Presented by

Airbus
Flight Dynamics, EYCDD

Validation of VESA

Vortex Encounter Severity Assessment

VESA

EYC Wake Vortex Group

AIRBUS

Presentation Outline

Objectives

Means of Validation

Sub Model Validations

- Wake Vortex Velocity Model
- Aerodynamic Interaction Model
- Pilot Model
- Base Aircraft Simulation
- Severity Criteria

Conclusions

Objectives

Validation objective:

- Demonstrate validity of results from VESA
- i.e. prove applicability and validity of VESA tool within computational chain (e.g. in combination with WakeScene) for comparative as well as absolute WVE risk assessments

Presentation objective:

- Show scope, possibilities and examples of VESA validation

Means of Validation

Validation of VESA results:

- Comparable data are not available

  (encounter severity following from well-defined wake encounter conditions)

➔ Approach for VESA validation:

1) Sub model validation
2) Plausibility checks & Sensitivity analysis

Means of Validation

1) Sub model validations

- Address each of VESA's sub models individually
- Model in- and outputs are validated against data from different external sources, e.g. flight tests, piloted simulator tests or data from validated and certified simulation models
- Plausibility of sub model results is evaluated

Means of Validation

2) Plausibility checks & sensitivity studies

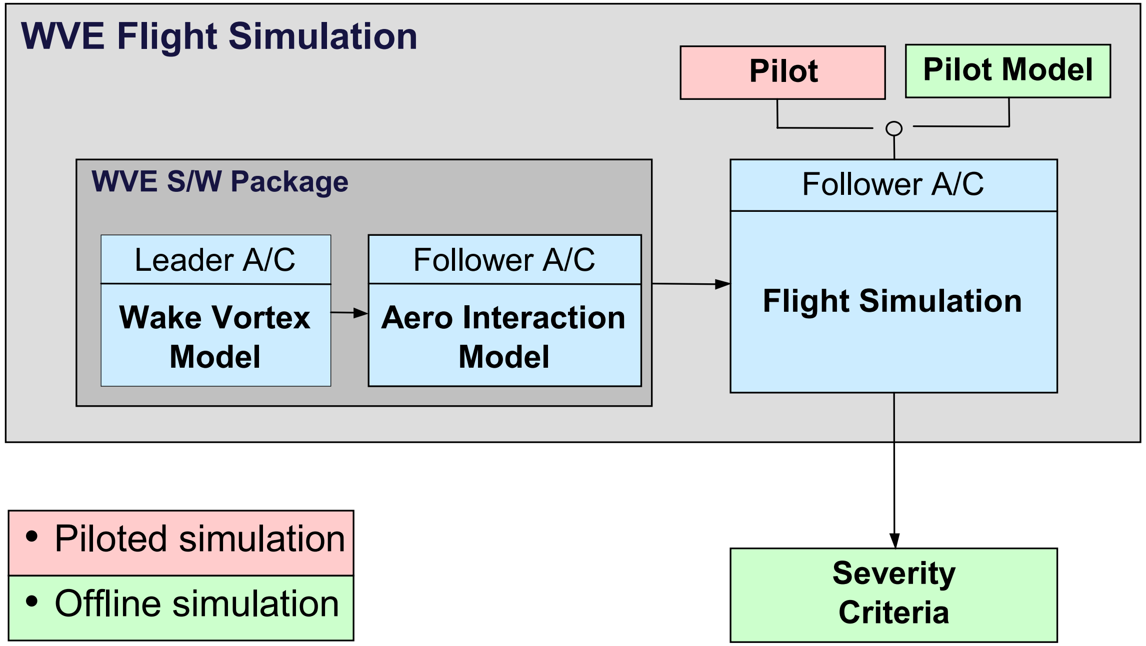
- Ensure a correct software implementation of the sub models
- Ensure a correct representation of wake encounter physics

  - scrutinise results with regard to expectation and common sense

  - analyse selected cases (“outliers”) in-depth

VESA Sub Models

VESA models:



- Piloted simulation
- Offline simulation

Validation necessary for the following sub models:

- Model for WV velocity profile
- Aerodynamic interaction model
- Pilot model
- Flight simulation (VFW614-ATD, A320, A300)
- Severity criteria

VESA Sub Models

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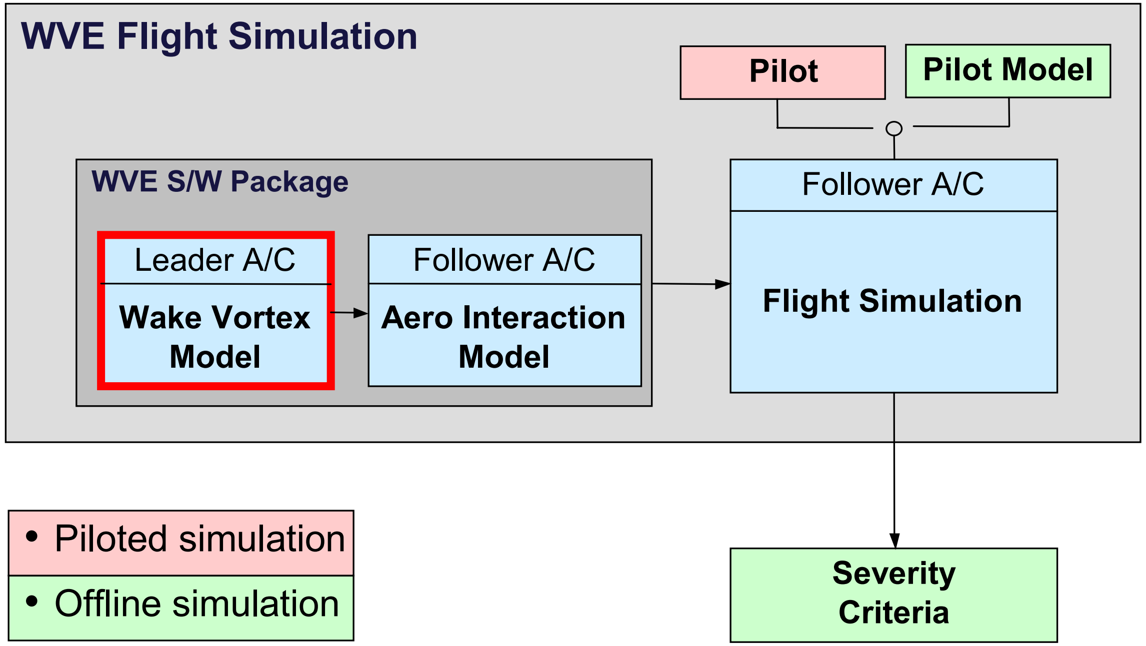

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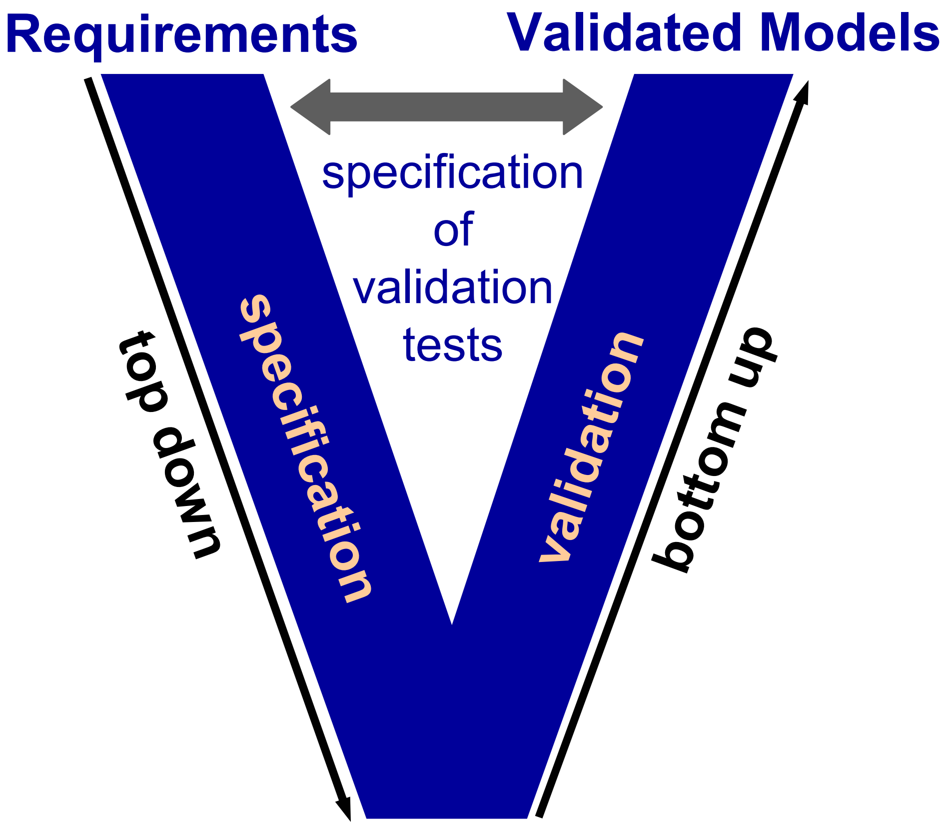
Wake Vortex Velocity Model

