

Green-GEAR

# Final Dissemination Workshop

## Separation Minima

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# Green-GEAR

Solution 0407

Separation

Minima

3



# Topics

- Collision Risk Assessment
- Wake turbulence risk assessment
- Safety case



# Collision Risk Assessment

**Bart KLEIN OBBINK**

# CRA – Assumptions

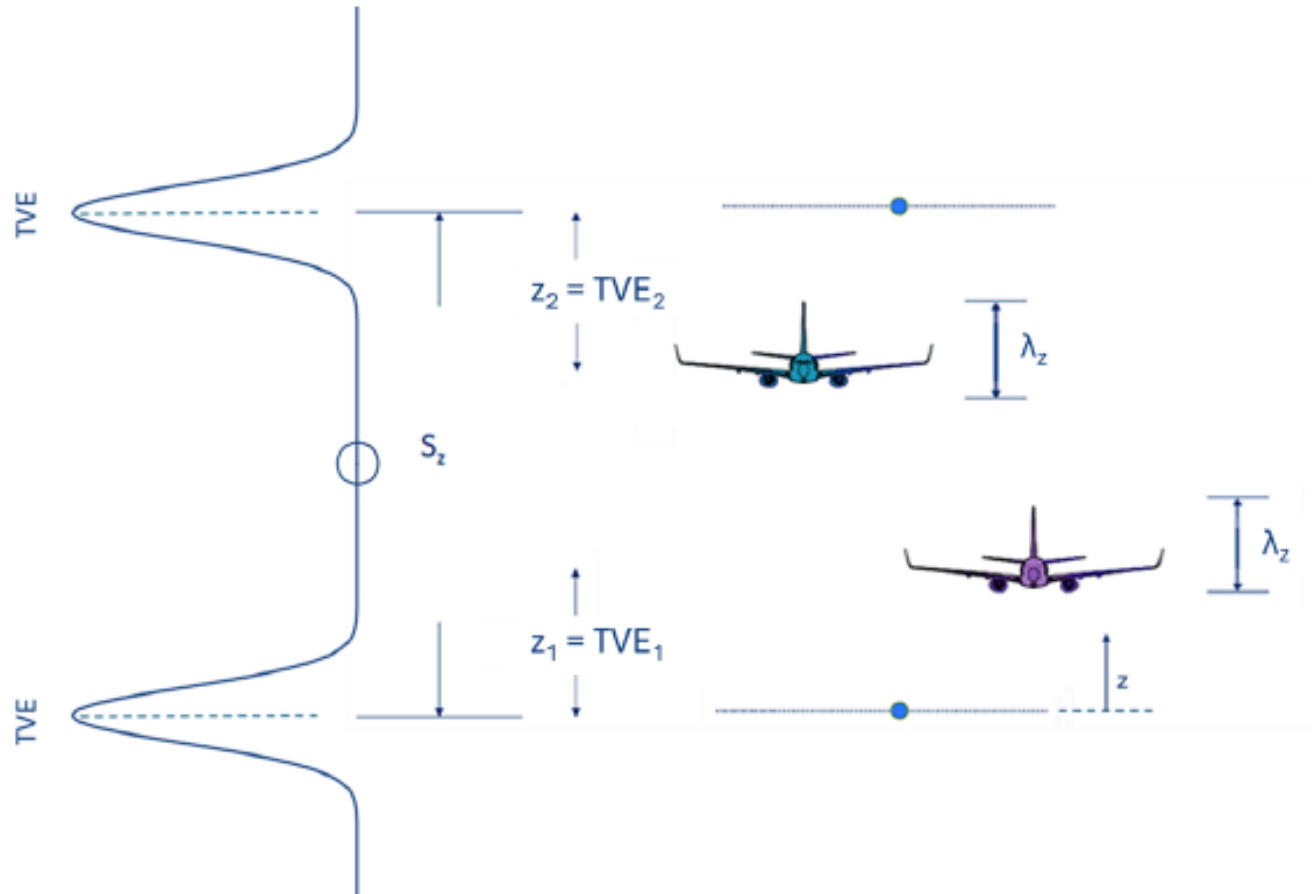
## Assumptions:

- EUR RVSM airspace
- No collision avoidance
- Geometric altimetry introduced and always available
  - Integrity, availability and continuity of GNSS



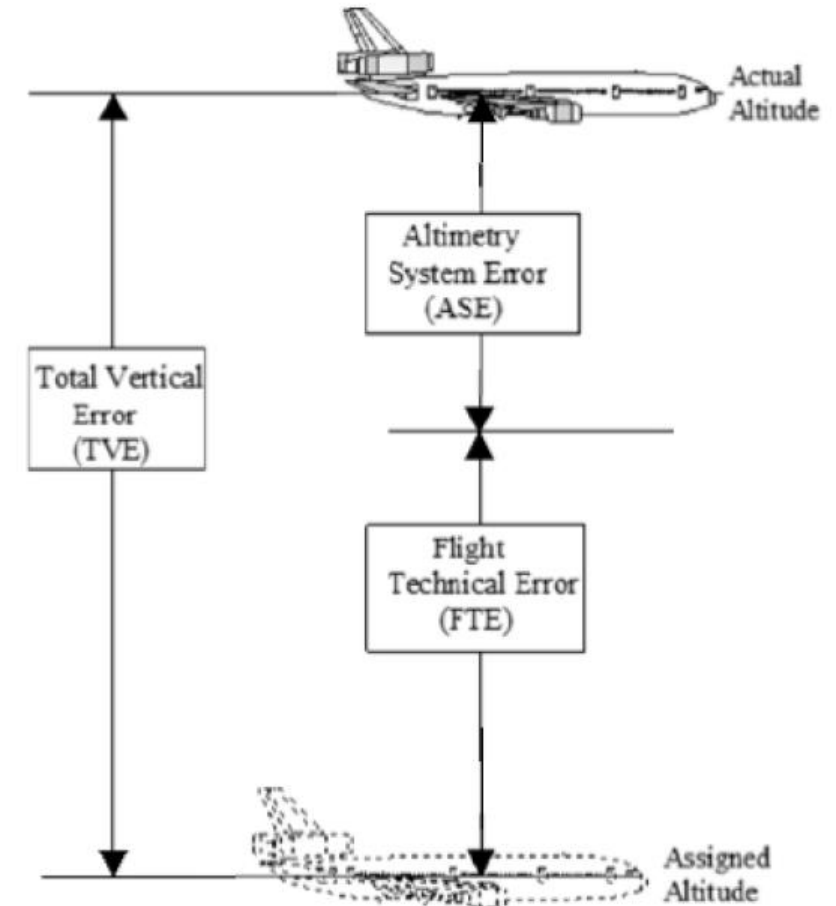
# CRA – ICAO Collision Risk Model

- Assessment of risk of a mid-air collision against a TLS of  $2.5 \cdot 10^{-9}$
- Nominal risk, due to variations in altimetry and height-keeping



