Presented by

Airbus
Flight Dynamics, EYCDD

VESA methodology

Vortex Encounter Severity Assessment

VESA

AIRBUS

Background
What is VESA?

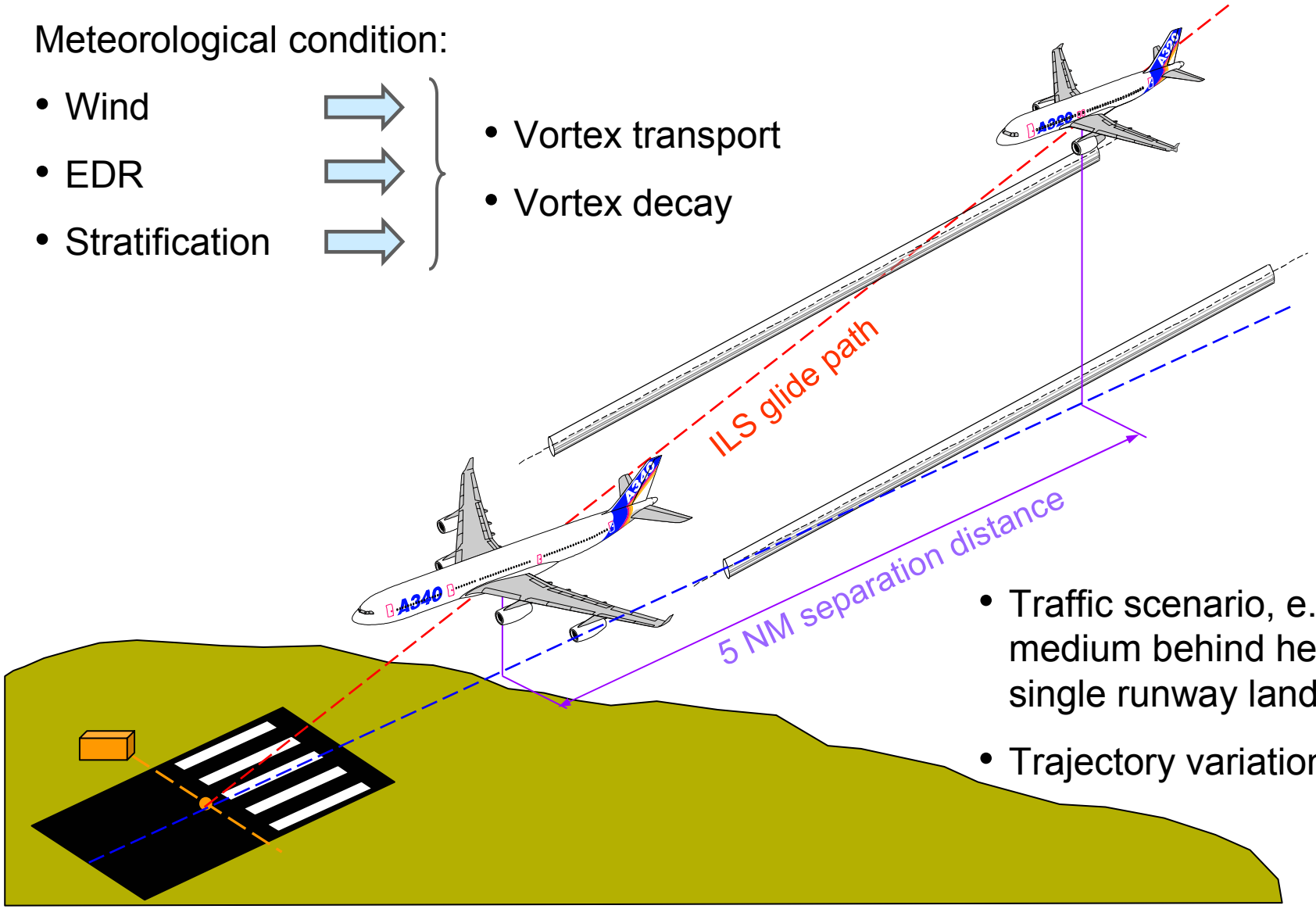
- VESA is a software tool developed by Airbus
- VESA's objectives:
  - Computation of the Wake Vortex Encounter (WVE) severity, i.e. the ***effect of the wake vortex on the follower aircraft***
  - Comparison of WVE severity for specific follower aircraft behind different generator aircraft
  - VESA can be used to assess the adequacy of separation standards for new and larger aircraft
- VESA is based on fast-time, high-fidelity aircraft simulations that are embedded in a MOPS/Matlab environment

Scenario

Meteorological condition:

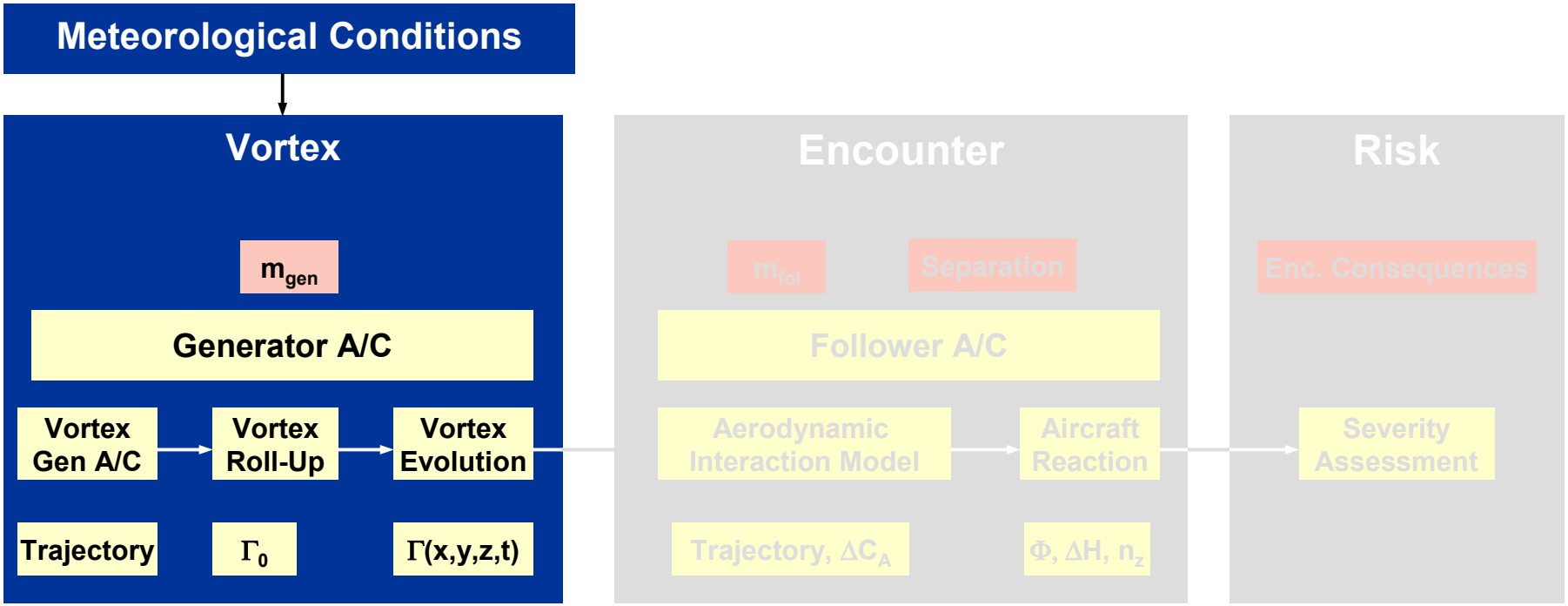
- Wind
- EDR
- Stratification

- Vortex transport
- Vortex decay



- Traffic scenario, e.g. medium behind heavy, single runway landing
- Trajectory variations

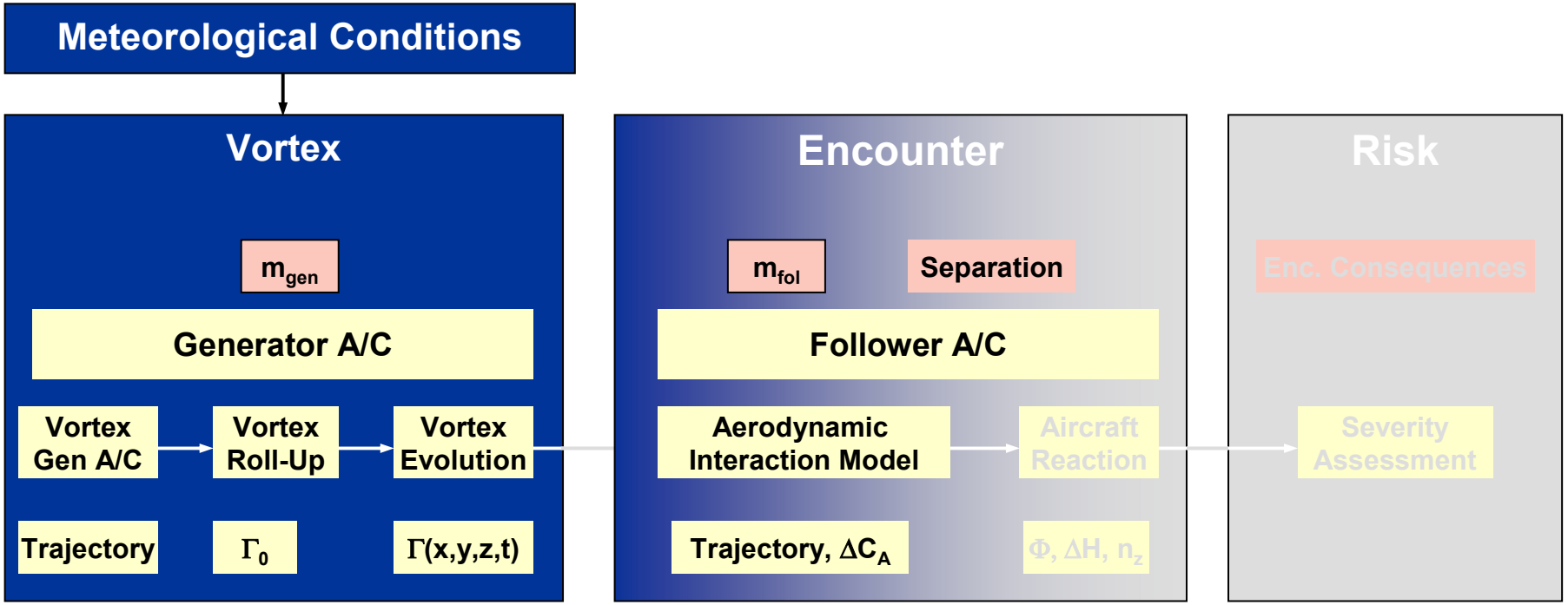
Wake vortex encounter chain of effects
Vortex evolution