Top level requirement:

- Sufficiently exact description of the wake vortex flow field

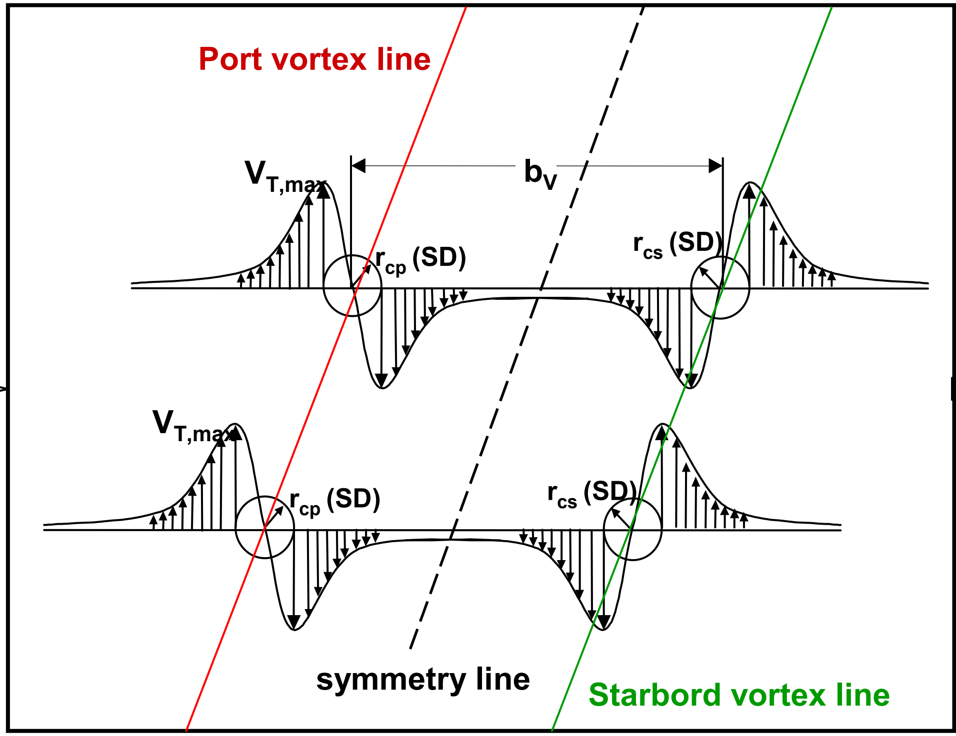


Specification of validation tests:

- Compare model data and measured data, e.g. from flight test and from LiDAR measurements

Wake Vortex Velocity Model

b_v,
Γ_p, Γ_s,
r_{cp}, r_{cs}



$v_{wv}(x,y,z)_{wv}$
$w_{wv}(x,y,z)_{wv}$

Input: Vortex characteristics

- b_v vortex span
- $\Gamma_{p,s}$ vortex circulations
- $r_{cp,s}$ vortex core radii

Output: Velocity flow field

- Velocities in a plane perpendicular to the wake axis
- No axial velocity defects

Wake Vortex Velocity Model

Model according Burnham-Hallock (*) is used primarily

2-vortex system:

$$V_t = \frac{\Gamma_p}{2\pi} \cdot \frac{r_p}{r_{cp}^2 + r_p^2} + \frac{\Gamma_s}{2\pi} \cdot \frac{r_s}{r_{cs}^2 + r_s^2}$$

Model function has been validated independently and seems acceptable to all stake-holders.

*** D.C. Burnham, J.N. Hallock, "Chicago Monostatic Acoustic Vortex Sensing System"**, Volume IV: Wake Vortex Decay, DOT/FAA/RD-79-103 IV, July 1982

If used stand-alone & no measured data are available

vortex span is based on elliptic loading:

$$b_W = \frac{\pi}{4} \cdot b_g$$

and vortex core radius set to 2.5 %:

$$r_{cp} = r_{cs} = 2.5\,\% \cdot b_g$$

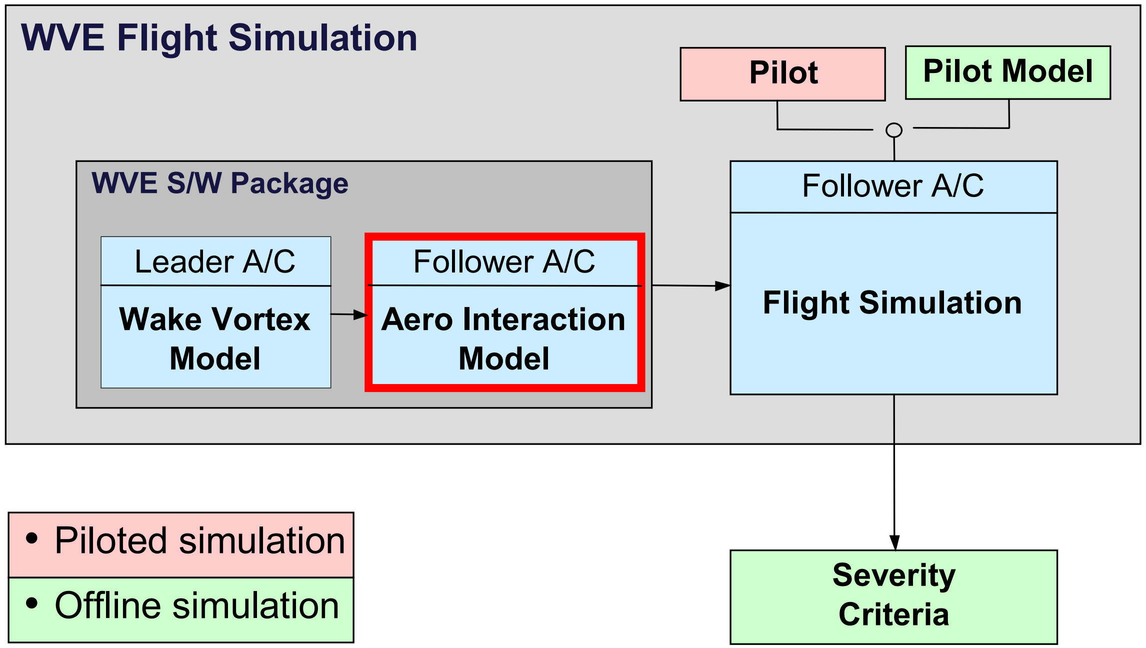
Wake Vortex Velocity Model

Outlook / Improvements

- Vortex characteristics for all phases of flight (landing approach, cruise, take-off)
- Adaptations for curved vortex systems

VESA Sub Models

VESA models:



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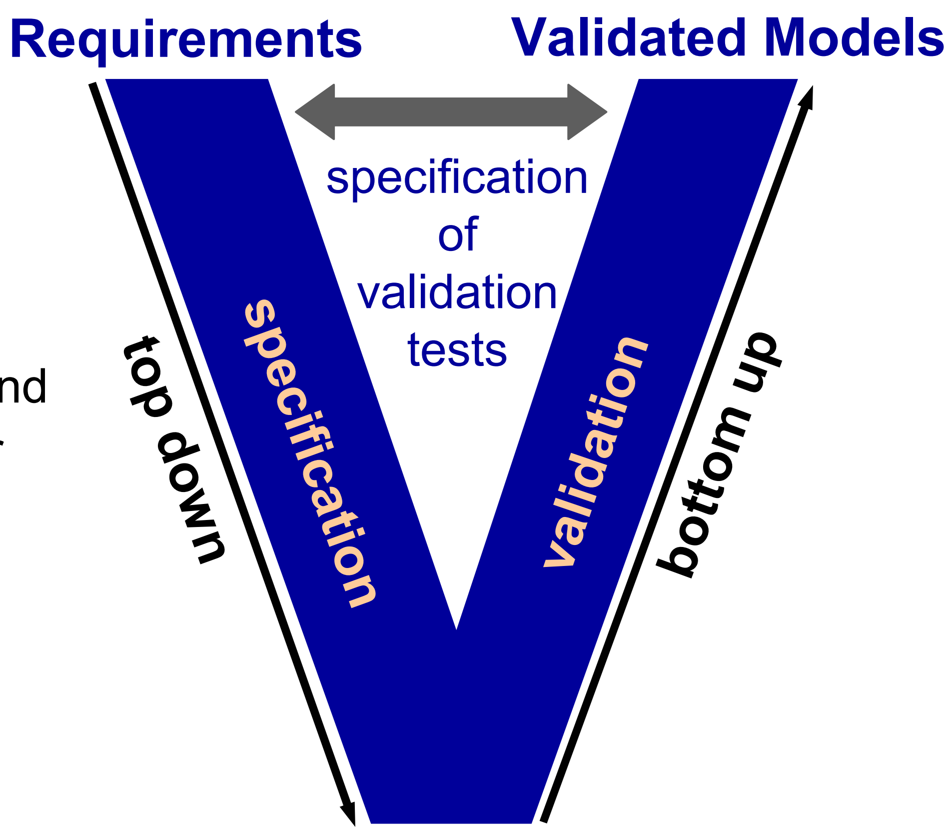
Aerodynamic Interaction Model



Top level requirement:

- Sufficiently accurate computation of vortex-induced forces and moments for all follower aircraft modelled
- Sufficiently accurate influence on flight dynamics

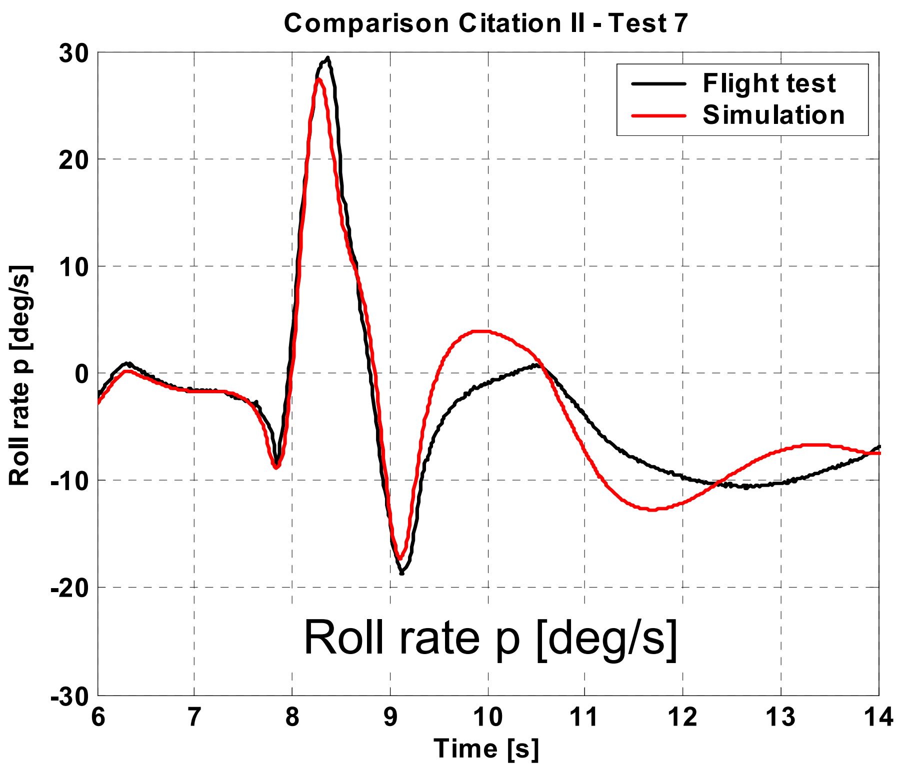
Specification of validation tests:

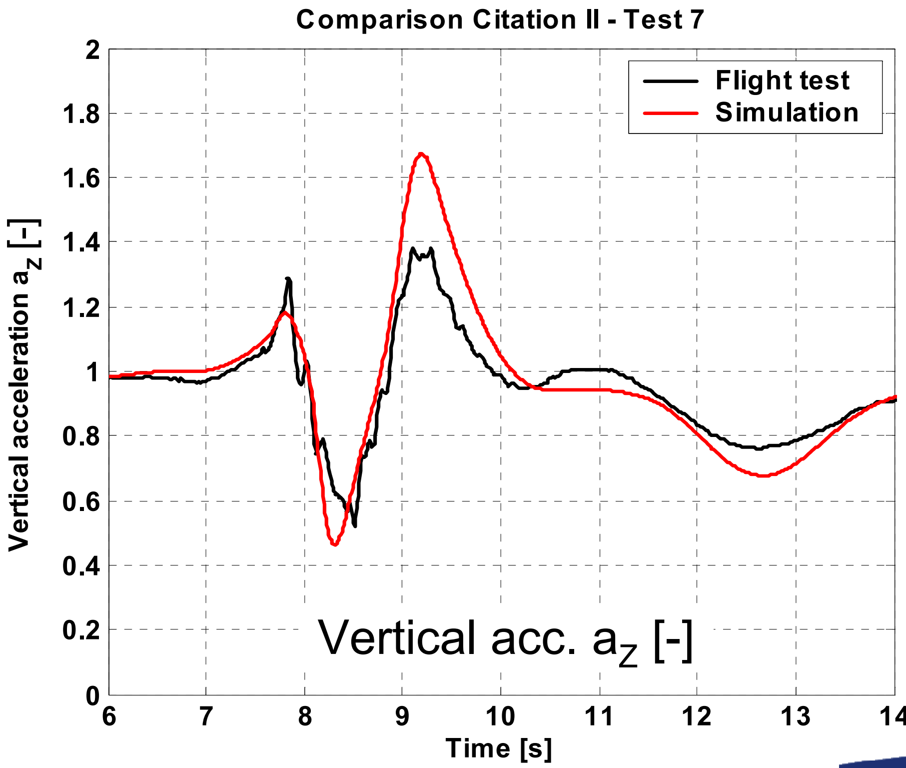
- Comparison with results from flight tests and wind tunnel measurements
- Plausibility checks & test to ensure correct implementation
- Comparison of (rigid body) aerodynamic derivatives

Aerodynamic Interaction Model

Example: Comparison with flight test results

- Most credible but expensive validation method
- Represents combined validation of vortex velocity model, aerodynamic inter-action model & base simulation model



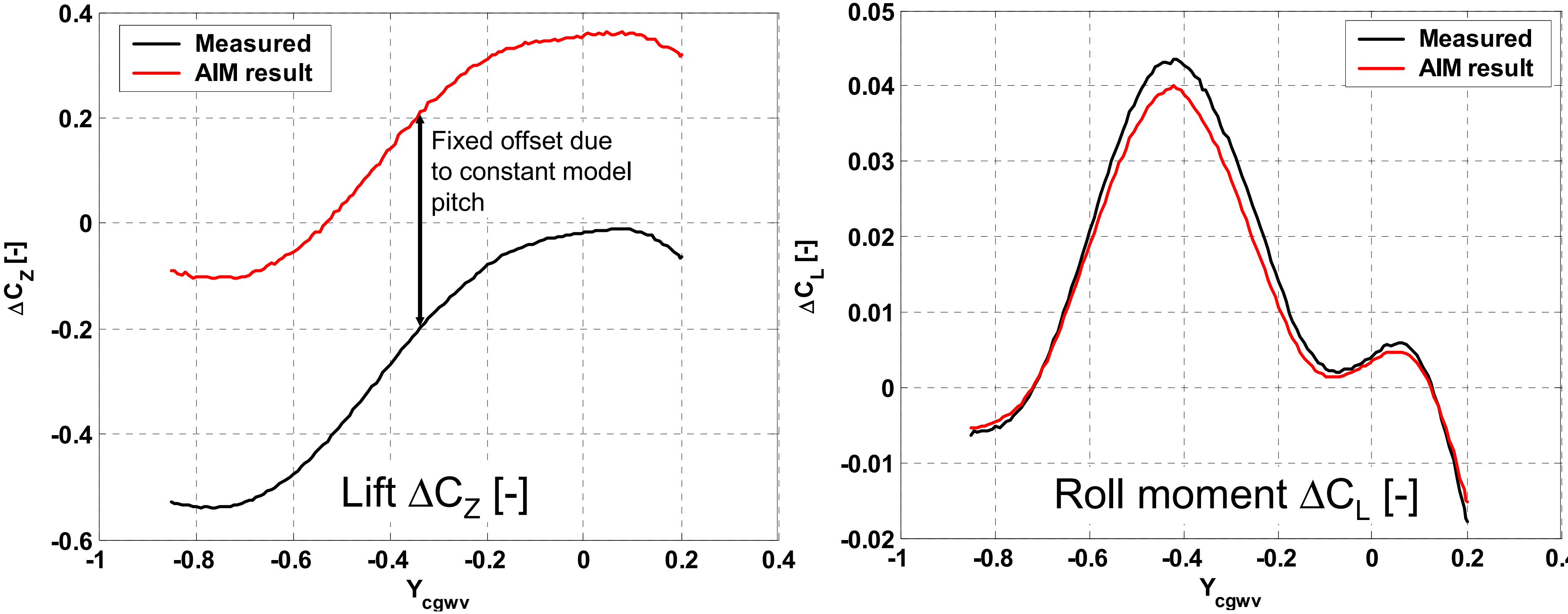


S-WAKE, Citation II behind ATTAS (DLR, NLR)

Aerodynamic Interaction Model

Example: Comparison with wind tunnel measurements

- Exact measurement of vortex flow field (→ input to the AIM) and resulting forces and moments (→ AIM output) is possible
- Typically static, dynamic wake fly-through difficult



