



R-WAKE

SESAR 2020 Exploratory Research Project

Project Presentation to SESAR Scientific Committee meeting

Javier Busto & Sergio Ruiz, Brussels 06/02/2018



Founding Members



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Agenda



1. R-WAKE project (5')
2. R-WAKE concept (5')
3. Relation to SESAR 2020 (5')
4. Achievements vs. Project Objectives (8')
5. Assessment of Maturity ER -> IR Gate (5')
6. What next? (proposed way forward to feed IR programme) (5')

R-WAKE Project

R-WAKE – The ER Project

“Wake Vortex simulation and analysis to Enhance en-Route separation management in Europe”

Applications Oriented Separation Management

Consortium Members:

- GTD SISTEMAS DE INFORMACION SA (ES)
 - UNIVERSITAT POLITECNICA DE CATALUNYA (ES)
 - TECHNISCHE UNIVERSITAT BRAUNSCHWEIG (DE)
 - DEEP BLUE SRL (IT)
 - M3 SYSTEMS BELGIUM SPRL (BE)
 - A-SYST SA (LU)
- Website: www.rwake-sesar2020.eu

- 1-April-2016 / 31-Mar-2018
- Grant # 699247

Total Cost: 998,745 €

R-WAKE Research Objectives and Expected Impact



Problem addressed

- Today en-route separation minima is 5NM / 1000 feet for all aircraft,
 - Over-conservative for some aircraft categories,
 - Insufficiently protecting against wake vortex hazards in other cases (e.g., wakes can be sometimes encountered up to 25NM behind a generating airplane).

Expected Impact

- New OIs based on improved en-route separation standards to:
 - Improve wake turbulence **safety** in en-route operations
 - Improve **ATM capacity** and potentially enhance **flight efficiency**, whilst maintaining the same level of safety
- New System & Procedural Enablers to support the OIs
 - On-board / On-ground WEPS (Wake Encounter Prediction System)
 - Dynamic Risk Modelling for **safety assessments** in sectors or in ECAC

R-WAKE Research Question (application-oriented)



'What Separation Minima Reductions can be applied in specific and clearly defined operational conditions keeping the current safety levels and taking into account the potential En-Route WVE hazards?'



**Simulation
platform**

(traffic trajectories, WV,
aircraft upsets & some
ATM constraints)



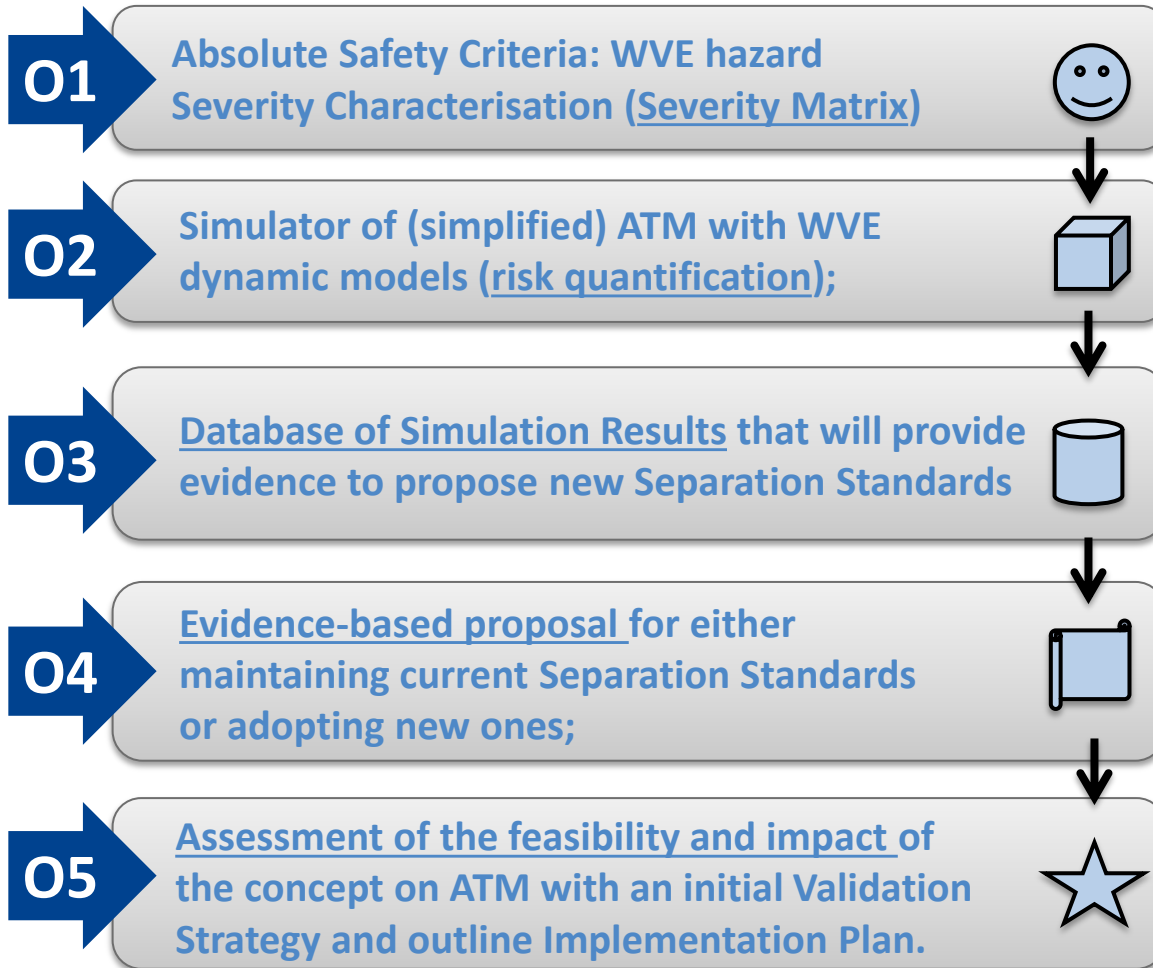
**Safety & Robustness
Analysis Method**

(tailoring SESAR SRM, to
generate quantitative and
qualitative safety evidence to
support project safety cases)

R-WAKE Project Objectives

Research structured in 5 tangible Project Expected Outcomes

(formulation following WP2/MS2 Review with SJU D2.1 assessment)



R-WAKE Concept

R-WAKE-1 OCD

R-WAKE-1 concept proposal defined as:

**“Aircraft Category and Geometry-Wise
Wake Separation Minima to improve En-Route
Separation Provision Advanced Traffic Services”.**

To be presented in the form of a matrix of separation adjustments:

RWAKE-1 SEPARATIONS ADJUSTEMENTS TABLE			GENERATOR AIRCRAFT								
			Generator Climbing ahead			Generator Flying level			Generator Descending ahead		
			C1 (H)	C2 (M)	C3 (L)	C1 (H)	C2 (M)	C3 (L)	C1 (H)	C2 (M)	C3 (L)
FOLLOWER AIRCRAFT	Follower Behind	C1 (H)	dV, dL, dO	dV, dL, dO	dV, dL, dO	dV, dL, dO	dV, dL, dO	dV, dL, dO	dV, dL, dO	dV, dL, dO	dV, dL, dO
		C2 (M)									
		C3 (S)									
	Follower Opposite	C1 (H)									
		C2 (M)									
		C3 (S)									
	Follower Crossing	C1 (H)									
		C2 (M)									
		C3 (S)									

Step-wise roadmap:

Following extensions:
**RWAKE-2 Separation
Minima Dynamic**

1st step : **RWAKE-1
Separation Minima
Wind-dependent**



R-WAKE Separation Standards (Proposals)

Key assumptions

1. Introduction of **Aircraft Categories** for En-route separation: **RA-RB-RC**
2. **Minimum Wake Separations (MWS)** co-existing with **Minimum Radar Separations (MRS)**
3. **Navigation accuracy of RNP-1 for en-route**
4. **MRS** set at **3NM** (Horizontal) and **500feet** (Vertical) (current ICAO MRS: 5NM / 1000 feet)

Initial choice of three categories to minimise complexity for ATCOs (HF criteria)

The most conservative of both must be applied at any instant

+/- 1 NM error in horizontal &
+/- 50 feet in vertical (in cruise)

Should be robust for RNP-1 capabilities

R-WAKE Separation Standards (Proposals)

Introduction of R-Wake Aircraft Categories for En-Route

Today in en-route: 1 unique category (=no categories)

R-WAKE categories	RECAT categories	ICAO categories (for airports)	Category representatives
CAT RA	CAT A	SUPER HEAVY	A380
CAT RB	CAT B + CAT C	HEAVY	B744, B764
CAT RC	CAT D+ CAT E	MEDIUM & LIGHT	A320, F100

R-WAKE Separation Standards (Proposals)

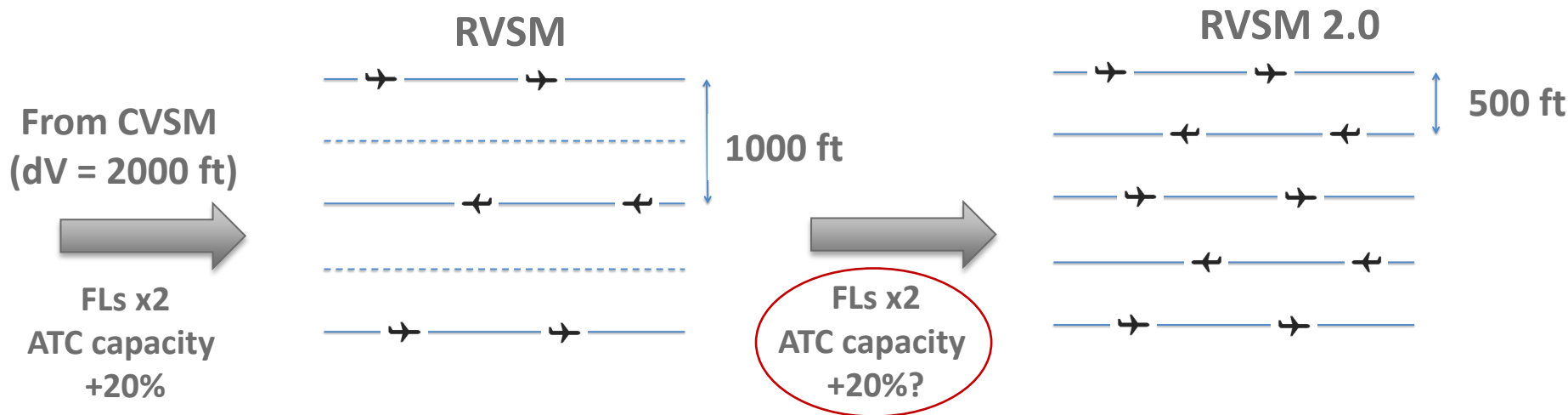
Factors considered in the definition of MWS (Min. Wake. Sep.)

- **Multiple possible geometries** of the encounter (**up to 45**: 5H x 3Vg x 3Vf)
- Distinction in **three basic separation types**
 - Vertical Separation (dV)
 - Lateral (orthogonal) Separation (d0)
 - Longitudinal Separation (dL)
- **Combined separations are also considered**
- **Category considered for the generator aircraft only**
 - ➔ Unlike in RECAT, the follower will not be considered to compensate for the extra en-route complexity

R-WAKE Separation Standards (Proposals)

Examples of concept OIs being explored:

- **Vertical separation minima reduced to 500 feet**, e.g. RVSM 2.0, allowing increase airspace capacity by using FL of ...,285, 295, 305, 315, 325,...
- **Combined Vertical and Lateral separation minima**, e.g. 500 feet and 1 or 2 NM horizontal separation
- **Wind dependent Lateral separation minima**



...further described in next sections

Relation to SESAR 2020

R-WAKE Programmatic context

Relation to SESAR 2020, Related Pj.'s

Airport-TMA Operations
Runway Capacity Increase

RECAT

Concept, Systems, Projects

Conops

TBS

PWS

D-PWS

WDS

Systems

Ground

ORD

WV-DSS

Airborn

WEPS-P

WEPS-C



SESAR 2020 Pj.02:

HIGH PERFORMING AIRPORT OPERATIONS –
INCREASED RUNWAY AND AIRPORT THROUGHPUT

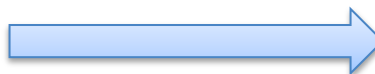
Advanced Air Traffic Services (ATS)
Separation Management
In En-Route Operations
Capacity (& Efficiency) Increase

RWAKE PROJECT

Concept Definition Exploratory Research
towards ER/IR gate (PreV1)

RWAKE
SYSTEM

RWAKE
CONCEPT(s)



Reference Methodology
For Wake Turbulence
Hazard Risk Safety
Assessment and
Separation Improvements

- ✓ WV Decay Model (TMA)
- ✓ WVE Impact (TMA)
- ✓ RECAT & Separations
adjustments

Reference CONOPS & Systems
of En-Route Separation
(current & future)



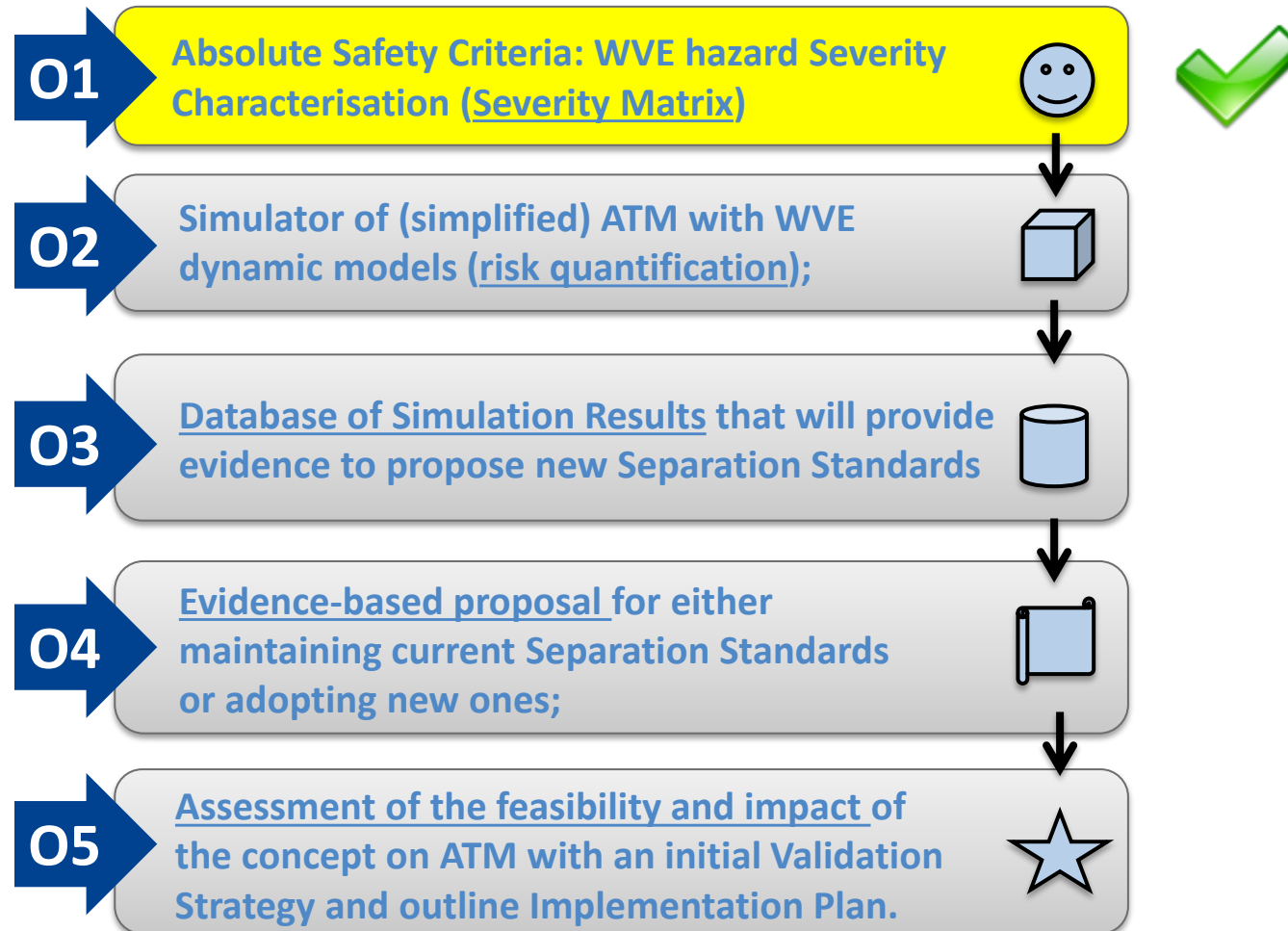
RWAKE contribution of
New potential CONOPS
Or improvement of existing
for Pj.10

SESAR-2020 Pj.10:

ADVANCED AIR TRAFFIC SERVICES –
SEPARATION MANAGEMENT EN-ROUTE AND TMA

Achievements to project objectives

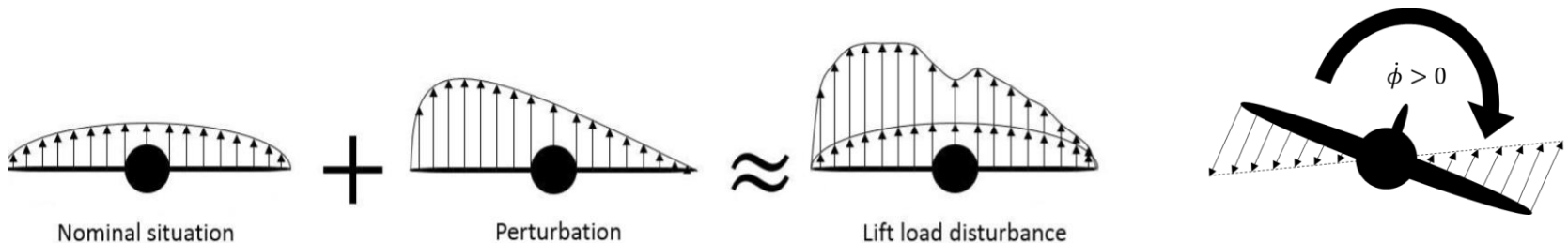
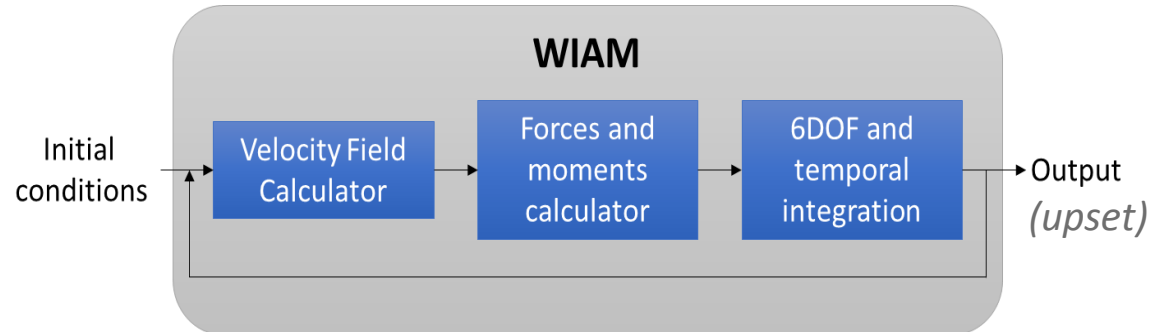
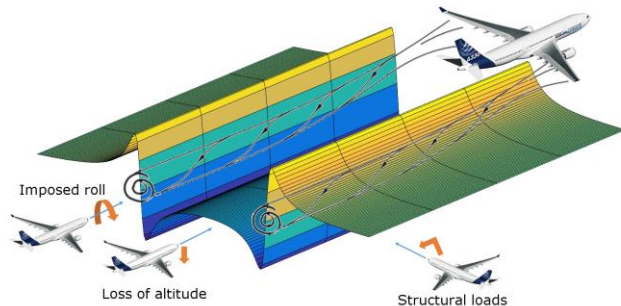
Achievements to Project Objectives



O1: Absolute Safety Criteria

WVE Hazard Severity Characterization

Wake vortex Aircraft Interaction Model (WIAM) tool



- WIAM Cross-Validated against **TU-Braunschweig's model** (which in turn it was **partially validated with real flights**)
- >20.000 simulations performed; a selection assessed by Experts Panel with pilots and ATCOs

O1: Absolute Safety Criteria

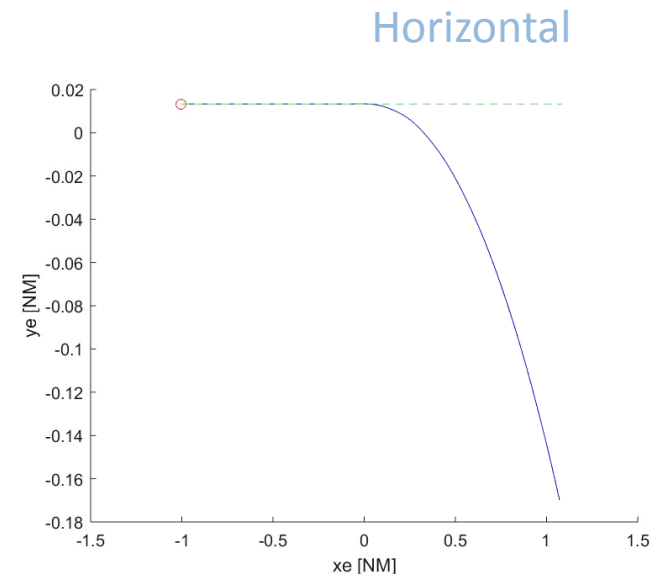
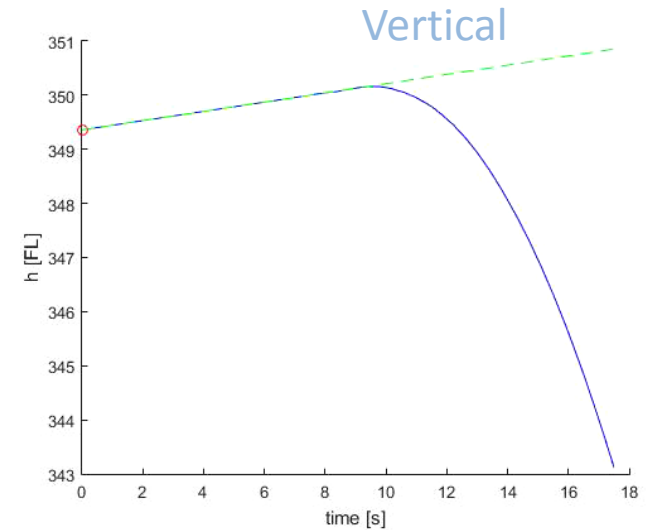
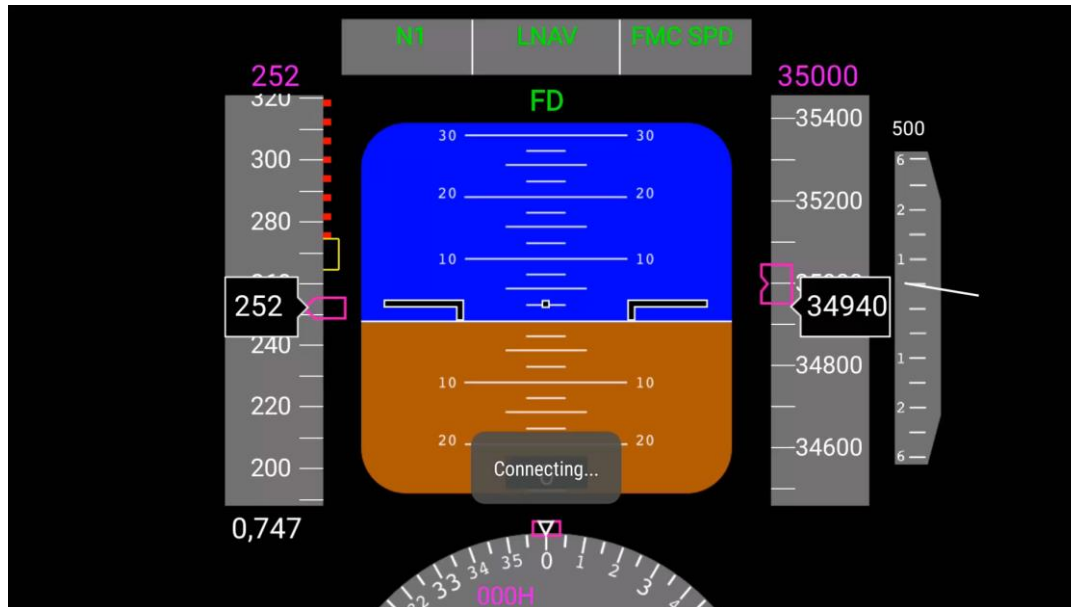
WVE Hazard Severity Characterization