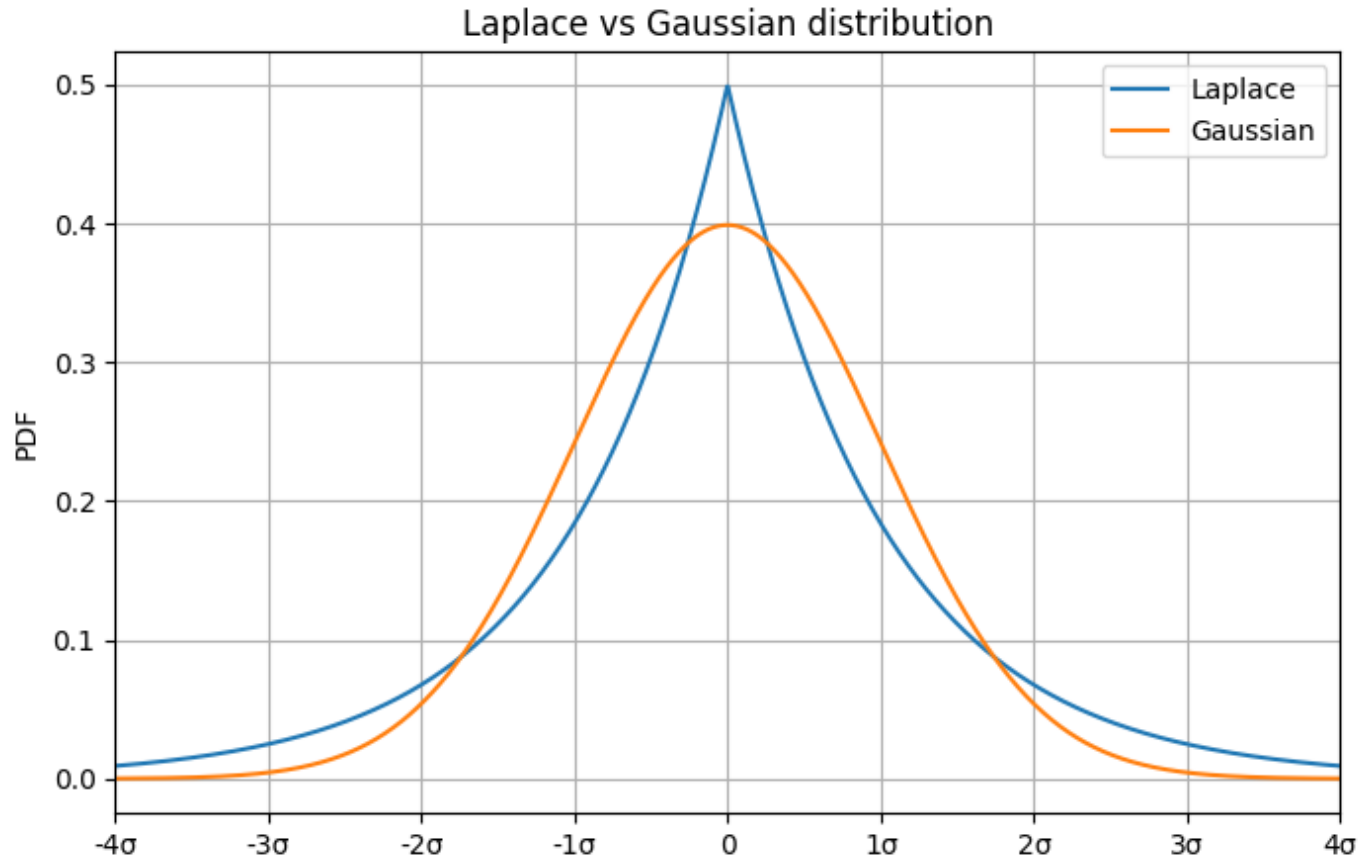
# CRA – Error sources

- Aircraft deviate from their assigned altitude due to:
  - Height-keeping deviations (FTE)
  - Navigation errors (ASE)
- Errors have a distribution

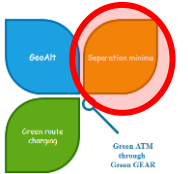


# CRA – types of error distribution

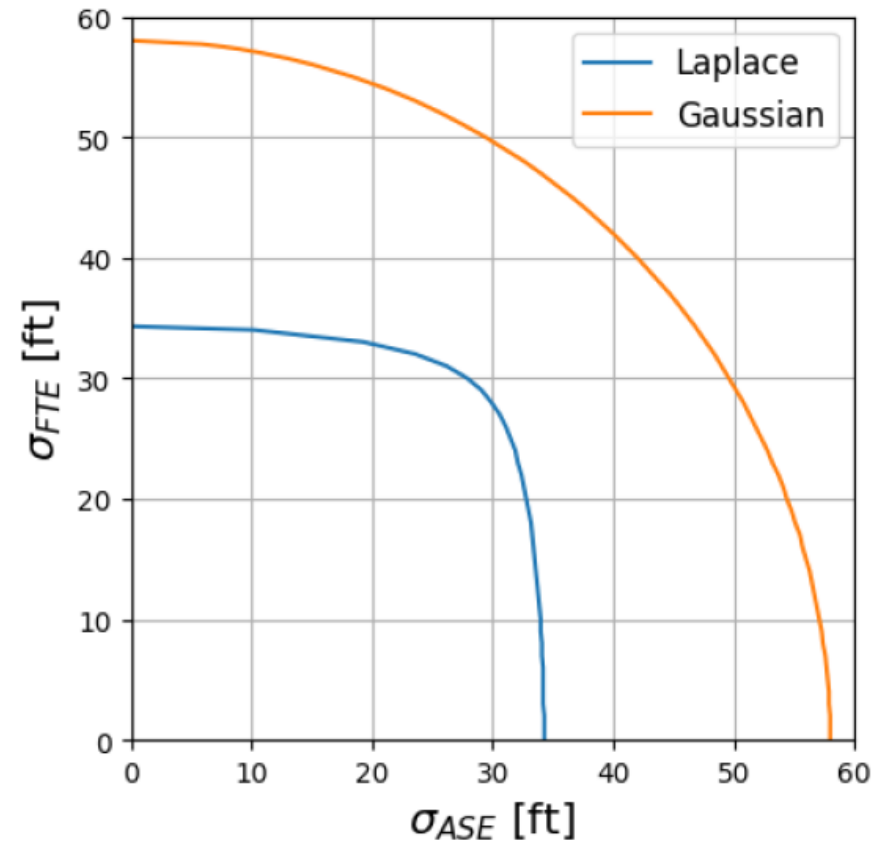
- The Gaussian distribution decays faster → smaller tails.
- Tail behaviour is important!