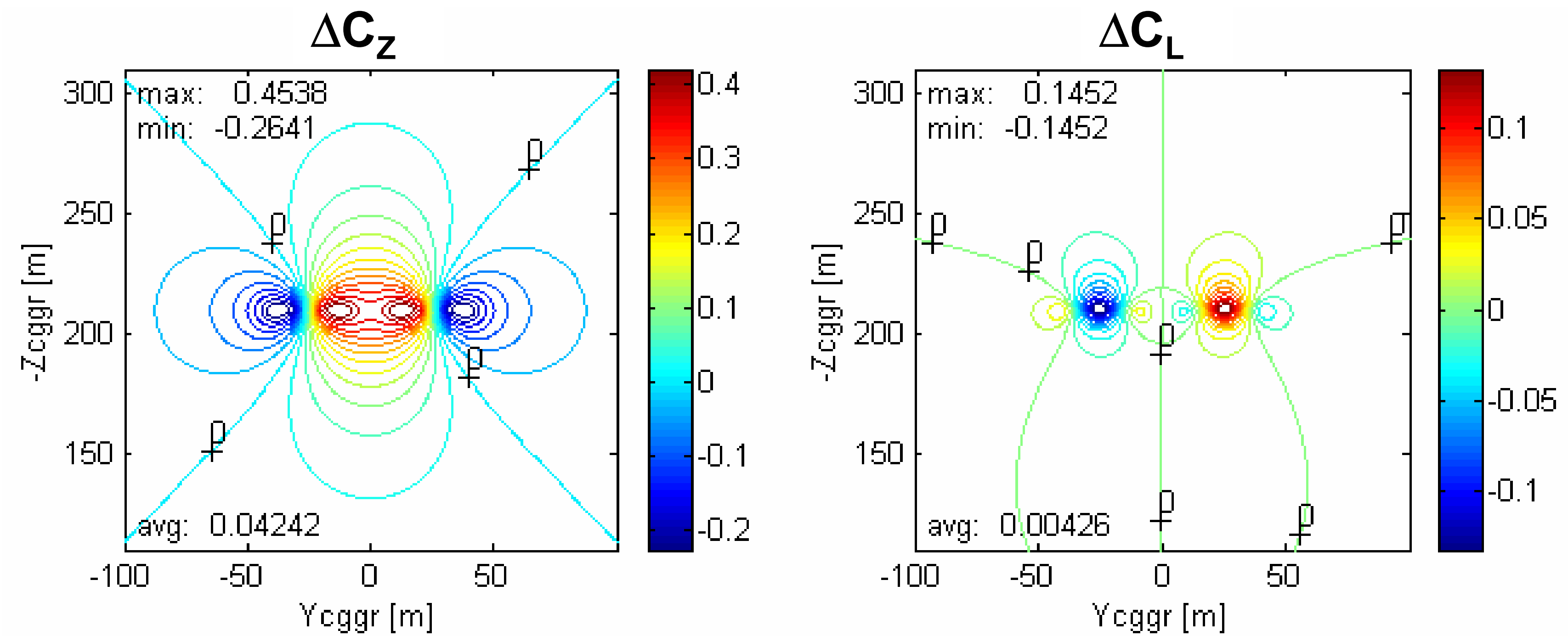
SWIM model vs. Strip method AIM

Lateral model traverse through vortex system (S-WAKE, NLR)

Aerodynamic Interaction Model

Example: Plausibility checks

- Examination of results in regard to plausibility for various situations:
  - vortex properties (circulation, core radii, span),
  - aircraft position and orientation within flow field,
  - aircraft CofG position, configuration and state.



Example: A320 geometry within vortex flow field

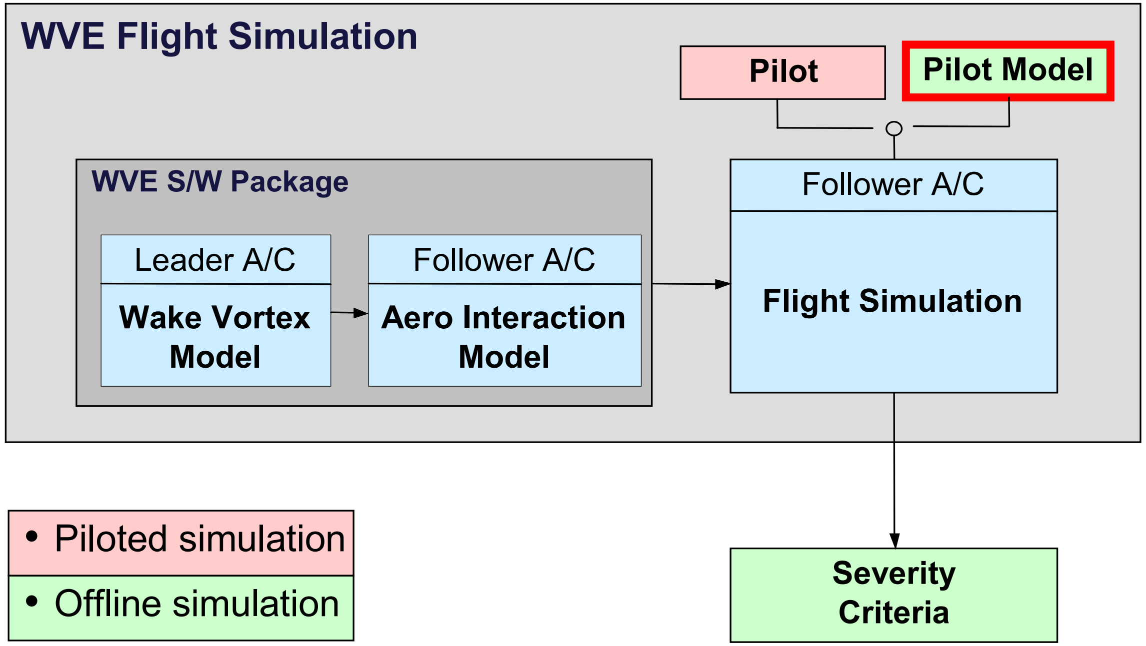
Aerodynamic Interaction Model

Outlook / Improvements

- Modelling of fuselage aerodynamics to improve lateral forces and yawing moments
- Improved validation by flight tests with follower aircraft simulated by VESA (e.g. A320)
- Improved validation by wind tunnel measurements with follower aircraft geometry as used by VESA (e.g. A320, VFW614-ATD, A300-B4)

VESA Sub Models

VESA models:



Validation necessary for the following sub models:

- Model for WV velocity profile
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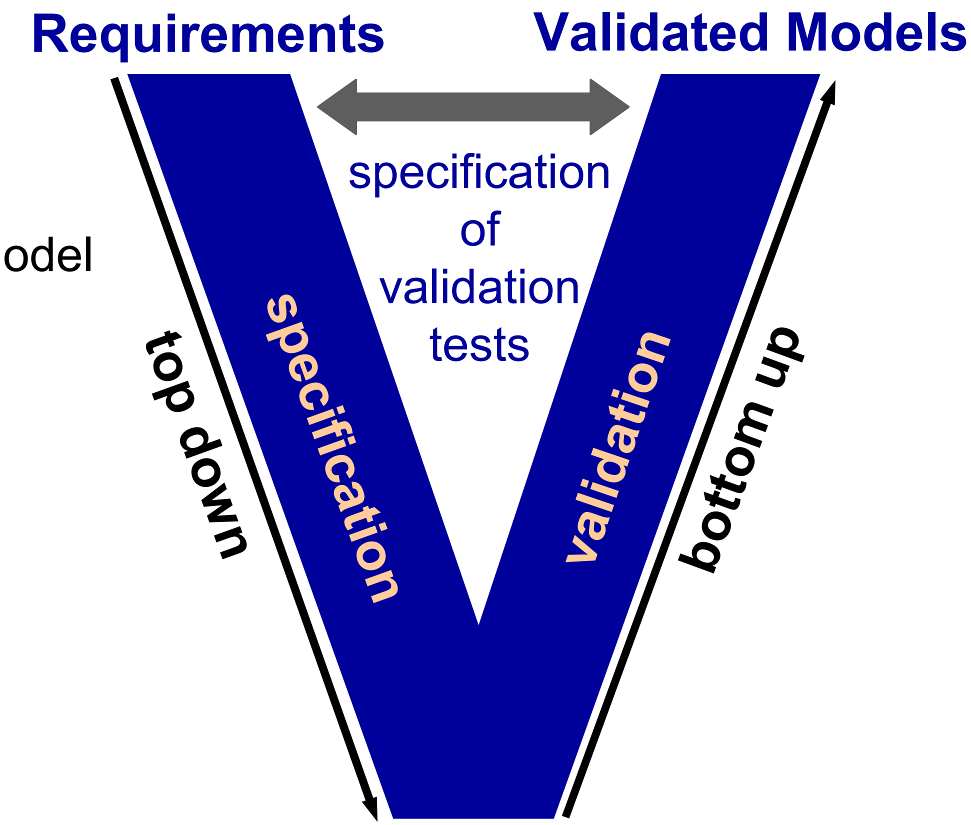
Pilot Model

Top level requirement:

- Sufficiently accurate model of pilot control inputs



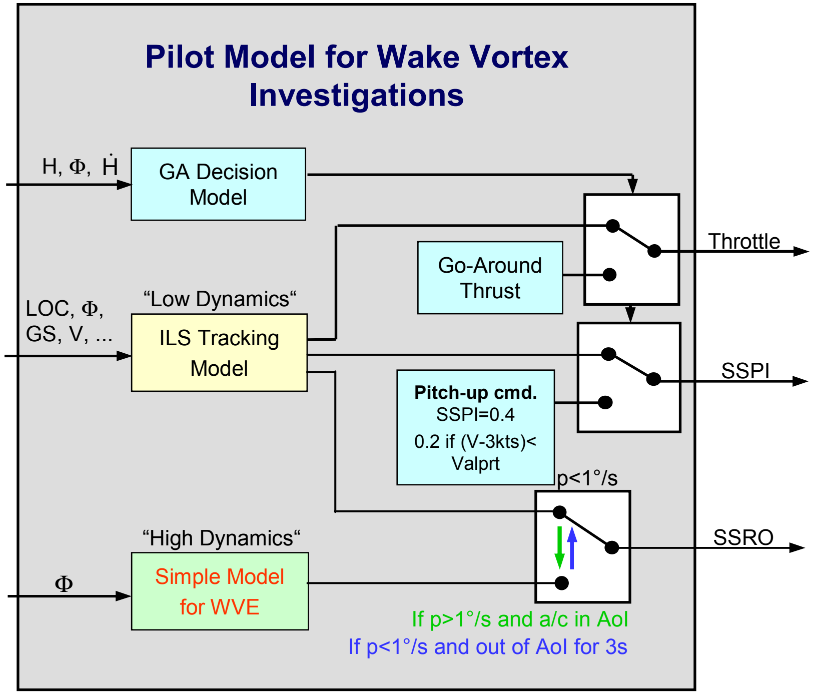
Specification of validation tests:

- Comparison of simulations with pilot model to data from piloted simulator tests

Pilot Model

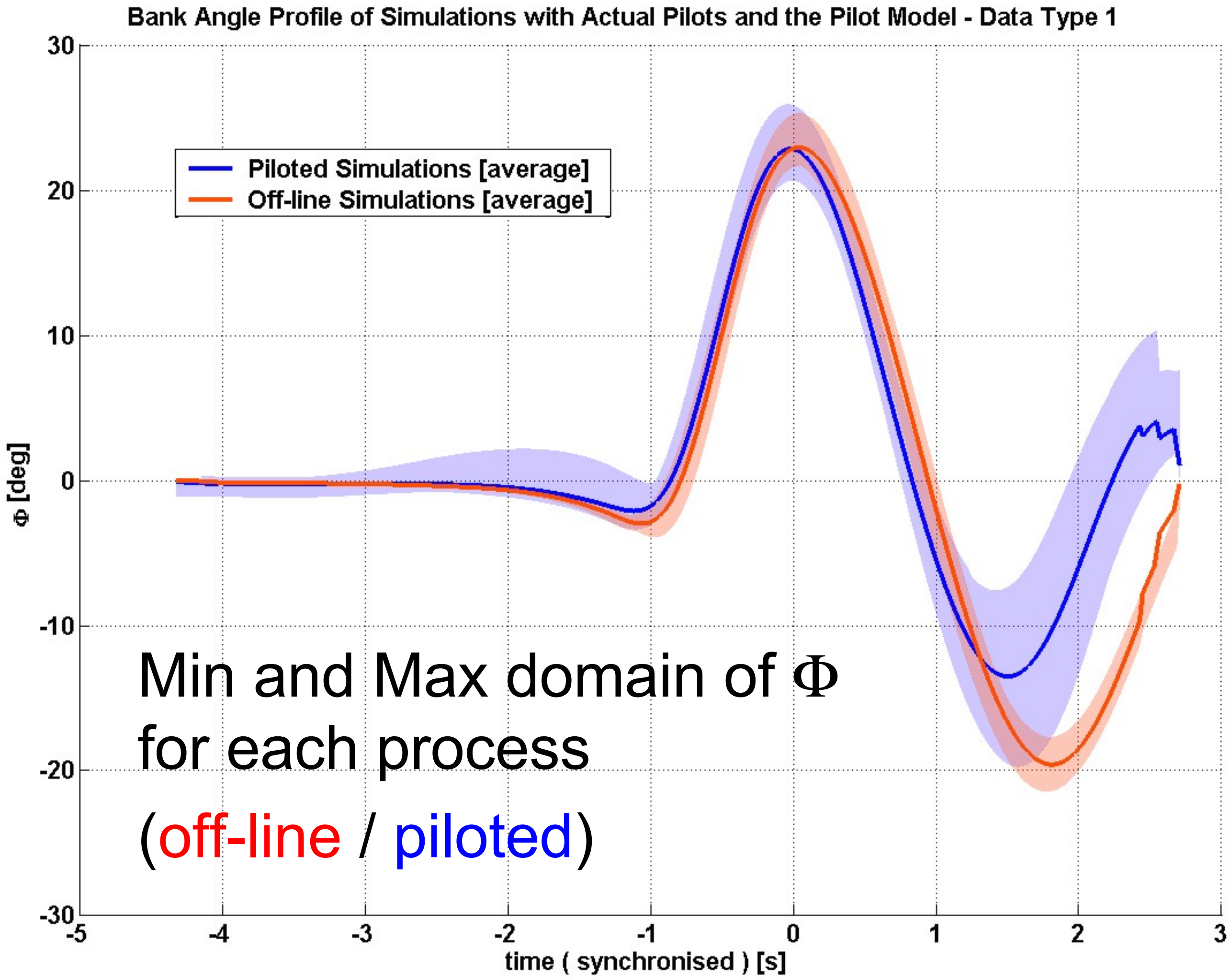
Validation data base:

- Insufficient real-life data existing, thus use of data from piloted simulations for
  a) development / parameter tuning and
  b) validation
  (2 independent data groups)



Pilot Model

Example: Comparison of piloted and off-line simulations (pilot model)



Bank angle for VFW614-ATD final approach cases with Γ = 317.5 m²/s and 20° horizontal encounter angle

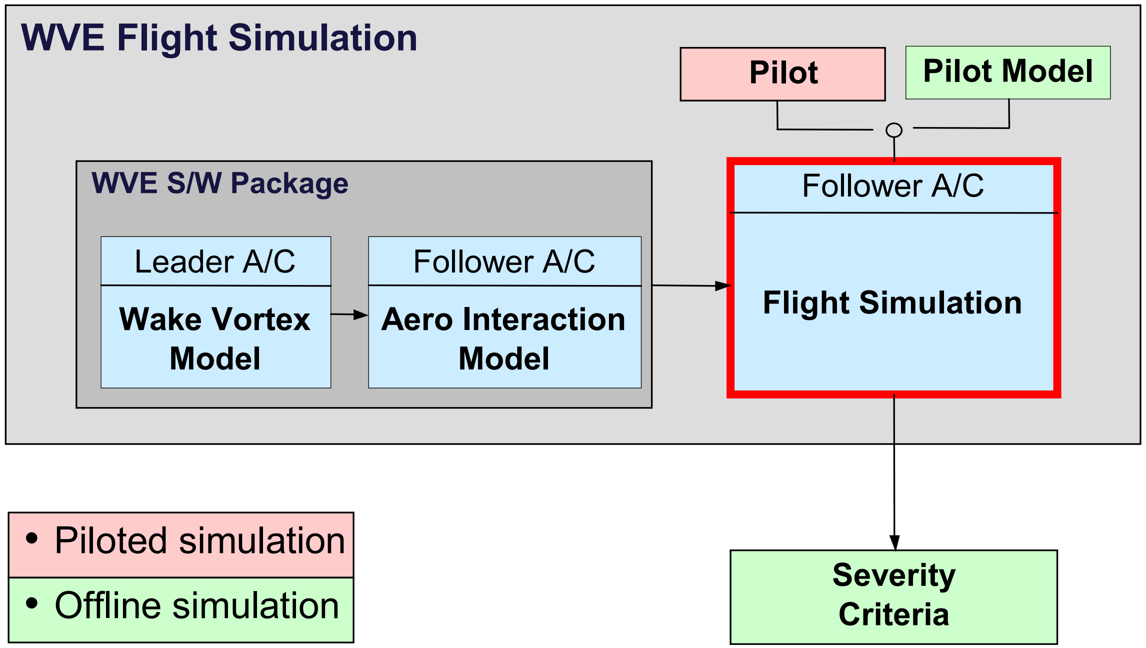
Pilot Model

Outlook / Improvements

- Extension with model for pitch and thrust inputs
- Additional piloted simulations for cruise and take-off and establishing of related pilot model coefficients or creation of improved pilot control models
- Introduction of WVE model in commercial full-flight simulator(s) and gathering of pilot inputs during surprise encounters

VESA Sub Models

VESA models:



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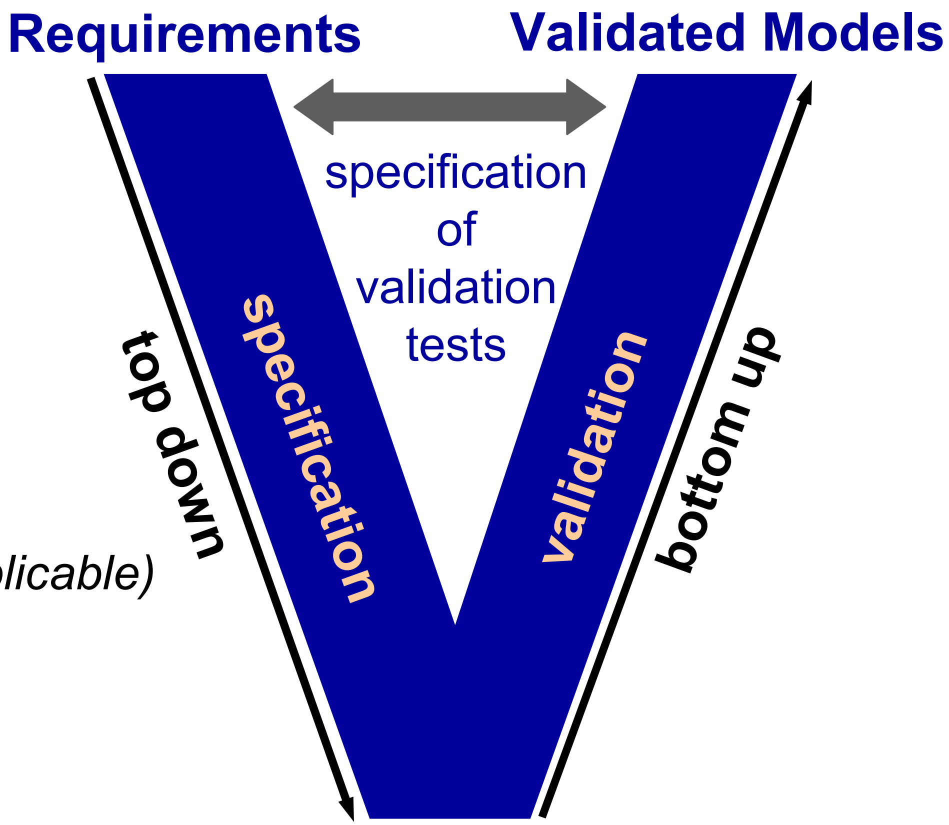
Base Aircraft Simulation



Top level requirement:

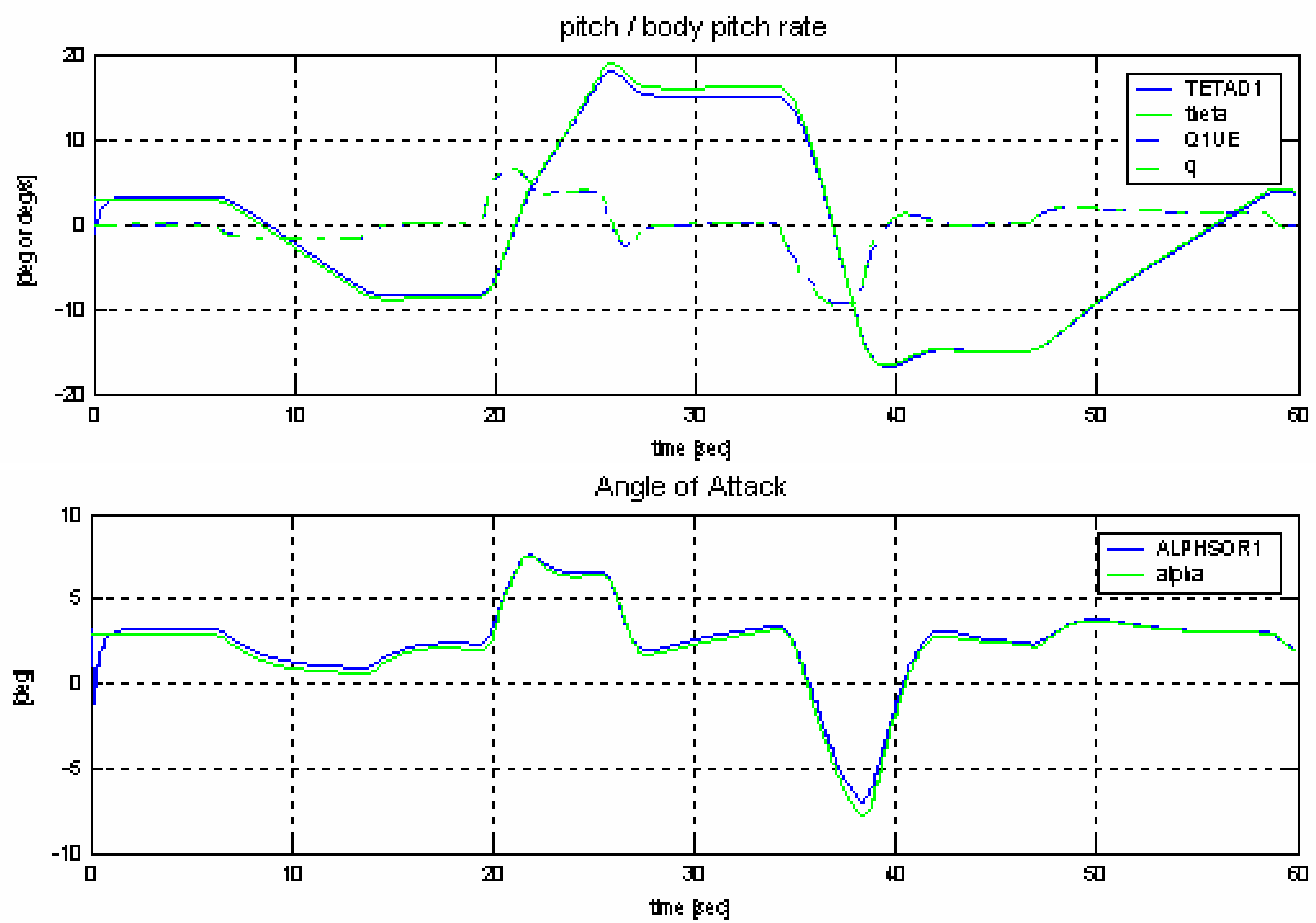
- Accurate 6-DOF simulations of different base aircraft including stability augmentation and automatisation (e.g. AP, A/THR) *(if applicable)*

Specification of validation tests:

- Assessments by type-rated pilots in flight simulator
- A/C specific comparisons of trim conditions and aircraft response with flight test data and/or high-fidelity simulations

Base Aircraft Simulation

Example: Comparison of dynamic manoeuvre data between VESA and certified training simulation (A320)



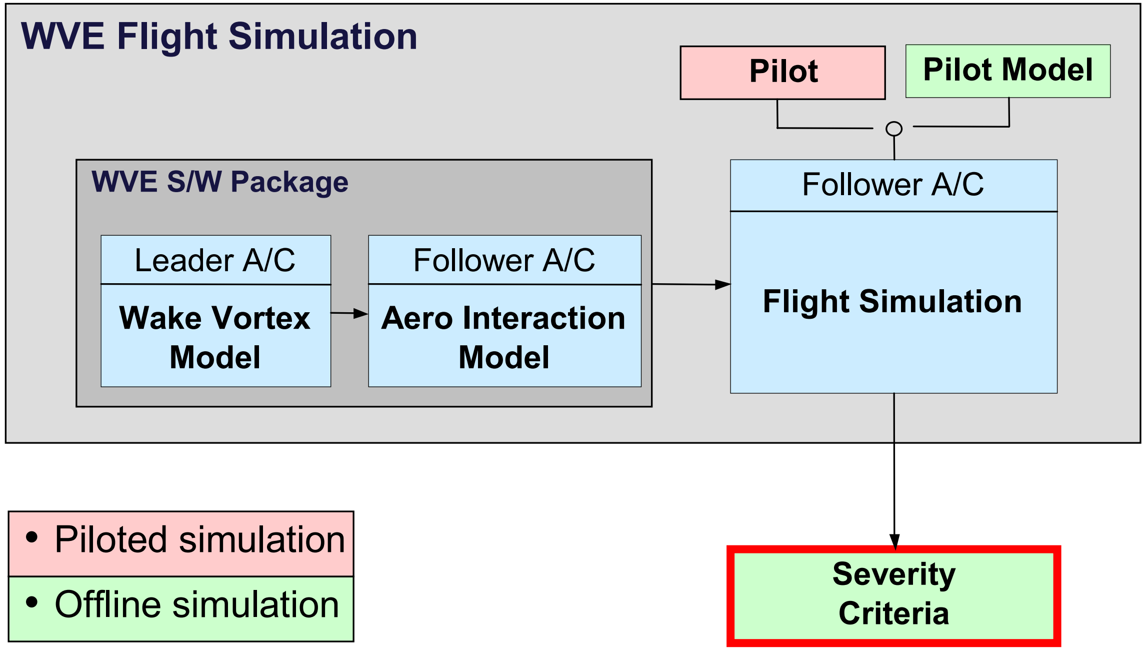
Base Aircraft Simulation

Outlook / Improvements

- Introduction of additional base aircraft model
  (e.g. ICAO “light” category)

VESA Sub Models

VESA models:



- Piloted simulation
- Offline simulation

Validation necessary for the following sub models:

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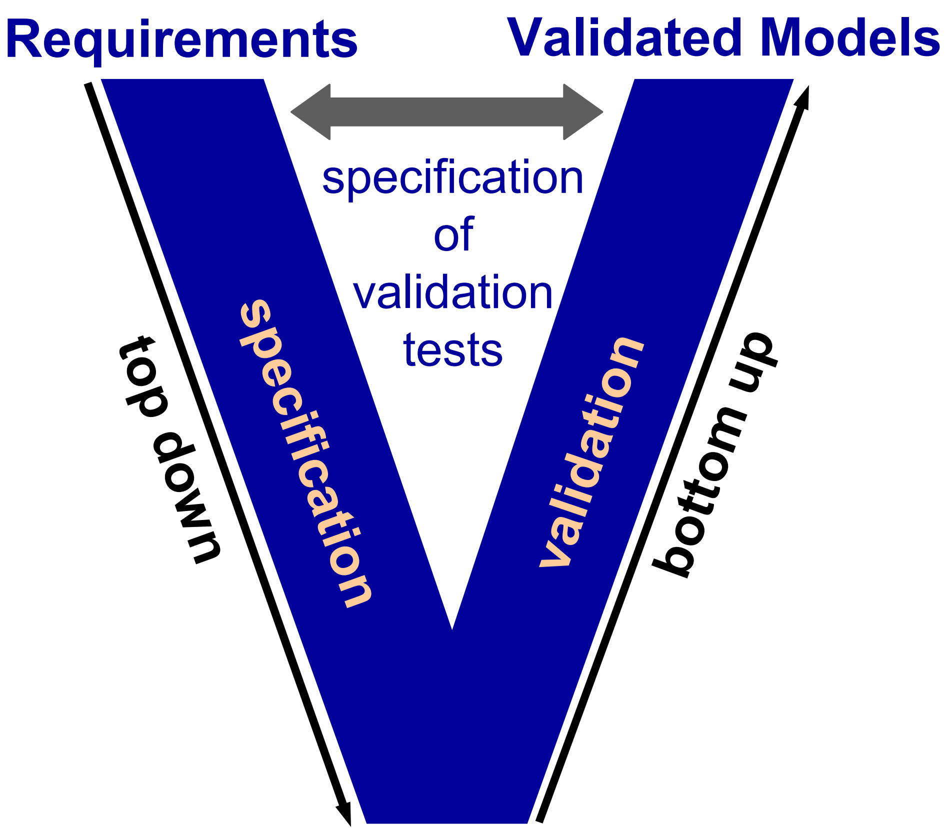
Severity Criteria



Top level requirement:

- Sufficiently accurate description of the wake encounter severity as a function of objective aircraft upsets

Specification of validation tests:

- Correlation of the severity criterion with pilot ratings and pilot comments from piloted simulator tests

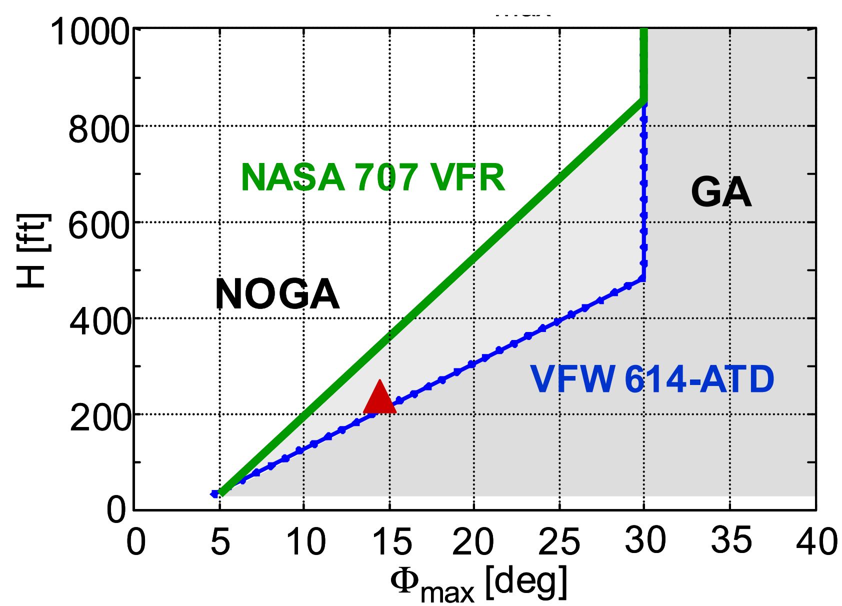
Severity Criteria

Validation data base:

- Insufficient real-life data existing, thus use of data from piloted simulations for
  a) development / parameter tuning and
  b) validation
  (2 independent data groups)

Currently VESA uses a (binary) G/A criterion for severity definition.

More elaborate models are still being evaluated.

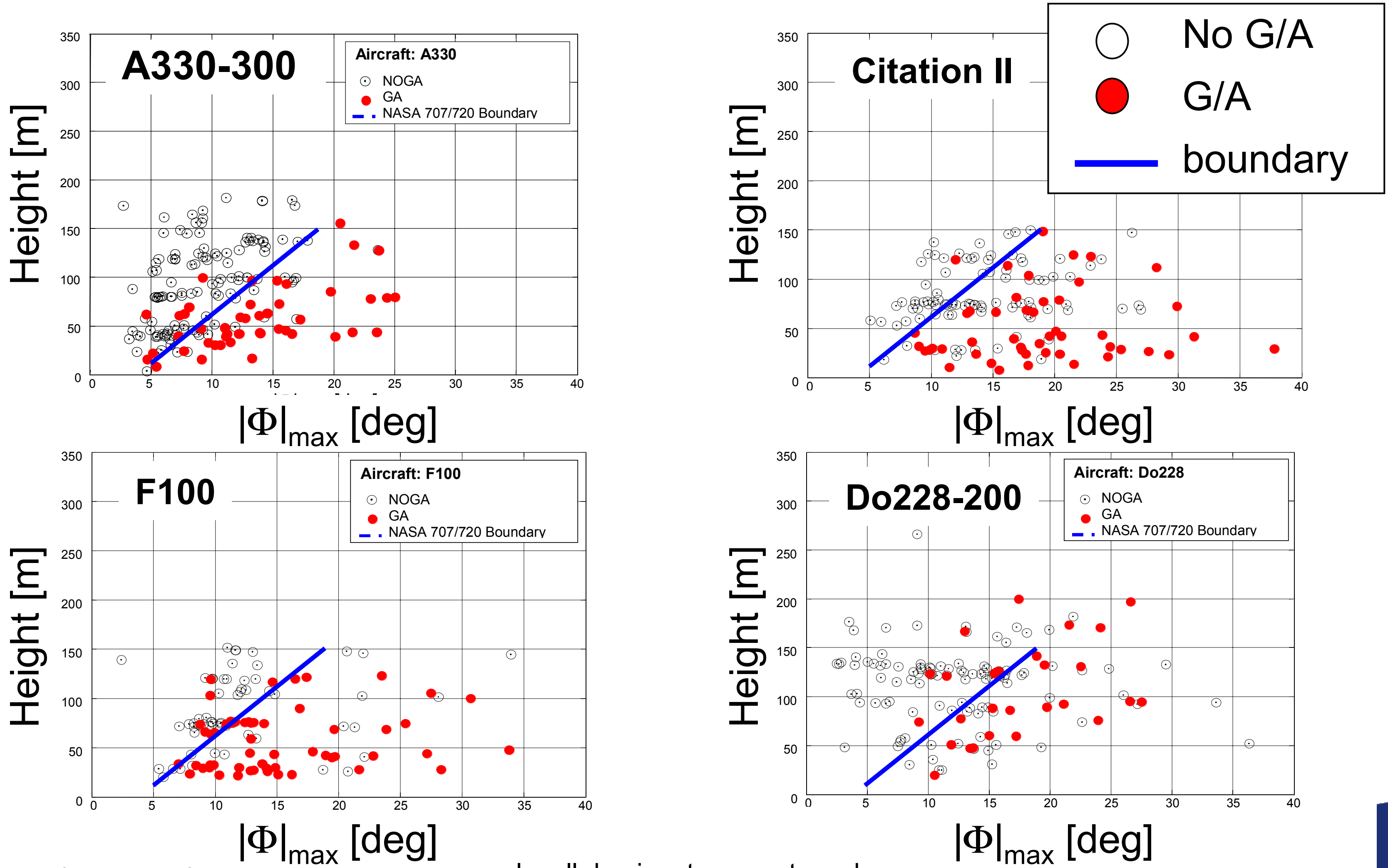


NASA 707/720 boundaries according to:

R. Sammonds, G. Stinnet, W. Larsen, 'Wake vortex encounter hazard criteria for two aircraft classes'; NASA TM X-73,113, June 1976 (also FAA-RD-75-206)

Severity Criteria

Example: NASA 707/720 bank angle criterion applied to different simulation results for G/A discrimination (1/2)



only roll dominant encounters shown

Severity Criteria

Outlook / Improvements

- Establishing of improved and generalized multi-parameter criteria (e.g. multiple objective data → multiple severity levels)
- Validation against piloted simulations AND broad consensus required
- Introduction of WVE model in commercial full-flight simulator(s) and gathering of pilot opinions following surprise encounters

Conclusions

- **Exact validation of a simulation tool like VESA is not possible due to non-availability of comparable data.**
  - VESA validation is thus based on a pragmatic sub model validation.
- **Extensive work performed so far shows good confidence in validation but remains insufficient.**
  - Some sub models need improvement.
  - Additional, more representative data for validation must be gathered (e.g. flight tests).
- **The required scope of validation work can not be assessed technically.**
  - Overal validation requirements can only be based on engineering judgement mutually agreed between authorities, pilots and engineering designers.