Vortex strength after a certain time (decay) at a certain place (transport)

No information how severe is the WVE

Wake vortex encounter chain of effects
Distance between vortex and trailing aircraft



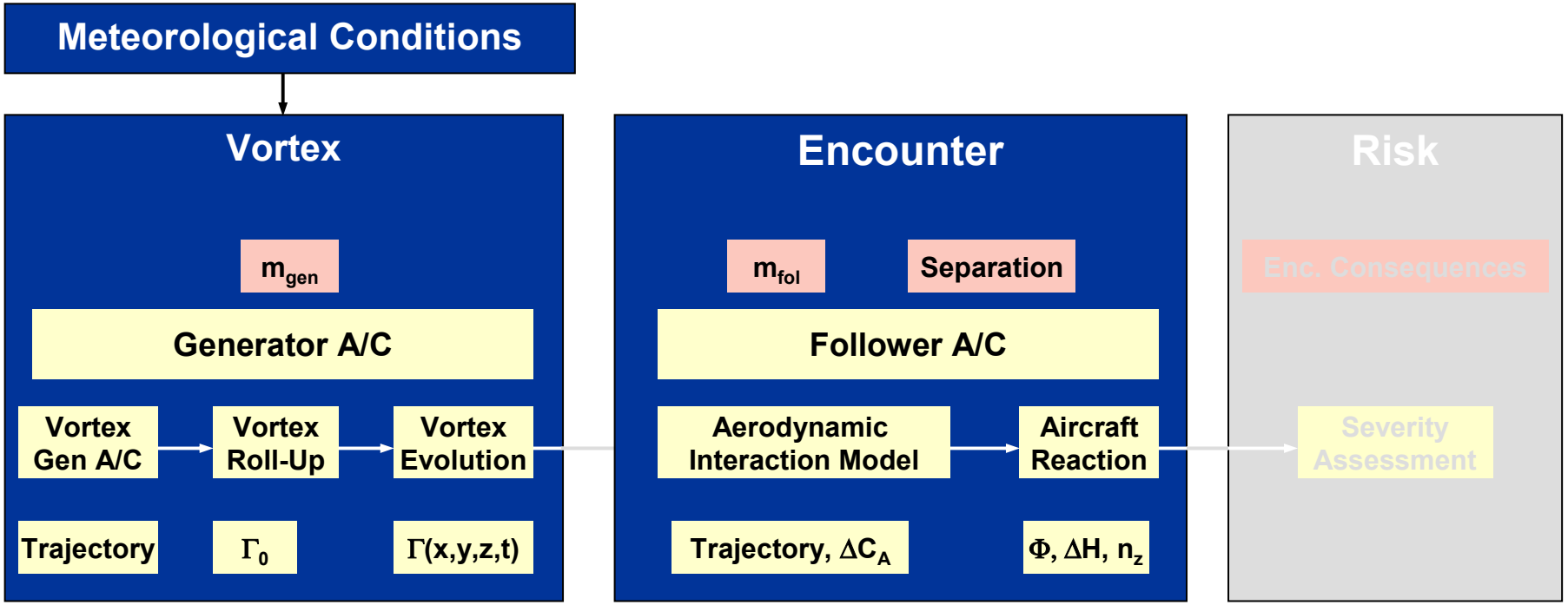
Vortex strength after a certain time (decay) at a certain place (transport)

+ Distance follower aircraft wake vortex for certain separation

➔ Probability to hit a vortex of a certain strength

No information how severe is the WVE

Wake vortex encounter chain of effects
Aircraft reaction



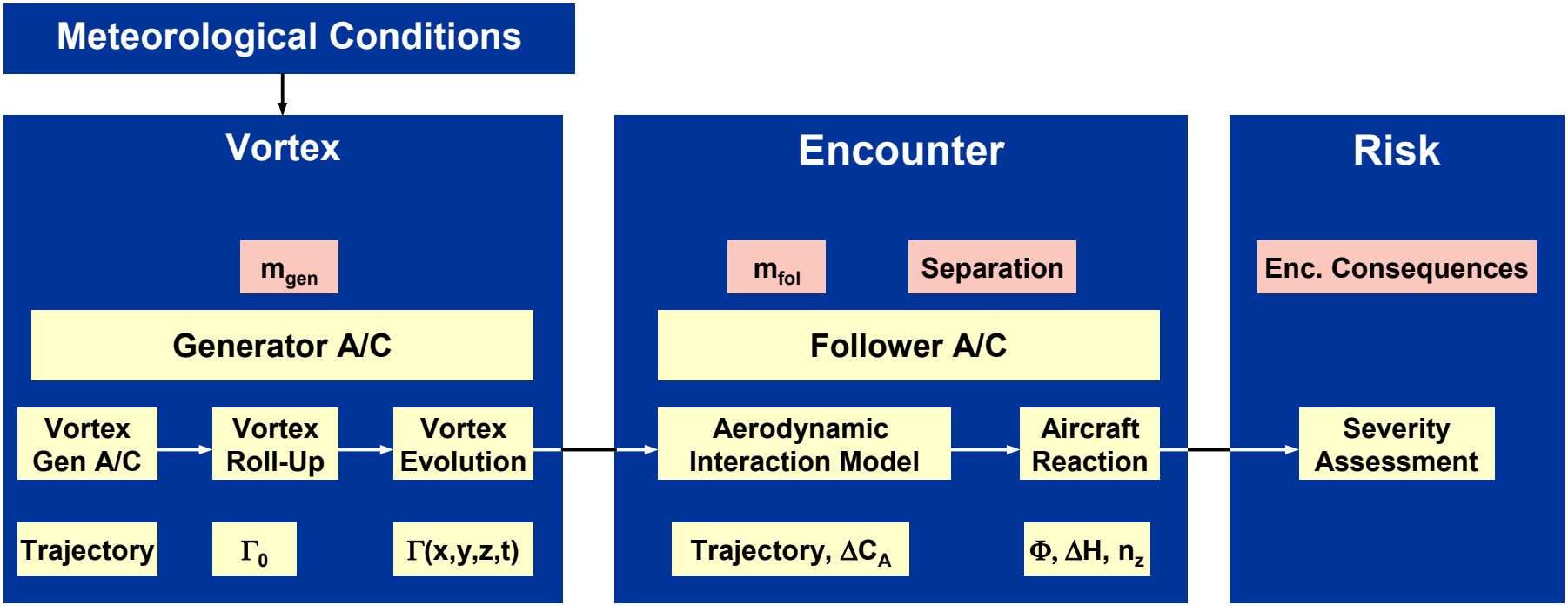
Vortex strength after a certain time (decay) at a certain place (transport)

+ Distance follower aircraft wake vortex for certain separation

+ Aircraft reaction (Φ_{max}, $n_{z,max}$, etc.)

➔ Probability of aircraft reactions of a certain value

Wake vortex encounter chain of effects
Severity assessment



Vortex strength after a certain time (decay) at a certain place (transport)

+ Distance follower aircraft wake vortex for certain separation
+ Aircraft reaction (Φ_{max}, $n_{z,max}$, etc.)
+ Severity criterion that relates aircraft reaction to pilot's opinion

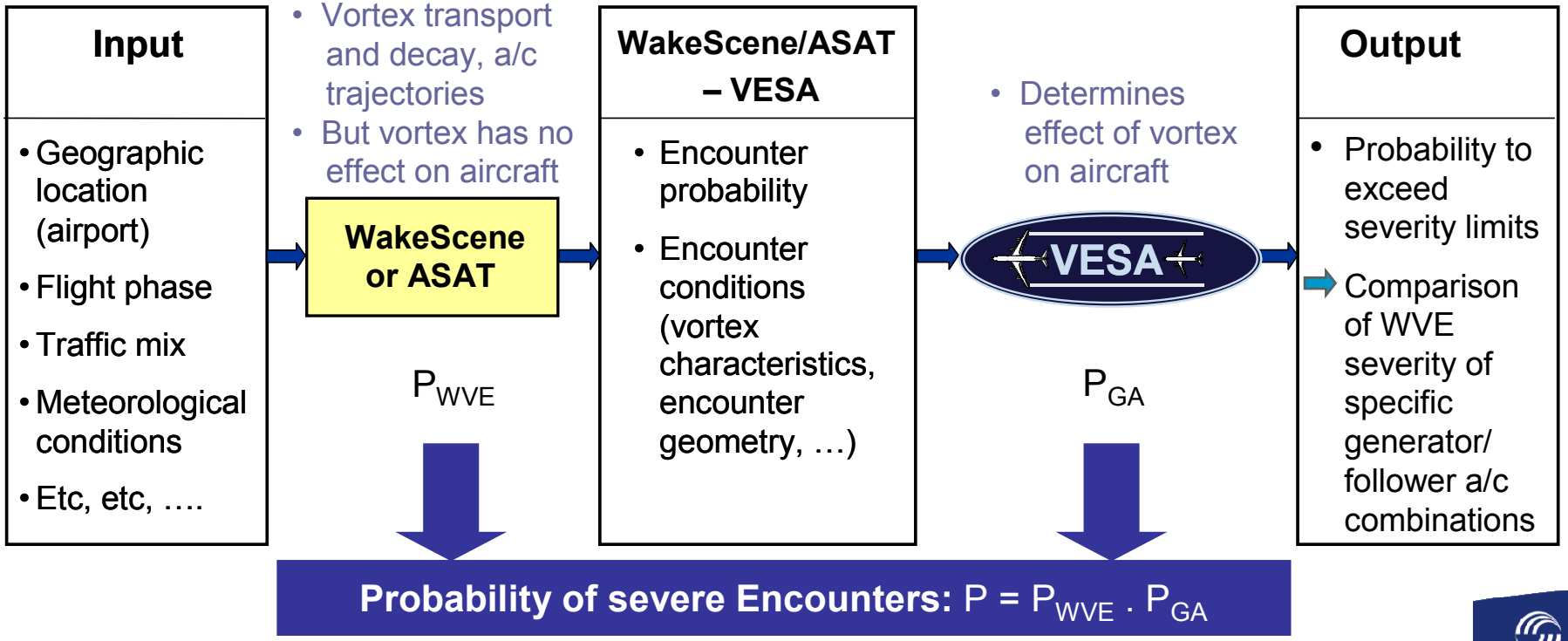
➔ Probability of severe wake vortex encounters

AIRBUS

Wake vortex risk assessment methodology

Two step methodology for wake vortex risk assessment

- Determination of vortex encounter probability and encounter conditions
  Tool: Air Space Simulation, e.g. WakeScene (DLR) or ASAT (FAA/ATSI)
- Determination of encounter severity
  Tool: VESA (Airbus)



Inputs and Outputs of VESA

Inputs from WakeScene/ASAT

- **Vortex parameters**
  - Vortex strengths: Γ_s, Γ_p
  - Vortex span: b_v
  - Vortex reference: WV_RLDEF
- **Encounter geometry**
  - Encounter height H_{ILS}
  - Encounter angles: $\Delta\gamma_{WV}$, $\Delta\Psi_{WV}$, $\Delta\Phi_{WV}$
  - Min. distance and angle (polar coordinates) between vortex and encountering a/c: R_{vortex}, φ_{vortex}
- **Leading aircraft**
  - Type
  - Ma number
  - Weight
  - Configuration
- **Follower aircraft**
  - Type
  - Ma number
  - Weight
  - Configuration
  - Landing gear position
- **Atmospheric conditions**
  - Wind velocity: u_{wg}, v_{wg}
  - Turbulence: EDR
  - Δtemperature from ISA at enc. pos.