Expert Panels

Each selected scenario presented to Experts with a video of the Aircraft PFD:

Upset Example (Climbing)

Scenario Ref. 17404



O1: Absolute Safety Criteria

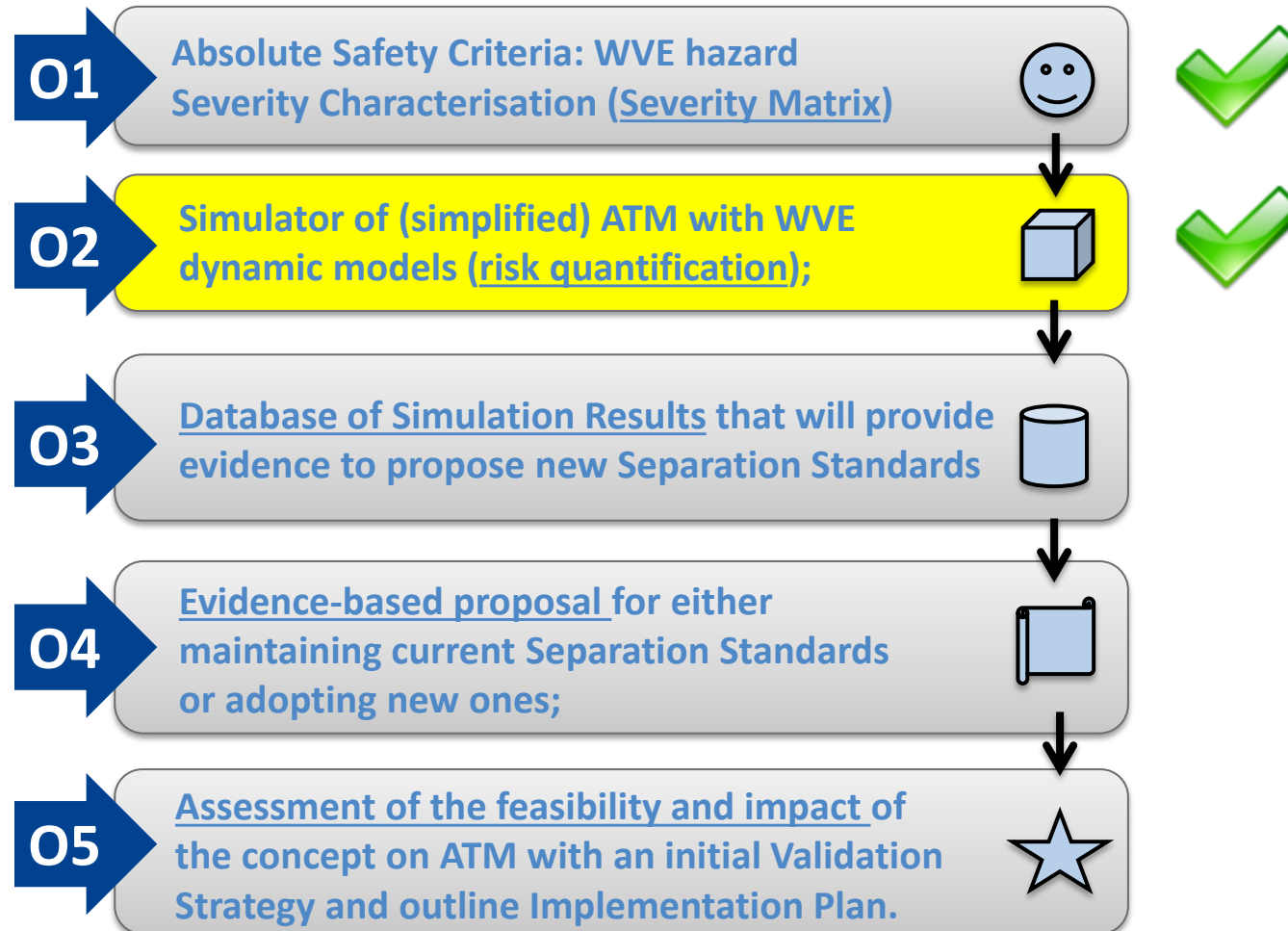
to support different safety cases

Severity Matrix with Upset Parameter Thresholds

- $\Delta\Phi$ [deg] - Max Bank Roll change
- ΔH [feet] - Max Altitude loss
- V_{zmax} [feet/min] - Max Vertical Speed change
- ΔV [knots] - Max True Airspeed change

Upset parameters	No safety effect 1	Minor 2	Major 3	Hazardous 4	Catastrophic 5
$\Delta\Phi$ [deg]	< 25°	25° to 30°	30° to 45°	45° to 60°	> 60°
ΔH [feet]	< 100 feet	100 to 500 feet	500 to 1000 feet	> 1000 feet	> 1000 feet
V_{zmax} [feet/min]	< 500 ft/min	500 to 1000 ft/min	1000 to 3000 ft/min	3000 to 6000 ft/min	> 6000 ft/min
ΔV [knot]	< 10 kn	10 to 15 kn	15 to 25 kn	> 25 kn	> 25 kn

Achievements to Project Objectives



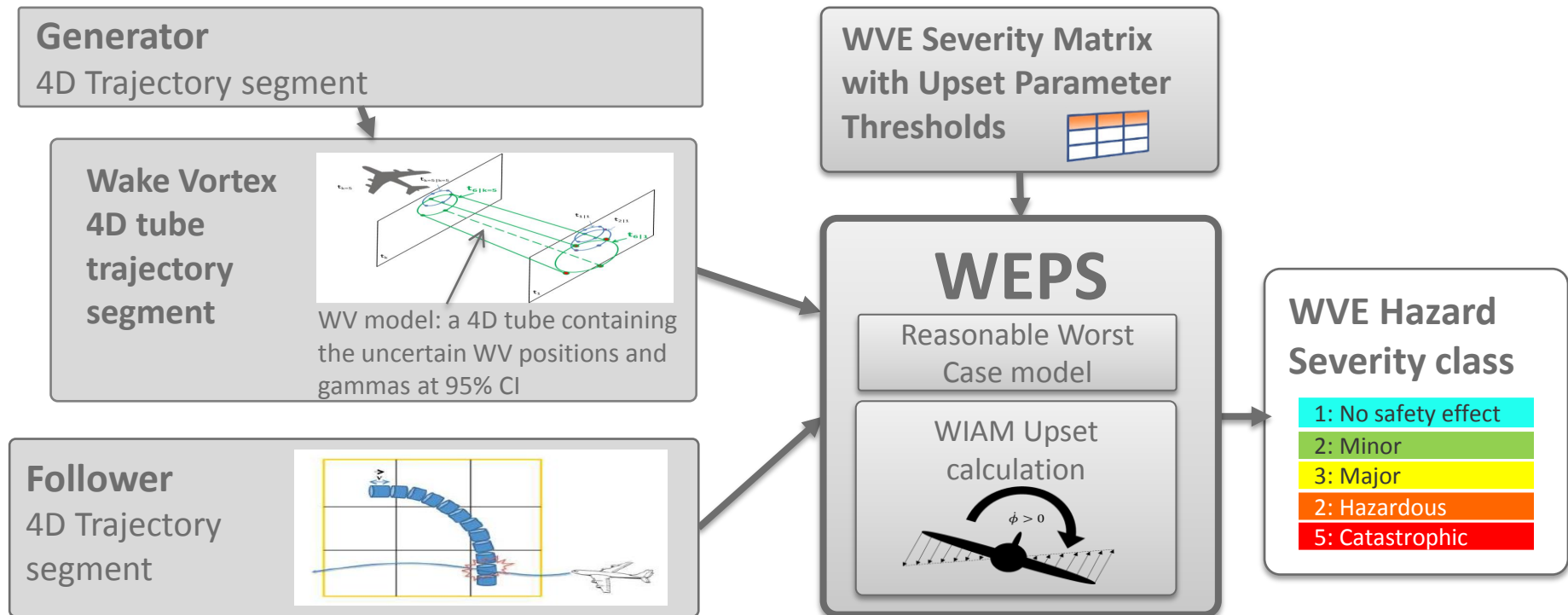
O2: Integrated Simulator System

Generator & Follower Trajectory Generator

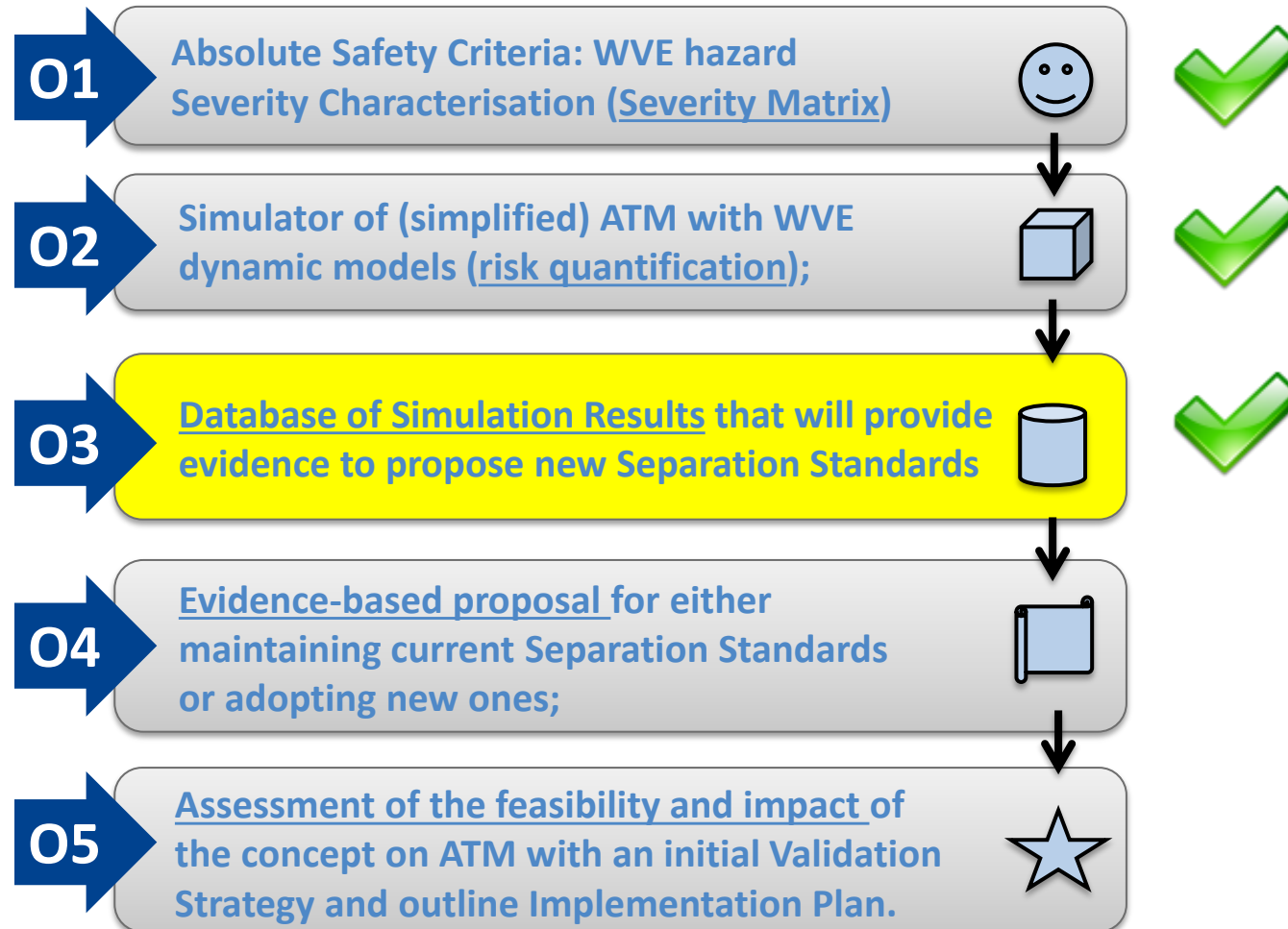
WV Simulator (WVS)

WV Encounter Prediction System (WEPS) - embeds WIAM and Severity Matrix

- Shown part of the system: configuration for **Conditioned Individual Risk (CIR)** study.
- Complete configuration includes realistic traffic generation of **ECAC-wide** or **Airspace Sector** areas for **systemic risk assessment (SER and SAR)**.

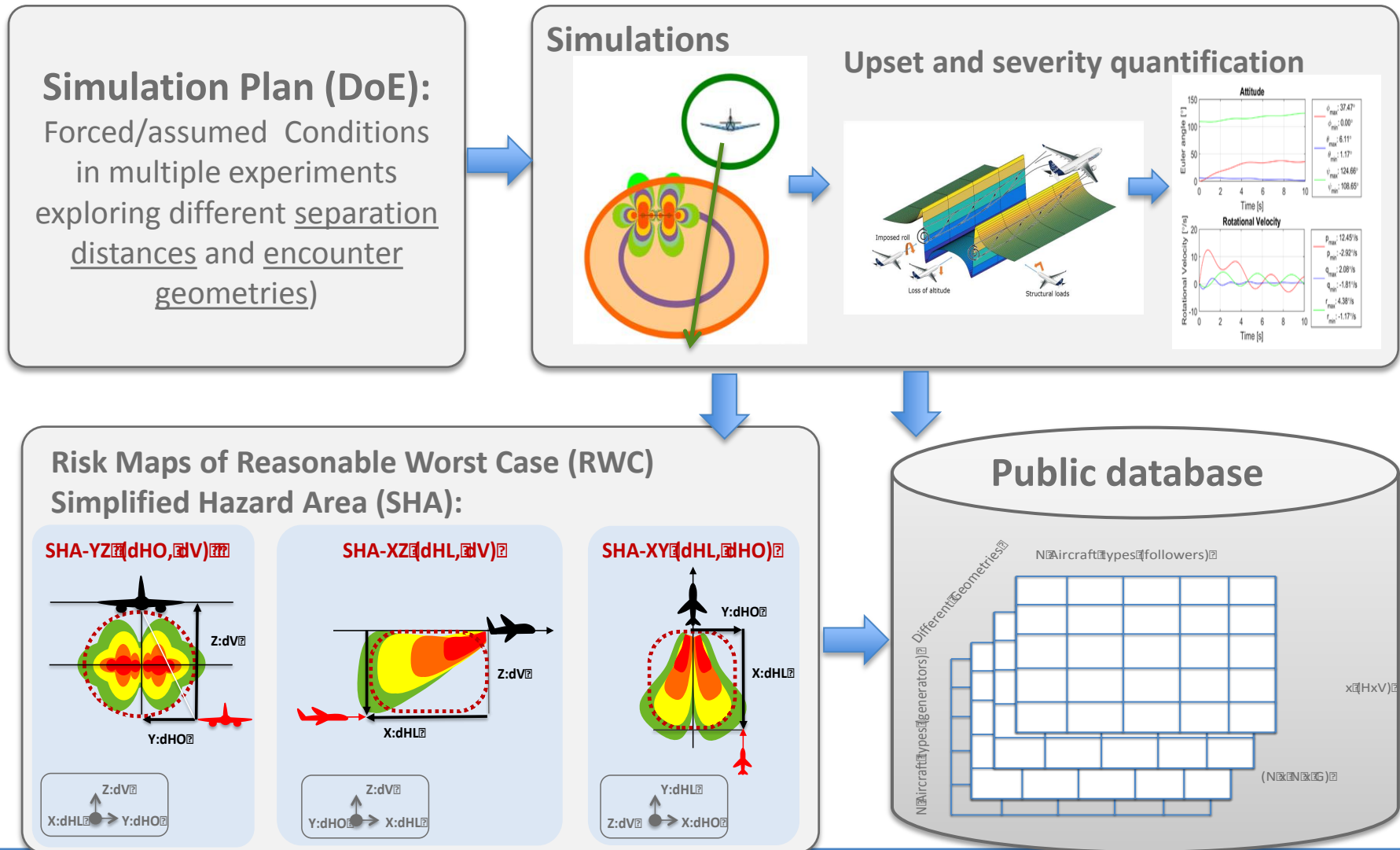


Achievements to Project Objectives



O3: Simulation database

Generation of evidence and openness of results

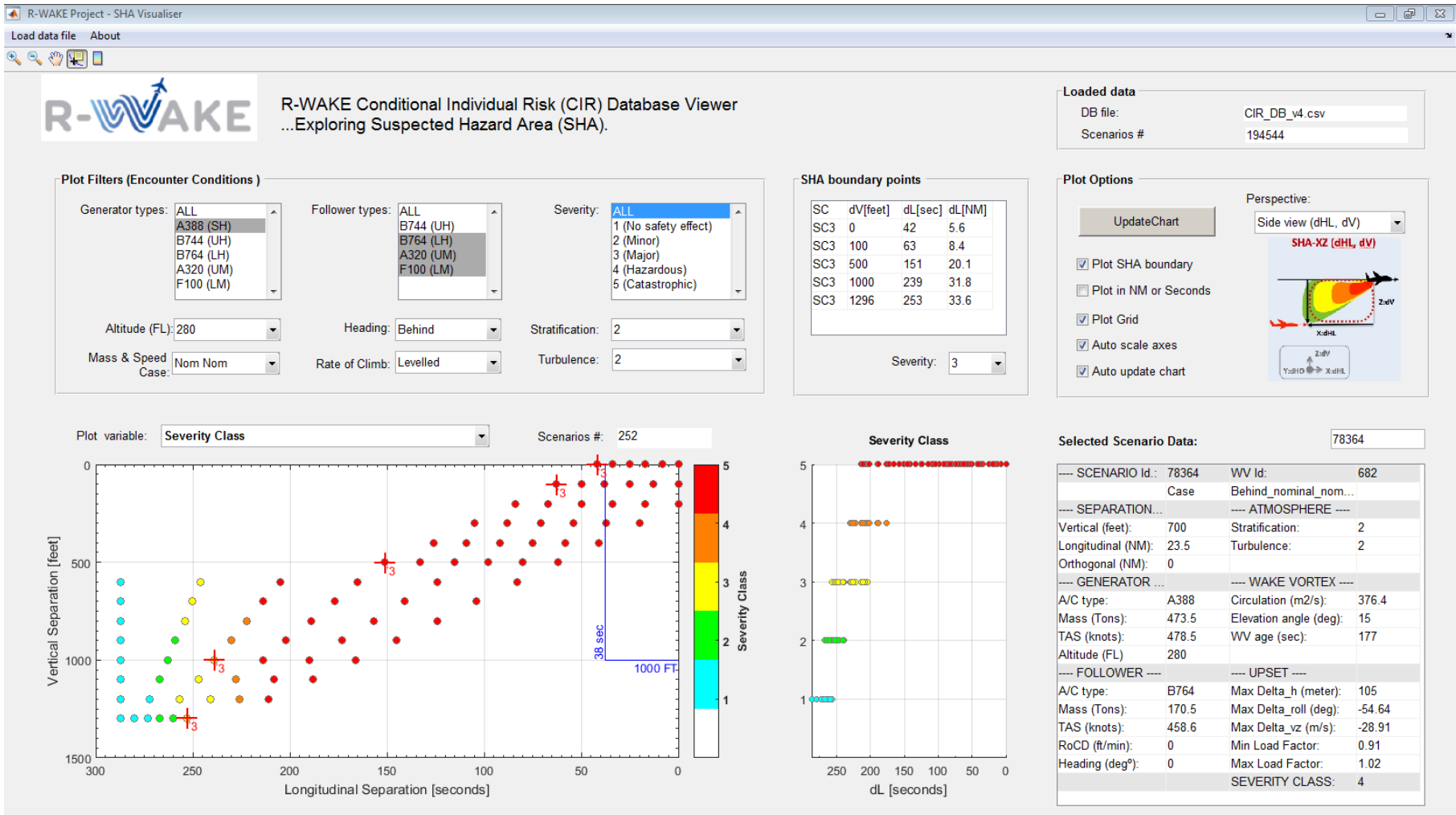


O3: Simulation database

Conditioned Individual Risk (CIR)

Suspected Hazard Area (SHA) - Risk Maps

DEMO (2-min)



O3: Simulation database

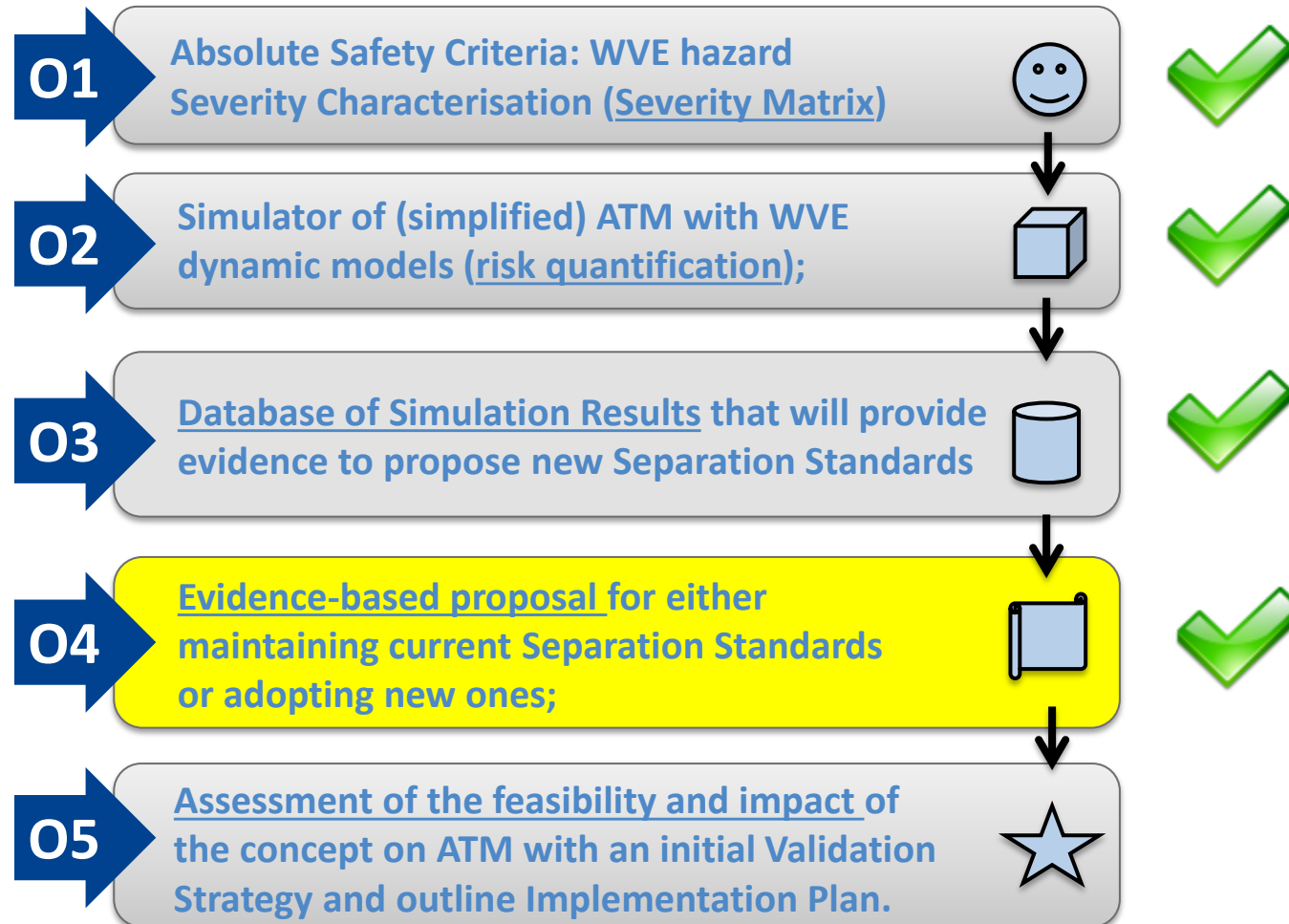
Example of SHA Area boundary
Category-Wise Matrix
 per Severity Class = 3 (SC3),
 having Generators
 flying at **FL280**,
 Mass & Speed = **Nominal**,
 and Followers
 flying **Behind**
 with RoCD = **levelled**,
 and Atmosphere
 with **Stratification=2**,
 And **Turbulence=2**