# CRA – conditions on FTE and ASE



$\sigma_1$	$\sigma_2$ , both Laplace	$\sigma_2$ , both Gaussian
0 ft	34 ft	58 ft
10 ft	34 ft	57 ft
20 ft	33 ft	54 ft
30 ft	28 ft	50 ft
40 ft	N.a.	42 ft
50 ft	N.a.	30 ft



# CRA – FTE distribution

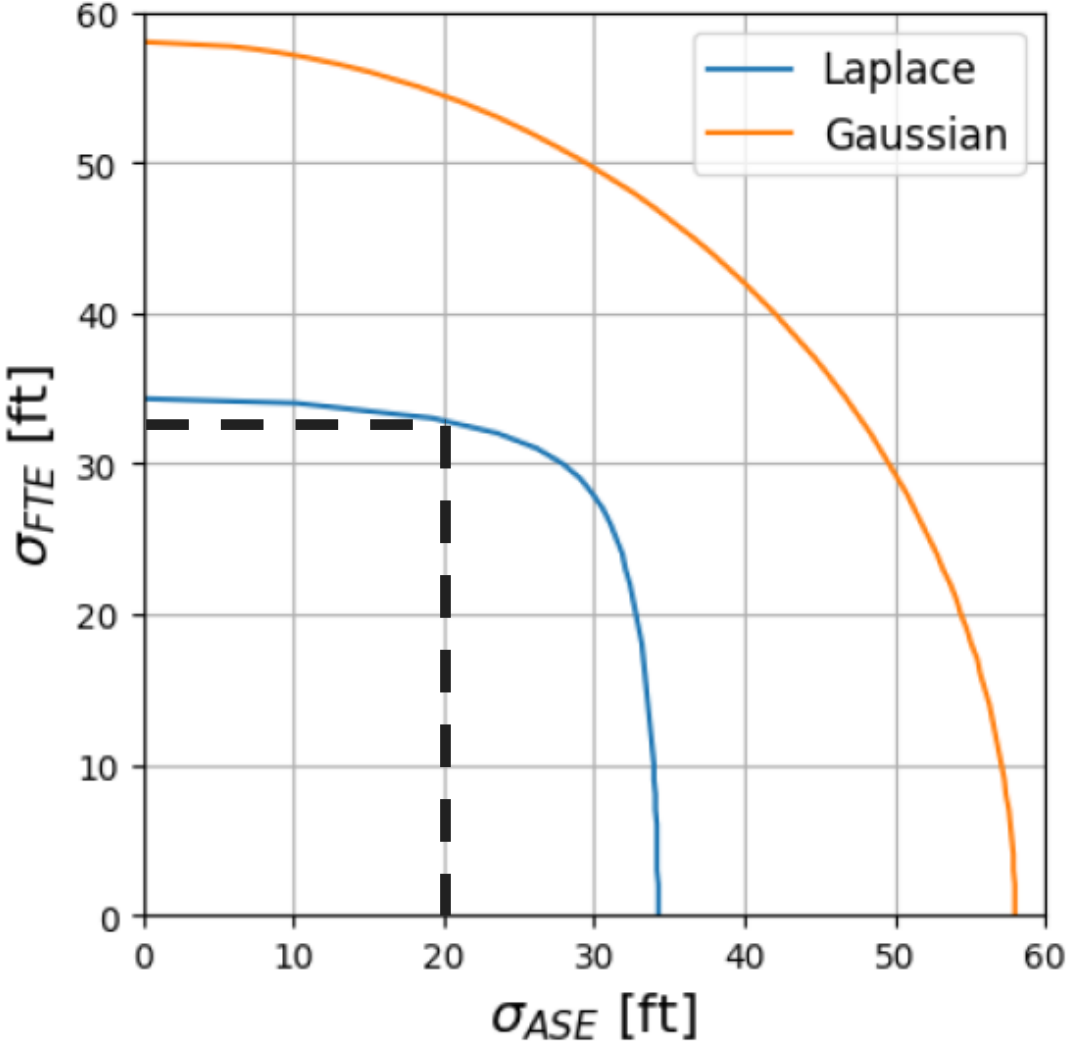


## MASPS for RVSM:

The FTE has a distribution with an exponential decay, or a possibly faster decay.

Current estimations in the ICAO EUR region find a  $\sigma_{FTE}$  of 33 ft. This is lower than the value prescribed by the current MASPS for RVSM.

# CRA – ASE distribution



# CRA – ASE distribution



- GPS and Galileo
  - Specified vs actual performance
  - SF vs DF

	<b>VPE (95%)</b>	<b>VPE (1<math>\sigma</math>)</b>
GPS	3.98 m / 13.1 ft	2.03 m / 6.7 ft
Galileo	3.17 m / 10.4 ft	1.62 m / 5.3 ft

# CRA – conclusions



- The TLS could theoretically be met by a small margin;
- Adopting actual not specified performance!

# Wake Turbulence Risk Assessment

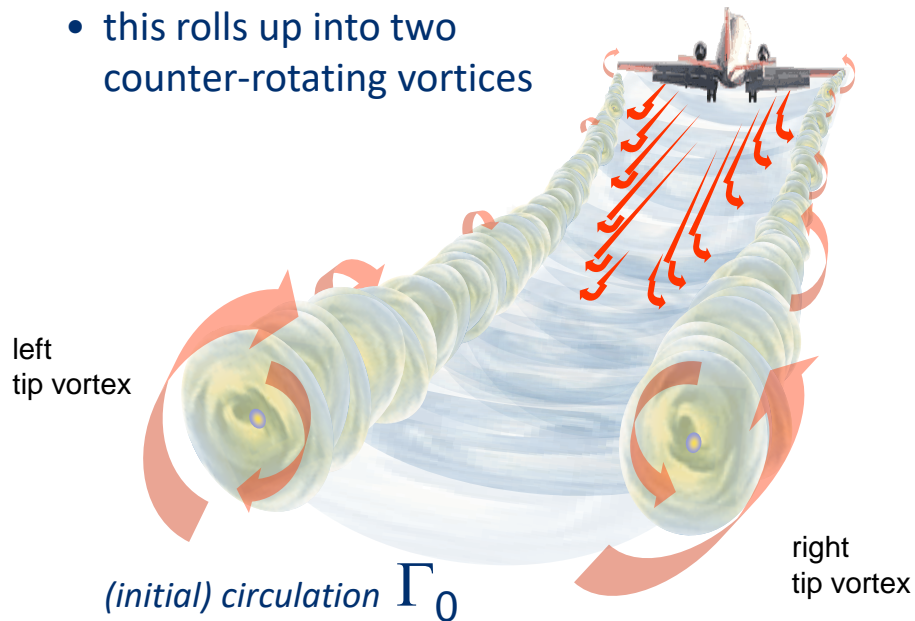
Tobias BAUER & André KOLOSCHIN

# Introduction – Wake vortices



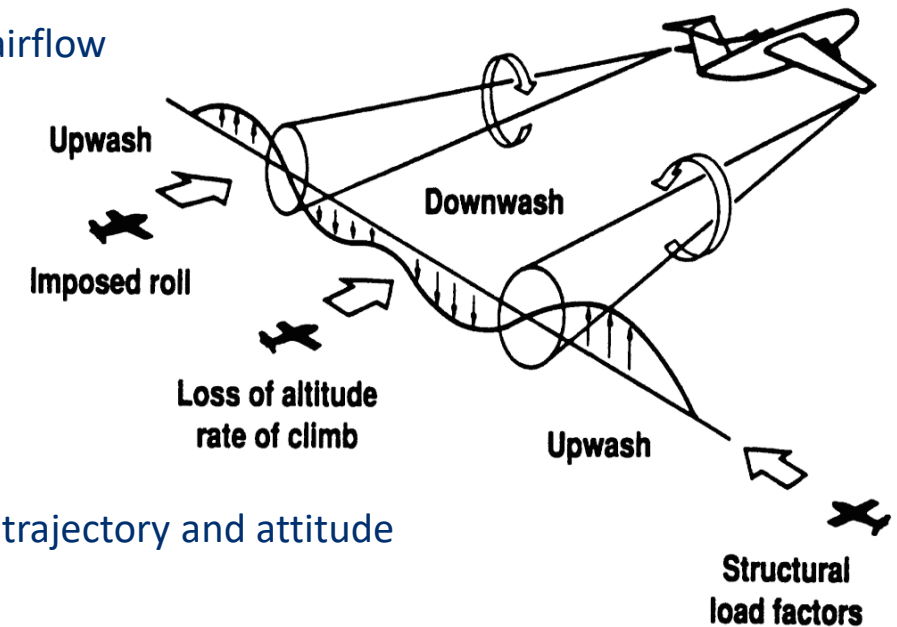
[DLR / Fischenberg]

