-10	***Determine and specify En-Route WVE-based Separation Decision Support Tools for ATCOs*** [Relevant for proposed separation schemes: **RMWS-2** Static vertical (dV) in all horizontal geometries; **RMWS-3** Static longitudinal (dL) for levelled followers in-trail of crossing behind; and, **RMWS-4** Static longitudinal (dL) for aircraft climbing/descending behind ofr crossing in FL below a generator's trajectory (not separated vertically)] Complexity of the separation scheme coupled with the need to minimise impact on ATCO workload means that support tools will	R-WAKE-1 separation schemes and application feasibility and use issues

FRN#	Description	Limitation addressed
	be required to assist ATCOs to apply the proposed schemes. The scope and functional requirements of the tool need to be defined.	
FRN-11	***Further validate WV models with real flight data*** [Relevant for proposed separation schemes: **RMWS-2** Static vertical (dV) in all horizontal geometries; and, **RMWS-4** Static longitudinal (dL) for aircraft climbing/descending behind or crossing in FL below a generator's trajectory (not separated vertically)] The amount of real WVE data available to for validating the R-WAKE Simulation Framework has been very restricted. In order to ensure credibility of the proposed separation schemes it is important that further validation of the framework and its models with real WVE and flight data are conducted.	R-WAKE-1 separation schemes and application feasibility and use issues **(linked with FRN-7)**
FRN-12	***En-Route WVE-based Separation Decision Support Tools for ATCOs to include wind/weather data*** [Relevant for proposed separation schemes: **RMWS-5** Wind dependent Lateral-Orthogonal (dO) for parallel tracks; and, **RMWS-6** Wind dependent Combined Vertical and Lateral/Orthogonal (dV & dO) in parallel tracks] Complexity of the separation scheme coupled with the need to minimise impact on ATCO workload means that support tools will be required to assist ATCOs to apply the proposed schemes. The nature of RMWS-5 and RMWS-6 are that wind/weather data are a required input to determine the separations to be applied. Any separation management support tool will need to incorporate wind/weather data.	R-WAKE-1 separation schemes and application feasibility and use issues
FRN-17	***Refinement of Horizontal (Offset and Longitudinal) Separation Schemes and Application*** Although identified as feasible further development is required to clarify: - when to apply lateral and longitudinal rules if 3NM separation is not always applicable. - The apparent incompatibility between levelled flight separations and those applying when ascending/descending to/from a FL - the role and function of an ATCO support tool will need to be defined if a combination of offset and longitudinal rules are to be applied.	Concept feasibility

FRN#	Description	Limitation addressed
FRN-18	***Refinement of Vertical Separation Schemes and Application*** Identified as partially feasible, with further investigation and definition required regarding: - Potential increase in ATCO workload when applying multiple vertical separations depending on generator aircraft in the same airspace sector with a 500ft FL altitude spacing scheme - Sector coordination required where separation minima between pairs of aircraft exceed the 500ft FL altitude spacing scheme The role and function of tools to advise on moving to a more efficient 500ft separation and safety net of increasing to 1500ft separation.	Concept feasibility
FRN-19	***Confirm feasibility of RMWS-4 (Climbing/Descending/Crossing static longitudinal), RMWS-5/6 (Wind dependent schemes)*** Significant concerns about the feasibility of these separation schemes and associated applications were raised by the ATCO focus group. Further work is required to confirm whether these proposed separation schemes should be retained for further development	Concept feasibility

D.3 Arising from Key Questions Assessment

Further research required to develop the Business Case for the R-WAKE-1 Concept:

FRN#	Description	Limitation addressed
FRN-13	***Quantify performance impact by macro-simulations.*** Conduct systemic level simulations in order to: - establish a current baseline measurement of wake vortex encounters (WVEs) and performance measures based on current traffic volumes and mix, current ATC procedures and standards (i.e. the Unit Safety Case). - establish the effect on (WVEs) and performance measures based on applying the proposed R-WAKE-1 separation schemes based on current and future traffic volumes and mix (i.e. the Project Safety Case). - investigate the effect of proposed R-WAKE-1 separation schemes and their application in terms of types of En-Route airspace and the management of transferring aircraft to/from adjoining sectors that are not applying the separation schemes.	Lack of quantifiable performance data To complete R-WAKE-1 Business Case development (Assessment Key Question). **(linked with FRN-8)**

FRN#	Description	Limitation addressed
	The set of simulations would also enable a sensitivity analysis to be performed on the performance effects to identify which influencing factors have the most effect on projected performance gains.	