Questions ?

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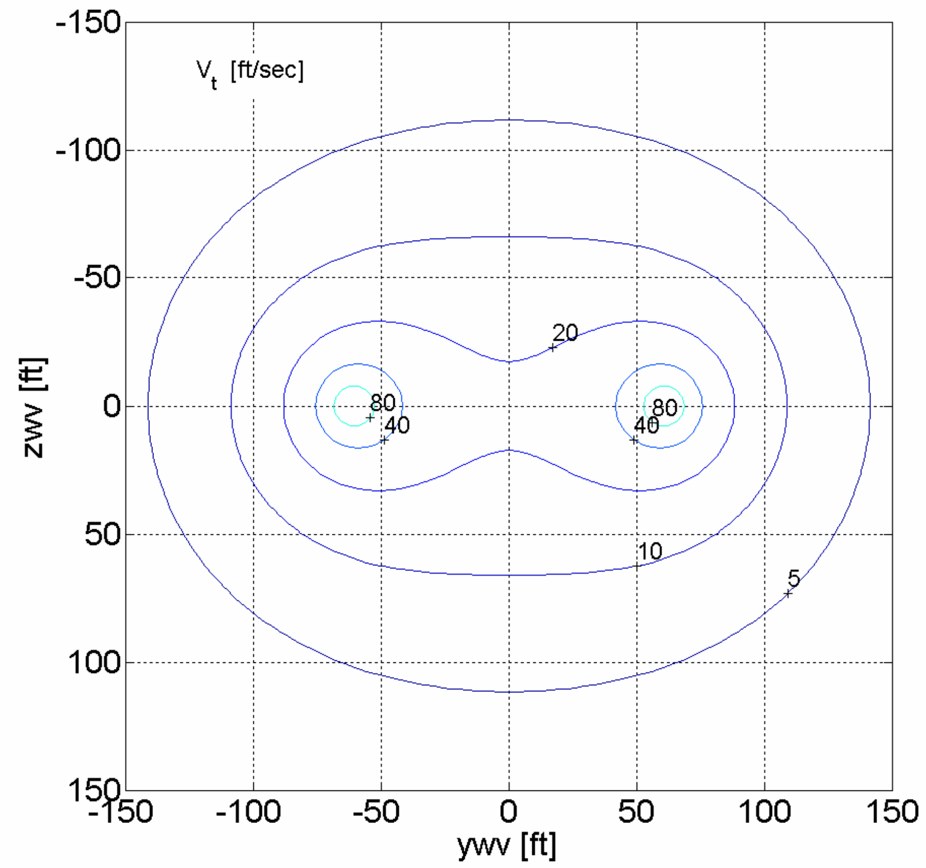
Wake Vortex Velocity Model

Example: Check of implementation

Tangential velocity flow field of a double vortex system calculated by the Burnham-Hallock model implemented in the WVE software package :



Tangential velocity V_t

- Vortex strength : 4160 ft²/sec
- Core radius : 2 ft
- Vortex spacing : 122.4 ft

Identical inputs and results reported by
Eric C. Stewart, NASA (*)

*** „A parametric Study of Accelerations of an Airplane Due to a Wake Vortex System“,**
NASA / TM-1999-208745, May 1999

Base Aircraft Simulation

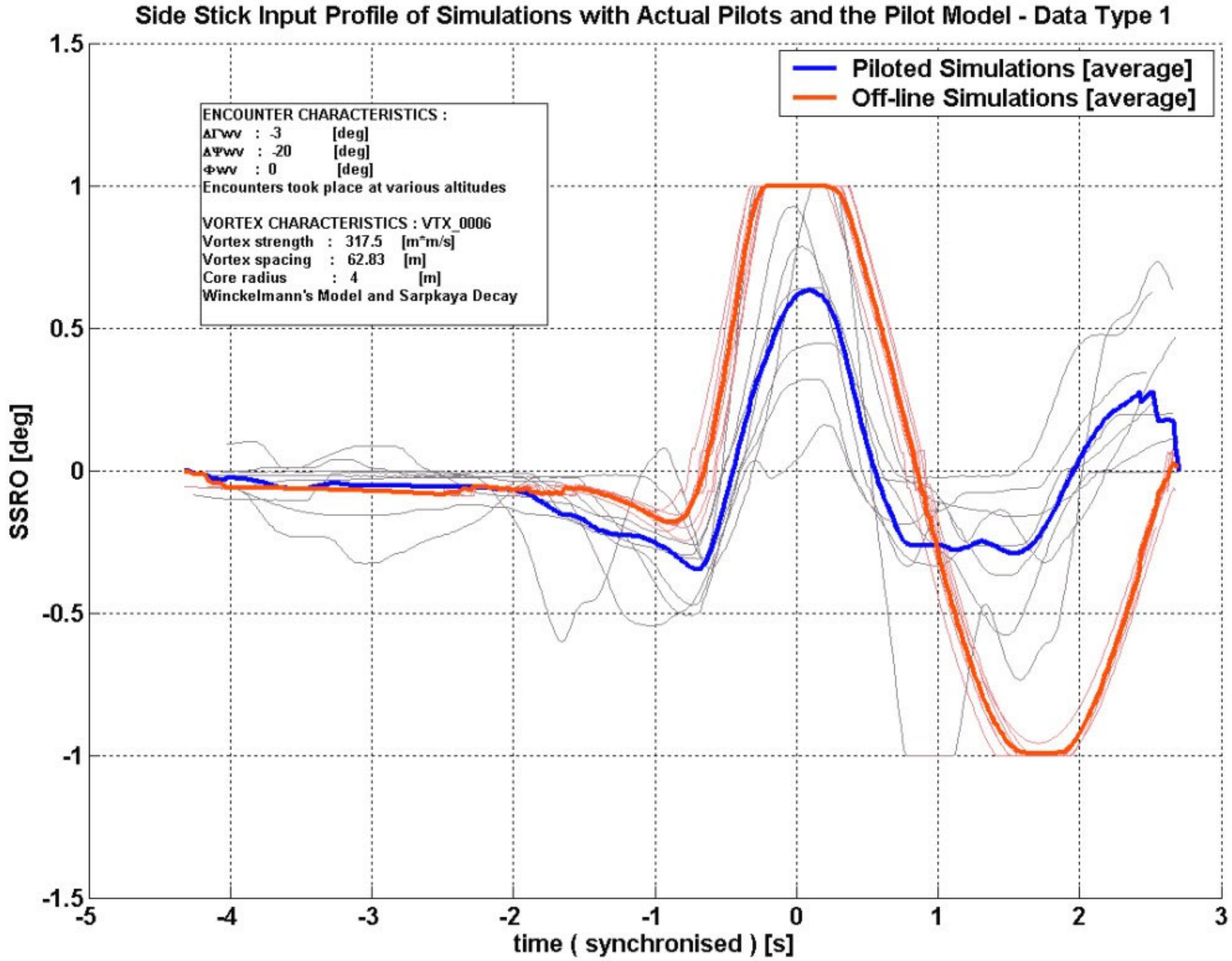
Example: Comparisons of trim conditions between DLR and VESA VFW-614 simulations

No	Flight condition	TAS	ALT	Spoiler	Gear	Flaps
		[m/s]	[m]	[deg]	[up/ down]	[deg]
2.3	steady level flight	100	100	40	down	5
2.4	steady level flight	100	100	40	down	14

Flugzustand	2.3			2.4		
	DLR	DA	Δ [%]	DLR	DA	Δ [%]
α [°]	1.954	1.960	– 0.31	– 0.037	– 0.031	19.36
i_H [°]	1.097	1.092	0.46	1.962	1.959	0.15
$N1_{L/R}$ [%]	84.63	84.37	0.31	89.77	89.58	0.21
F_N [N]	33290.9	33127.4	0.49	39709.3	39647.6	0.16
Ca	0.4084	0.4090	– 0.15	0.4105	0.4111	– 0.15
Cw	0.08518	0.08512	0.07	0.1021	0.1021	0.00
Cm25	0.02088	0.02082	0.29	0.02362	0.02362	0.00

Pilot Model

Example : Comparison of piloted and off-line simulations (pilot model)



Side-stick roll input for VFW614-ATD final approach cases with Γ = 317.5 m²/s and 20° horizontal encounter angle

Severity Criteria

Example: NASA 707/720 bank angle criterion applied to different simulation results as G/A criterion (2/2)

Objective measures

	A330	F100	VFW614	Cessna	Do228
HTR	82.5%	73.9%	65.8%	61.9%	69.2%
POP_{GA}	80.4%	78.6%	96.8%	98.0%	71.4%
POP_{NOGA}	83.2%	69.5%	43.8%	42.4%	68.6%
FAR	36.2%	29.0%	45.1%	50.2%	62.3%
KSS	63.6%	48.1%	40.7%	40.4%	40.0%

- HTR: Hit Rate
- POP_{GA}: Probability Of correct G/A Prediction
- POP_{NoGA}: Probability Of correct No-G/A Prediction
- FAR: False Alarm Rate (G/A predicted but did not occur)
- KSS: Kuiper's Skill Score (overall quality criterion)

only roll dominant encounters shown