Green indicates
reduction from current

Red indicates
increase from current

R-WAKE MWS				Severity Class			3			Generators conditions			Follower conditions			
Category-wise Minimum				Stratification			2			Altitude			FL280			
Wake Separation per				Turbulence			2			Mass&Speed			Nominal			
Altitude													Heading			
													Behind			
													RoCD			
													levelled			
GENERATORS																

Achievements to Project Objectives



O4: Separation Standard proposal

R-WAKE1 Minimum Wake Separation (MWS)

Six types of separation improvements proposed:

STATIC

1. MWS Lateral

2. MWS Vertical

3. MWS Longitudinal in same FL

4. MWS Longitudinal during
climbing/descending operations

WIND-DEPENDENT

5. MWS Lateral Wind-dependent

6. MWS Combined vertical–lateral
Wind-dependent

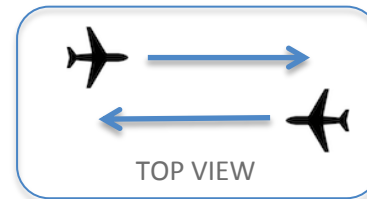
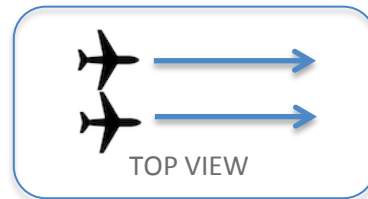
O4: Separation Standard proposal

R-WAKE1 Minimum Wake Separation (MWS)

1. MWS Lateral

Geometries

H



Separation Adjustments & Benefits

MWS required for the follower	Change relative to the current standard
3 NM (same for all the categories)	-2 NM

Capacity increased

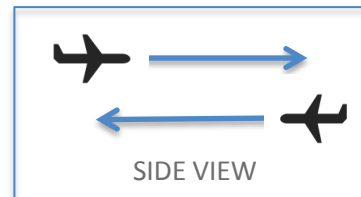
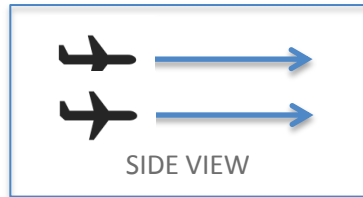
O4: Separation Standard proposal

R-WAKE1 Minimum Wake Separation (MWS)

2. MWS Vertical

Geometries

V



Separation Adjustments & Benefits

Generator	Minimum Wake Separation required for the follower	Change relative to the current standard
CAT RA	1500 FT	+500 FT
CAT RB	1000 FT	0 FT
CAT RC	500 FT	-500 FT

Safety increased

Capacity increased

Considerations

- The capacity and efficiency increments will also depend on the traffic mix and on how the traffic is organised in FLs

O4: Separation Standard proposal

R-WAKE1 Minimum Wake Separation (MWS)

3. MWS Longitudinal in same FL

Geometries



Separation Adjustments & Benefits

Generator	Separation required for the follower	Change relative to the 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

Safety increased

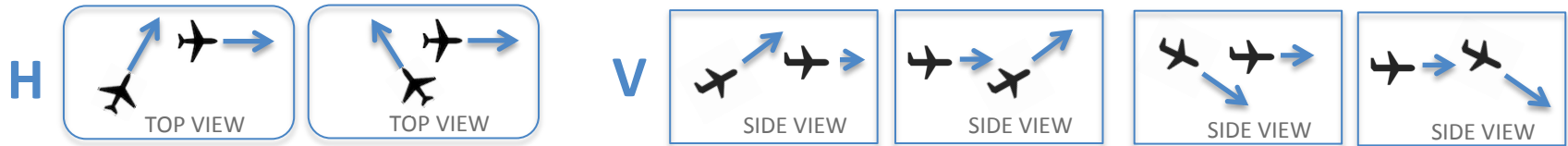
Capacity increased

O4: Separation Standard proposal

R-WAKE1 Minimum Wake Separation (MWS)

4. MWS Longitudinal during climbing/descending

Geometries: Follower climbing/descending behind
or generator climbing/descending ahead
or follower crossing below (not separated vertically)



Separation Adjustments & Benefits

Generator	Separation required for the follower	Change relative to the current standard
CAT RA	240 s / 32 NM	N/A
CAT RB	200 s / 27 NM	N/A
CAT RC	120 s / 15 NM	N/A

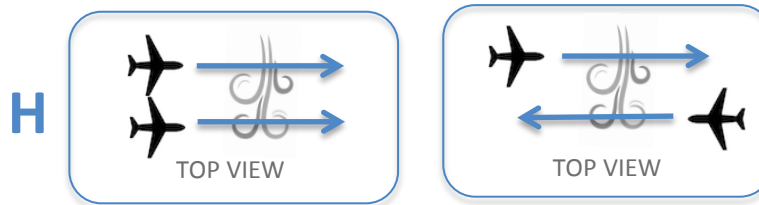
Not defined today:
Safety increased
Capacity?

O4: Separation Standard proposal

R-WAKE1 Minimum Wake Separation (MWS)

5. MWS Lateral Wind-Dependent

Geometries



Separation Adjustments & Benefits

Minimum lateral separation (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

Safety increased

Capacity increased
(for winds < 75 Kts)

Considerations

- 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)

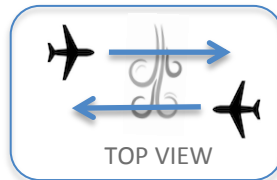
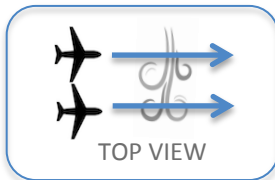
O4: Separation Standard proposal

R-WAKE1 Minimum Wake Separation (MWS)

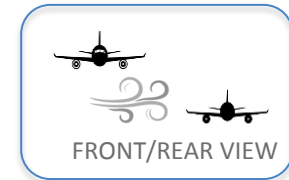
6. MWS Combined Vertical-Lateral Wind-Dependent

Geometries

H



V+H



Separation Adjustments & Benefits

Minimum lateral separation (upwind)	Max crossed wind component tolerated	Change relative to the current standard
1 NM (only if dV >= 500ft)*	15 Kts	N/A
2 NM (only if dV >= 500ft)*	30 Kts	N/A

Safety increased

Considerations

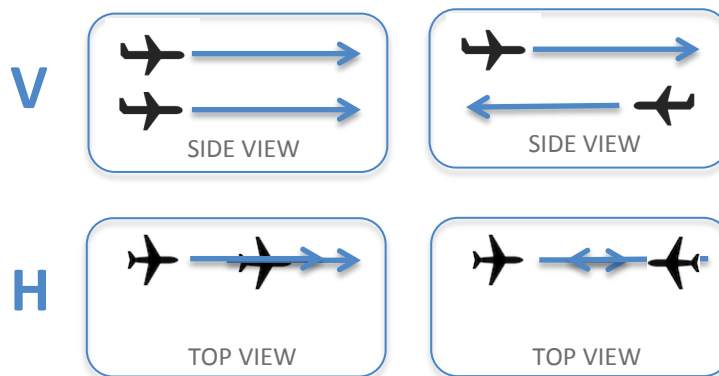
- Note that these are **combined separations** (vertical - lateral) that can be useful to apply special procedures, e.g., separating traffic in head-on geometry (**SLOP, as recommended by EASA**)

O4: Separation Standard proposal

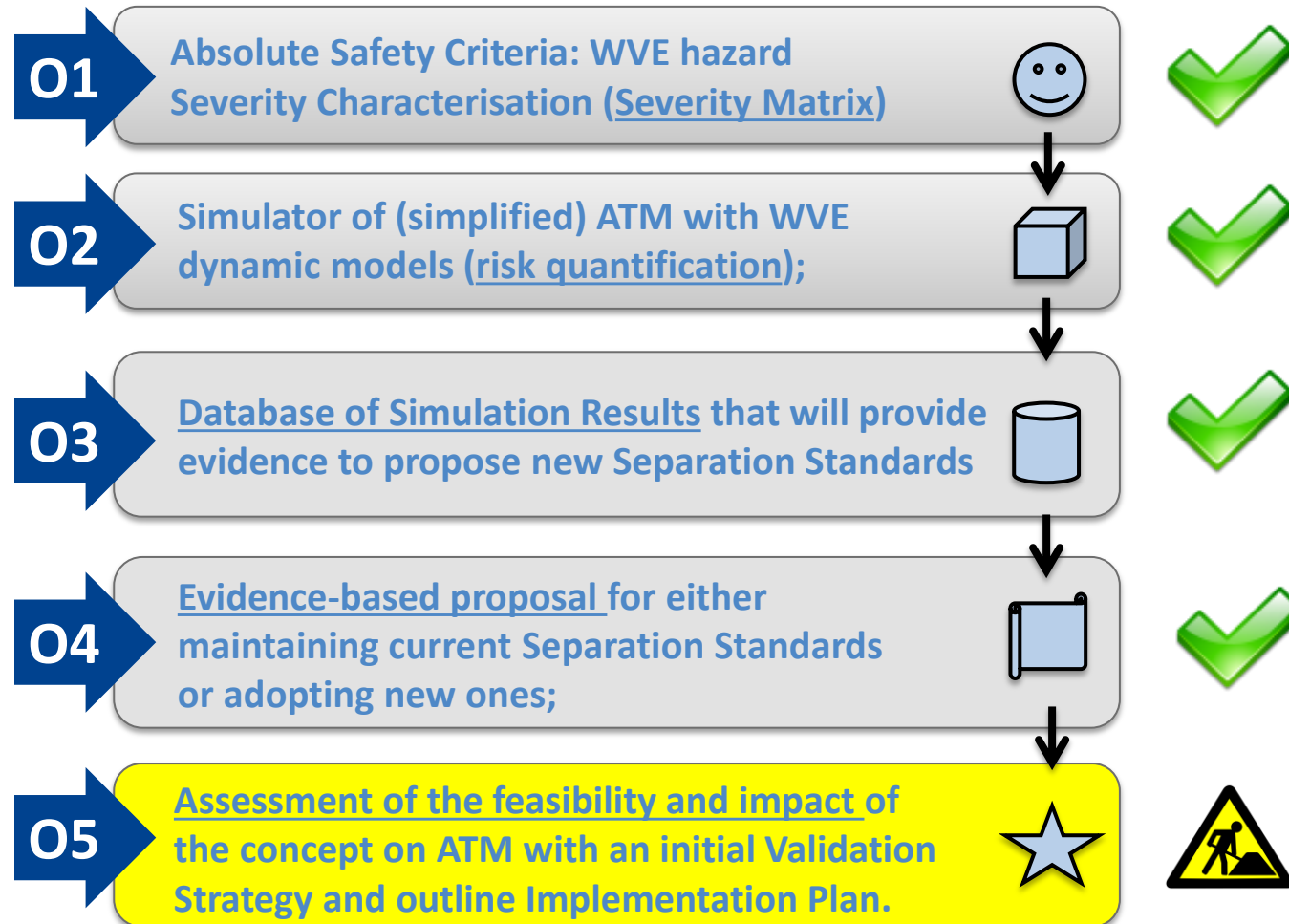
Subliminal off-sets supported by on-board systems

Idea for new OI:

- aircraft could be equipped with **on-board WVE preventing systems** (with similar technological basis as Extended-TCAS –not a safety net);
- 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 with today's separation standard)

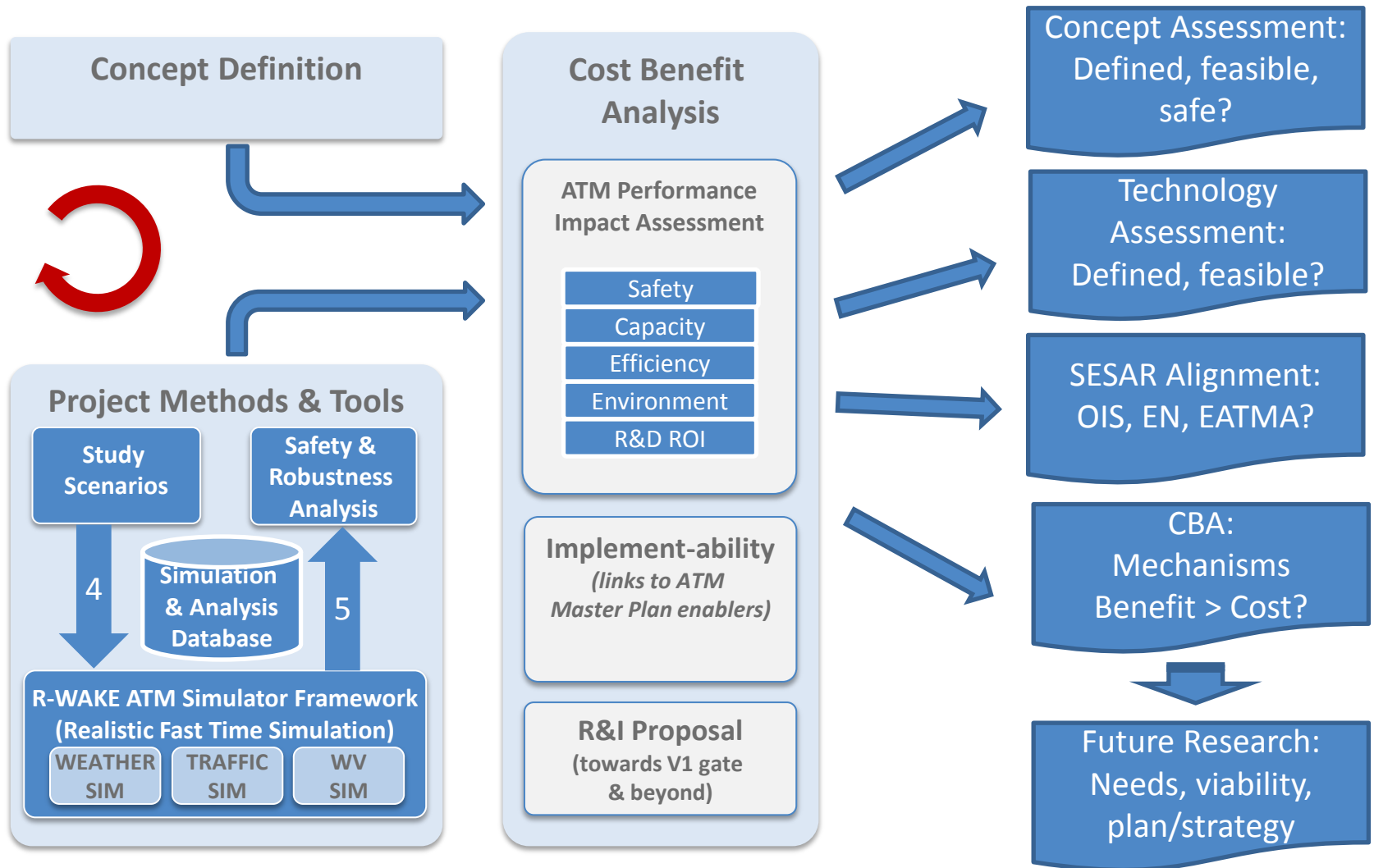


Achievements to Project Objectives



O5: Feasibility and Impact Assessment

Cost Benefit Analysis & ATM Roadmap fitness



Maturity Assessment to ER/IR Gate

Maturity Assessment

Related to App-oriented R-WAKE Concept Definition

Separations case	Expected Impact on ATM Performance	Integrity aspects (issues) & confidence level	Further research needed
1. MWS Lateral	Capacity: +	· No issues identified	· Validate the <u>MRS</u> (3NM)
2. MWS Vertical	Safety: + Capacity: + Efficiency: +	· ATCOs' <u>radar 2D view</u> (difficult separation provision) · Risk is sensitive to <u>vertical navigation uncertainty</u>	· <u>DSTs</u> for ATCOs · <u>WV models</u> to be further validated with real flights · Refine <u>risk models</u>
3. MWS Longitudinal – same FL	Safety: + Capacity: +	· Risk is sensitive to <u>vertical navigation uncertainty</u> · Difficult with dense traffic	· Include vertical uncertainties in <u>risk models</u> · <u>DSTs</u> for ATCOs
4. MWS Longitudinal – climbing/descend or crossing in FL below	Safety: + Capacity: (?)	· Very large region to protect (while risk of WVE is low) · Possibly difficult for ATCOs	· <u>WV models</u> to be further validated with <u>real flights</u> · <u>DSTs</u> for ATCOs
5. MWS Wind-dep. – lateral	Safety: + (winds > 75kts) Capacity: +	· Possibly difficult for ATCOs if wind info is not available	· <u>DSTs</u> for ATCOs (incl. <u>wind/weather info</u>)
6. MWS Wind-dep. – vertical-lateral	Safety: + (winds > 75kts) Capacity: +	· Possibly difficult for ATCOs if wind info is not available · Difficult with dense traffic	· <u>DSTs</u> for ATCOs (incl. <u>wind/weather info</u>) · <u>On-board WEPS</u>

Maturity Assessment

Related to the R-WAKE Research System

Key system achievements	Relevant features	Further research needed
Absolute Safety Criteria	Includes pilot and ATCo perspectives.	- Incorporate Load Factor variations - Further validation (not trivial), with more experts - Find severity for combinations of upset parameters
R-WAKE Integrated Simulator System	- Based on background enhanced simulators - WEPS partially validated	- WVS models in different weather conditions - More aircraft models in WIAM - Validation with real flights
Dynamic Risk Models	Analogue to RECAT to support the en-route safety cases	- Probability Risk models taking into account position uncertainty - Integration with AIM models for SRM - New models to assess the risk in sectors or in ECAC
R-WAKE Safety and Robustness (SRA) approach	Fully aligned with the methodologies and requirements of ESSAR4, SAME and SESAR SRM	- Include more effort on analysing Systems, Human Factors and Procedures - Generate evidence and safety requirements for higher maturity levels - Wider systemic approach (including AIMs analysis)

Maturity Assessment

Preliminary Conclusions

- **Potential new OIs:**
 - The **R-WAKE-1 Concept (OCD)** presents **good potential for enhancing current separations**, in terms of safety, capacity and flight efficiency.
 - **Several OIs can be defined from the baseline proposed** (ANSPs could adapt the OIs to their different needs and capabilities)
- **Potential new Enablers:**
 - The **R-WAKE System as a new safety tool** (e.g., to develop new safety standards)
 - The **R-WAKE System as concept-prototype of new real-time DSTs** for ATCOs and/or pilots (dynamic separations)
- **Maturity:**
 - We have **identified and quantified some ATM needs** and we propose a **Validation Strategy** (goals of V0).
 - Proposed Concept to be formally assessed in ER/IR gate by mid March: **partial V1 expected**
 - Some R-WAKE elements may be at higher TRL (TRL-2,3) (**e.g., WEPS**)

Way forward in ER/IR programme

R-WAKE Potential Next Steps

Concept development step-wise

Like RECAT, R-WAKE can take a step-wise approach:

- New aircraft category-wise and geometry-wise minima wake separation
 - Static MWS
 - Wind-dependent MWS
- New pair-wise geometry-specific wake minima separation
- And ultimately, dynamic pair-wise encounter-specific wake minima separation
- Need to consider wind and atmospheric conditions from the start (e.g. tropopause altitude)

❖ **RWAKE-1:** R-MWS-CATwise-GEOMwise

RWAKE-1

❖ **RWAKE-2:** R-MWS-CATwise-GEOMwise-WINDdep

RWAKE-2

❖ **RWAKE-3:** R-MWS-PAIRwise-GEOMwise-WINDdep

RWAKE-3

Way Forward, Strategy/Roadmap

Potential Next Steps to continue the Concept Research, Definition & Validation

1. Further Validation and consolidation of the results by cross-checking them with **measured data**.
2. Further develop the **Separation OI concepts** for near/medium term implementation
→ This timeframe could **initially** restrict the field of investigation to the **increased separations only**.
3. Further validation of the **reduced separations (3NM, 500ft) robustness against** different atmospheric conditions.
4. Investigate **operating conditions possibilities** including type of Airspace / Network and working Methods
→ Develop the **Unist Safety Case (USC) and Project Safety Case (PSC)** (e.g., adapting the OIs to a specific sector) and assess the **systemic risk** (ECAC/Airspace Sector wide)
5. Continue Research of **longer term concept OIs (e.g. ADS-B data links and 4D environments)** where it might be possible to envisage a cooperative mode ATCO/CREW
→ E.g., Dynamic Pairwise Separations, Avionic Subliminal Offsets, ...

SESAR Solution mapping

Overall preliminary conclusions



- There are **no existing Solutions, OI Steps, Enablers etc.** that exactly cover the scope of what we are researching
- **R-WAKE provides evidence for the recommendation** of adding some OIs and Enablers related to the management of en-route wake vortex hazards
- **More recommendations could be done if the R-WAKE System is further developed as well as more R-WAKE Concept research conducted in the direction of new Enablers and OIs for SESAR Solutions**



Thank you for your attention



Founding Members



BACKUP slides

R-WAKE Partners roles

**Project Coordination,
System engineering
& Weather Data**



**Traffic and Flight dynamics
simulation tools**



WV Simulation



Safety Analysis



WV & ATM Expert



**Outcomes
Assessment**

CBA, ROI,
ATM R&I
roadmap



R-WAKE System

RECAT background reference

Initial assumptions: RECAT-EU methodology as a reference

RECAT-EU

RECAT-EU scheme		"SUPER HEAVY"	"UPPER HEAVY"	"LOWER HEAVY"	"UPPER MEDIUM"	"LOWER MEDIUM"	"LIGHT"
Leader / Follower		"A"	"B"	"C"	"D"	"E"	"F"
"SUPER HEAVY"	"A"	3 NM	4 NM	5 NM	5 NM	6 NM	8 NM
"UPPER HEAVY"	"B"		3 NM	4 NM	4 NM	5 NM	7 NM
"LOWER HEAVY"	"C"		(*)	3 NM	3 NM	4 NM	6 NM
"UPPER MEDIUM"	"D"						5 NM
"LOWER MEDIUM"	"E"						4 NM
"LIGHT"	"F"						3 NM

RECAT-EU categories

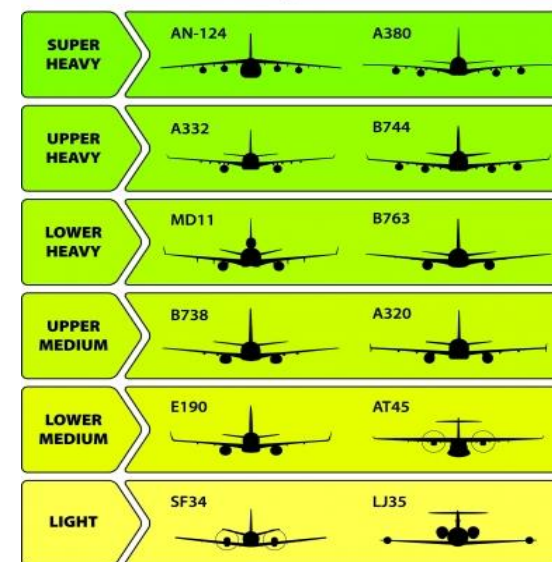


Table 3: RECAT-EU WT distance-based separation minima on approach and departure

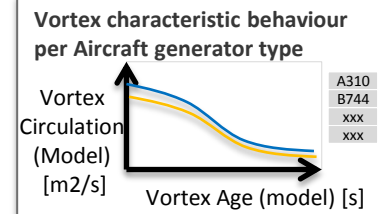
(*) means minimum radar separation (MRS), set at 2.5 NM, is applicable as per current ICAO doc 4444 provisions.