D.4 Arising from the ER/IR Gate Criteria

With reference to the ER-IR gate criteria, the following further research is required to complete the assessment of ER-IR criteria (the other ER-IR criteria not fully achieved are already covered by FRN in the previous FRNs).

FRN#	Description	Limitation addressed
FRN-20	Formal case-based assessment of Stakeholder expectations to be performed.	Full achievement of OPS.ER.5 (stakeholders id.)
FRN-21	Regarding (sub)operating environments where, if deployed, the concept would bring performance benefits: Investigate the effect of proposed R-WAKE-1 separation schemes in terms of airspace applicability and the management of transferring aircraft to/from adjoining sectors that are not applying the separation schemes.	Full achievement of OPS.ER.6 (operating environments id.)

Appendix E IR V1 Criteria and R&D needs assessment

The following tables provides the project achievements assessment against the Industrial Research (IR) V1 criteria, in order to determine the further R&D needs specifically required for the proposed R-WAKE-1 SESAR Solution to meet the V1 maturity threshold. The tables reflect the project view, since a formal IR V1 maturity assessment meeting with SJU was not performed.

Level	Thread	Criteria	Achieved	Partial Non-Blocking	Partial-Blocking	Not Achieved	Not Applicable
IR V1	OPS	OPS-V1.1 (concept)	-	X	-	-	
		OPS-V1.2 (EATMA link)		-	X		
		OPS-V1.3 (variants)		X	-		
		OPS-V1.4 (ops.env.)		X	-		
		OPS-V1.5 (stakeholders)		X	-		
	SYS	PER-V1.1 (impact EATMA)	-	X			
		PER-V1.2 (functional blocks)			X		
		PER-V1.3 (constraints)				X	
		PER-V1.4 (techs. Supporting)				X	
		PER-V1.5 (CNS needs)				X	
	PER	PER-V1.1 Human (6)	-	-	1	5	-
		PER-V1.2 Performance (4)	-	2	-	2	-
		PER-V1.3 CBA (1)	-	-	1	-	-
		PER-V1.4 Safety (4)	3	1	-	-	-
		PER-V1.5 Security (3)	-	-	-	-	3
		PER-V1.6 Environmental (2)	-	-	1	1	-
	S&R	S&R-V1.1 (standard needs)			X		
	TRA	TRA-V1.1 (trans. issues id.)				X	
		TRA-V1.2 (V2 plans)				X	
	VAL	VAL-V1.1 (VALS conform)			X		
		VAL-V1.2 (R&D needs)			X		
	PRG	PRG-V1.1 (EATMA Baseline)			X		
		PRG-V1.2 (relations to other SESAR solutions)				X	
		PRG-V1.3 (related SESAR solutions maturity)				X	

Table 5-5 Summary of IR V1 Criteria assessment

E.1 IR V1 Criteria Assessment

Thread	ID	Sub-ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
OPS	OPS. V1.1		Is the initial documented description of the concept consistent with the SESAR 2020 CONOPS?	Partial - Non Blocking	Concept description (proposed separation schemes and their application) as detailed in D5.2 and summarised in D5.3 Assessment Report Section 3.1. Reference is made to the relevance of R-WAKE to the SESAR CONOPS (D5.3 Section 3.2.1); however further work is required in the further refinement and definition of the concept and its application which will affect assessment of how it relates to the SESAR 2020 CONOPS
OPS	OPS. V1.2		Is there an initial identification and description of the SESAR Solution and related OI steps available in EATMA (Integrated Roadmap)?	Partial - Blocking	A SESAR Solution and related OI Steps are proposed in D5.3 Assessment Report Section 3.3, which have not yet been approved and included in the EATMA/ATM Master Plan Integrated Roadmap
OPS	OPS. V1.3		Are the different concept variants (if any) described?	Partial - Non Blocking	As detailed in D5.1 and summarised in D5.3 Assessment Report Section 3.1, a number of options for the application of the proposed R-WAKE-1 Separation Schemes are identified; however further work is required in the further refinement and definition of the concept and its potential application to finalise any concept variants.
OPS	OPS. V1.4		Have potential (sub)operating environments been identified where, if deployed, the SESAR Solution could bring performance benefits? *Note: the relevant (sub) operating environments associated to the SESAR Solution shall be consistent with those available in EATMA*	Partial - Non Blocking	As summarised in D5.3 Assessment Report Section 3.3.2, the potential (sub)operating environments of En-Route for the application of the R-WAKE-1 concept have been identified; further work is required in the further refinement and definition of the concept and its potential application. The SAR and SER fast time simulations of the Unit and Project safety cases will need to be performed in order to demonstrate the performance benefits that could be achieved in the identified operating environments
OPS	OPS. V1.5		Have all stakeholders been identified, their needs and expectations for the SESAR solution discussed and documented?	Partial - Non Blocking	An initial identification of affected Stakeholders is provided in D5.3 Assessment Report Section 3.1.7. A formal Stakeholder Impact analysis will need to be performed.