- behind every lift-generating surface of finite span a vortex sheet will form;
- this rolls up into two counter-rotating vortices



[DLR / Hahn]

- lifespan (decay) and transport of the wake vortices are determined by the atmospheric conditions
- the locally strongly disturbed airflow generates forces and moments on the airframe, possibly causing
  - structural damage of the airframe
  - injuries to occupants
  - loss of control (exceedance of control power)
    - ⇒ deviations from desired trajectory and attitude



[picture source: V J Rossow, Prog. Aerosp. Sci. 35, pp. 507-660]

- (procedural) mitigation: (partially mass dependent) minimum separation distances, trade-off practicability & capacity ↔ safety

# Sample wake vortex encounter





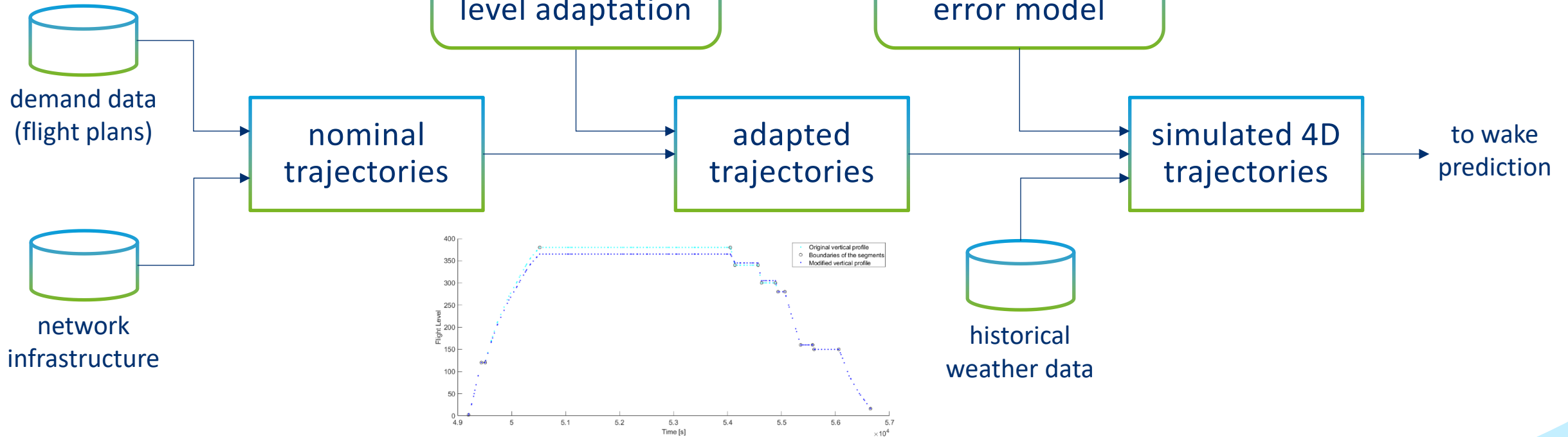
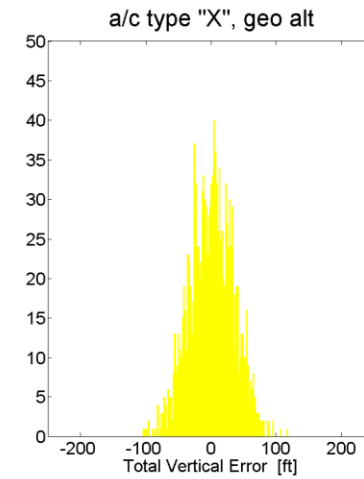
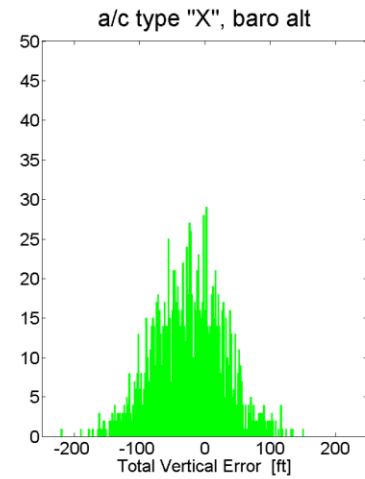
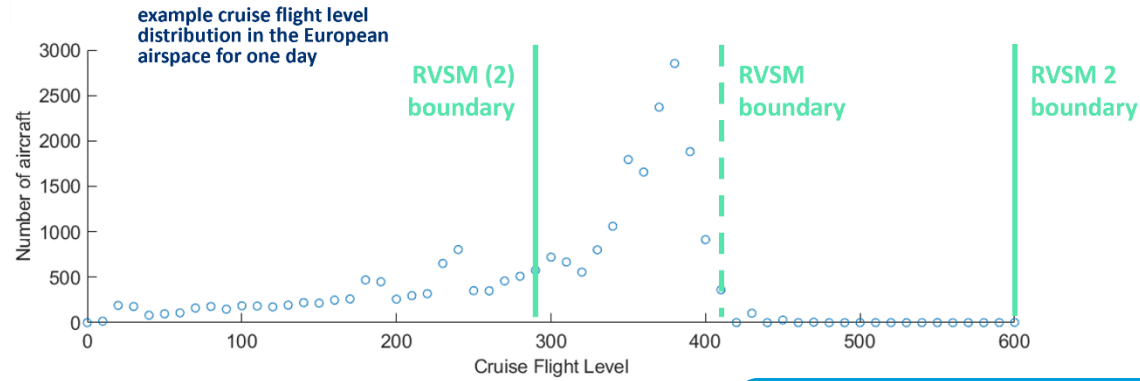
## Method (Simulation Environment)