RWAKE System: Method view

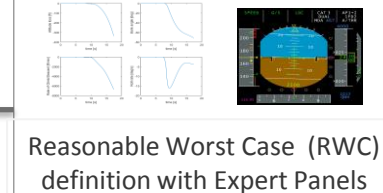
(flow chart inspired in RECAT's)

Key differences with RECAT

Dynamic model



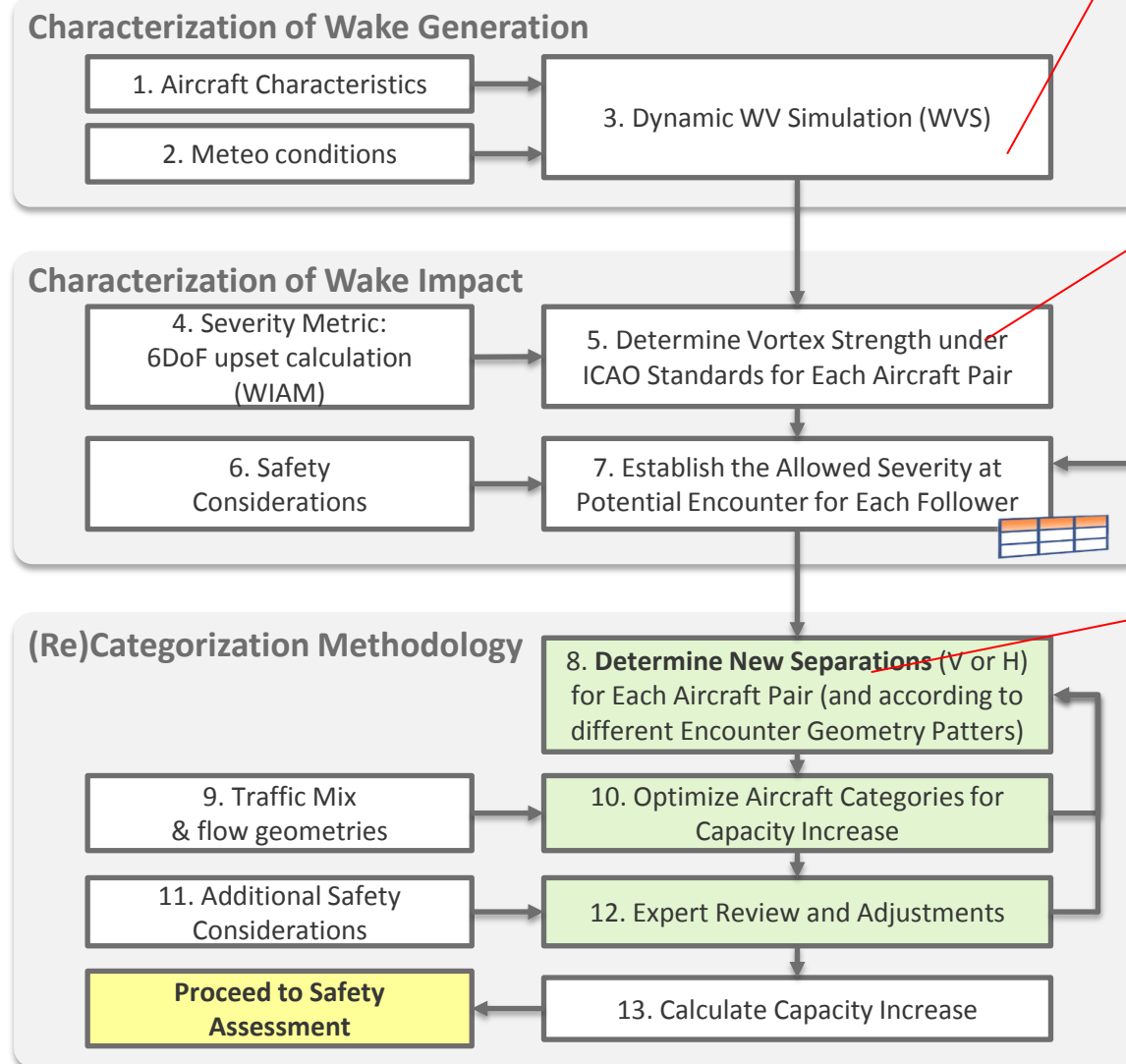
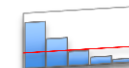
Severity Metric:
RECAT: 1D (RMC) vs
RWAKE: 6DoF



RECAT: 1D (Longitudinal)
RWAKE: 3D (Vertical, Offset,
Longitudinal)

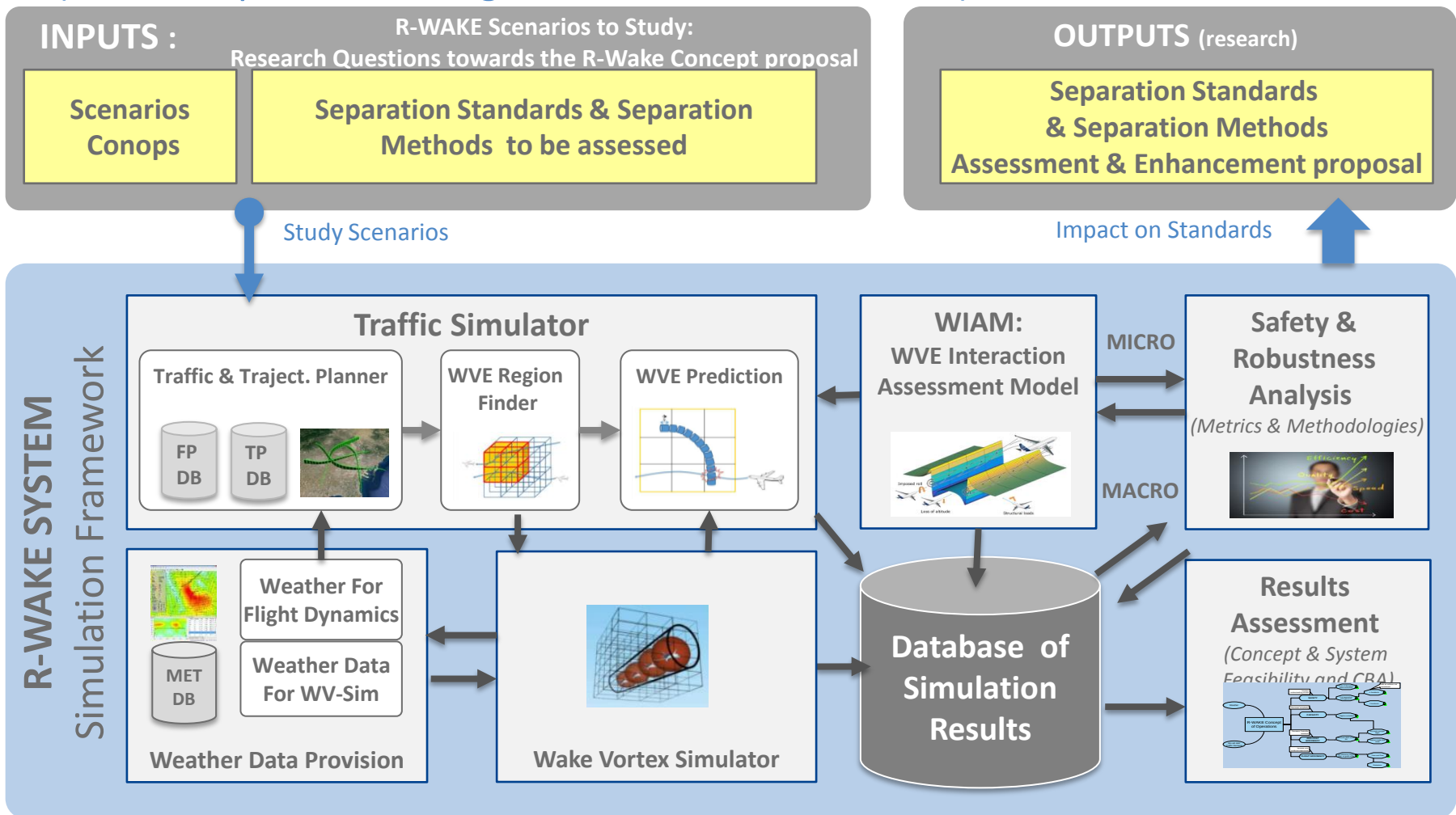
(Concept-Development)

Aircraft Clustering into Categories
and Separation adjustments to
keep RMC under a limit for all the
Aircraft



R-WAKE System : Integrated Simulation Platform

(based on previous background simulation modules)



R-WAKE System : framework view

R-WAKE system as a framework of methods & tools for the simulation and analysis of safety and robustness of En-route Wake Turbulence Hazard to support the development of new separation standard concepts.

3 levels

L1

ATM CONOPS

Needs and Opportunities

Scoping and prioritizing the Research Objectives.
Business Case

L2

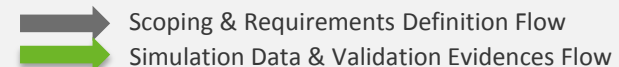
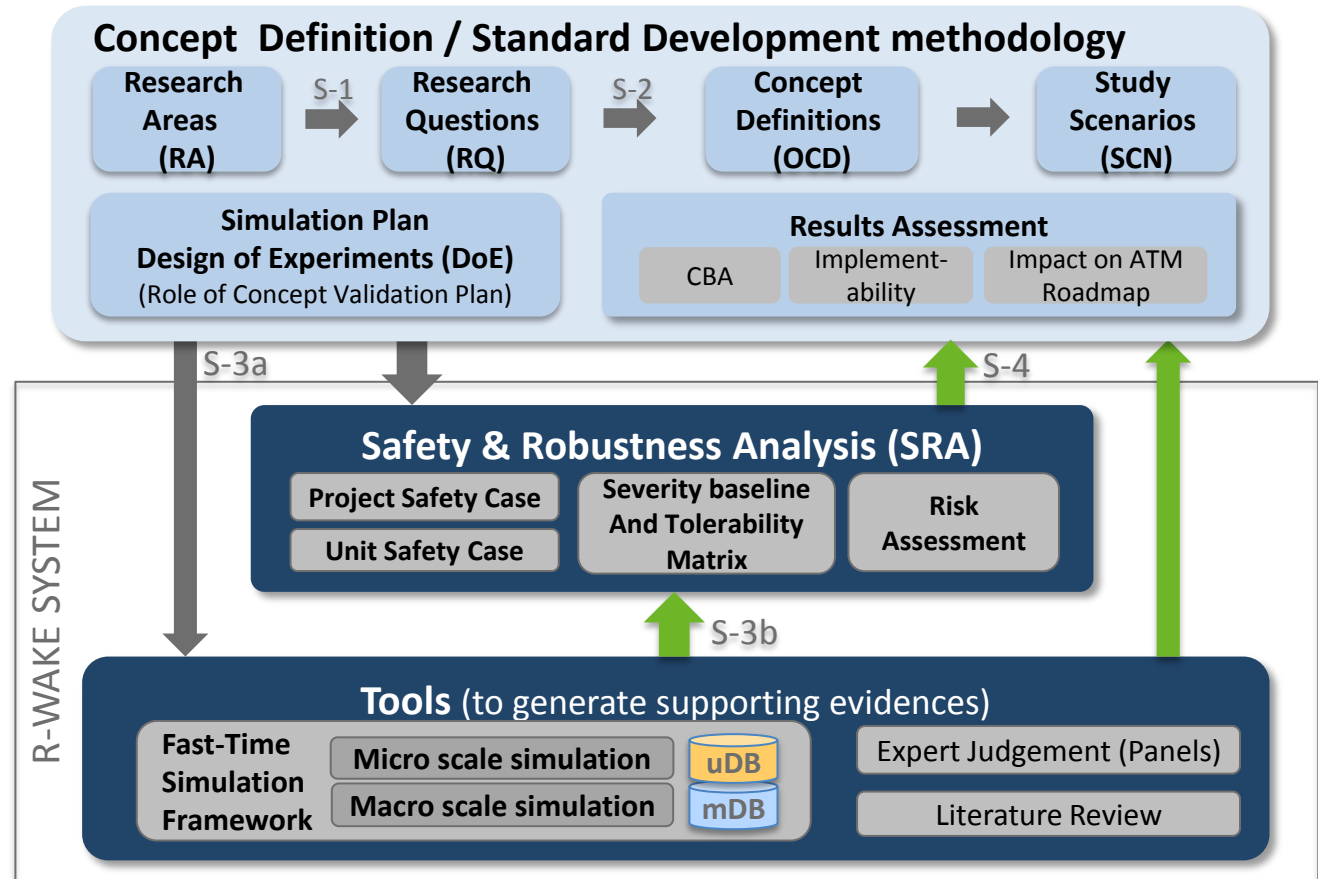
CONCEPT SAFETY

ASSESSMENT METHOD

L3

MODEL & SIMULATION / VALIDATION TOOLING

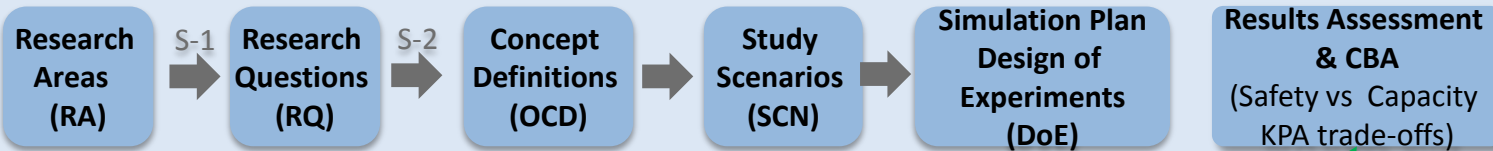
Evidences Consolidation by background literature, Modeling and Simulation, & Expert Judgement.



R-WAKE System: Safety Analysis Approach

L1

Concept Definition - Standard Development methodology



L2

SRA: Safety & Robustness Analysis

(Based on ESARR4 + SESAR SRM tailored)

Scn-2A

USC
"Unit Safety Case"

(1) Scope the Assessment (USC)

(2) Modelling the Nominal operations (USC)

(3) Hazards Identification (Pre-existing; System-Gen) (USC)

(4) Severity and Risk Framework (USC)

(5) Risk evaluation (probability) (USC)

(6) Robustness Analysis (USC)

(7) Risk Mitigation measures: Standard development

(8) Verification (as PSC)

Scn-3A

PSC
"Project Safety Case"

PSC increment

PSC increment

PSC increment

PSC increment

(5) Risk evaluation (probability) (PSC)

(6) Robustness Analysis (PSC)

(8) Verification

Mapping to Simulator Use

DoE (simulation plan)

Micro SM
Upset Severity Assessment (WIAM)

Macro CIR
Individual Risk (WEPS & WVS)

DoE Macro SAR
Traffic pattern per Area (full integrated simulator)

Severity Assessment & Matrix

Quantitative
(Model-based Risk Modelling)

Qualitative
(Experts Panels – Pilots & ATCOs)

Risk Occurrence Frequency measures
(Model based quantitative)

Benefit (Capacity & Efficiency) measures

L3

SIMULATION TOOLS

Micro Simulation

(One Encounter Scenario case)

WIAM

Micro Sensitivity Analysis

Severity Expert Panels

Macro Simulation

(Traffic per area Scenario case)

TP

WEPS

WXS

WVS

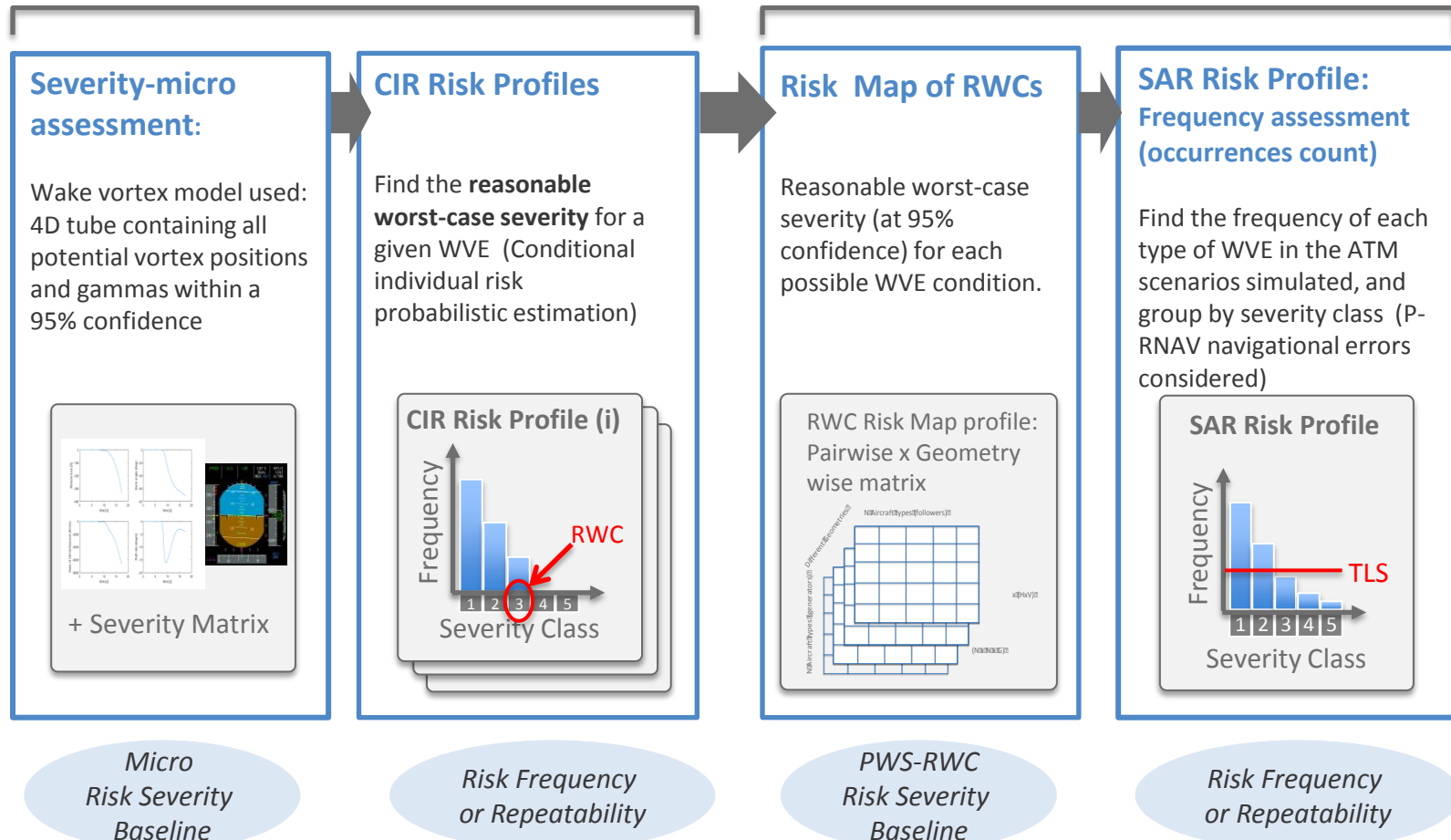
R-WAKE System: Risk Assessment and Risk Models

Macro analysis to assess CIR

(multiple experiments reproducing 1 WVE each with different a/c pair and geometries)

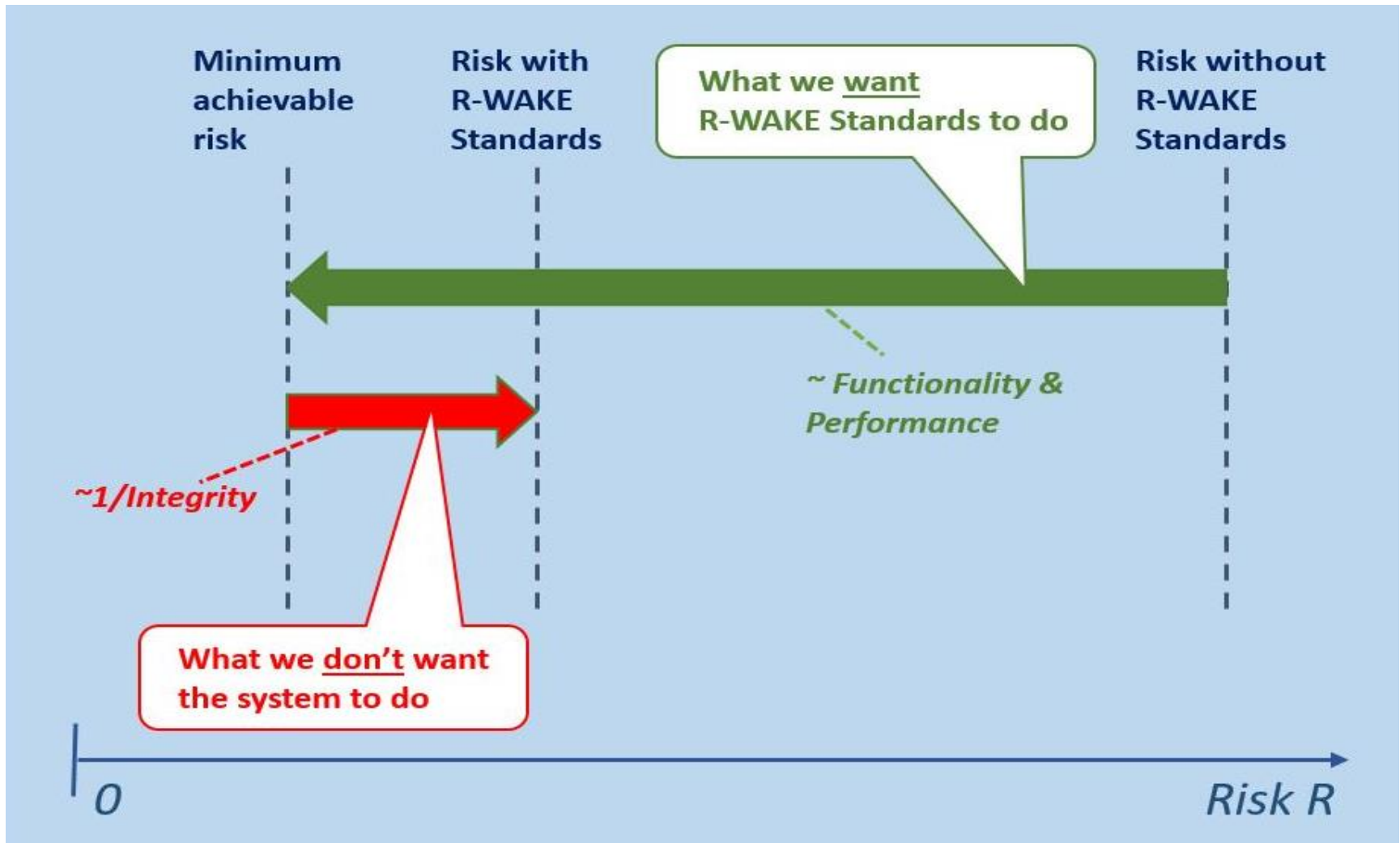
Macro analysis to assess SAR

(few experiments finding potential WVEs in traffic)



R-WAKE System as a Safety tool

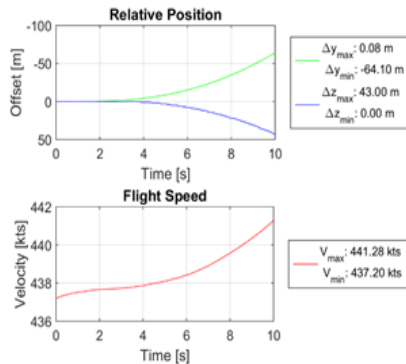
The SESAR SRM broader approach to safety assessment



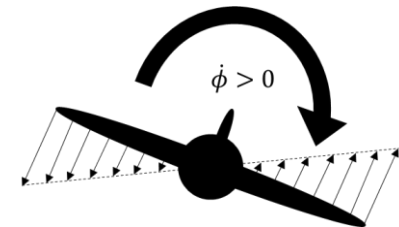
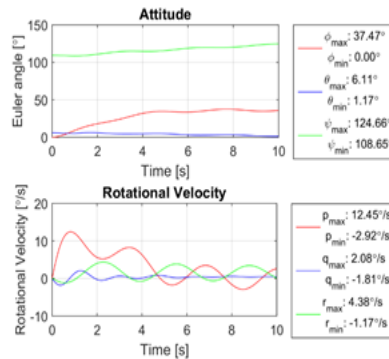
R-WAKE System: WIAM tool

Computing the dynamic response of the aircraft interacting with a Wake Vortex : Upset parameters derivation

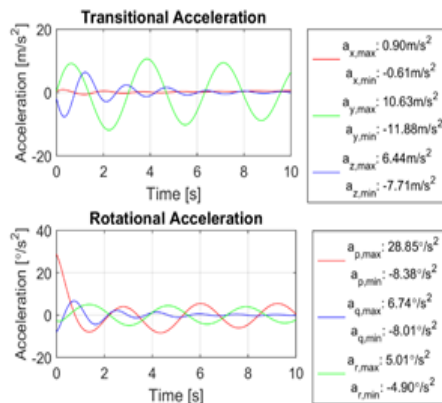
Lateral and vertical deviations and airspeed changes.