Thread	ID	Sub-ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
SYS	SYS. V1.1		Has the potential impact of the concept on the target architecture been identified?	Partial - Non Blocking	An initial identification of the relationship between the proposed SESAR Solution and the reference architecture as defined by EATMA is discussed in D5.3 Assessment Report Section 4. This will need to be updated as the concept definition is refined
SYS	SYS. V1.2		Is there a clear identification and description of the impacted Functional Blocks by the SESAR Solution in EATMA (Integrated Roadmap / ADD)?	Partial - Blocking	D5.3 Assessment Report Section 4 includes an indicative analysis of the possible impact on the EATMA reference architecture. A full analysis will need to be performed when R-WAKE is represented in the Integrated Roadmap and the concept definition is finalised
SYS	SYS. V1.3		Have any architectural constraints been identified?	Not Achieved	Not addressed in the R-WAKE project
SYS	SYS. V1.4		Are different supporting technological alternatives defined, if any?	Not Achieved	Not addressed in the R-WAKE project
SYS	SYS. V1.5		Are there needs for supporting CNS infrastructure (if any) adequately identified and justified for the different (sub)operating environments relevant for the SESAR Solution?	Not Achieved	Not addressed in the R-WAKE project
PER	PER. V1.1	Sub-criteria below shall be consolidated at criterion level	Has a V1 Human Performance assessment been performed and documented following PJ19 SESAR HP Reference Material? *Note: In the corresponding VALP V1, these criteria and sub-criteria should have been already covered and they might constitute quality acceptance criteria of the V1 VALP itself*	Partial - Blocking	Partly addressed by R-WAKE activities with results indicating the concept has a good potential; a formal assessment following PJ19 reference material will need to be performed in order to complete V1.
		PER.V1.1.1	Have all relevant HP arguments been identified (through the screening) and addressed at the level required in V1?	Not Achieved	Not addressed in the R-WAKE project
		PER.V1.1.2	Are the benefits and issues in terms of human performance and operability related to the proposed SESAR solution identified and sufficiently assessed at the level required for V1?	Not Achieved	Not addressed in the R-WAKE project
		PER.V1.1.3	Have potential interactions with related SESAR Solutions been considered?	Not Achieved	Not addressed in the R-WAKE project

Thread	ID	Sub-ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
		PER.V1.1.4	Is the level of human performance needed to achieve the desired system performance for the proposed SESAR solution consistent with human capabilities?	Not Achieved	Not addressed in the R-WAKE project
		PER.V1.1.5	Have the major factors been identified that influence the transition feasibility (e.g. changes in automation levels, competence requirements, training needs of human actors, changes in staff requirements, need for relocation of the workforce)? Are there any potential mitigation identify on how to overcome these issues?	Not Achieved	Not addressed in the R-WAKE project
		PER.V1.1.6	Have any impacts been identified that may require changes to regulation in the area of HP/ATM? *This includes changes in roles & responsibilities, competence requirements, or the task allocation between human & machine.*	Partial - Blocking	The pilot/ATCO Expert Panels and Focus Group, as performed in R-WAKE detailed in D5.2 and summarised in D5.3 Assessment Report Section 5.1, identified a number of human factor issues, especially for ATCOs, relating to the application/operation of the R-WAKE-1 concept, that need to be further studied
PER	PER.V1.2	Sub-criteria below shall be consolidated at criterion level	Has a V1 Performance Assessment been performed and documented following PJ19 SESAR Performance Reference Material? *Note: In the corresponding VALP V1, these criteria and sub-criteria should have been already covered and they might constitute quality acceptance criteria of the V1 VALP itself*	Partial - Blocking	Partly addressed by R-WAKE activities with results indicating the concept has a good potential (an initial qualitative assessment of benefits is detailed in D5.3 Assessment Report Section 5.2); a formal assessment following PJ19 reference material will need to be performed in order to complete V1
		PER.V1.2.1	Is there a documented analysis and description of the benefit Impact mechanisms (BIMs) and associated Influence Factors (and the rationale for their selection) for the different alternatives to the solution, aligned with SESAR guidelines e.g. Performance Framework KPAs and KPIs?	Partial - Non Blocking	An initial analysis of benefit mechanisms are identified in D5.3 Assessment Report Section 5.2,2. These will require updating with the further refinement of the R-WAKE concept and its application, including the identification of alternatives.