Inputs generated for VESA

- **Vortex parameters**
  - Vortex core radii: r_{cs}, r_{cp}
- **Follower aircraft**
  - C.G. position
  - Moments of inertia: I_{xx}, I_{yy}, I_{zz}, I_{xz}

VESA

Output

Encounter Severity

- Exceeding Hazard Levels, e.g.:
  - Attitudes, that cause go-around in approach, or
  - g-loads that cause discomfort in cruise,
  - Etc, etc …

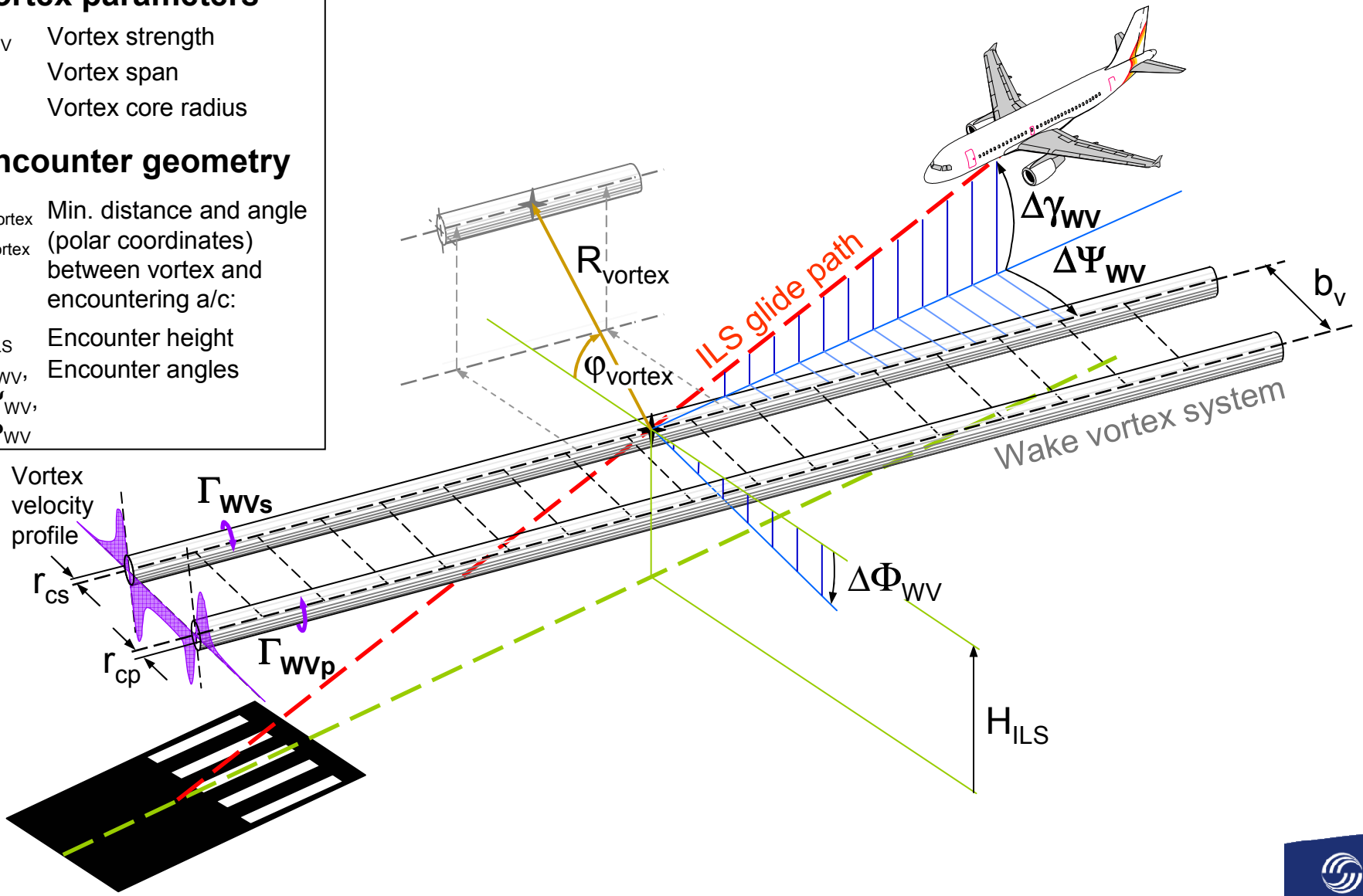
Encounter condition

Vortex parameters

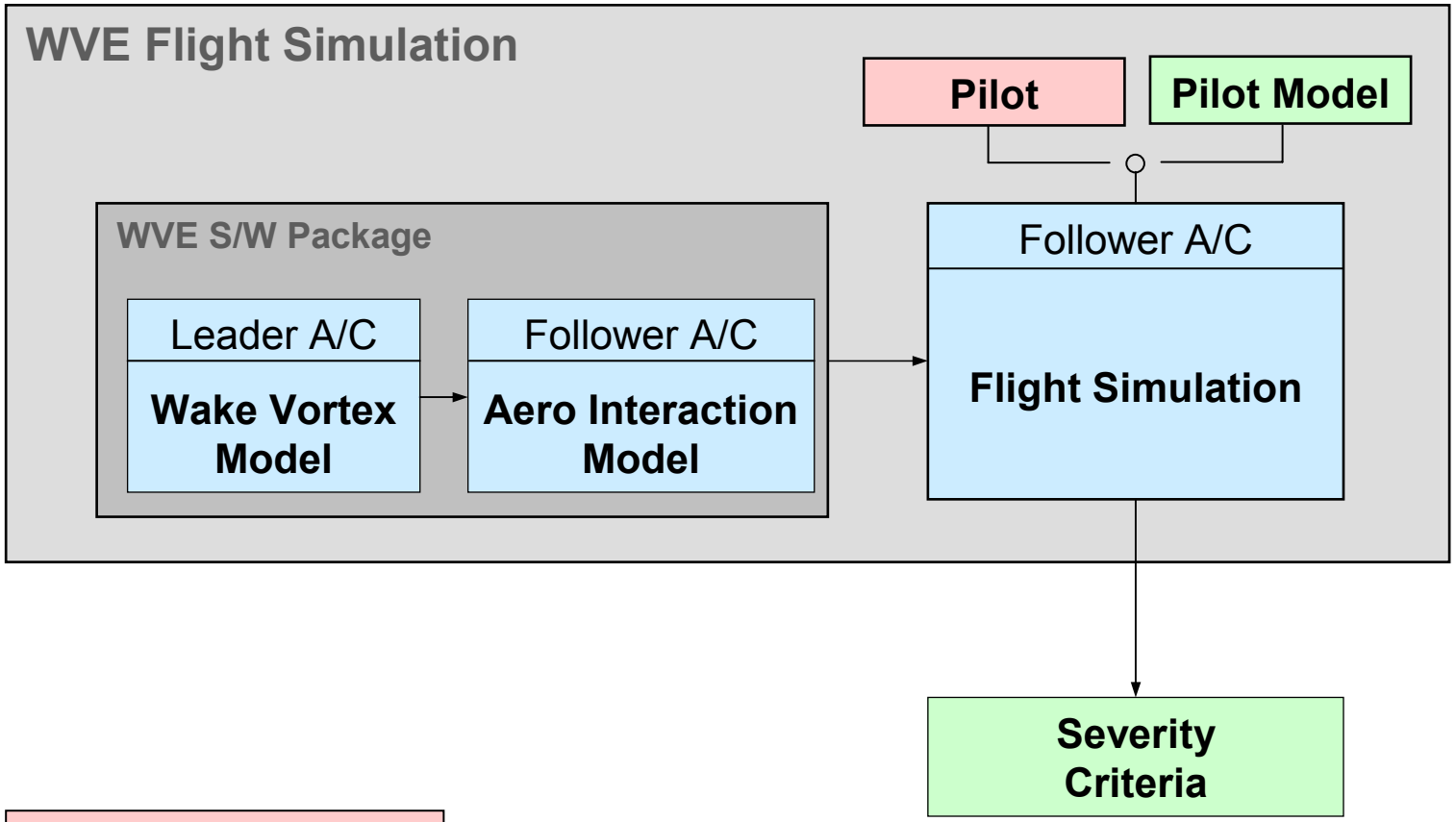
Γ_{WV}	Vortex strength
b_V	Vortex span
r_C	Vortex core radius

Encounter geometry

R_{vortex} φ_{vortex}	Min. distance and angle (polar coordinates) between vortex and encountering a/c:
H_{ILS}	Encounter height
$\Delta\gamma_{WV}$, $\Delta\Psi_{WV}$, $\Delta\Phi_{WV}$	Encounter angles



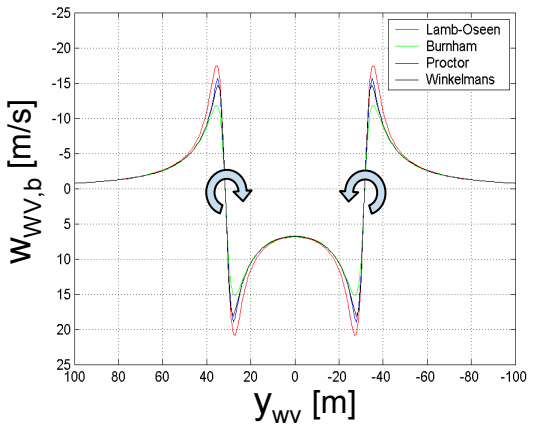
Simulation Setup



- Piloted simulation
- Offline simulation

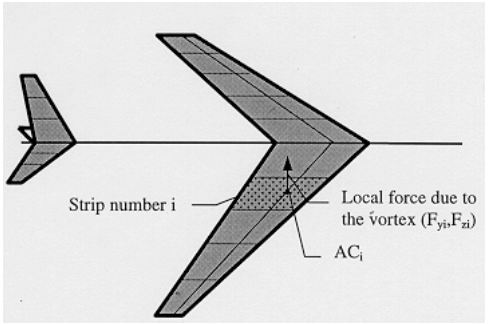
WVE Flight Simulation

Wake Vortex Model



- Four generic models are available
- Parameters: Γ_{WV}, b_v, r_c
- Further velocity profiles can be included

Aerodynamic Interaction Model



- **Strip Method** used to compute local aerodynamic forces and moments
- Aircraft specific data sets

Flight Simulation of Follower Aircraft, e.g.