# Wake turbulence risk in cruise – Comparative study

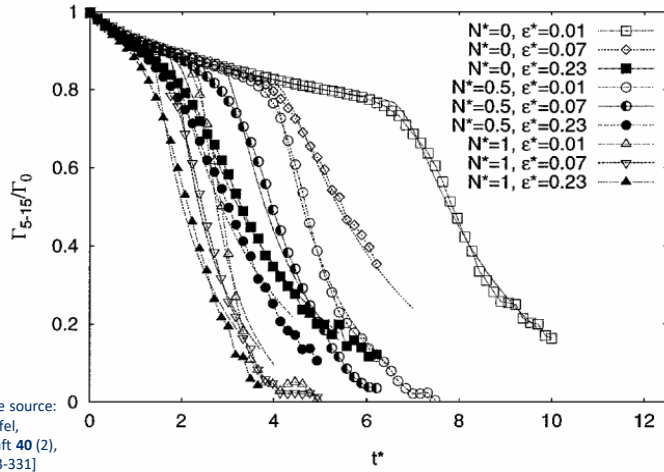
- by contrast to collision risk, no established modelling exists
- likewise, no TLS is available → **comparative study necessary**
- safety analyses accepted by the responsible authorities have been performed on a case-by-case basis, mainly for approach (UK wake categories, A380 WTSG, RECAT-EU, REDSEP, ...)
- DLR approach in Green-GEAR: Fast-Time-Simulation (FTS)
  - simulation of network flow
  - identification of sufficiently close pairings
  - prediction of generator's wake vortex evolution and transport
  - *assessment of encounter severity*
  - collision detection of follower's position with wake corridor
  - assessment of encounter "type" for statistics

} combined through SHAPe method
- comparison between current / new concept for 24h of traffic in whole of European airspace for two days
  - one with particularly high average wind speeds (approx. 19500 movements)
  - one with particularly low average wind speeds (approx. 23500 movements)

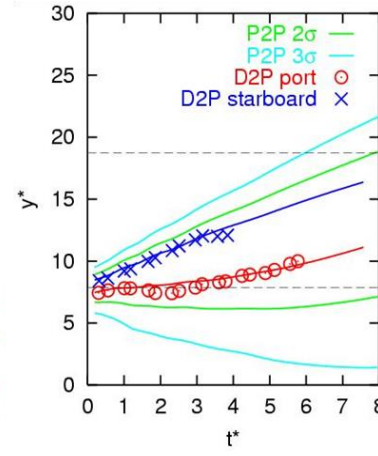
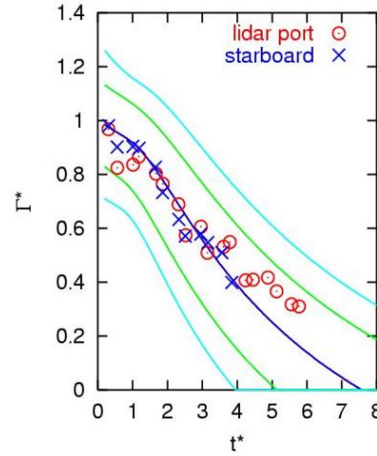
# Trajectory simulation



# Wake and encounter prediction



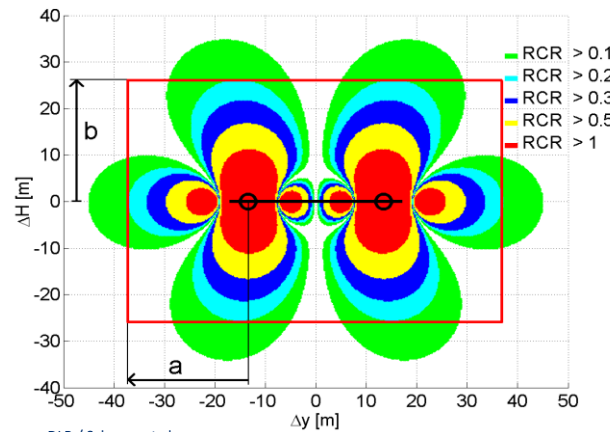
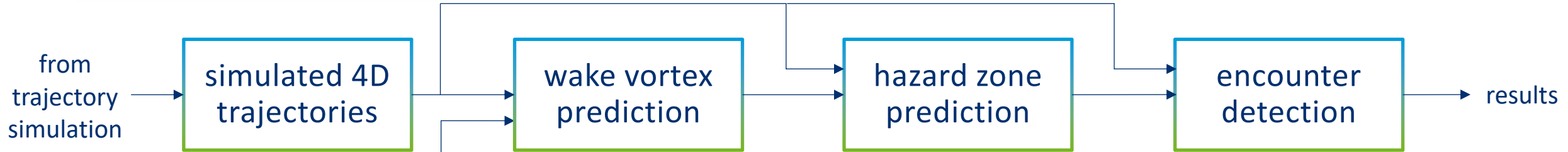
[picture source: Holzäpfel, J Aircraft 40 (2), pp. 323-331]



[DLR / Holzäpfel]

## P2P vortex model

- modelling of (normalised) decay over (normalised) time [far left]
- prediction of uncertainty bounds in circulation [left], decay and lateral motion [right]



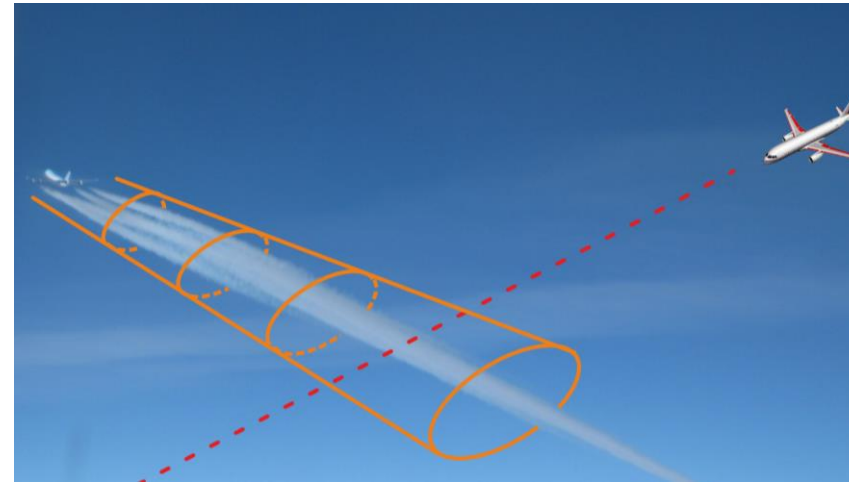
[picture source: DLR / Schwarz et al. in Holzäpfel / Gerz (eds.), DLR-FB 2018-15]