Thread	ID	Sub-ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
		PER.V1.2.2	Do validation results provide the qualitative and quantitative (if possible, or at least estimated) evidences about impact on all KPAs which are relevant (e.g. Capacity, Operational Efficiency, Cost-efficiency, Predictability, Flexibility etc.), using KPIs/PIs from SESAR Performance Framework for the different alternatives to the solution? *The obtained results should provide a rank in terms of benefits to identifiy the most promising alternative, and in the most relevant (sub) operating environments relevant for the SESAR Solution (extrapolation to other relevant (sub)operating environments are available to facilitate the consolidation of performance results at ECAC level)* *Note: In the corresponding VALP V1, the project should have planned per SESAR Solution the qualitative and quantitative (if possible, or at least estimated) measurement of the impact on those KPAs that are applicable to the SESAR Solution (according to the VALS) and confirmed through the benefit mechanisms for the different alternatives to the solution*	Not Achieved	As reported in D5.3., Assessment Report Section 5.2.3, the planned simulation runs investigating a number of different traffic volume and mix profiles in accordance with the Unit and Project Safety Cases that would have provided the base data for quantification of benefits were not performed. A full set of traffic volume/traffic mix fast time simulations need to be run (as originally planned) in order for the R-WAKE-1 concept to validated in terms of feasibility and benefit gains
		PER.V1.2.3	Are Baseline, Reference and Solution scenarios aligned with SESAR guidelines?	Partial - Non Blocking	Unit and Project Safety case scenarios have been defined (D4.2 System Relase 2) to demonstrate the effect of the R-WAKE concept and application on the performance KPAs compared with a baseline of today's situation. These will need to be reviewed and updated to be consistent with the refinement of the concept and its application
		PER.V1.2.4	Did the validation activities at V1 level address all the expectations for V1 set at VALS level e.g. Validation Targets at solution level? *Note: In the corresponding VALP V1, validation objectives should have been already aligned to VALS*	Not Achieved	Not addressed in the R-WAKE project. Solution level validation targets need to be identified following the conduct of the performance assessment

Thread	ID	Sub-ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
PER	PER.V1.3		Has an outline CBA been developed and documented in line with PJ19 Reference Material including: (1) Description of Cost and Benefit mechanisms with links to the SESAR KPA Indicators and Stakeholders impacted (2) First description of alternatives to the solution and the CBA scenarios with links to validation plans so that the validation exercises gather factual data to measure the benefits in the CBA (3) Qualitative assessment or orders of magnitude of deployment costs and/or benefits to rank alternatives *(Validation exercises provide the evidence needed for a building a credible CBA)*	Partial - Blocking	D5.3 Assessment Report Section 5.2.2 identifies outline benefit mechanisms. No cost assessment was performed. A full V1 CBA in accordance with PJ19 reference material is required with a ranked cost/benefit assessment of possible deployment alternatives linked to planned validation exercises.
PER	PER.V1.4	Sub-criteria below shall be consolidated at criterion level	Has a V1 safety assessment been performed and document following SESAR PJ19 SESAR Safety Reference Material? *Note: In the corresponding VALP V1, these criteria and sub-criteria should have been already covered and they might constitute quality acceptance criteria of the V1 VALP itself. The SESAR Solution Safety Plan (appended to the V1 VALP) shall include:* *- a list of suitable Safety Criteria for the Solution operations;* *- a Safety strategy in terms of relevant set of SRM-based safety assurance activities* *- a description of safety roles and responsibilities at solution / project level.*	Partial - Non Blocking	As detailed in D5.2 Safety and Robustness Analysis and summarised in D5.3 Assessment Report Section 5.3 Severity Matrix Baseline (Absolute Safety Criteria), Accident Incident Model and candidate Safety Criteria have been developed. A full V1 Safety Assessment in accordance with PJ19 reference material is required including the derivation of Safety Objectives using frequency of occurrence data to be obtained from the previously planned Unit and Project Safety Case fast time simulations.
		PER.V1.4.1	Does the SESAR Solution Safety Assessment Report (appended to the SPR-INTEROP/OSED) describe the key properties of the Operational Environment that are relevant to the safety assessment?	Achieved	D5.2 Safety and Robustness Analysis details the definition of the Accident Incident Model that reflects the Operational Environment
		PER.V1.4.2	Does the SESAR Solution Safety Assessment Report (appended to the SPR-INTEROP/OSED) identify the pre-existing hazards that are inherent in aviation within the scope of the Solution operations?	Achieved	D5.2 Safety and Robustness Analysis details the definition of the Accident Incident Model that reflects the assessment of pre-existing hazards