VFW614 ATD

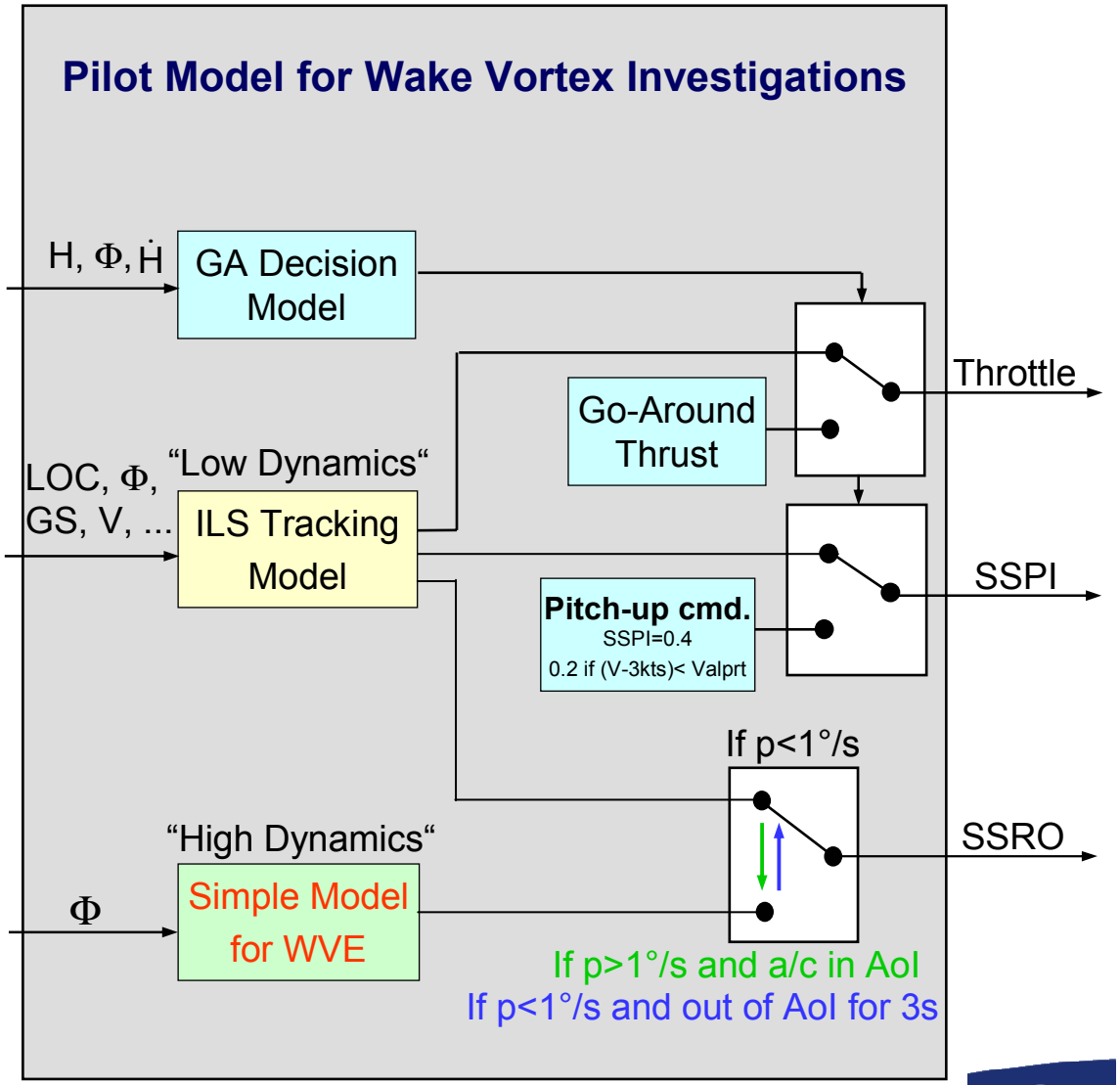
Airbus 320

Airbus 300

Pilot Model

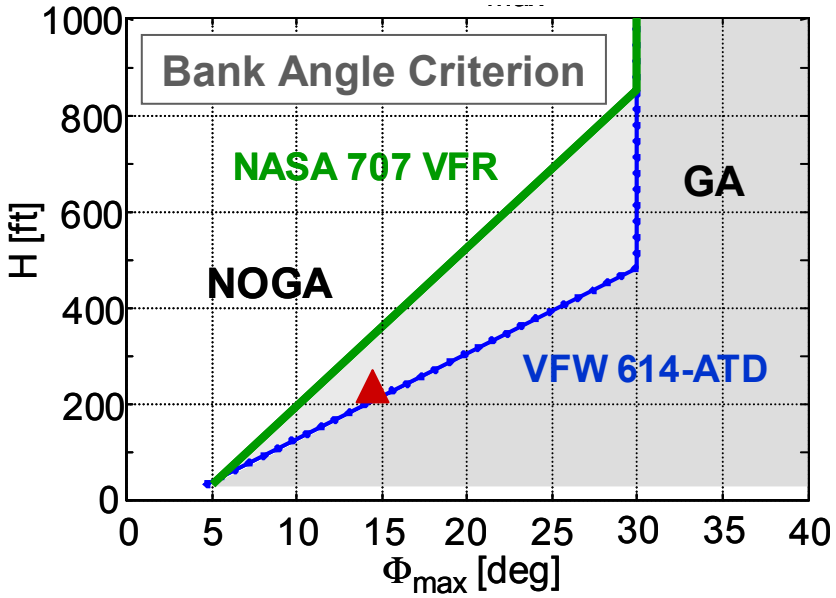
Three pilot tasks:

- Tracking of ILS glide path
- Recovery during/after the wake vortex encounter
- Initiation of a go-around when severity limits are exceeded



Severity Criteria

- Necessary to assess WVE severity in offline simulations
- Relate severity of WVE, which is perceived by the pilot, to objectively measurable data
- Criteria are developed on the basis of piloted simulations



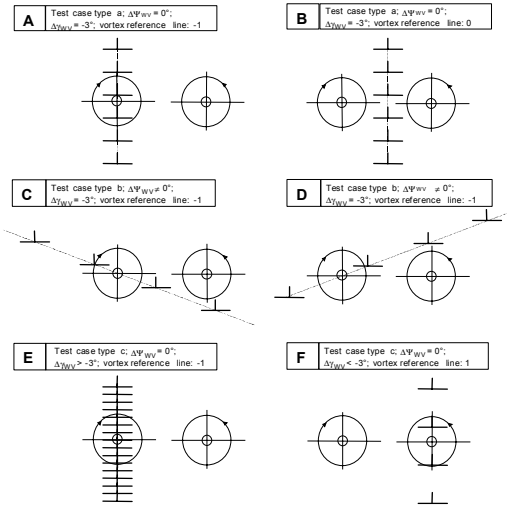
Criteria Development

VESA

Piloted Simulator Tests

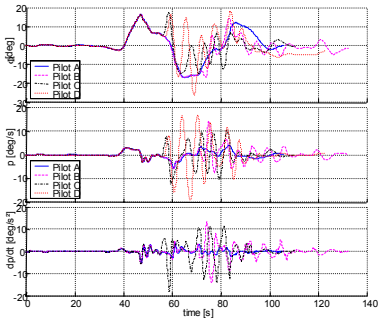
VESA and THOR simulation software is the same