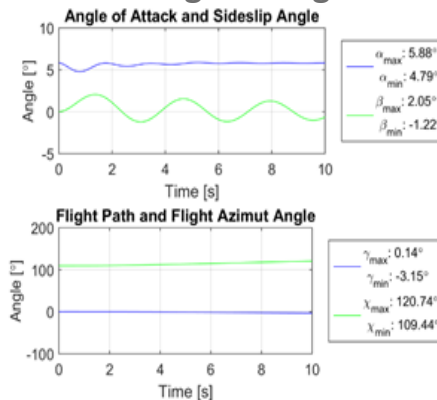
Attitude and rotational velocity changes.



Linear and rotational acceleration changes



Angle of attack, sideslip angle, flight path angle and flight path azimuth angle changes.

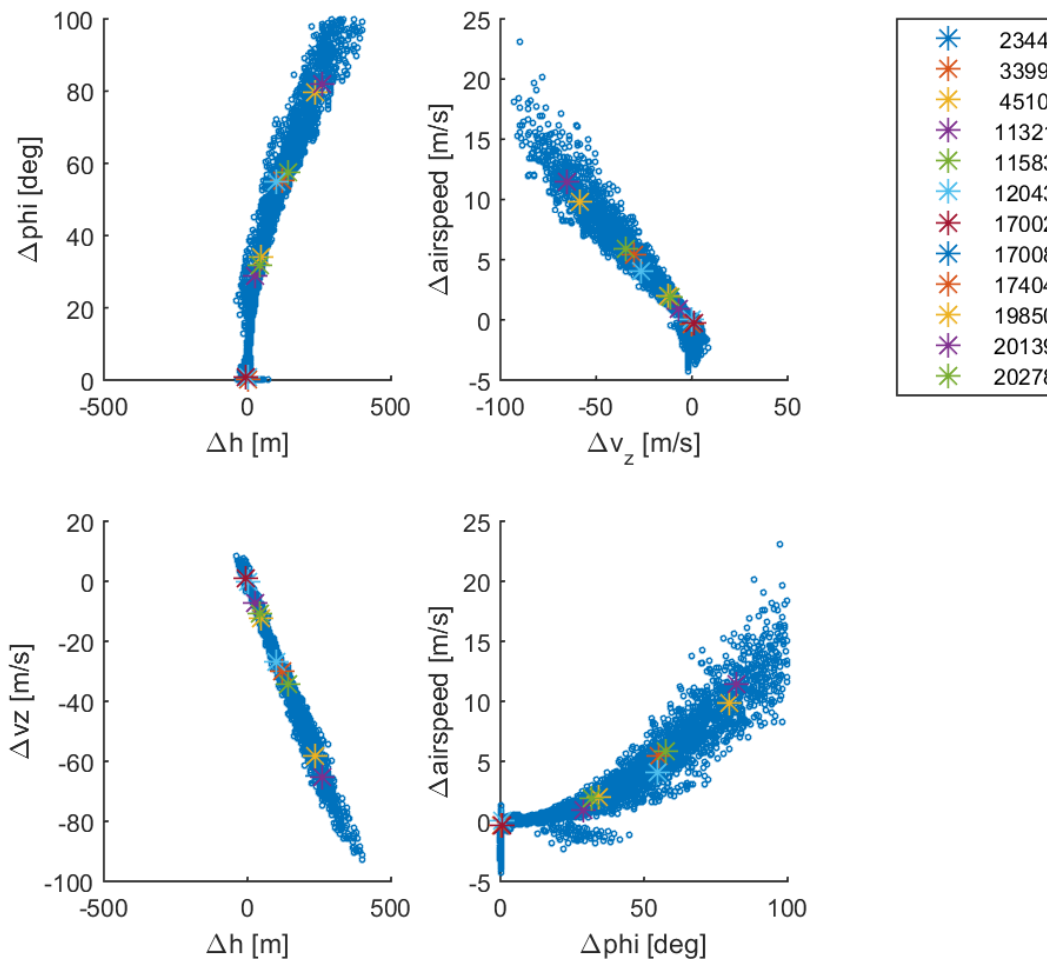


Maximum upsets obtained in the coaxial encounter

Altitude change	43 m
Bank angle	0.65403 rad
Rate of Climb/Descent	12.471 m/s
Airspeed change	2.0987 m/s

R-WAKE System: Upset Severity Assessment & Expert Panel

WIAM Micro-simulation Scenario selection to present the results to

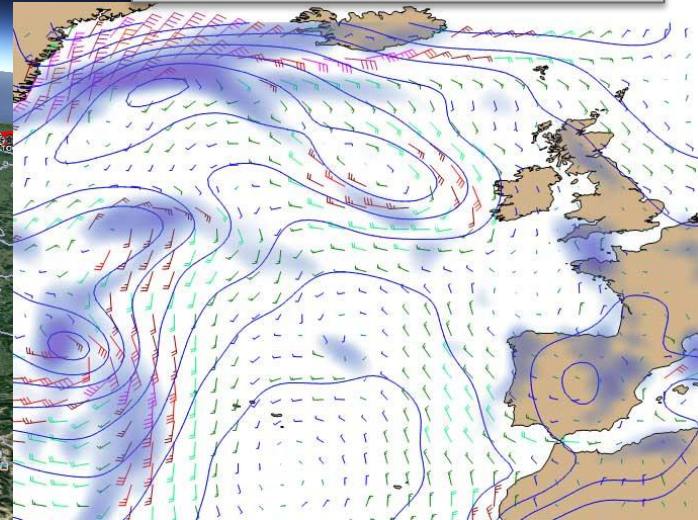
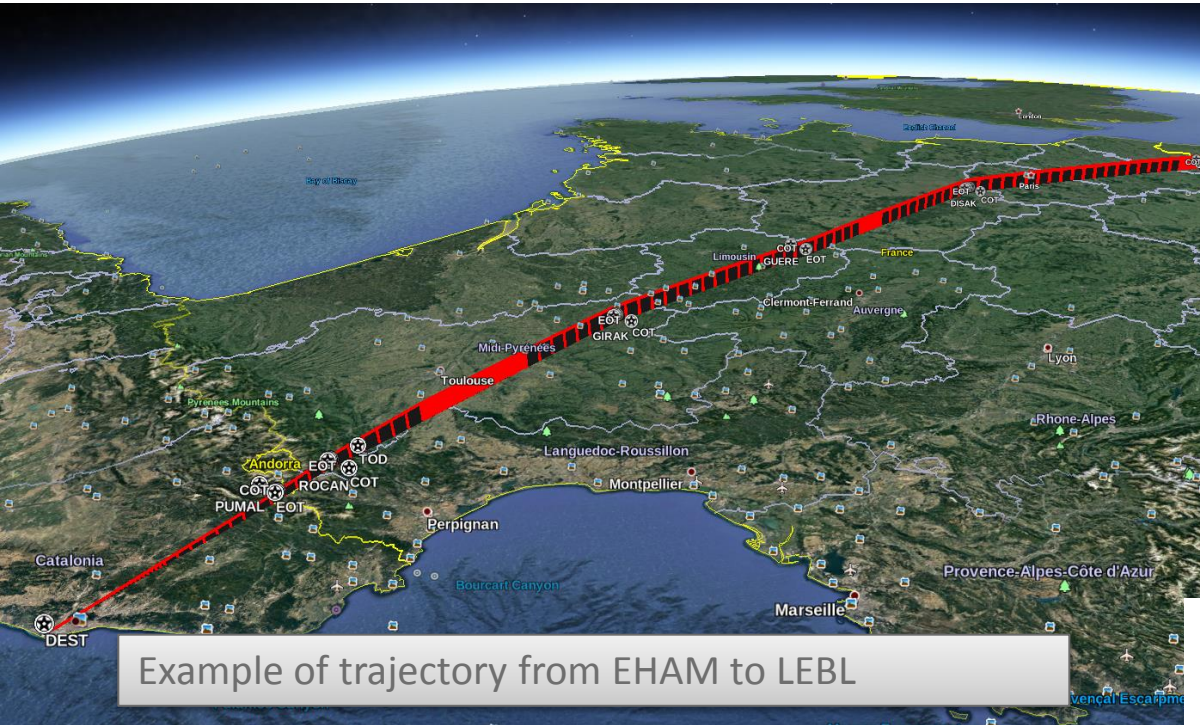


- 20302 scenarios were simulated
- Only 12 presented to pilots and ATCOs
- Every scenario is considered according the following outputs:
 - Maximum change in altitude
 - Maximum change in the bank angle
 - Maximum change in the airspeed
 - Maximum change in the vertical speed

R-WAKE System: Simulators

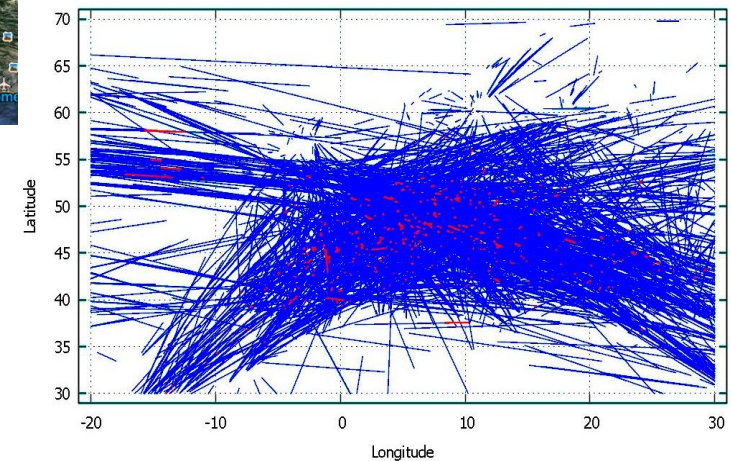
Trajectory Planner (TP) module

Access to real weather data



Example of trajectory from EHAM to LEBL

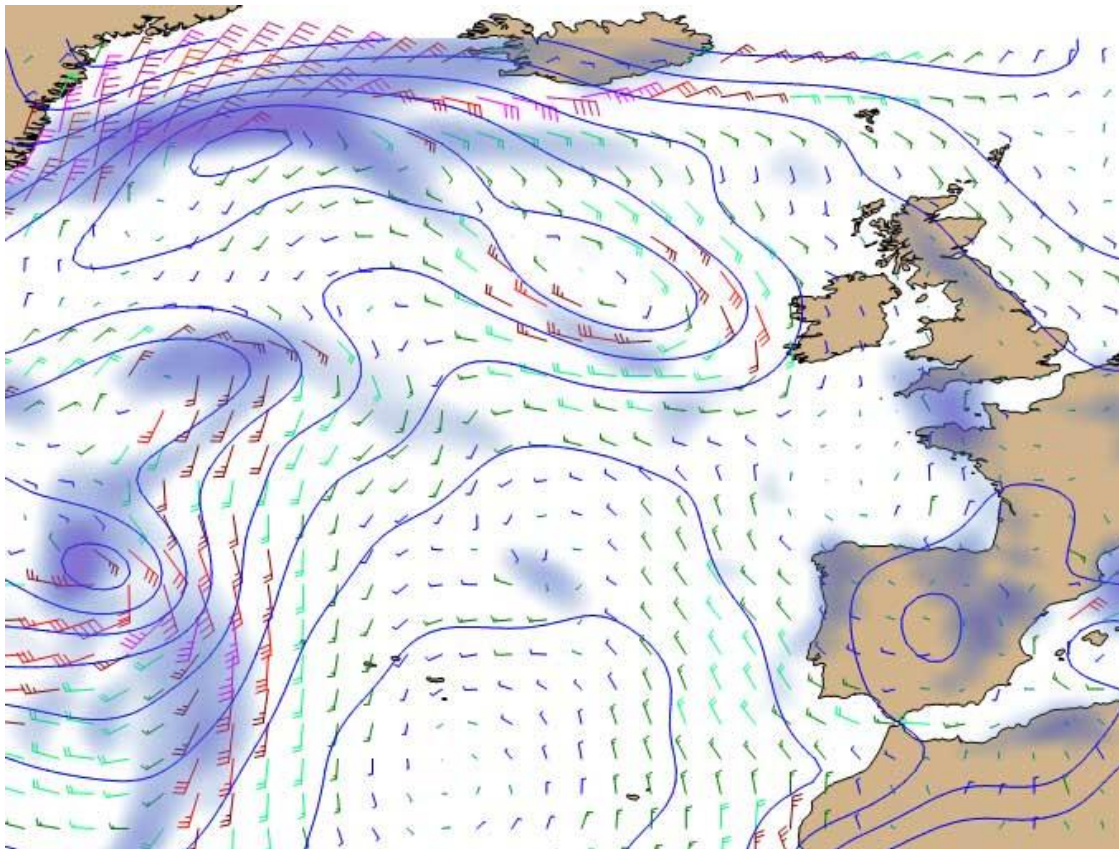
The result is a set of trajectories non deconflicted



R-WAKE System: Simulators

Weather Module (WXM) integrated with the Trajectory Planner

Provide accurate weather data to both LPOM and VPOM modules



Needed data:

- $W_n(\varphi, \lambda, h, t)$
- $W_e(\varphi, \lambda, h, t)$
- $\tau(\varphi, \lambda, h, t)$
- $p(\varphi, \lambda, h, t)$

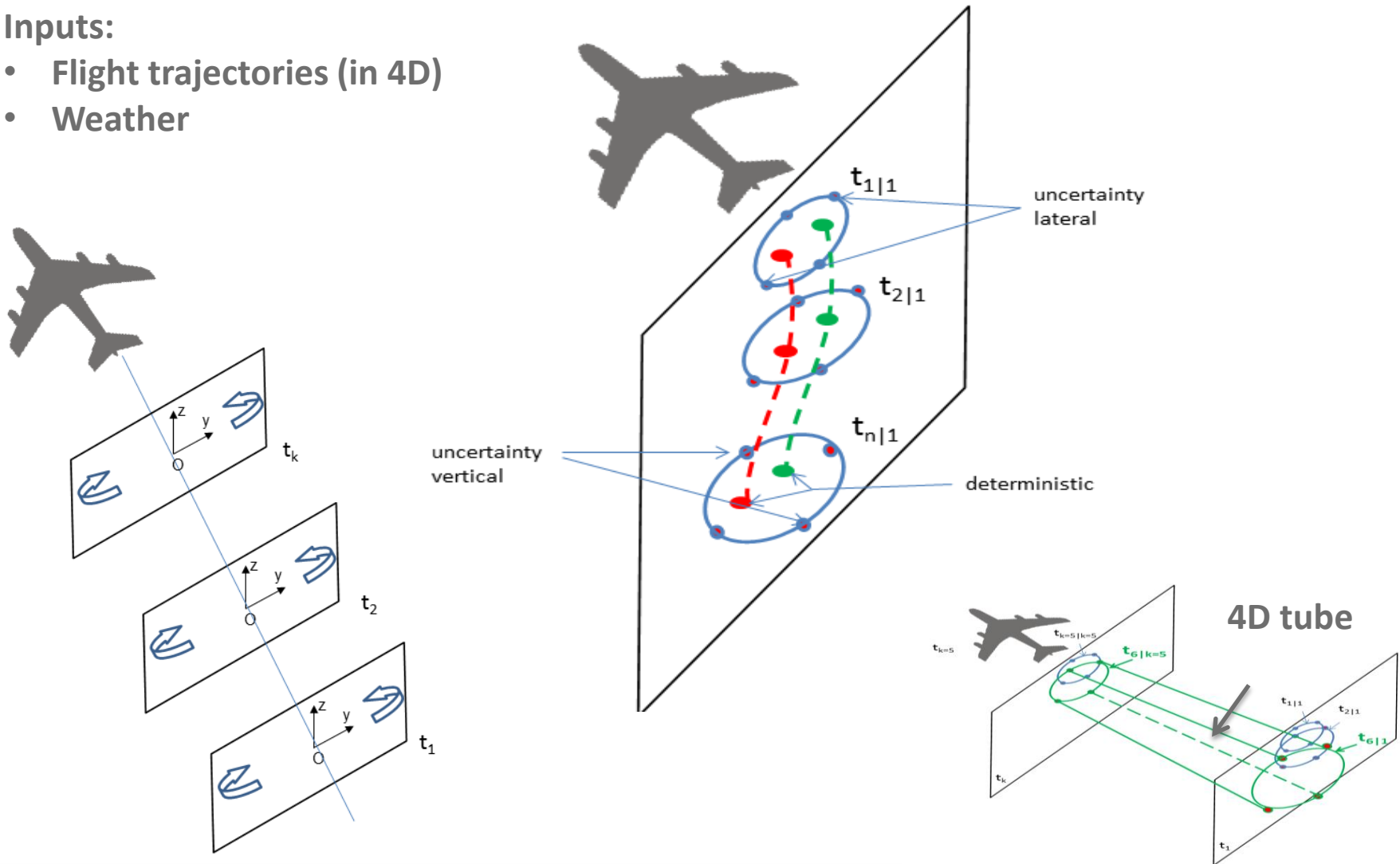
- | | |
|------------------------|-------------------------|
| • W_n : north wind | • h : altitude |
| • W_e : east wind | • φ : latitude |
| • τ : temperature | • λ : longitude |
| • p : pressure | • t : time |

R-WAKE System: Simulator modules

WakeVortex Simulator (WVS)

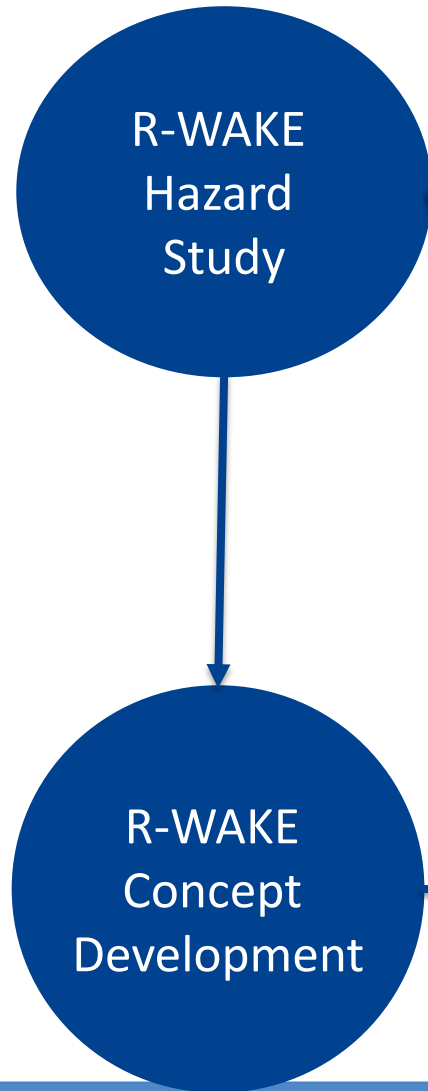
Inputs:

- Flight trajectories (in 4D)
- Weather

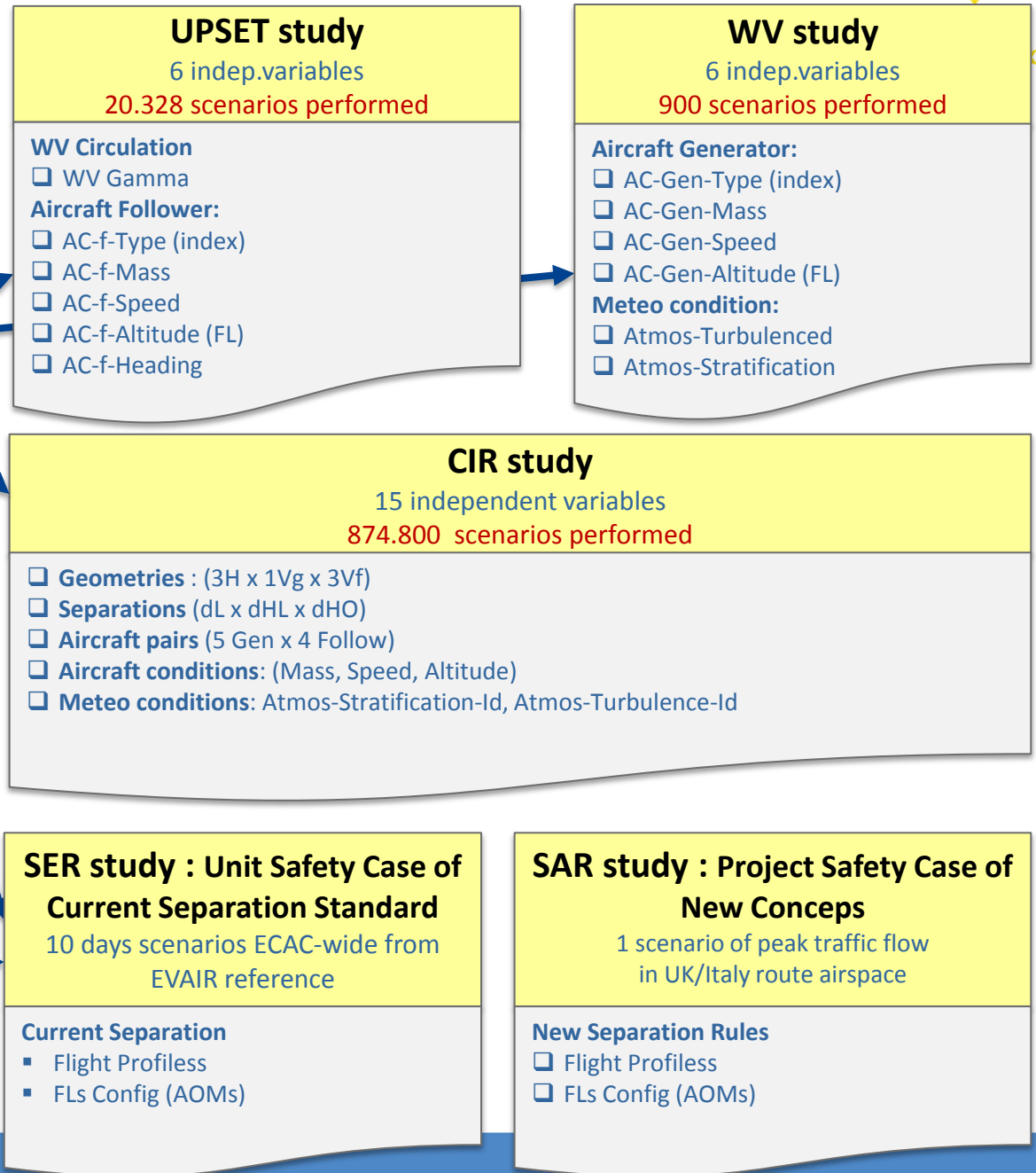


R-WAKE Research Performed Simulations

Simulation-based research process



DoE FILES:



R-WAKE Hazard Study

R-WAKE Concept Development

STUDY VARIABLES

DoE FILES:

UPSET study

20.302 scenarios
6 indep.variables

WV Circulation

- WV Gamma
- ### Aircraft Follower:
- AC-f-Type (index)
 - AC-f-Mass
 - AC-f-Speed
 - AC-f-Altitude (FL)
 - AC-f-Heading

WV study

1.500 scenarios
6 indep.variables

Aircraft Generator:

- AC-Gen-Type (index)
 - AC-Gen-Mass
 - AC-Gen-Speed
 - AC-Gen-Altitude (FL)
- ### Meteo condition:
- Atmos-Turbulenced
 - Atmos-Stratification

CIR study

570.240 scenarios
13 indep.variables

- Geometries : (3H x 1Vg x 3Vf)
- Separations (dL x dHL x dHO)
- Aircraft pairs (5 Gen x 4 Follow)
- Aircraft conditions: (Mass, Speed, Altitude)
- Meteo conditions: Atmos-Stratification-Id, Atmos-Turbulence-Id

SER study

Unit Safety Case of
Current Separation
10 days scenarios
ECAC-wide from
EVAIR reference

Current Separation

- Flight Profiles
- FLs Config (AOMs)

SAR study

Project Safety Case
of New Concepts
1 scenario of peak
traffic flow in UK/Italy
route airspace

New Separation Rules

- Flight Profiles
- FLs Config (AOMs)

WIAM

Flight dynamics vs
Vortex Circulation

UPSET (.csv file)

UPSET Database

SRA:
Upset Severity
Baseline
Assessment

SMUT table

Severity Matrix of
Upset Parameter
Thresholds

UPSET MICRO SIM

TRS:

Individual
Trajectories
for WV study

Batch of
Individual
Encounters

AER.xml

WVS

WVTR .xml file

WV Database

WVS MACRO SIM

TRS:

Individual
Trajectories
for CIR study

Batch of
Individual
Encounters

AER.xml

WEPS for CIR

SMUT

WIAM

SHA charts
Simplified
Hazard Areas

SRA:
CIR Hazard
Assessment

CIR (.csv file)

CIR Database

CIR MACRO SIMULATOR

ATM KPI

TRS:

Traffic Plan
for SER/SAR

WERF

WEPS

For SER/SAR

WIAM

SMUT

GRIB

AER

WVTR

WVER

Historic
Real
Meteo

WXS

WVS

SAR

SER

Risk Frequency
Profile Database

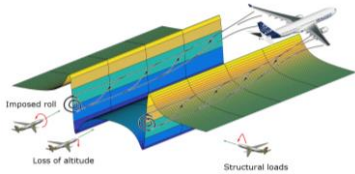
SRA: SER & SAR
Hazard Frequency
Assessment

FULL INTEGRATED SIMULATOR
For MACRO SER/SAR
(TP+WER+WVS+WXS+WIAM+WEPS)

DoE for Micro analysis of Upset

WV object exploration plan

WV object



WV is modelled in WIAM as Two infinite tubes

☐ Generator a/c Type

Values (4): { A320-212, A330-301, B772LR, A380-841}

☐ WV Relative Circulation (%)

Range: [33%, to 100%], step=33%
Values (3): {33%, 66%, 100%}

☐ WV Sink Angle (deg)

Range: [-5 to 5], step=5
Values (3): {-5, 0, 5}

☐ WV Core Radius (m)

Values (1): {0.035b}

☐ WV Spacing (s)

Values (1): {0.8b}

Follower WV-Encounter exploration plan

Follower A/C

☐ Follower a/c Type

Values (1): { A320-212}

☐ Follower Rel. Mass (%)

Range: [OEW+0.8MPL, MTOW]
Step: (MTOW-(OEW+0.8*MPL))/2

☐ Follower airspeed (mach)

Range: [M_MRC, M_MO]
Step: (M_mo-M_mrc)/2

☐ Follower Altitude (FL)

Range: [200, ceiling]
step= (ceiling-200)/2;

WVE Geometry: 4 x 3 geometries

Horizontal

☐ Follower Relative Track (deg)

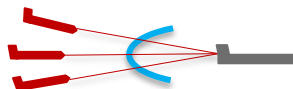
Range: [0,90], step=45; 2 target points when 0°
Values (4): {0.a, 0.b, 45, 90}



Vertical

☐ Follower Rate of Climb (ft/min)

Range: [-1000 , 1000], step=500;
Values (5): {-1000, -500, 0, 500, 1000}



WIAM
UPSET
Calcu-
lator

Upset

5 vars:

- ☐ Max Delta Altitude
- ☐ Max Delta Roll (BankAngle)
- ☐ Max Delta Altitude/dt
- ☐ Max Delta Roll/dt
- ☐ Max Load Factor

Context Vars:

- ☐ A/C Thrust Excess

Micro
Data
Analysis

Expert Judgement
Purpose:
Upset identification
and severity
assessment

DoE for Macro CIR-SHA risk maps generation

Among other variables, we studied different separations

STUDY ASPECT		STUDY PARAMETERS	Number of Values	Study Values approach
WVE GEOMETRY	9	Geometry H of follower	3	LONGITUDINAL, CROSSING, DIAGONALS
		Geometry V of Generator	1	Generator flying level
		Geometry V of Follower	3	Follower climbing, flying level, descending
SEPARATION to TEST	270	Longitudinal separation	6	WVE point + sigma (dHL is calculated from WV trajectory and dV)
		Cross-track separation	1	Target points (assuming SLOP)***
		Vertical separation*	15*	Scan (From - to - by) (0 to Max-WVV-decay by 100). Depends on WV geometry.
AIRCRAFT PAIR	60	Generator Aircraft type	5	
		Follower Aircraft type	4	
AIRCRAFT CONDITION	18	Generator Altitude (FL)	3	
		Generator Mass (% MTOW)	2	NC & RWC
		Generator Speed	1	NC & RWC as function of Mass and Altitude
		Follower Mass (% MTOW)	1	NC
		Follower Speed****	1	NC as function of Mass and Altitude
METEO CONDITIONS	27	Atmos. Stratification (Temperature profile)	3	Enumerated list (tabulated)
		Atmos.Turbulence (EDR)	3	Enumerated list (tabulated)
		Wind-Horizontal	1	A-posteriori analytic
		Wind-Vertical	1	A-posteriori analytic
ESTIMATED EXPECTED TOTAL WEPS runs			874.800	
RESULTED FINAL NUMBER of WV Encounters scenarios computed (WEPS runs)			583.632	

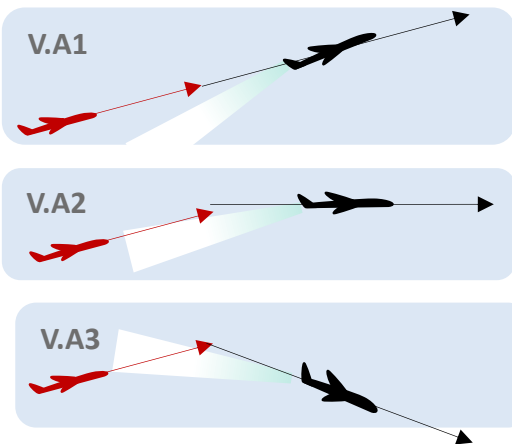
R-WAKE Separation Standards (Proposals)

Factors considered in the definition of MWS. *3 Basic Geometries*

In VERTICAL plane:

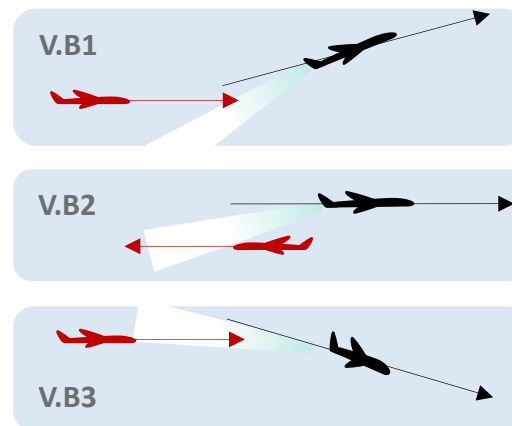
A. Follower climbing

- A1. Generator climbing ahead
- A2. Generator flying level
- A3. Generator descending ahead



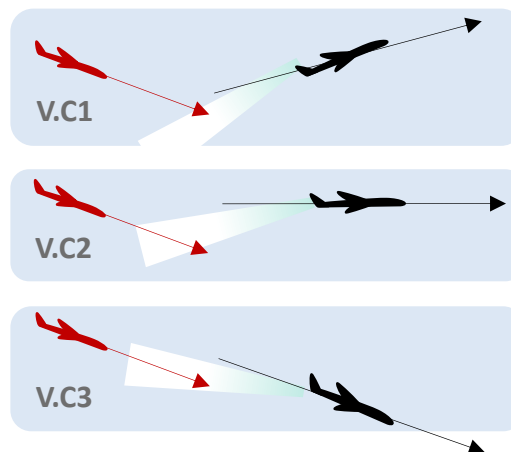
B. Follower flying level

- B1. Generator climbing ahead
- B2. Generator flying level – crossing above level in opposite direction
- B3. Generator descending ahead

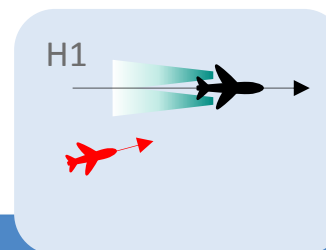
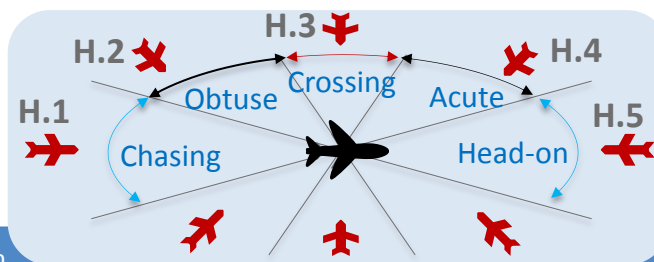


C. Follower descending

- C1. Generator climbing ahead
- C2. Generator flying level
- C3. Generator descending ahead



In HORIZONTAL plane:

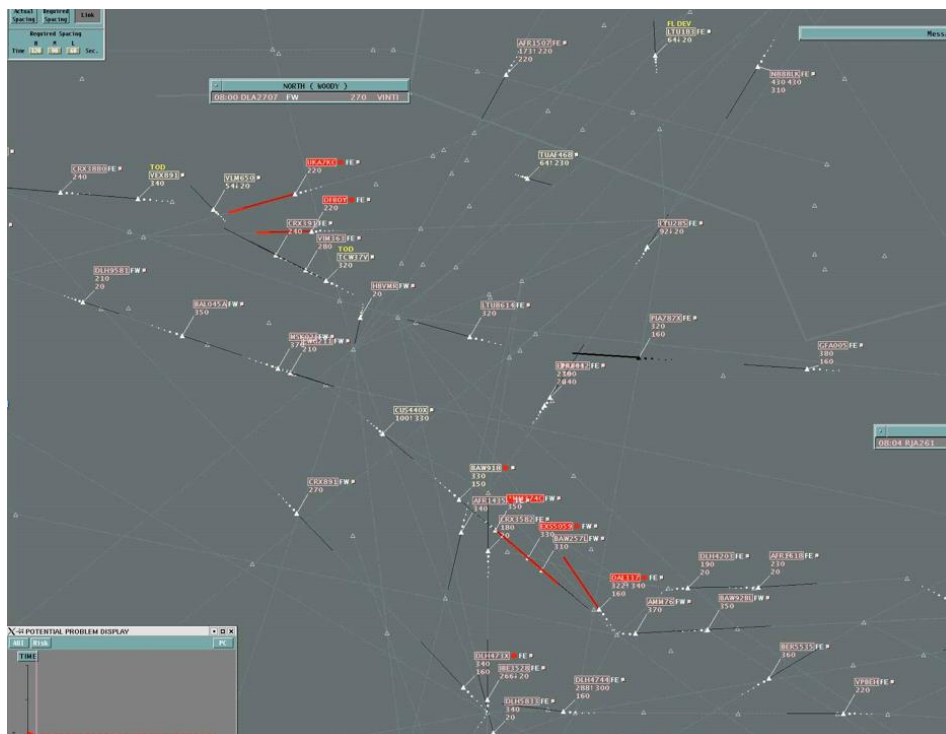


↔
dH range:
5-25NM

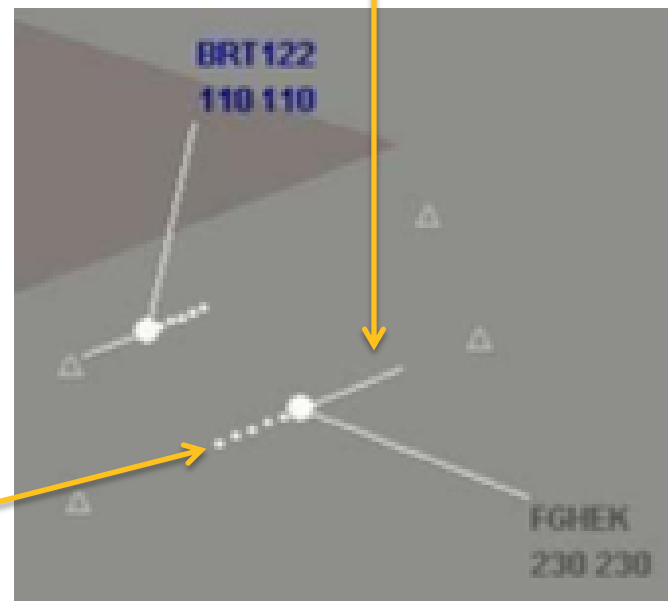
Concept Development (OI illustrative use cases)

R-WAKE-1 Concept

Typical ATC radar view



Velocity vector
set at 1 min
look-ahead time
(can be set by the ATCO to
other values)

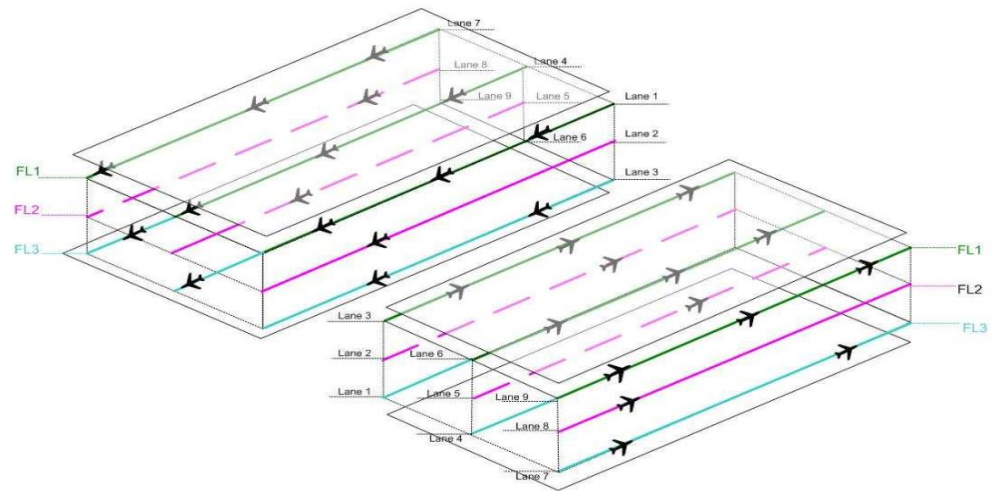


Rough wake trail
representation

R-WAKE-1 Concept

Potential applications

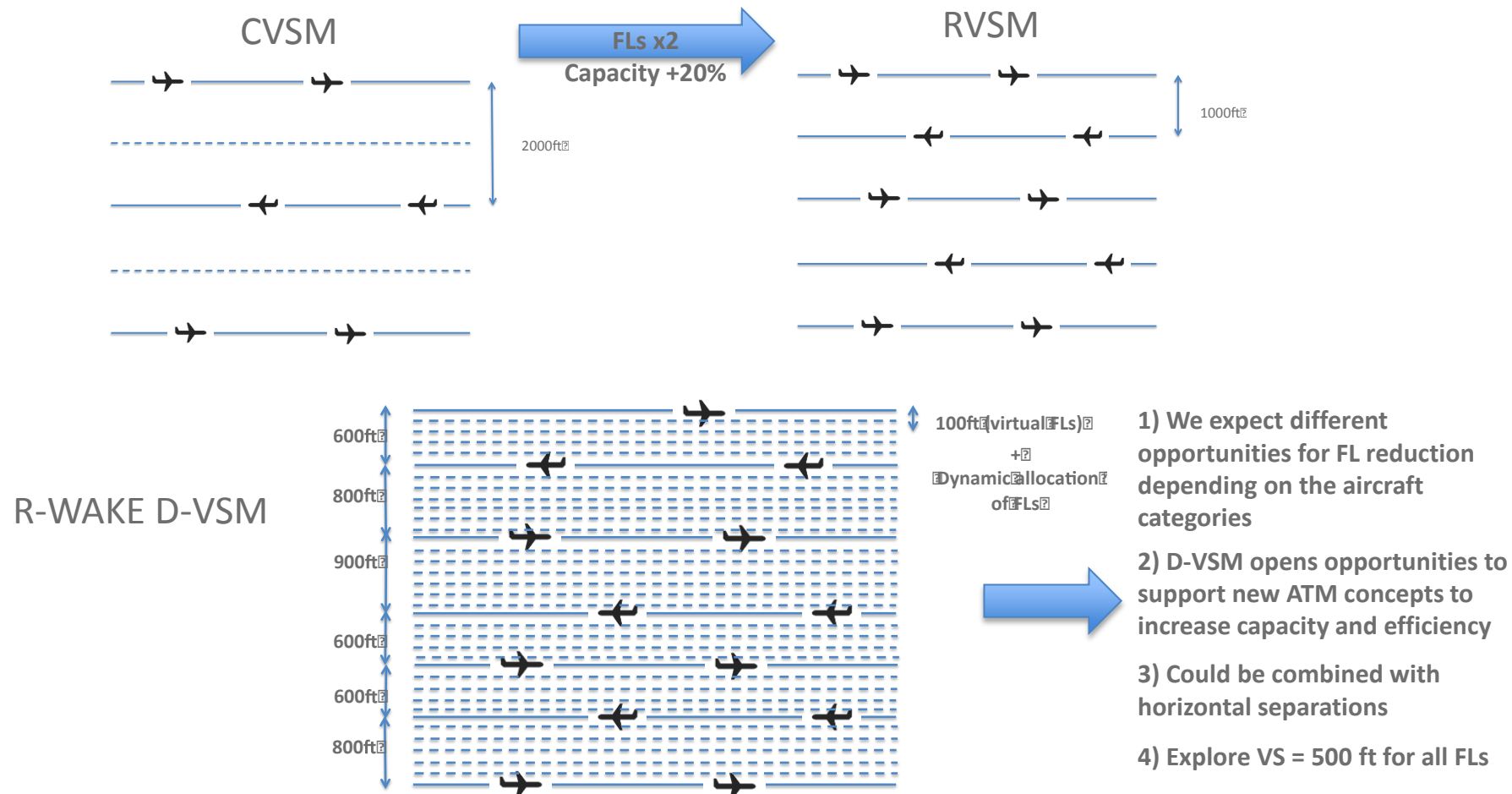
- Combined Separations in flows to facilitate the quantification of capacity and efficiency that can be obtained, and the link with ATC (integrity analysis)
 - 1) The PSC should **compress traffic in 4D** to increase capacity
 - 2) The risks of PSC will be **benchmarked with historical traffic** (USC) to develop a new standard
 - 3) Still **room for flight optimisation**: "the lighter the higher"



R-WAKE-1 Concept

Potential applications

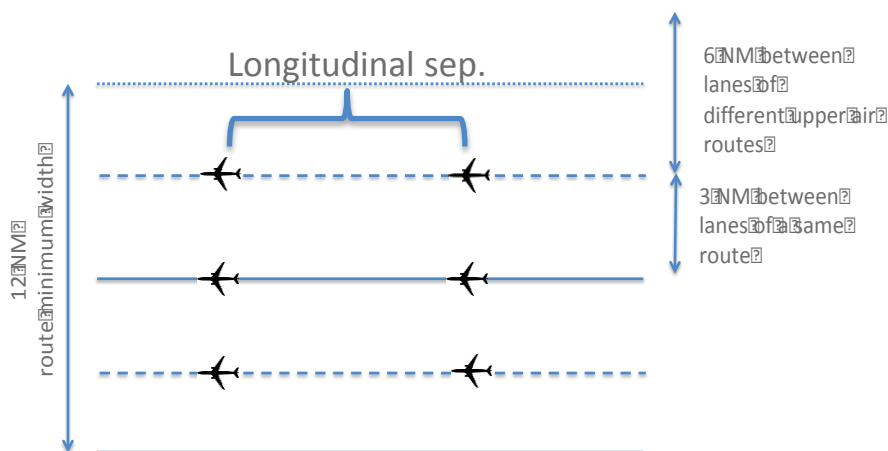
- Reductions of Vertical separation (possibly combined with horizontal)



R-WAKE-1 Concept

Potential applications

- **Reductions of Horizontal separation (parallel and longitudinal)**
 - In the future: **RNP-1** (+/- 1NM max deviation the 95% of the time)
 - **Parallel tracks** (not necessarily following routes, e.g., free-route conops): **3NM could provide a robust separation** of 6 sigma with respect to the navigational standard error, and it might be still acceptable for ATC controllability



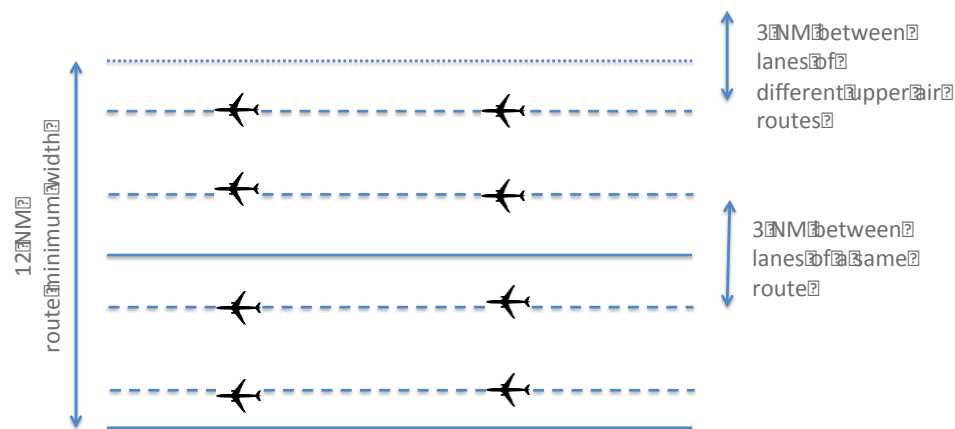
- **Longitudinal:** It may be also interesting to be able to **compress the traffic one behind the other**, in same level or below.

Note: the use of parallel lanes, since they allow overcomes between flights, can also facilitate the sequencing and merging at the coordination points of the sectors that feed TMAs and airports.