Thread	ID	Sub-ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
		PER.V1.4.3	Does the SESAR Solution Safety Assessment Report (appended to the SPR-INTEROP/OSED) determine the operational services that support the Solution operations?	Achieved	D5.2 Safety and Robustness Analysis details the definition of the Accident Incident Model that reflects the operational services and associated risks
		PER.V1.4.4	Does the SESAR Solution Safety Assessment Report (appended to the SPR-INTEROP/OSED) contain a list of suitable Safety Criteria for the Solution operations?	Partial - Non Blocking	D5.2 Safety and Robustness Analysis, as summarised in D5.3 Assessment Report Section 5, identifies candidate Safety Criteria, which will require review and possible update to be consistent with the refinement of the concept and its application
PER	PER. V1.5	Sub-criteria below shall be consolidated at criterion level	Has the V1 security assessment been carried out and documented in conformance with the SESAR Security Reference Material?	Not Applicable	Not relevant to R-WAKE
		PER.V1.5.1	Have the security risk assessment scope and security assumptions on the environment been documented?	Not Applicable	Not relevant to R-WAKE
		PER.V1.5.2	Have primary assets been documented?	Not Applicable	Not relevant to R-WAKE
		PER.V1.5.3	Has the primary assets impact assesment been documented?	Not Applicable	Not relevant to R-WAKE
PER	PER. V1.6	Sub-criteria below shall be consolidated at criterion level	Has been a V1 environmental assessment been performed following SESAR PJ19 Environmental Reference Material? *Note: In the corresponding VALP V1, these criteria and sub-criteria should have been already covered and they might constitute quality acceptance criteria of the V1 VALP itself*	Partial - Blocking	As recorded in D5.3 Assessment Report, Section 5.5, there are potential environmental benefits arising from increased flight efficiency; the trade off against possible increased capacity has not been analysed. A formal V1 environmental assessment in accordance with PJ19 reference material is required.
		PER.V1.6.1	Have the SESAR Solution environmental benefits and risks mechanisms been identified?	Not Achieved	Not addressed in the project