Test Cases comprising different encounter conditions

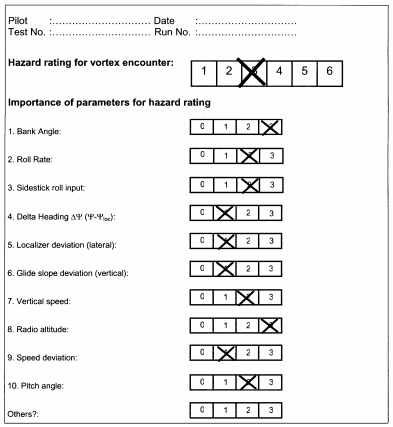


Simulation Results

- Time histories

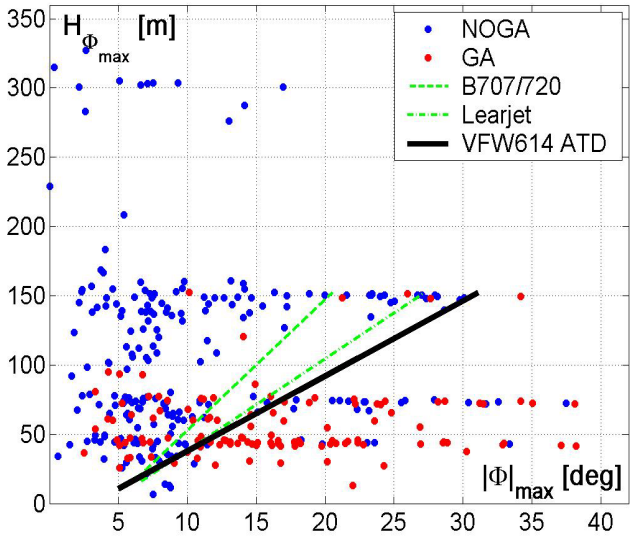


- Pilot ratings for WVE severity



Evaluation

- Finding severity metrics
- Definition of boundaries



Example: S-Wake tests for VFW614 ATD

AIRBUS

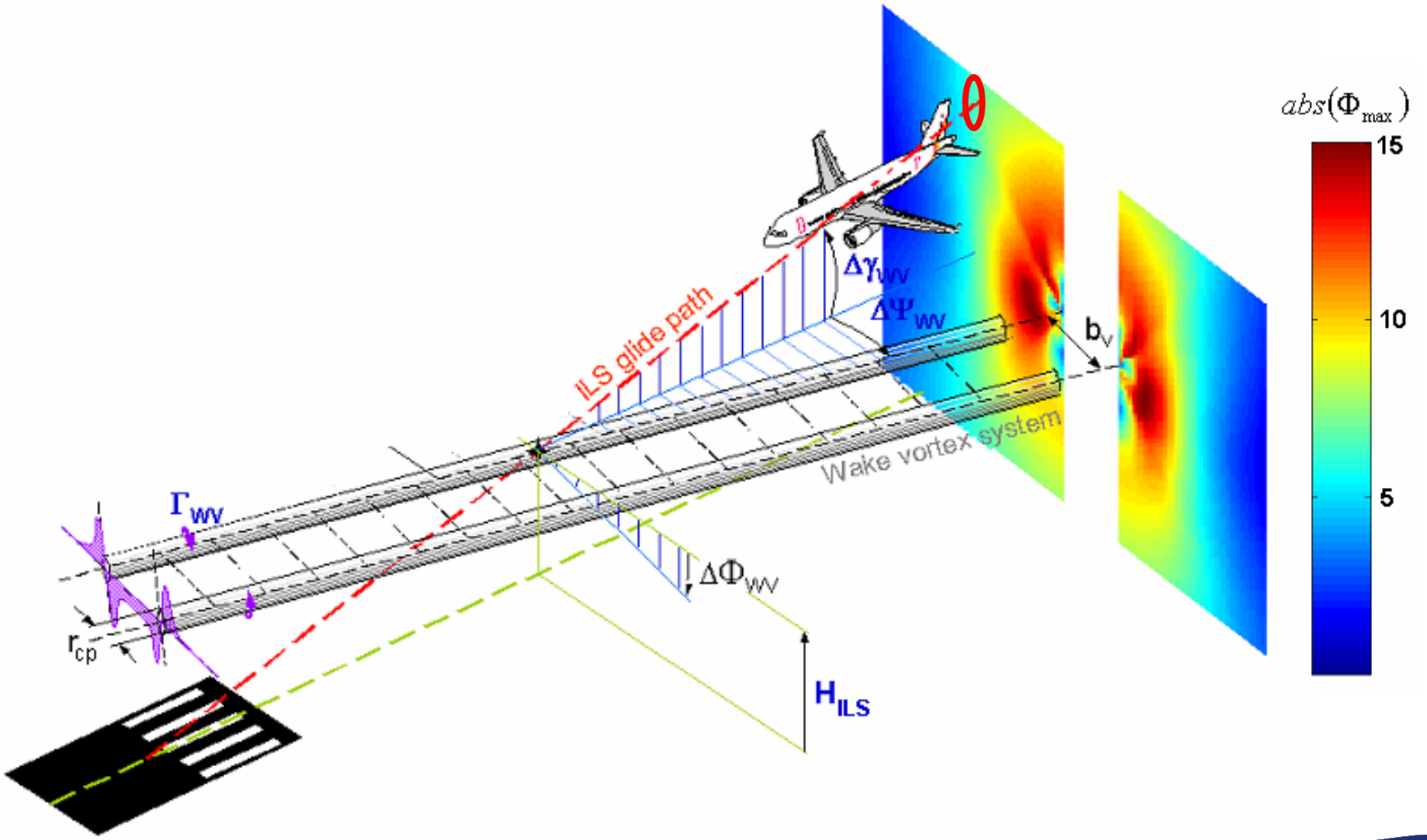
VESA applications

Steps	Results
Static Analysis (STA)	Comparison of vortex-induced forces and moments
Sensitivity Analysis (SA)	Influence of parameter values on encounter severity
Worst Case Search (WCS)	Worst-case encounter conditions, critical vortex strength
Monte Carlo Simulation (MCS)	Comparison of probabilities to exceed WVE severity limits for assumed encounter conditions
Air space simulation & VESA (ASV)	Comparison of probabilities for severe encounters for computed encounter conditions

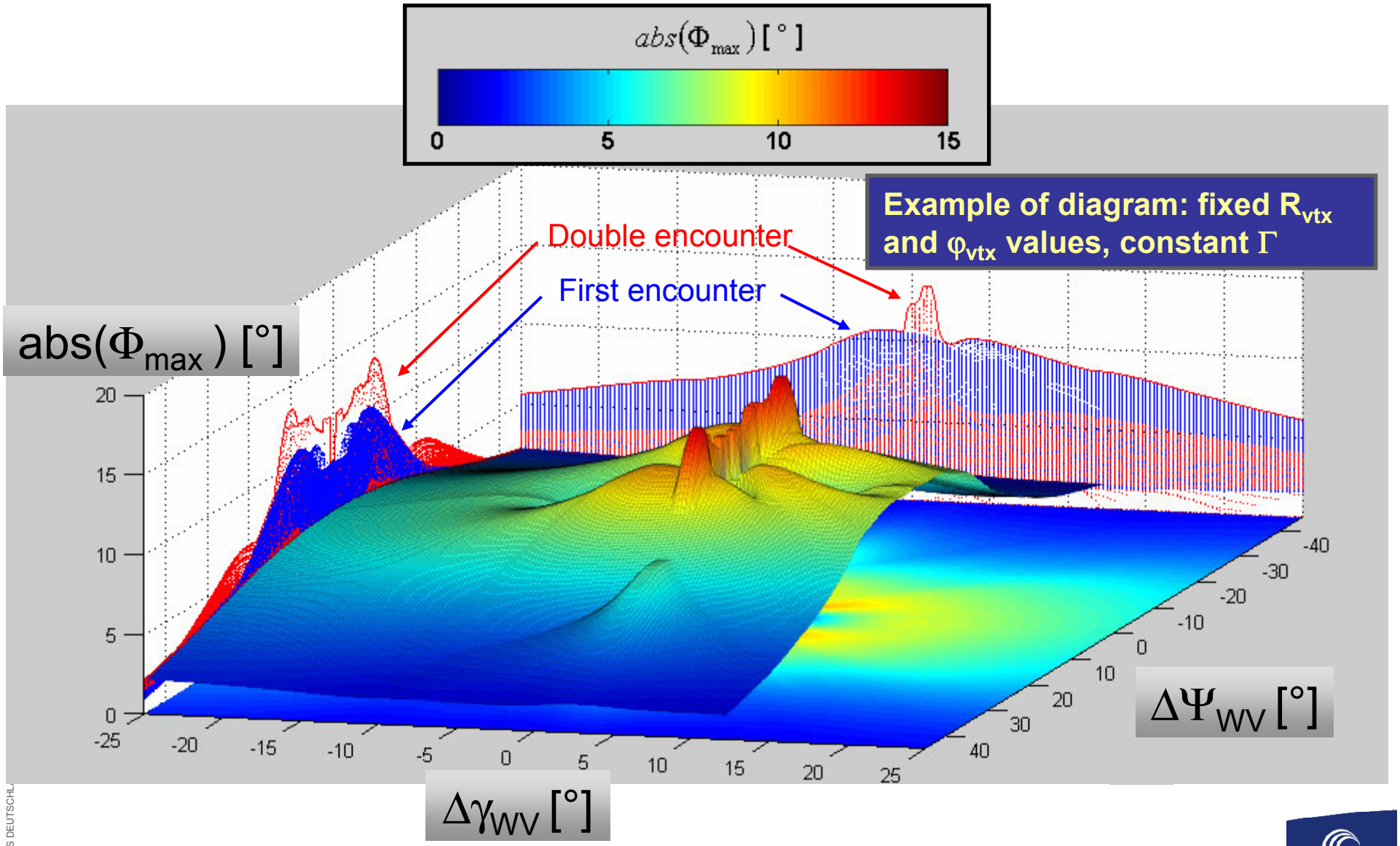
Sensitivity Analysis (SA)

- Influence of parameter values on encounter severity
- Using VESA
- Example: Variation of horizontal and vertical encounter angles