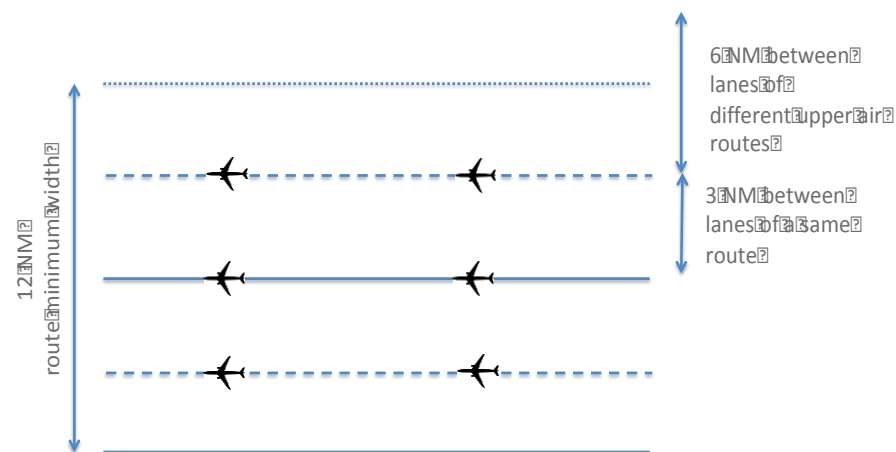
R-WAKE-1 Concept

Potential applications

- Reductions of Horizontal separation and opportunities to increase capacity
 - In the future: RNP-1 (+/- 1NM max deviation the 95% of the time)



1 upper route – 4 lanes: robust separation of 6 sigma with respect to the navigational standard error, and it might be still acceptable for ATC controllability



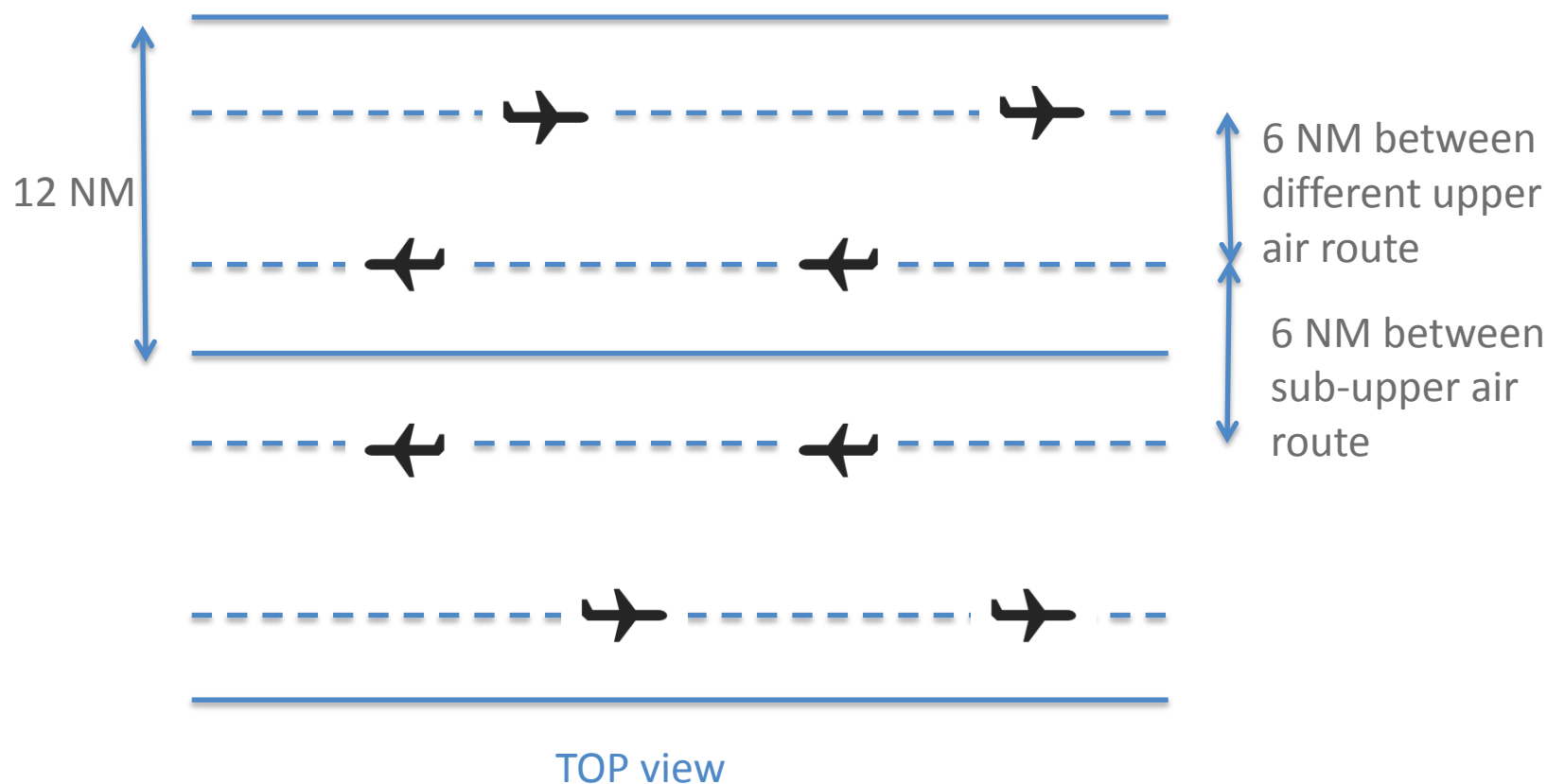
1 upper route – 3 lanes: even more robust separation and perhaps easier to manage

The use of parallel lanes, since they allow overcomes between flights, can also facilitate the sequencing and merging at the coordination points of the sectors that feed TMAs and airports.

R-Wake1: Use Case Examples

Horizontal separation

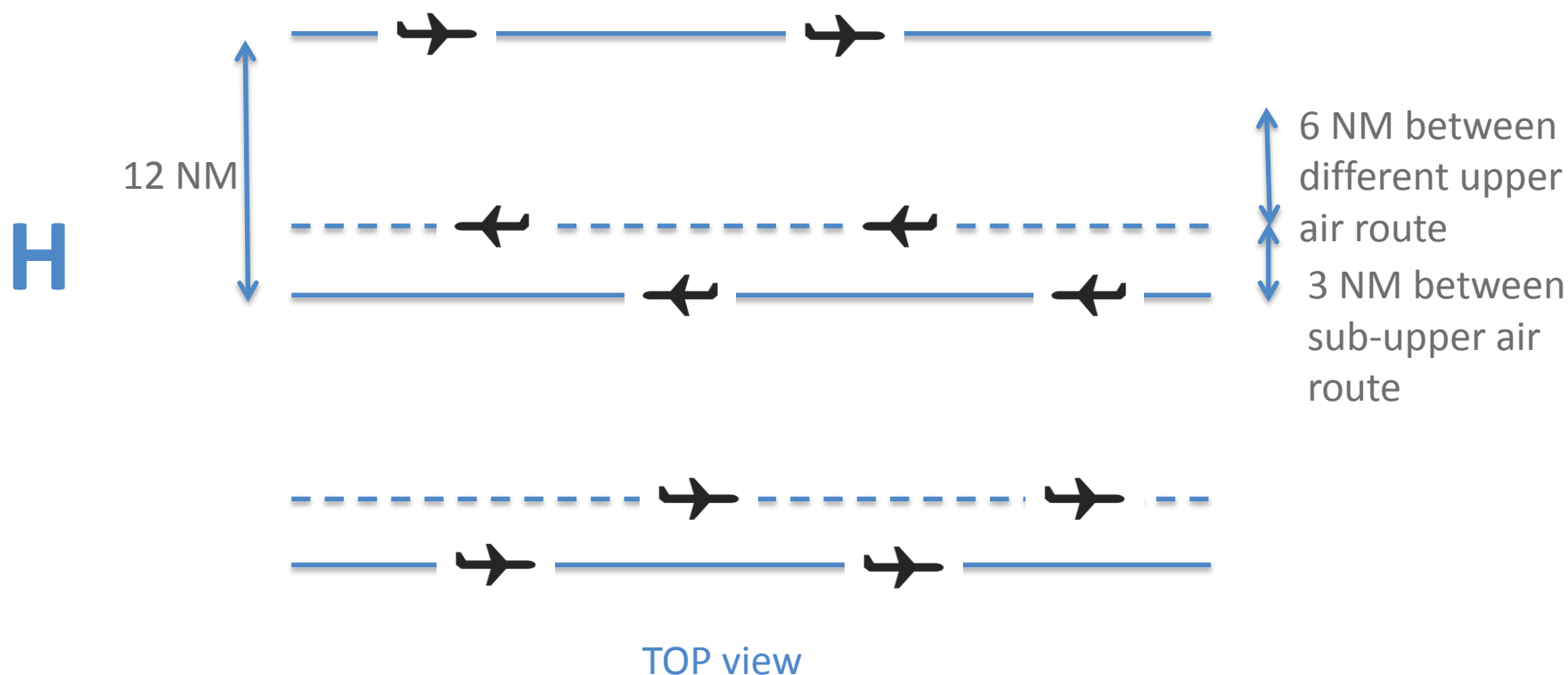
Option 2: 2 sub-upper air route by nominal airway



R-Wake1: Use Case Examples

Horizontal separation

Option 3: 1 sub-upper air route by nominal airway



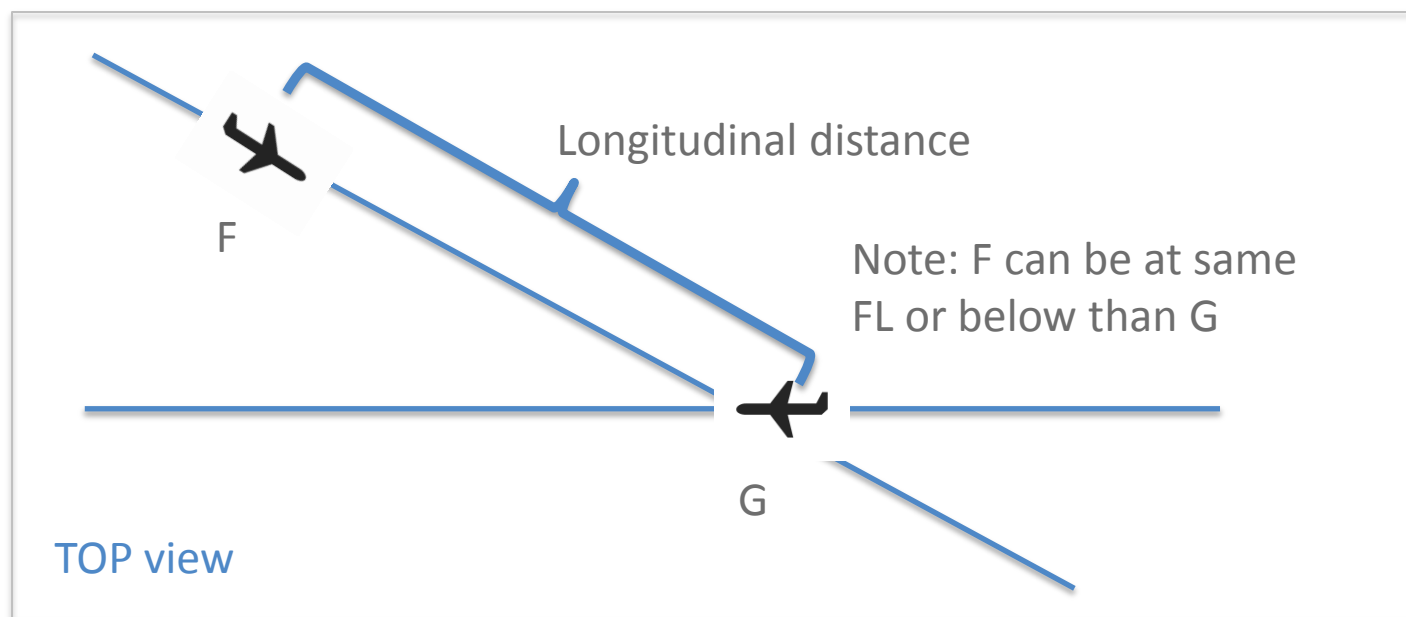
R-Wake1: Use Case Examples

Longitudinal separation

in follower flying levelled

in crossing/diagonal geometries

H



Flight F should not be at the crossing point earlier than a certain time (TBS). Time can be converted to distance if an average speed is assumed for F.

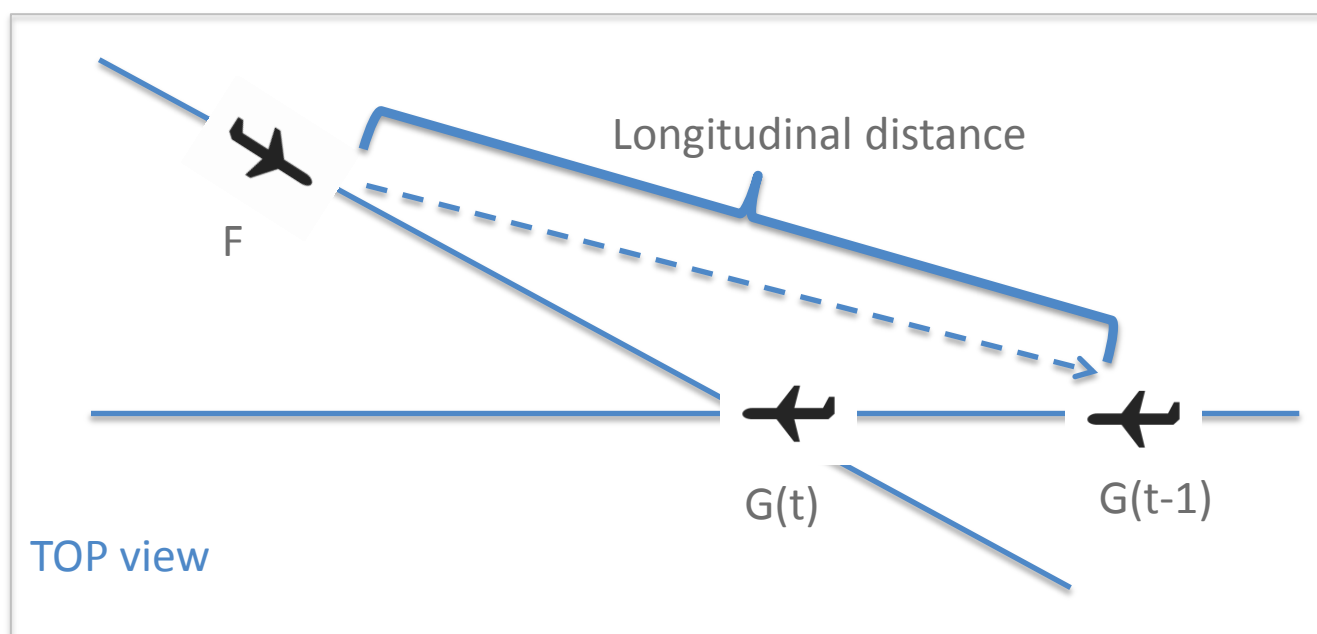
R-Wake1: Use Case Examples

Longitudinal separation

in follower flying levelled

in crossing/diagonal geometries

H



Flight F could be vectored to another point to avoid a potential conflict, but the required longitudinal distance at the crossing point to protect against a potential WVE will be always the same.

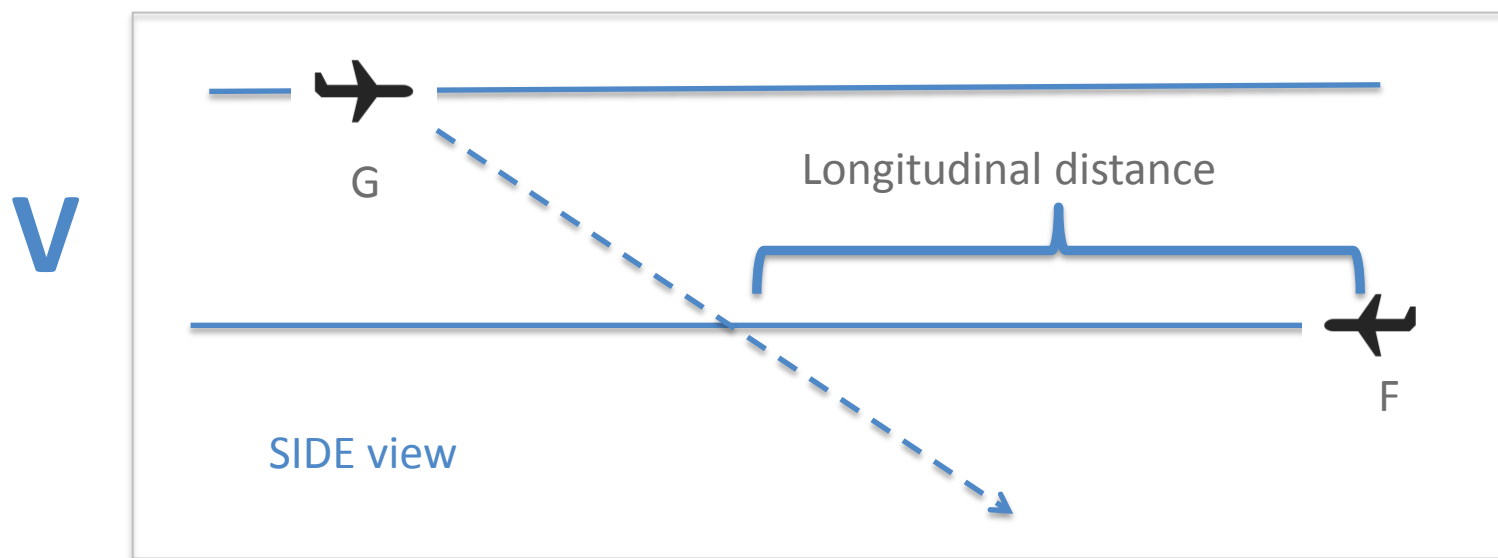
R-Wake1: Use Case Examples

Longitudinal separation

in follower flying climbing or descending

in crossing/diagonal geometries –

Case A (head-on descending crossing FL ahead)



Flight G in the same track as F wants to descend and cross the FL used by F. The ATCo should only clear the manoeuvre of G if longitudinal separation for F is guaranteed (if $dO = 0$)

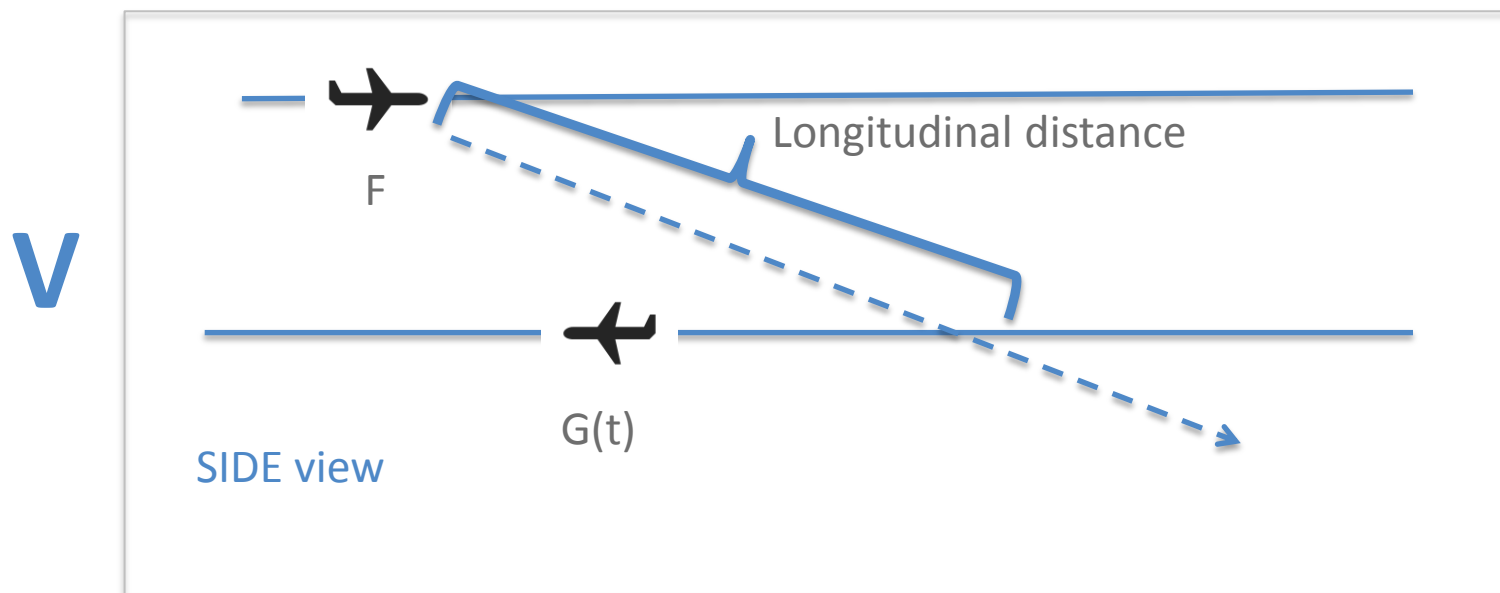
R-Wake1: Use Case Examples

Longitudinal separation

in follower flying climbing or descending

in crossing/diagonal geometries –

Case B (head-on descending crossing FL behind)



Flight F in the same track as G wants to descend and cross the FL used by G, crossing behind. The ATCo should separate the traffic F longitudinally (if $dO = 0$)

R-Wake1: Use Case Examples

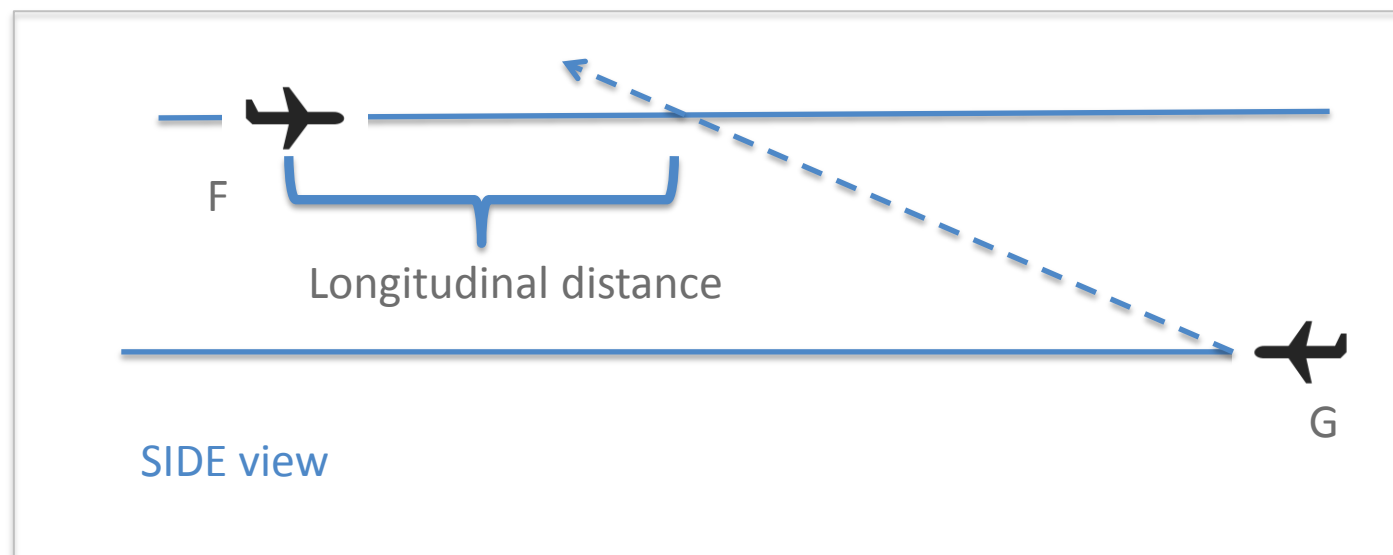
Longitudinal separation

in follower flying climbing or descending

in crossing/diagonal geometries –

Case C (head-on climbing crossing FL ahead)

V



Flight G in the same track as F wants to climb and cross the FL used by F. The ATCo should only clear the manoeuvre of G if longitudinal separation for F is guaranteed (if $dO = 0$)