Thread	ID	Sub-ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
		PER.V1.6.2	Have the environmental impacts (Noise, Local and Global emissions) that should be investigated for the SESAR Solution been identified?	Partial - Blocking	As recorded in D5.3 Assessment Report, Section 5.5, there are potential global environmental benefits arising from increased flight efficiency; the trade off against possible increased capacity has not been analysed
STD & REG	S&R. V1.1		Have Standardisation needs been identified?	Partial - Blocking	As recorded in D5.3 Assessment Report, Section 3.3.3, it is recognised that the proposed separation schemes could result in changes to the existing separation standards. The Standardisation Needs will need to be developed.
TRA	TRA. V1.1		Are there any major transition issues identified e.g. institutional changes, infrastructure changes, training, etc.?	Not Achieved	Not addressed in the R-WAKE project - the concept is not yet an appropriate level of maturity
TRA	TRA. V1.2		Are there recommendations proposed to be addressed during V2 related activities? E.g. additional testing conditions, open HP issues to be addressed in V2,…	Not Achieved	Not addressed in the R-WAKE project - the concept is not yet an appropriate level of maturity
VAL	VAL. V1.1		Do the validation activities (e.g. validation objectives) at V1 conform to the VALS content apportioned to the SESAR Solution? *Note: In the corresponding VALP V1, these criteria and sub-criteria should have been already covered and they might constitute quality acceptance criteria of the V1 VALP itself*	Partial - Blocking	D2.2 D5.3 Assessment Report, Section 6, assesses the validation activities performed during the R-WAKE Project, which focussed on the validation of the R-WAKE integrated simulation framework and development of the proposed separation schemes. None of the planned simulation runs that were designed to validate the R-WAKE concept and associated SESAR Solution as a whole were performed. A formal Validation Strategy based on the accepted SESAR Solution will need to be developed using the identified R&D needs.
VAL	VAL. V1.2		Are the relevant R&D needs identified and documented? Have the validation objectives covered by V1 validation activities addressed the relevant and Key SESAR Solution R&D needs? *Note: R&D needs state major questions and open issues to be addressed during the development, verification and validation of a SESAR Solution. They justify the need to continue research on a given SESAR Solution, and the definition of validation exercises and validation objectives in following maturity phases.*	Partial - Blocking	A comprehensive list of R&D Needs arising from the R-WAKE project activities have been identified and are summarised in D5.3, Assessment Report Section 6.3. These will form the basis of developing the V1 validation objectives.

Thread	ID	Sub-ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
PRG	PRG. V1.1		Is there a clear identification of the corresponding baseline (applicable EATMA version and/or aplicable Integrated Roadmap Dataset version e.g.SESAR Solution, OI steps, Functional Blocks)	Partial - Blocking	D5.3 Assessment Report sections 3.3.3 and 4.1 refer to ATM Master Plan Dataset 17b and EATMA v9.1. R-WAKE is currently not represented in the Master Plan or EATMA, therefore this analysis will need to be reviewed with future versions of the reference data.
PRG	PRG. V1.2		Have related SESAR Solutions (and relevant OI steps & enablers) been identified and their interdependencies documented?	Not Achieved	This analysis was not performed as part of the R-WAKE project. The interdependency between the proposed SESAR Solution and other Solutions will need to be assessed.
PRG	PRG. V1.3		Are there evidences that the inter-dependent SESAR Solutions (and relevant OI steps & enablers) are at the expected level of maturity?	Not Achieved	This analysis was not performed as part of the R-WAKE project. The maturity of interdependent Solutions and the proposed Solution will need to be assessed.

Table 5-6 IR V1 Criteria assessment

E.2 R&D Needs Arising from IR V1 Criteria Assessment

A number of the IR V1 Criteria are assessed as being Partial (-Blocking or non-Blocking) or Not Achieved; therefore, these will require further research activities in order to meet the V1 maturity gate. The following table summarises the R&D Needs that are identified from the IR V1 criteria assessment, cross referring to existing R&D Needs (as previously listed in D5.3 Assessment Report, Section 6.3) as appropriate, or identifying new ones (with the designation V1RN-xx).

Thread	ID	Sub-ID	Criteria	Satisfaction	R&D Needs
OPS	OPS. V1.1		Is the initial documented description of the concept consistent with the SESAR 2020 CONOPS?	Partial - Non Blocking	V1RN-01 Update alignment with SESAR 2020 CONOPS Further work is required in the further refinement and definition of the concept and its application which will affect assessment of how it relates to the SESAR 2020 CONOPS
OPS	OPS. V1.2		Is there an initial identification and description of the SESAR Solution and related OI steps available in EATMA (Integrated Roadmap)?	Partial - Blocking	V1RN-02 Include R-WAKE SESAR Solution and related OI Steps in the Integrated Roadmap
OPS	OPS. V1.3		Are the different concept variants (if any) described?	Partial - Non Blocking	V1RN-03 Identify concept variants Further work is required in the further refinement and definition of the concept and its potential application(s) to finalise any concept variants.