Sensitivity analysis (1)
Representation of results



Sensitivity analysis (2)
$\Phi_{max} = f(\Delta\Psi_{wv}, \Delta\gamma_{wv})$

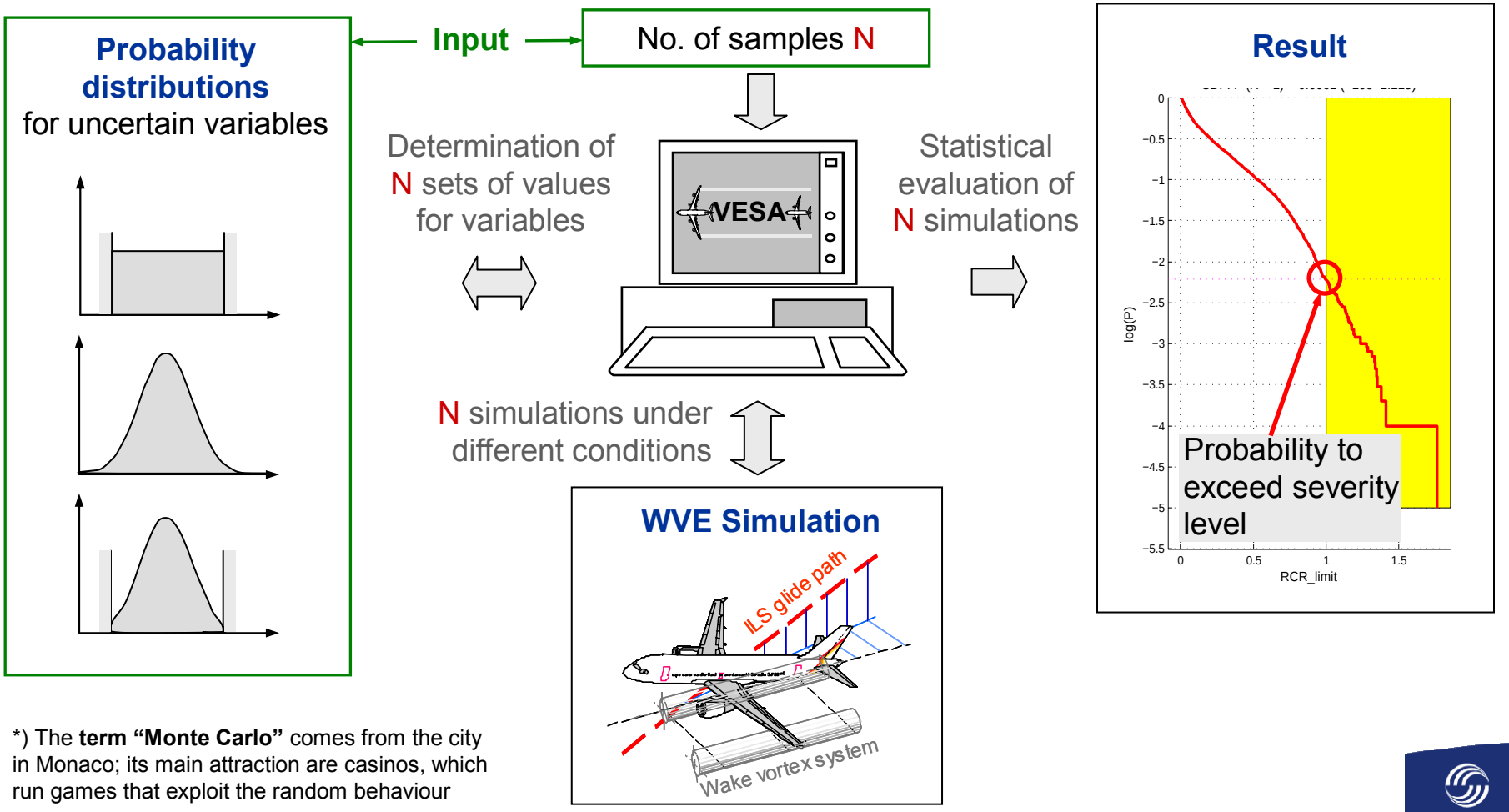


Monte Carlo Simulation (MCS)

- Comparison of probabilities to exceed WVE severity limits for assumed encounter conditions
- Using VESA
- Example: max. bank angle versus separation for various generator aircraft

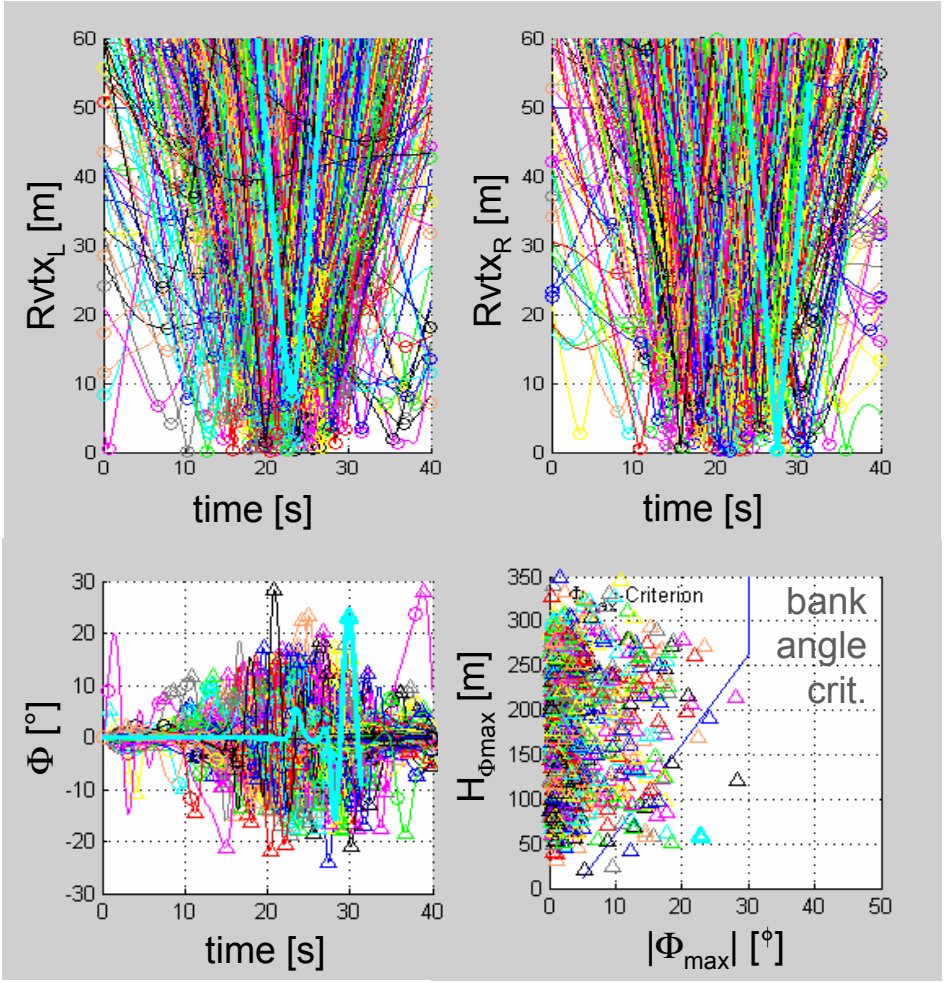
Monte Carlo Simulation (1)
What is MCS?

- **Definition:** Monte Carlo* Simulation (MCS) randomly generates values for uncertain variables to simulate a model
- **Objective:** To automatically analyse the effect of varying inputs on outputs of a modelled system



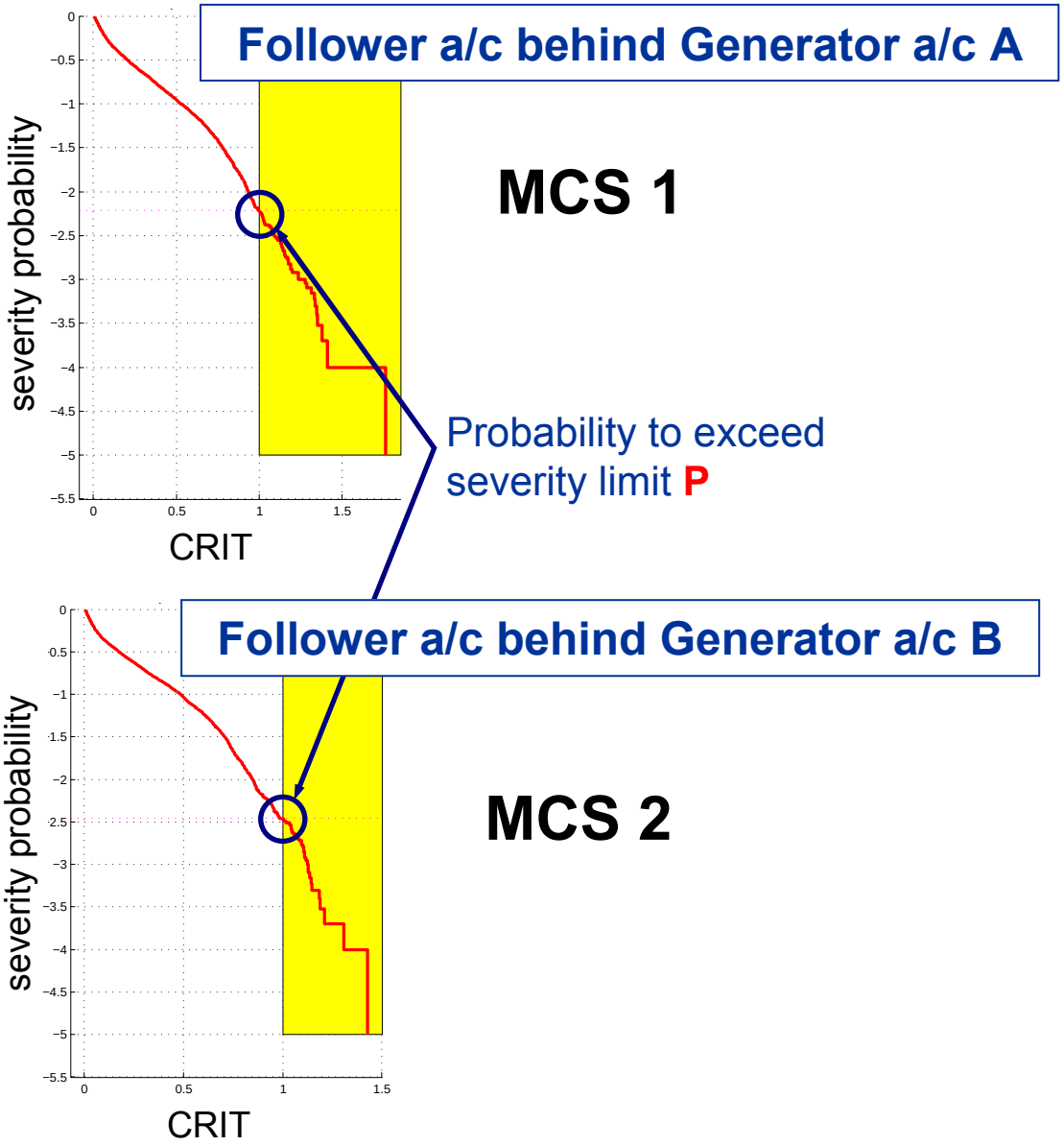
*) The **term "Monte Carlo"** comes from the city in Monaco; its main attraction are casinos, which run games that exploit the random behaviour

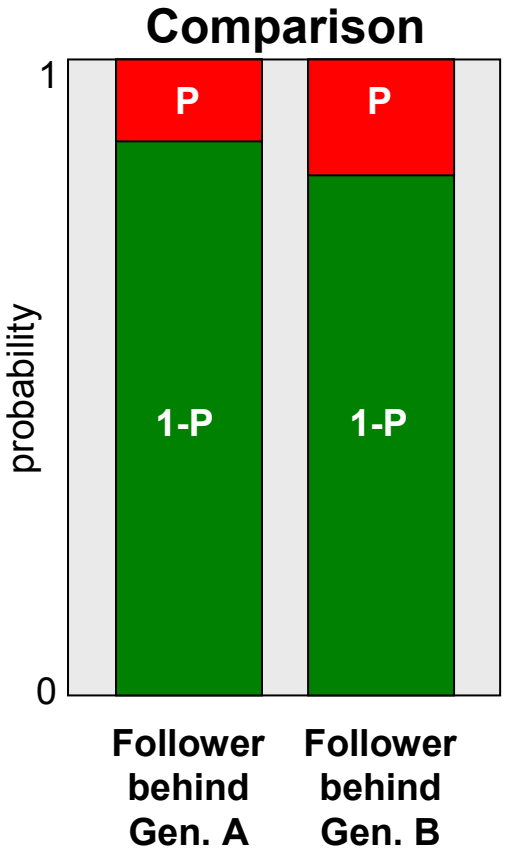
Monte Carlo Simulation (2)
Example of time history and criteria plots