R-Wake1: Use Case Examples

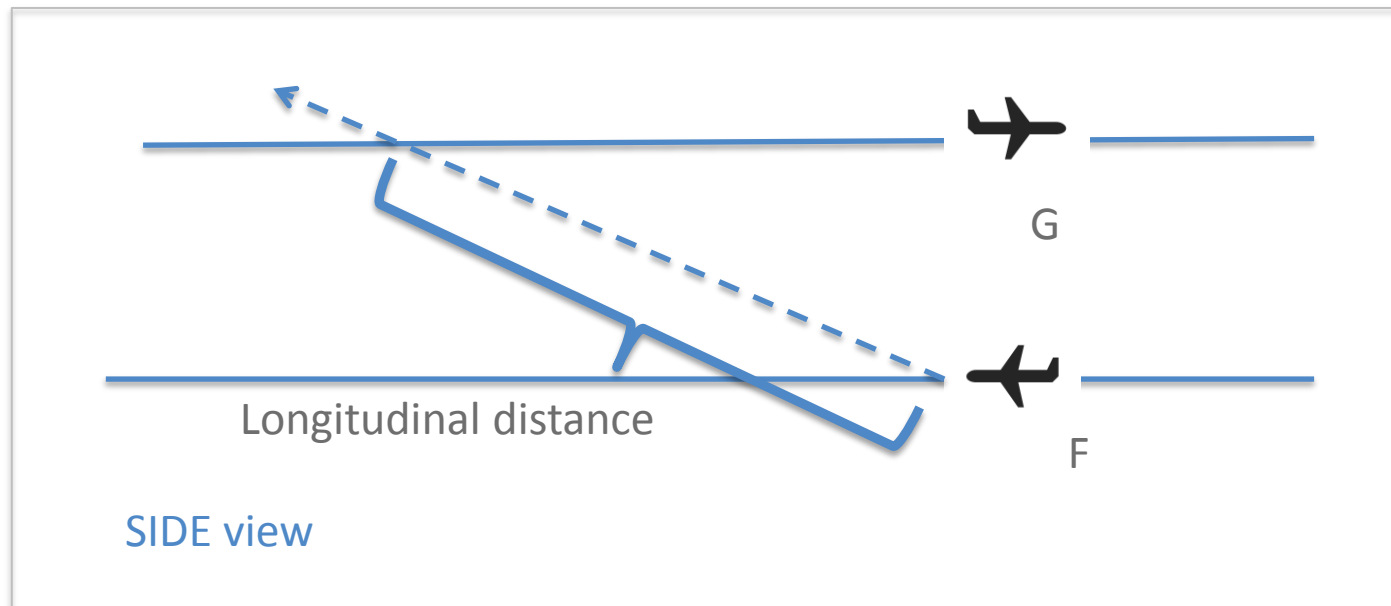
Longitudinal separation

in follower flying climbing or descending

in crossing/diagonal geometries –

Case D (head-on climbing crossing FL behind)

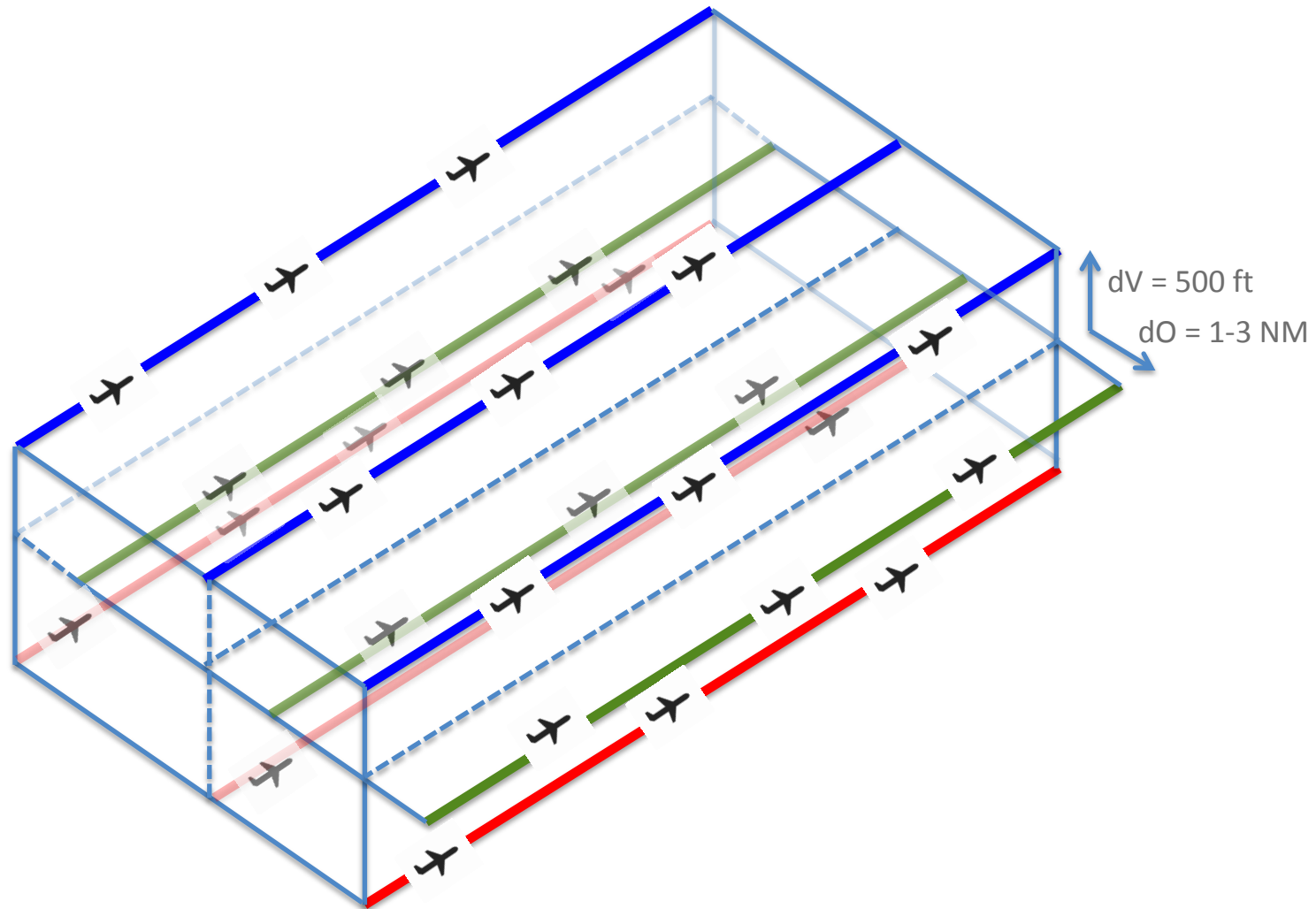
V



Flight F in the same track as G wants to climb and cross the FL used by G. The ATCo should separate the traffic F longitudinally (if $dO = 0$)

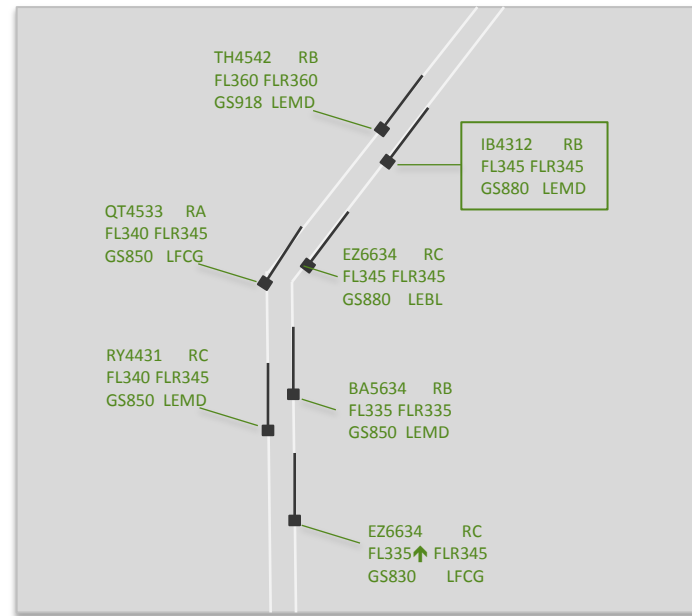
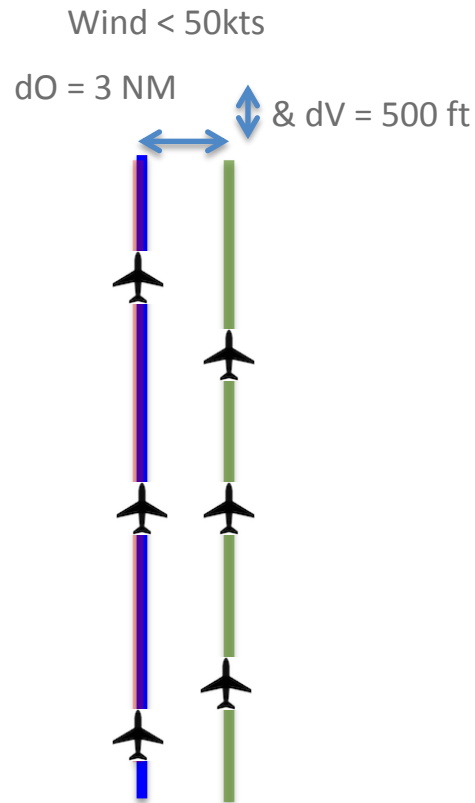
R-Wake1: Use Case Examples

Combined separations in dense flows



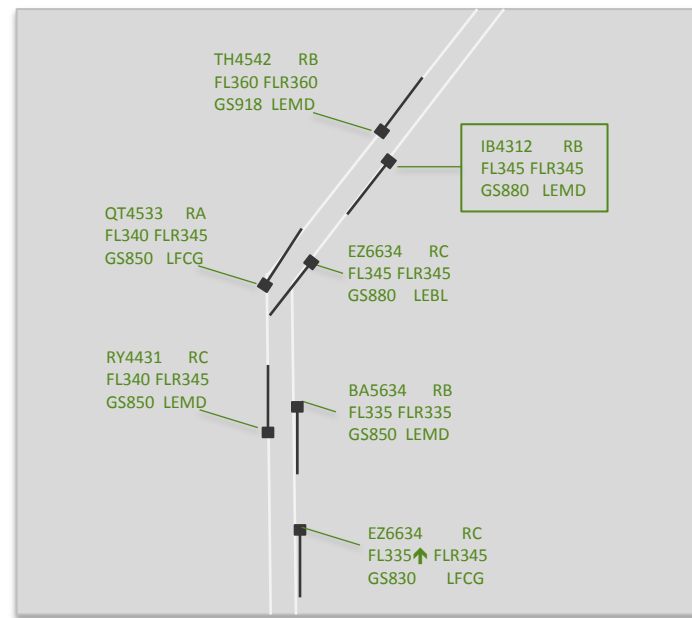
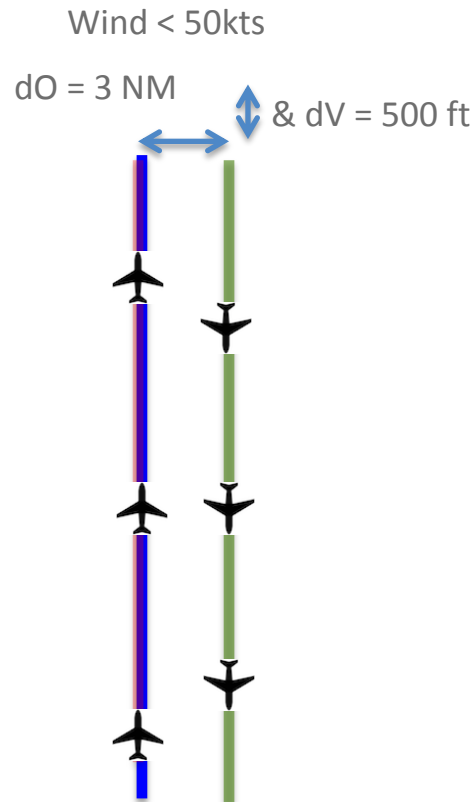
Combined separations in dense flows

One-directional routes



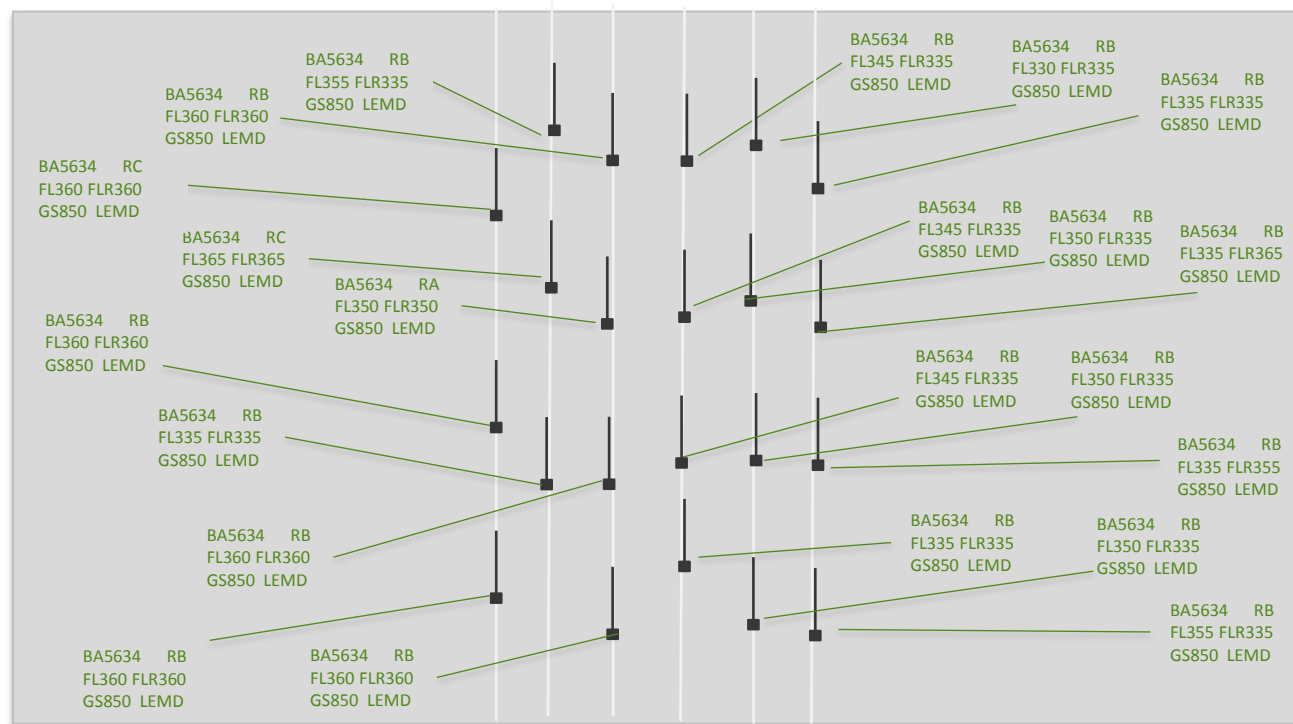
Combined separations in dense flows

Bi-directional routes



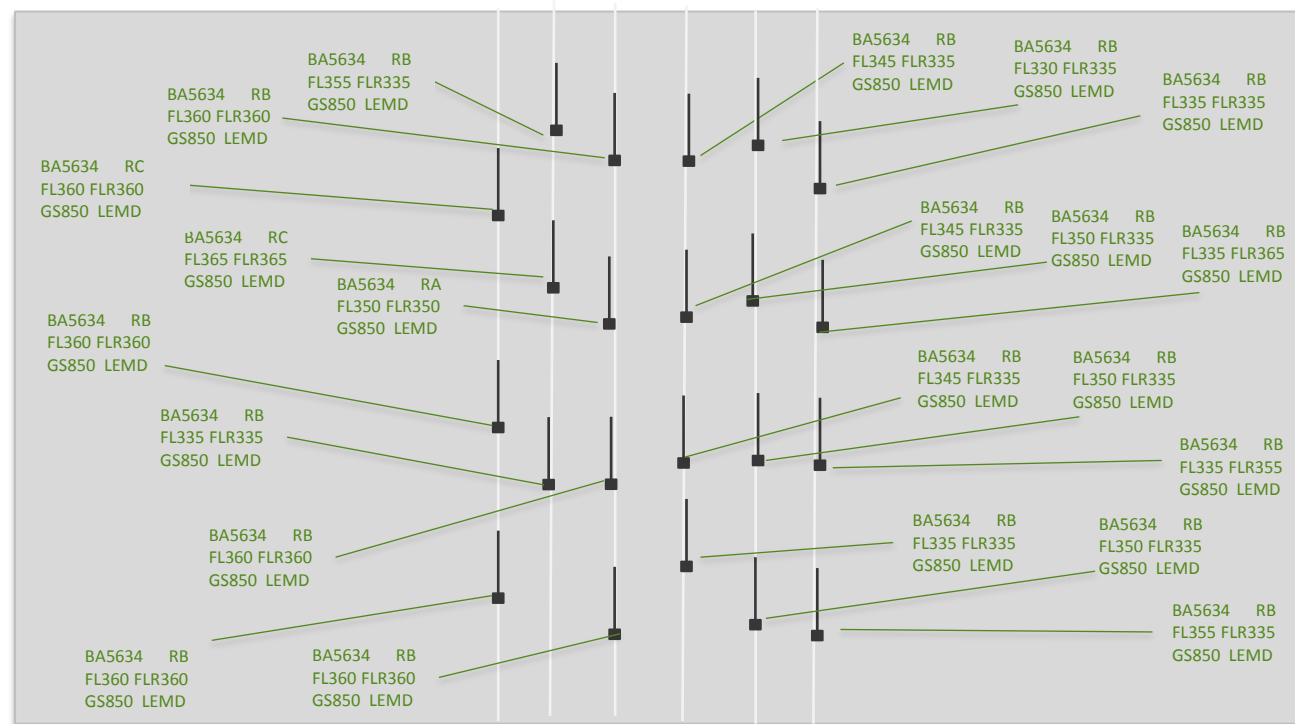
SESAR
JOINT UNDERTAKING

Diagram illustrating a 3D runway layout with three parallel runways. The runways are represented by vertical lines, with the left and right runways colored blue and the middle runway colored green. A double-headed arrow above the runways indicates a width of 500 ft. Aircraft are shown at various heights above each runway segment, representing different flight levels or altitudes.



SESAR
JOINT UNDERTAKING

Diagram illustrating the concept of a "300 ft" spacing between aircraft. It shows three vertical columns of aircraft. The first column has five aircraft, the second has four, and the third has five. A double-headed arrow at the top indicates a 300 ft horizontal distance between the first and second columns.



Maturity Assessment to ER/IR Gate

The SESAR 2020 ER-IR Criteria

Thread	Criteria ID	Criteria
OPS	OPS.ER.1	Has a potential new idea or concept been identified that employs a new scientific fact/principle? Have the basic scientific principles underpinning the idea/concept been identified? Does the analysis of the "state of the art" show that the new concept / idea / technology fills a need?
	OPS.ER.2	Has the new concept or technology been described with sufficient detail? Does it describe a potentially useful new capability for the ATM system?
	OPS.ER.3	Are the relevant stakeholders and their expectations identified?
	OPS.ER.4	Are there potential (sub)operating environments identified where, if deployed, the concept would bring performance benefits?
SYS	SYS.ER.1	Has the potential impact of the concept/idea on the target architecture been identified and described?
	SYS.ER.2	Have automation needs e.g. tools required to support the concept/idea been identified and described?
	SYS.ER.3	Have initial functional requirements been documented?
PER	PER.ER.1	Has a feasibility study been performed to confirm the potential usefulness of the new concept / idea / Technology being identified?
	PER.ER.2	Is there a documented analysis and description of the benefit and costs mechanisms and associated Influence Factors?
	PER.ER.3	Has an initial cost / benefit assessment been produced?
	PER.ER.4	Have the conceptual safety benefits and risks been identified?
	PER.ER.5	Have the conceptual security risks and benefits been identified?
	PER.ER.6	Have the conceptual environmental benefits been identified?
	PER.ER.7	Have the conceptual Human Performance aspects been identified?
VAL	VAL.ER.1	Are the relevant R&D needs identified and documented?
TRA	TRA.ER.1	Are there recommendations proposed for completing V1 (TRL-2)?

Way forward in ER/IR programme

R-WAKE Potential Impacts on ATM Master Plan – OI steps & enablers

- The current ATM Master Plan has no **Operational Improvement Steps (OI Step)** directly related to en-route wave vortices.
- An **analysis of the current released ATM Master Plan data** (“Dataset 16”) reveals 22 OI Steps dealing with wave vortices of which:
 - 16 relate specifically to arrival and departure management at airports;
 - 1 relates to arrival/departure in TMA;
 - 2 relate to the use of digital data exchange or on-board detection systems for pilot management of wave vortices;
 - 2 deal with the provision of systems to exchange wave vortex related data); and,
 - 1 dealing with wave vortex data being used by Arrival/Departure/Surface Manager systems.
- It is envisaged that **R-WAKE will recommend new OI Steps and related Enablers** for inclusion in future ATM Master Plans. These are likely to be in the area of Conflict Management, for example,
 - *“Static-Category-wise separation management for wave vortex encounters in en-route”*
 - *“Automated controller tools for pre-deconfliction of wave encounter risks in en-route”.*

Links to SESAR Solutions, European ATM Architecture and ATM Master Plan

- ☐ SJU identified Operational Improvement Step AUO-0505; Improved Air safety using data exchange via e.g. ADS-B for Wake Turbulence prediction
- ☐ This is one of 21 wake turbulence related OI Steps in the Master Plan DS16 – all are in arrival/departure phase of flight and not directly relevant to the R-WAKE scope
- ☐ An outcome of R-WAKE is to identify potential new OI Steps and related Enablers for inclusion in future SESAR Solutions and associated ATM Master Plan
- ☐ Existing OI Steps give an indication of the types of OI Step we may propose depending on macro-analysis results e.g.
 - ☐ Wake turbulence separations (en-route) based on static/dynamic aircraft data;
 - ☐ Dynamic adjustment of en-route spacing depending on Wake turbulence;
 - ☐ Wake turbulence (en-route) conflict detection and resolution
- ☐ Possibly contributes to SESAR 2020 Solutions in some Operating Environments, e.g.:
 - ☐ PJ.01-03 Dynamic and Enhanced Routes and Airspace
 - ☐ PJ.10-02a Improved performance in Provision of Separation and PJ.10-02b Advanced Separation Management
 - ☐ PJ.11-G1 Enhanced Ground-based Safety Nets adapted to future operations
 - ☐ Note: PJ.02-01 Wake turbulence separation optimisation is specifically for arrival and departure operations
- ☐ The macro-analysis will refine the R-WAKE operational concept to identify associated Enablers (system, procedural and statutory)
- ☐ OI Steps and Enablers provide ability to identify traceable links to EATMA data elements (Capability Configurations, Services, Systems etc.) and SESAR Solutions

R-WAKE Potential Next Steps

How to use results in the next phase (ER/IR)

1. The idea of looking for new static standards could be further explored in some regions of interests (also below current RVSM airspace, i.e., below FL290)
2. The system for real-time evaluation of hazards could be further developed, towards dynamic real-time risk evaluation and dynamic pairwise separations
3. The models are key in the safety case, thus they should be further refined and validated (especially WV and WIAM components, and the risk models)
4. The Severity Matrix and the SHAs require further validation and refinement
5. The quantification of system risk at sectors with realistic conditions would be possible with the R-WAKE system and would be compliant with ESSAR4 (ANSPs risk assessment)
6. New opportunities arise with the R-WAKE concept to potentially increase the ATC capacity, the traffic efficiency and the quality of service:
 - New FLAS/FLOS schemes, possibly dynamic, can contribute to organize the traffic and constraints so that capacity and flight efficiency could be optimized
 - The new FLAS/FLOS together with new parallel lanes and/or combined separations give more flexibility (and complexity) in the optimization process



Thank you for your attention



Founding Members