Thread	ID	Sub-ID	Criteria	Satisfaction	R&D Needs
OPS	OPS. V1.4		Have potential (sub)operating environments been identified where, if deployed, the SESAR Solution could bring performance benefits? *Note: the relevant (sub) operating environments associated to the SESAR Solution shall be consistent with those available in EATMA*	Partial - Non Blocking	V1RN-04 Update (sub) operating environment applicability Further work is required in the further refinement and definition of the concept and its potential application. The SAR and SER fast time simulations of the Unit and Project safety cases will need to be performed to demonstrate the performance benefits that could be achieved in the identified operating environments
OPS	OPS. V1.5		Have all stakeholders been identified, their needs and expectations for the SESAR solution discussed and documented?	Partial - Non Blocking	V1RN-05 Perform formal Stakeholder Impact Analysis
SYS	SYS. V1.1		Has the potential impact of the concept on the target architecture been identified?	Partial - Non Blocking	V1RN-06 Update assessment of impact on target architecture An initial identification of the relationship between the proposed SESAR Solution and the reference architecture as defined by EATMA was performed. This will need to be updated as the concept definition is refined to include: - Identification and description of impacted Functional Blocks - Identification of architectural constraints - Identification of supporting technology alternatives - Identification and justification of needs for supporting CNS infrastructure in the relevant (sub) operating environments
SYS	SYS. V1.2		Is there a clear identification and description of the impacted Functional Blocks by the SESAR Solution in EATMA (Integrated Roadmap / ADD)?	Partial - Blocking	Covered by V1RN-06
SYS	SYS. V1.3		Have any architectural constraints been identified?	Not Achieved	Covered by V1RN-06
SYS	SYS. V1.4		Are different supporting technological alternatives defined, if any?	Not Achieved	Covered by V1RN-06
SYS	SYS. V1.5		Are there needs for supporting CNS infrastructure (if any) adequately identified and justified for the different (sub)operating environments relevant for the SESAR Solution?	Not Achieved	Covered by V1RN-06

Thread	ID	Sub-ID	Criteria	Satisfaction	R&D Needs
PER	PER.V1.1	Sub-criteria below shall be consolidated at criterion level	Has a V1 Human Performance assessment been performed and documented following PJ19 SESAR HP Reference Material? *Note: In the corresponding VALP V1, these criteria and sub-criteria should have been already covered and they might constitute quality acceptance criteria of the V1 VALP itself*	Partial - Blocking	V1RN-07 Perform a formal Human Performance assessment in accordance with SESAR PJ19 reference material to include: - Identification of relevant HP arguments - Identification of HP and operability benefits and issues - Identification of potential interactions with other SESAR Solutions - Assessment of HP required vs. capabilities - Assessment of HP transition issues - Identification of changes to HP related regulation
		PER.V1.1.1	Have all relevant HP arguments been identified (through the screening) and addressed at the level required in V1?	Not Achieved	Covered by V1RN-07
		PER.V1.1.2	Are the benefits and issues in terms of human performance and operability related to the proposed SESAR solution identified and sufficiently assessed at the level required for V1?	Not Achieved	Covered by V1RN-07
		PER.V1.1.3	Have potential interactions with related SESAR Solutions been considered?	Not Achieved	Covered by V1RN-07
		PER.V1.1.4	Is the level of human performance needed to achieve the desired system performance for the proposed SESAR solution consistent with human capabilities?	Not Achieved	Covered by V1RN-07
		PER.V1.1.5	Have the major factors been identified that influence the transition feasibility (e.g. changes in automation levels, competence requirements, training needs of human actors, changes in staff requirements, need for relocation of the workforce)? Are there any potential mitigation identify on how to overcome these issues?	Not Achieved	Covered by V1RN-07
		PER.V1.1.6	Have any impacts been identified that may require changes to regulation in the area of HP/ATM? *This includes changes in roles & responsibilities, competence requirements, or the task allocation between human & machine.*	Partial - Blocking	Covered by V1RN-07

Thread	ID	Sub-ID	Criteria	Satisfaction	R&D Needs
PER	PER. V1.2	Sub-criteria below shall be consolidated at criterion level	Has a V1 Performance Assessment been performed and documented following PJ19 SESAR Performance Reference Material? *Note: In the corresponding VALP V1, these criteria and sub-criteria should have been already covered and they might constitute quality acceptance criteria of the V1 VALP itself*	Partial - Blocking	V1RN-08 Perform a formal Performance Assessment in accordance with SESAR PJ19 reference material to include: - Updated benefit impact mechanisms and influence factors - Validation Report detailing the qualitative and quantitative impact on relevant KPAs - Updated validation scenarios - Assessment of validation achievements vs. concept validation strategy - Outline CBA including cost and benefit mechanisms for each concept option including qualitative ranking of them
		PER.V1.2.1	Is there a documented analysis and description of the benefit Impact mechanisms (BIMs) and associated Influence Factors (and the rationale for their selection) for the different alternatives to the solution, aligned with SESAR guidelines e.g. Performance Framework KPAs and KPIs?	Partial - Non Blocking	Covered by V1RN-08