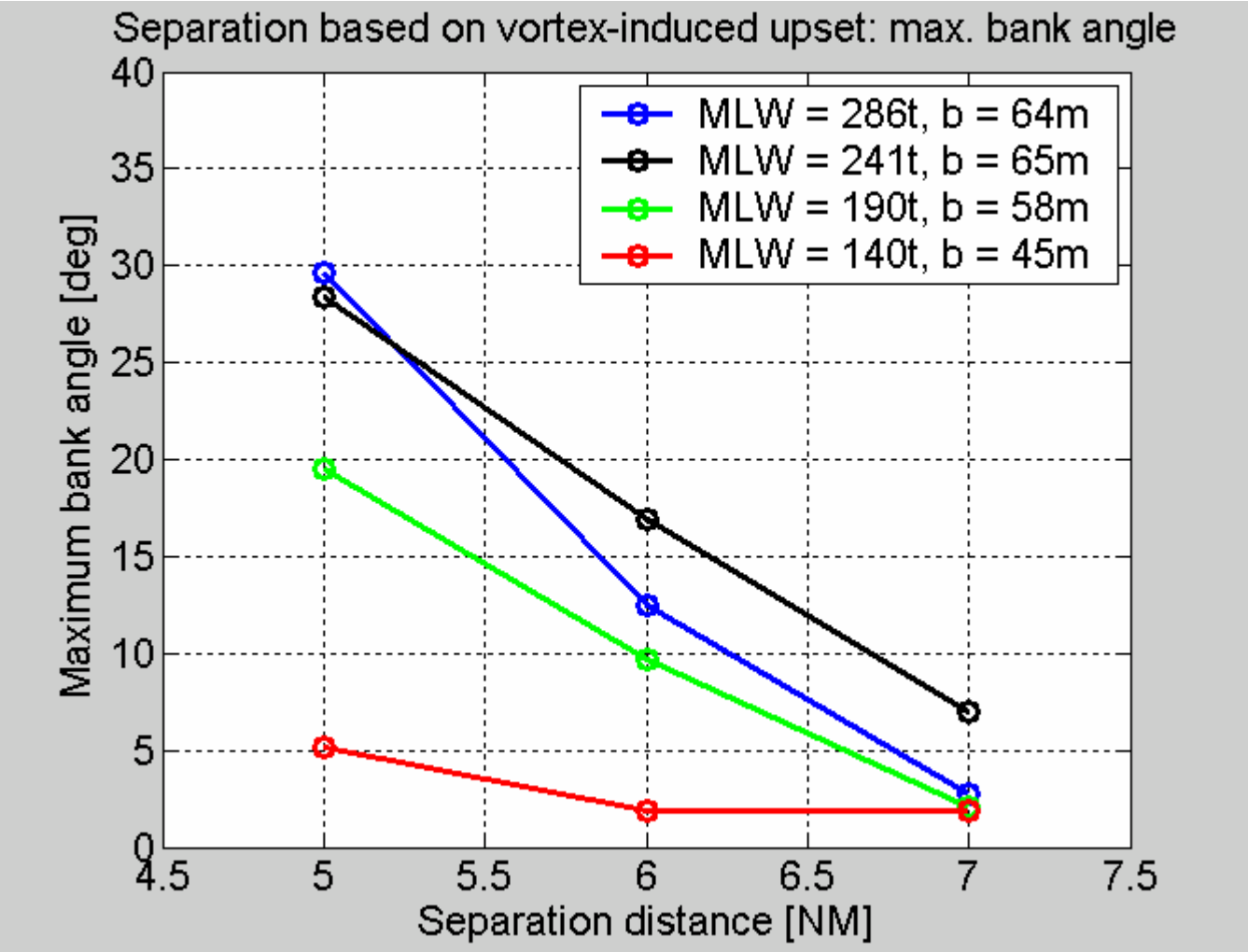
- Example of 1000 samples
- Plot permits post analysis:
  clicking on any symbol or curve highlights corresponding symbols and curves of test case
- Worst case indicated in “cyan”

Monte Carlo Simulation (3)
Comparison of WVE severity





Monte Carlo Simulation (4)
Example of result



- **Follower a/c:** A320
- **Scenario:** landing approach
  - Encounter height 200 ft
  - Varied encounter geometry
- **Meteorological condition:**
  - Low turbulence level (EDR = 10^{-6} m^2/s^3)
  - ISA conditions
- **Computation:**
  - 4 generator/follower a/c combinations
  - 3 separation distances
  - 4x3x10 000 = 120 000 simulated landing approaches

Values must not be interpreted quantitatively as specific scenarios were considered

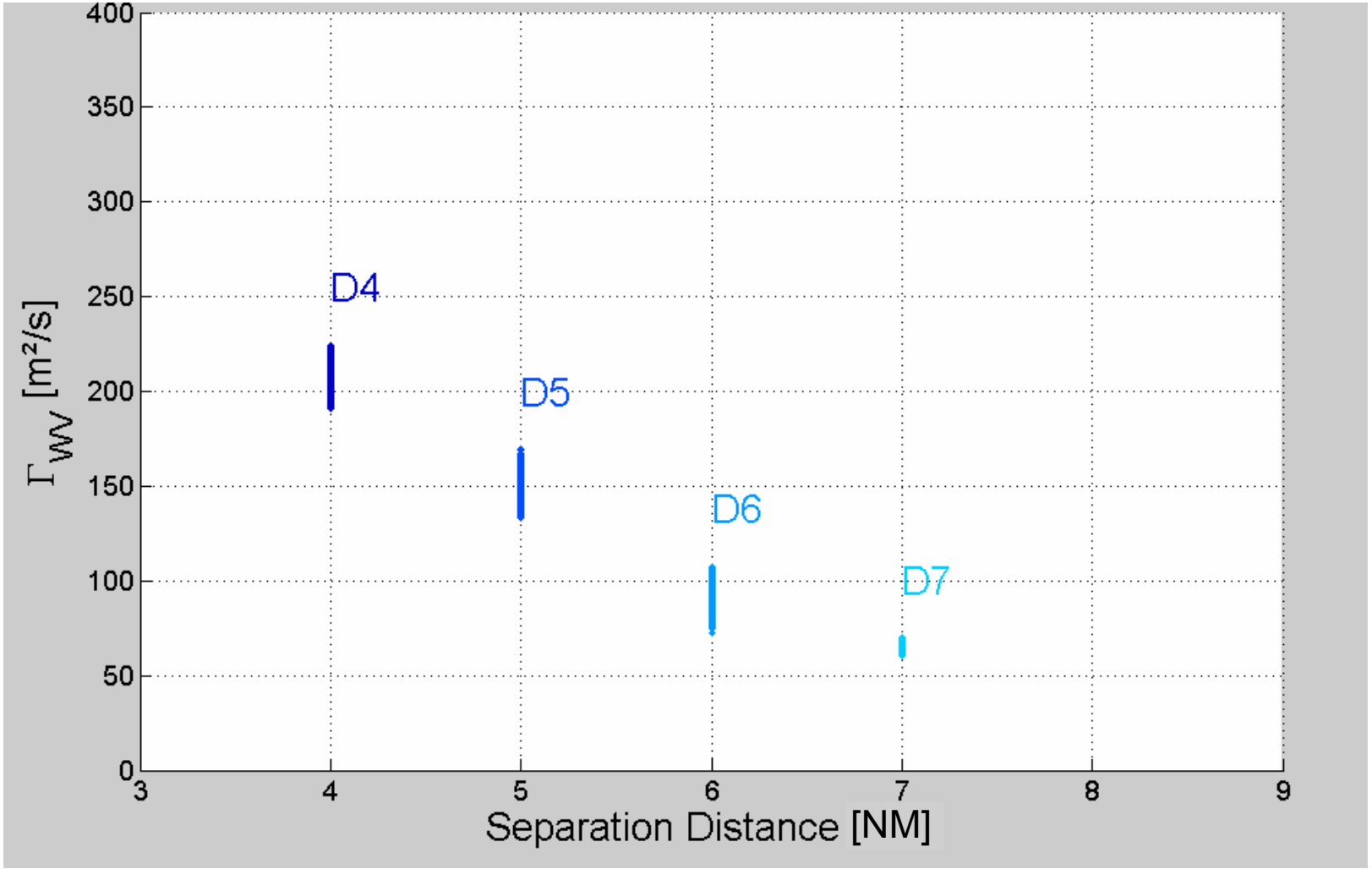
Air space simulation & VESA (ASV)

- Comparison of probabilities for severe encounters for computed encounter conditions
- One example