## SHAPE encounter severity assessment

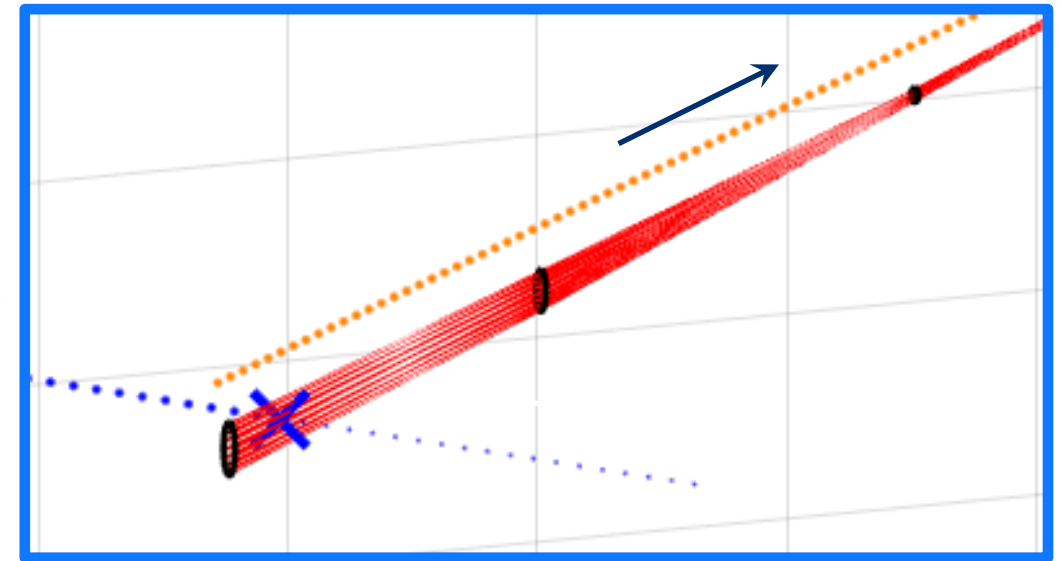
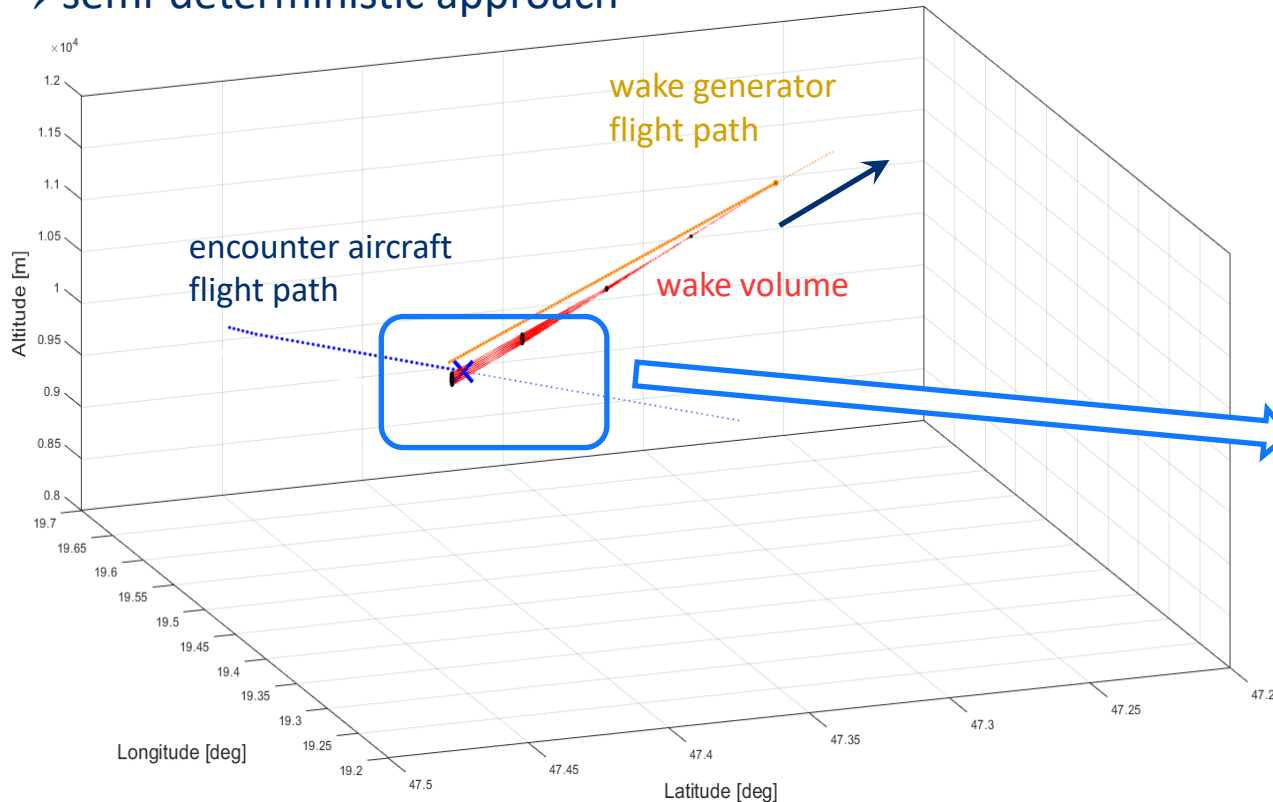
- roll control ratio (RCR) as relevant parameter
- concept: *individual* enlargement
  - by  $a$  in lateral direction
  - by  $b$  in vertical direction
- and shortening of wake corridors

# Encounter prediction

- collision detection is performed between the flight path and the habitation volume (*Wake Volume*)
- this does NOT imply an actual vortex encounter, nor an actually hazardous one**
- the assumption of typical uncertainties leads to very large Wake Volumes  
→ semi-deterministic approach



[DLR]



```
elif_operation == "MIRROR_Y":  
    mirror_mod.use_x = False  
    mirror_mod.use_y = True  
    mirror_mod.use_z = False  
elif_operation == "MIRROR_Z":  
    mirror_mod.use_x = False  
    mirror_mod.use_y = False  
    mirror_mod.use_z = True  
  
#selection at the end -add back the deselected mirror modifier object  
mirror_ob.select= 1  
modifier_ob.select=1  
bpy.context.scene.objects.active = modifier_ob  
print("Selected" + str(modifier_ob)) # modifier ob is the active ob  
#mirror_ob.select = 0  
#me = bpy.context.selected_objects[0]  
#my_data.objects[me.name].select = 1
```

## Results

# Low-wind-speed scenario, encounters categorisation

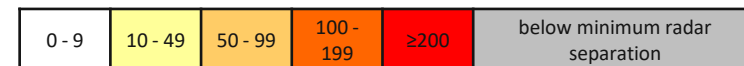
current (1000 ft)

Separation at the start of the wake encounter		horizontal separation [NM]							
		[0 ; 5]	[5 ; 10]	[10 ; 15]	[15 ; 20]	[20 ; 25]	[25 ; 30]	[30 ; ∞)	
vertical separation [ft]	(2000 ; ∞)	0	20	27	20	10	4	1	
	2000	0	4	1	0	0	0	0	
	(1500 ; 2000)	7	9	1	0	1	0	0	
	1500	0	0	0	0	0	0	0	
	(1000 ; 1500)	21	1	1	0	0	0	0	
	1000	1	0	2	0	0	0	0	
	(500 ; 1000)		2	4	0	0	0	0	
	500		0	0	0	0	0	0	
	(0 ; 500)		8	2	1	0	0	0	
	0		179	14	7	2	0	0	
	(-500 ; 0)		82	30	9	0	1	0	
	-500		2	1	0	0	0	0	
	(-1000 ; -500)		59	22	18	9	1	1	
	-1000		0	6	16	21	30	14	10
	(-1500 ; -1000)		3	24	7	3	4	1	0
	-1500		0	0	0	0	0	0	0
	(-2000 ; -1500)		0	13	7	4	3	0	0
-2000		0	1	1	5	1	0	0	
(-∞ ; -2000)		1	0	12	12	3	1	3	

RVSM 2 (500 ft)