Table 5-7 IR V1 Criteria assessment arising R&D needs

Appendix F Acronyms and definitions

F.1 Table of Acronyms

Acronym	Description	Group
CIR	Conditional Individual Risk	Safety
D-PWS	Dynamic Pair Wise Separation	ATM
DRM	Dynamic Risk Model	Safety
EN	Enabler (European ATM Master Plan data element)	ATM
E-OCVM	European Operational Concept Validation Methodology	ATM
EP	Expert Panel	Research Method
ESARR	European Safety Regulatory Requirements	Safety
ESARR2	Reporting and Assessment of Safety Occurrences in ATM	Safety
ESARR4	Risk Assessment and Mitigation in ATM	Safety
EVAIR	Eurocontrol Voluntary ATM Incident Reporting	Safety
FL	Flight Levels	ATM
FLAS	Flight Level Allocation Scheme	ATM
FRN	Further Research Need	
HMI	Human Machine Interface	Simulator
MWS	Minimum Wake Separation	ATM
OIS	Operational Improvement Step (European ATM Master Plan data element)	ATM
PSC	Project Safety Case	Safety
PWS	Pair Wise Separation	ATM
RMWS	En-Route Minimum Wake Separation	ATM
RNP-1	Required Navigational Performance of 1 NM	ATM
RQ	Research Question	Research Method
RSM	Radar Separation Minima	ATM
RVSM	Reduced Vertical Separation Minima	ATM
RWC	Reasonable Worst Case	Safety
SAC	Safety Criteria	Safety
SAM	Safety Assessment Methodology (Eurocontrol´s)	Safety
SAME	SAM Easy (Eurocontrol´s)	Safety
SAR	Segregated Airspace Risk	Safety
SCN	Scenario	Research Method
SER	System ECAC-wide Risk	Safety
SM	Severity Matrix	Safety
SMI	Separation Minima Infringement	ATM
SMR	Separation Minima Reduction	ATM
SMUP	Severity Matrix with Upset Parameters	Safety

SO	Safety Objective	Safety
SR	System Release	Simulator
SRA	Safety and Robustness Analysis	Safety
SRM	Safety Reference Material (from SESAR´s P16.1.6)	Safety
TRS	Traffic simulator	Simulator
TTP	Traffic Planner & Simulation	Simulator
USC	Unit Safety Case	Safety
WEPS	Wake Encounter Prediction & Severity (part of TRS)	Simulator
WERF	Wake Encounter Region Finder (part of TRS)	Simulator
WIAM	Wake vortex encounter Interaction Aircraft Model	Simulator
WPS	Weather Planning System	Simulator
WVE	Wake Vortex Encounter	Simulator
WVS	Wake Vortex simulator	Simulator
WXS	Weather simulator	Simulator

Table 5-8 Table of acronyms in use

F.2 Risk terms definitions

Term	Definition
Risk	SRM definition: ‘Risk’ shall mean the combination of the overall probability, or frequency of occurrence of a harmful effect induced by a hazard and the severity of that effect – as defined in Article 2(9) of Regulation (EC) No 1035/2011;
Conditional Individual Risk (CIR)	The level of risk supported by the follower/encountering aircraft given that the condition assumed (i.e., aircraft pair, geometry and separation distance) is true;
System ECAC-wide Risk (SER)	The level of actual risk supported by traffic at the ECAC region
Segregated Airspace Risk (SAR)	The level of actual risk supported by traffic at a given volumetric airspace region of the ECAC system (possibly, but not necessarily, an ATC sector).
Dynamic Risk Model (DRM)	A model to quantify risk based on counting frequencies of a certain type of events occurred in simulations that explicitly represent and reproduce the dynamic performance of the elements in the operation (people, equipment, procedures, environment) and their time-dependent interactions (in the case of R-WAKE, reproducing and counting wake vortex encounters with different severities, between flights and wake vortices, subject to a simplified ATM barrier model).

Table 5-9 Risk term definitions that have been established in the R-WAKE project.

R-WAKE Consortium Partners