Air space simulation and VESA
Example: overview

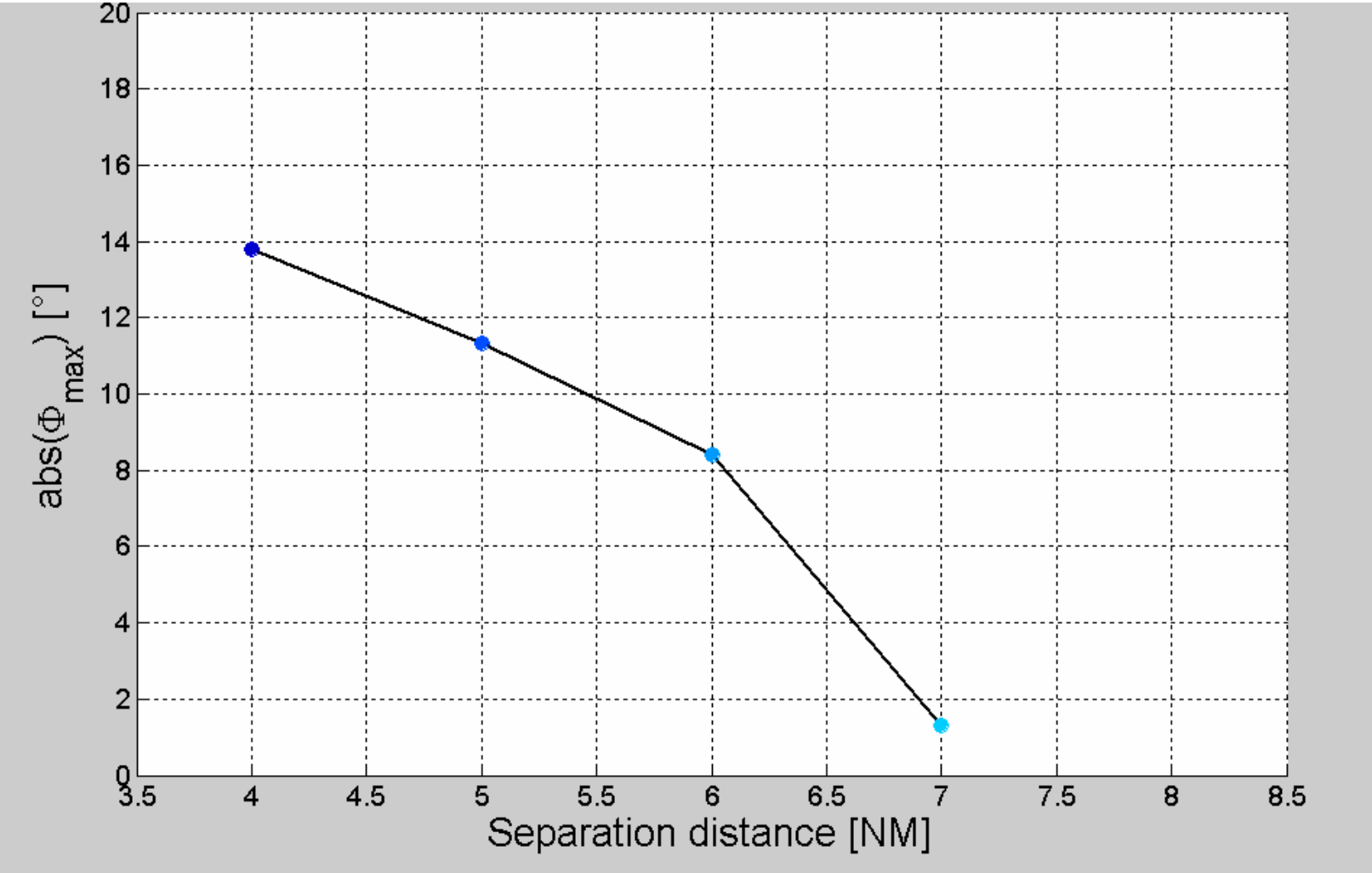
- **Vortex system:** r_c = 1.6 m, b_v = 50.6 m
- **Trailing aircraft:** A320
- **Wind speed range:** 0 to 5 kts
- **Wind profile:** Constant with altitude
- **Separation distance:** 4, 5, 6, 7, 8 NM
- **Turbulence level:** 10^{-4} m^2/s^3
- **No. of air space simulation runs:** 10000

Air space simulation and VESA
Example: med. turbulence, Γ = f(sep. dist.)



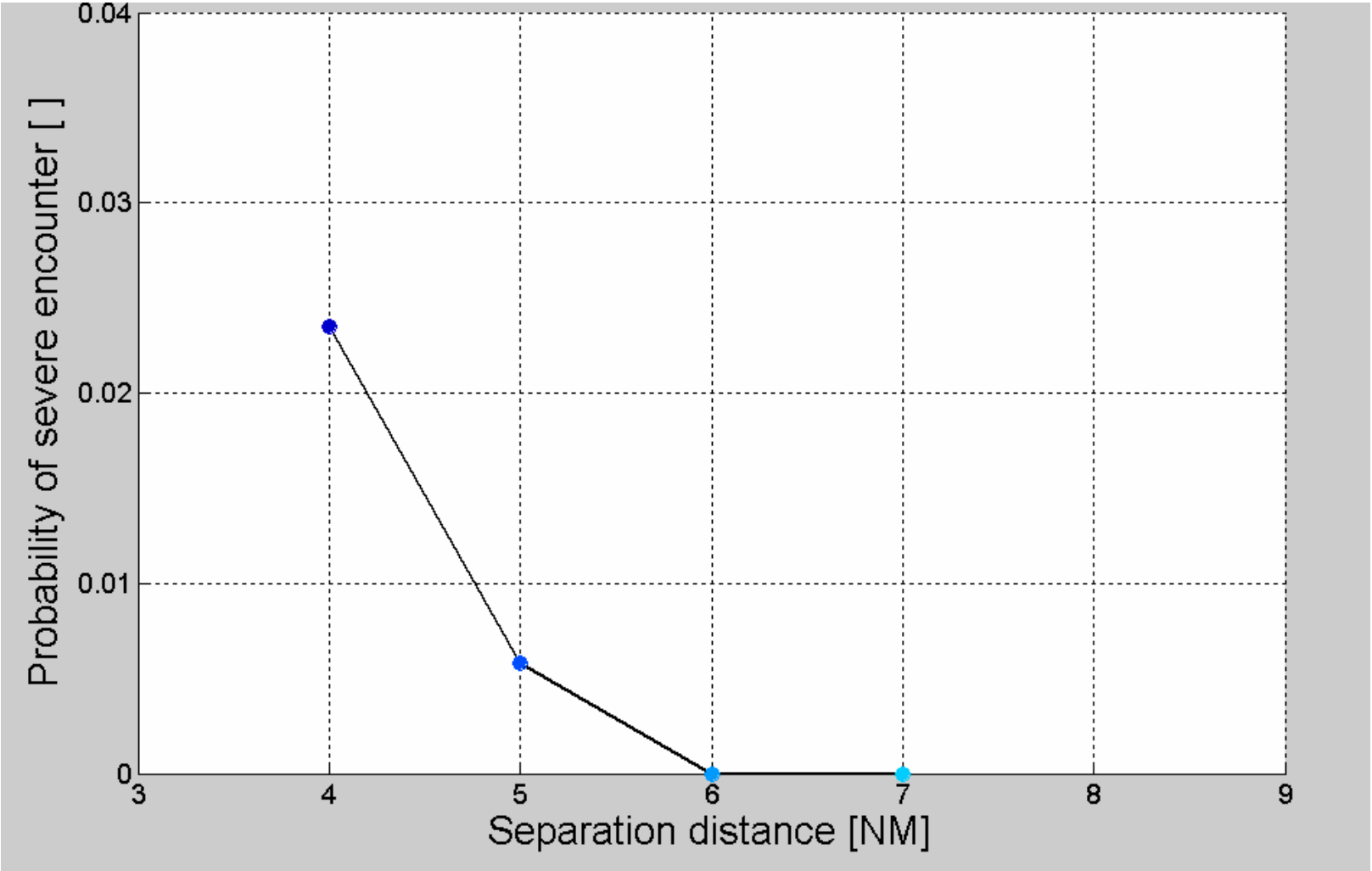
Values must not be interpreted quantitatively as specific scenarios were considered

Air space simulation and VESA
Example: med. turb., abs(Φ_{max}) = f(sep. dist.)



Values must not be interpreted quantitatively as specific scenarios were considered

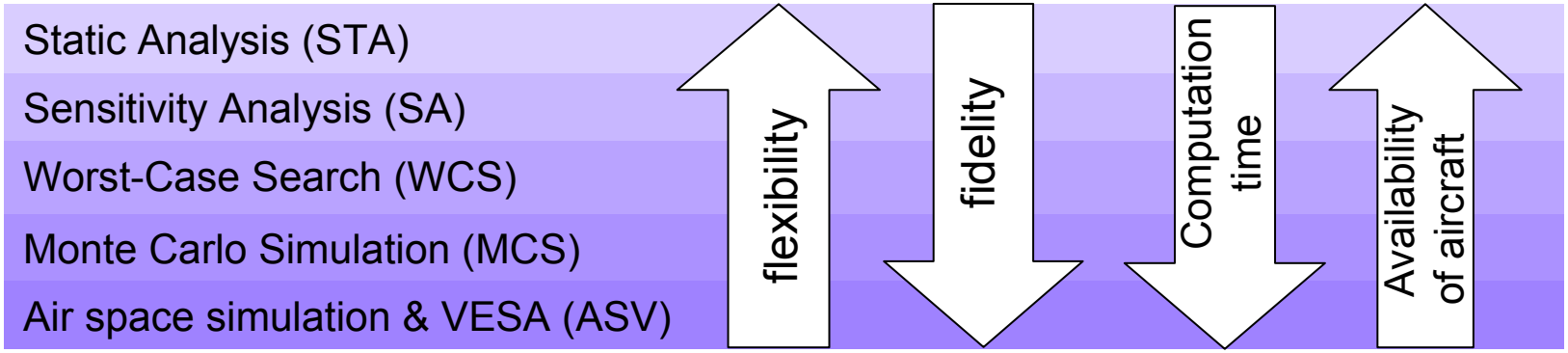
Air space simulation and VESA
Example: med. turb., P_{severe} = f(sep. dist.)



Values must not be interpreted quantitatively as specific scenarios were considered

Conclusions

- Airbus Flight Dynamics Department works in the field of wake vortex encounter (WVE) simulation and risk assessment for six year
- With WakeScene (DLR) and VESA powerful tools for WVE analysis are available.
- VESA application spectrum offers different possibilities w.r.t. accuracy and effort:



- Airbus used the WVE Software Package successfully for piloted simulations on different simulators: A330 (TUB), THOR (Airbus) for VFW614-ATD and A320
  - more than 1400 simulated WVEs with 34 pilots

Outlook (1)

- Improvements of VESA:
  - Extension of VESA to other flight phases (departure, climb, cruise, descent),
  - Adaption of the pilot model to these flight phases,
  - Severity criteria:
    - Improvement of the severity criterion for the landing approach,
    - Development of severity criteria for other flight phases,
    - Generalization of severity criteria,
  - Consideration of wake vortex transport and vortex shape during VESA simulation, i.e. a close link between the airspace simulation (WakeScene) and VESA.

Outlook (2)

- Airbus will continue with WVE investigations:
  - Internal programs
  - Research projects:
    - FLYSAFE (WVE in cruise),
    - CREDOS (WVE during departure),
    - MODYAS (WVE in cruise)

- Airbus main emphases:
  - Systems and human-machine-interface (HMI) to prevent trailing aircraft from encountering wake vortices by early detection, i.e. prior information is used to evade wakes
  - Flight control systems that are capable of an improved compensation of vortex-induced effects – in case of an unwanted encounter
  - Vortex alleviation of the leading aircraft ➔ reduction of wake vortex encounter hazard for trailing aircraft