Separation at the start of the wake encounter		horizontal separation [NM]							
		[0 ; 5]	[5 ; 10]	[10 ; 15]	[15 ; 20]	[20 ; 25]	[25 ; 30]	[30 ; ∞)	
vertical separation [ft]	(2000 ; ∞)	1	20	43	18	6	3	0	
	2000	0	0	0	0	0	0	0	
	(1500 ; 2000)	5	13	3	2	0	0	0	
	1500	0	0	1	1	0	0	0	
	(1000 ; 1500)	14	5	2	1	0	0	0	
	1000	0	1	0	0	1	0	0	
	(500 ; 1000)	31	5	3	1	0	0	0	
	500	0	5	5	0	0	0	0	
	(0 ; 500)		10	9	1	1	0	0	
	0		115	13	3	2	0	0	
	(-500 ; 0)		126	40	9	3	1	0	
	-500		89	670	972	244	36	2	2
	(-1000 ; -500)		26	76	59	27	9	3	1
	-1000		0	6	19	3	3	1	0
	(-1500 ; -1000)		1	19	13	3	1	1	0
	-1500		0	0	5	1	1	0	1
	(-2000 ; -1500)		0	3	7	1	0	0	0
-2000		0	1	1	0	0	0	0	
(-∞ ; -2000)		1	1	11	12	2	0	0	

number of possible encounters  
(NOT number of actual encounters)

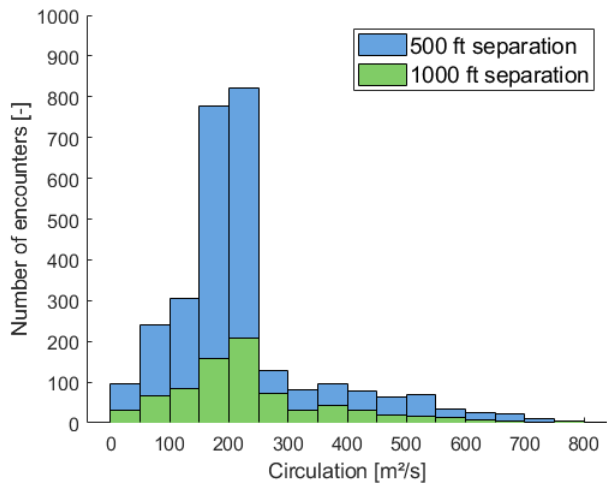


# Aggregated encounter risk

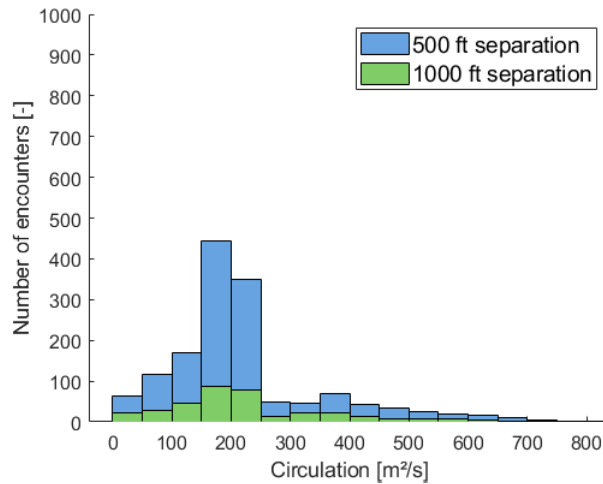
- wake encounter risk is roughly increased by a factor of 4
- increase is roughly independent of wind speeds, only absolute figures differ
- risk increase is very probably unacceptable but there is no target level of safety (TLS)

→ mitigations are necessary

encounter frequencies vs. circulation



low-wind-speed scenario



high-wind-speed scenario

number of possible encounters with range of possible severities (NOT number of actual encounters)

low wind speeds

	RCR between 0.2 and 0.5	RCR between 0.5 and 1.0	RCR above 1.0
current separation	378	158	255
reduced separation	1200	690	964
Increase by a factor of	<b>3.2</b>	<b>4.4</b>	<b>3.8</b>



high wind speeds

	RCR between 0.2 and 0.5	RCR between 0.5 and 1.0	RCR above 1.0
current separation	171	96	95
reduced separation	615	335	512
Increase by a factor of	<b>3.6</b>	<b>3.5</b>	<b>5.4</b>

- comparative simulations of wake encounter risk for status quo and proposed new RVSM 2 concept performed
  - stochastic nature of wake evolution (transport and decay) makes comprehensive simulation difficult / extremely time-demanding
    - necessity for higher-fidelity traffic simulation than typical ATM simulation tools
    - extreme cases for wind show strong similarities though
  - severity assessment is an important issue, no agreed absolute / objective method nor margins
- increase of wake encounter risk under RVSM 2 by roughly a factor of 4 predicted
- relative assessment against status quo is negative  
(does not necessarily imply that it is unsafe, but very probably not acceptable)
- 500 ft need not be “one size fits all” approach
  - categorisation of encounters to be further analysed
  - see also R-WAKE results
- onboard or ground-based prediction as mitigation could be a possibility
- further R&I recommended also in view of rising concerns about status quo
  - increased traffic density, changing traffic mix (e.g. VLJs), improved lateral trajectory following against 1970s

# Safety Case

**Bart KLEIN OBBINK**

# Safety case - scope



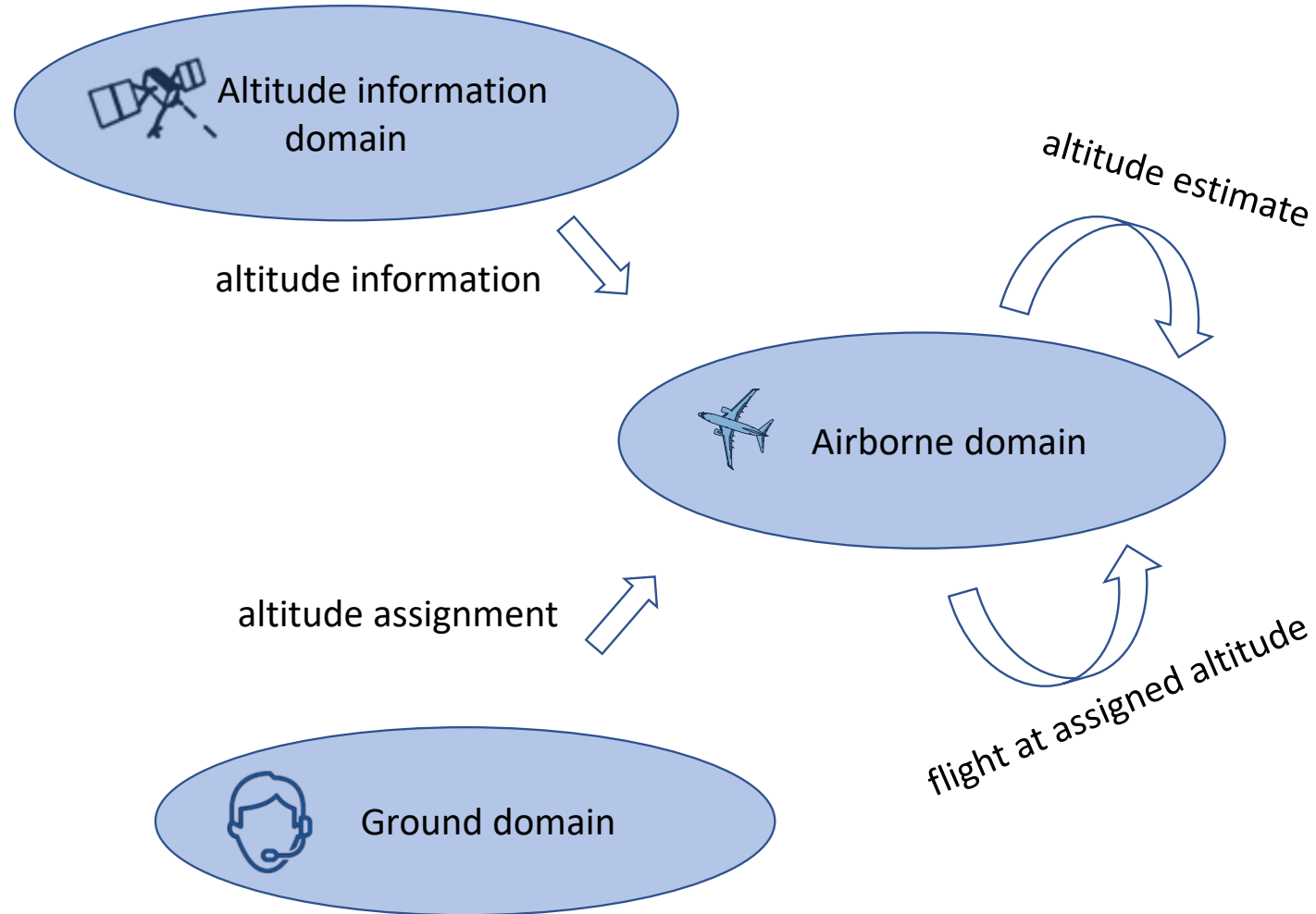
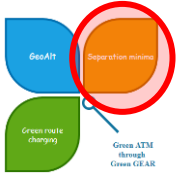
- Non-nominal mid-air collision risk (ATC errors, pilot errors, equipment failures, weather, ...);
- Geometric altimetry and 500 ft minimal vertical separation;
- Access rules and transition appropriately applied.

# Safety case - approach

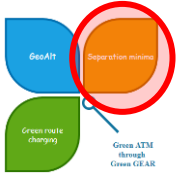


- Adopt TLS for total risk of RVSM ( $5 \cdot 10^{-9}$  per flight);
- Define system by means of primary functions;
- Identify hazards as failures of the primary functions;
- Determine their risks in accordance with Accident Incident Model;
- Identify secondary functions for detection and contingency;
- Deduce initial safety specifications.

# Safety case – primary functions



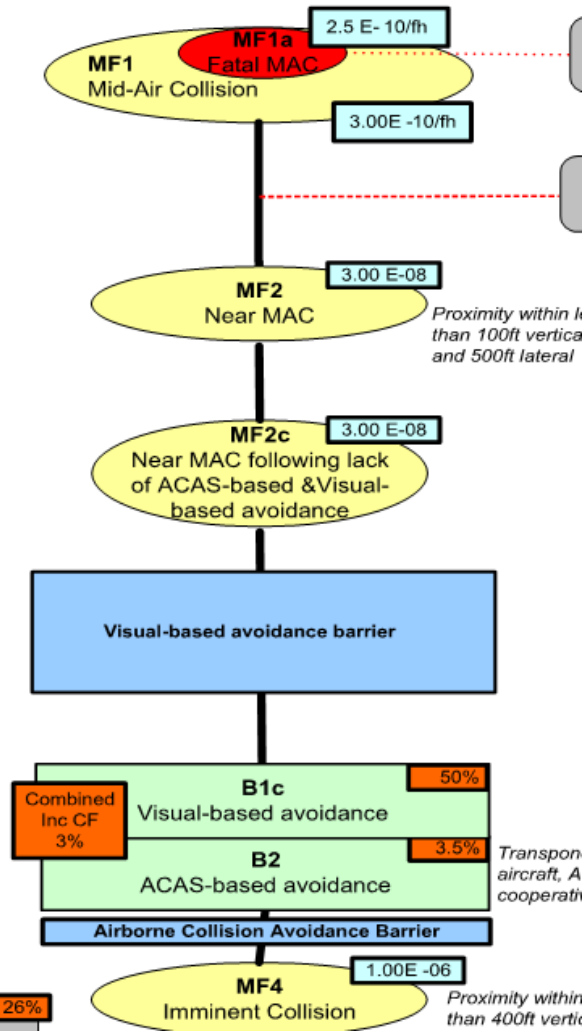
# Safety case – Accident Incident Model



## Reference situation Mid-Air Collision risk in En-Route

<b>Barrier ID</b> Name	Barriers in AIM model	<b>Event ID</b> Event Name	Causes of barrier failures in current ATM model (quantification based on SESAR Baseline 2012)
<b>ATM Barriers</b>	Barriers in ATM model	<b>Event ID</b> Event Name	Causes of barrier failure or induced precursor added with SESAR Solutions (but not impacting the quantification)
<b>Precursor ID</b> Name	Accidents & Precursors	<b>Base Event</b>	Base Event Failures
<b>Contribution ID</b> Name	Circumstantial Factors		

Precursor Frequency Per flight hour   
 Barrier Failure Probability %   
 ● Stepped OR gate (i.e. given the previous does not occur)   
 **KEY**



# Safety case – safety specifications altitude information domain



It would not be realistic to expect providers of satellite navigation services to adopt safety specifications.

# Safety case – safety specifications airborne domain



- Aircraft should use Dual Frequency receivers.
- GNSS altimetry systems should have a similar maximally allowed rate of failure as current barometric altimetry systems.
- The combined visual- and ACAS-based avoidance barrier is to have an effectiveness of at least 93%.
- Aircraft should broadcast unable altimetry messages, if applicable.

# Safety case – safety specifications ground domain



- Controlled operations are required in order to provide the ATC collision prevention barrier.
- ATC units should detect inadequacy of the altitude information by processing the following information items: a) receipt of lack of altimetry integrity messages from GNSS, b) receipts of unable altimetry messages from several aircraft, c) detection of several aircraft deviating from their assigned altitude and d) other information items, such as indications of jamming or spoofing.
- If an ATC unit has confirmation that altitude information in a part of the airspace is inadequate, it should coordinate with other ATC units and it should initiate a Procedure Multiple Unable Altimetry.

# Separation Minima – topics for discussion



- Is there a need for reduced vertical separation? Is that need large enough?
  - Should we rebuild ACAS such that it does not trigger RAs all the time (currently at 700 ft spacing, at higher altitudes)?
  - Are the risks of jamming and spoofing too large anyway?
- Is it really beneficial to extend RVSM to FL600?
- Should reduced vertical separation be introduced world-wide? Or could Europe develop its own standards?
- Can the nominal risk assessment be based on actual performance (as opposed to specified performance)?
- How often might the Procedure Multiple Unable Altimetry be applied?
- Should the research for this topic be continued?

Thank you

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