

FMRA

Fachgebiet Flugmechanik, Flugregelung und Aeroelastizität



Berlin Institute of
Technology

Application of Wake Vortex Models in Encounter Simulations

D. Bieniek, R. Luckner – November 7th/8th, 2011
WakeNet3 - Europe Specific Workshop: Operational Wake Vortex Models

Application of Vortex Models in...

- Flight Simulation
- Parameter Studies
- Simplified Encounter Simulation
- Fast-time Simulations

What we need...

- **For Detection, Warning and Avoidance Systems:**

(Objective: Evaluate potential of such systems)

- Models for vortex transport by wind
- Models for vortex descend by mutual induction

- **For Encounter Simulation:**

(Objective: Simulate aircraft upset due to the vortices)

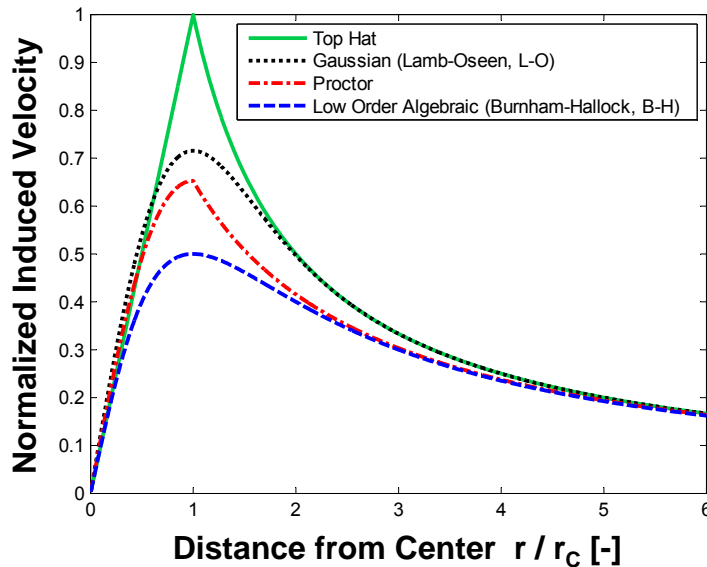
- Models for vortex-induced velocity field
- Approx. 1m resolution
- Parametric models, scalable models
- Analytical or numeric models
- Models with low computational effort
(e.g. real-time or fast-time simulations)

Subject of this
presentation

Analytical Models

e.g. Low-order algebraic
(Burnham-Hallock, B-H)

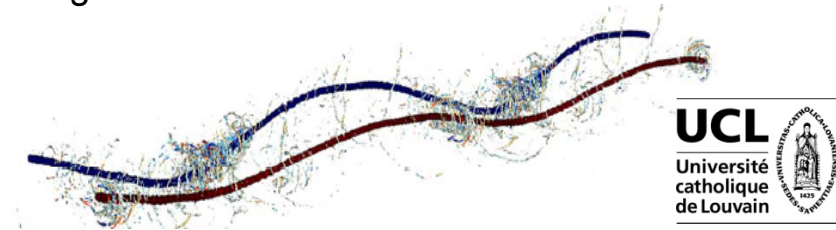
$$V(r) = \frac{\Gamma}{2 \cdot \pi} \cdot \frac{r}{r_c^2 + r^2}$$



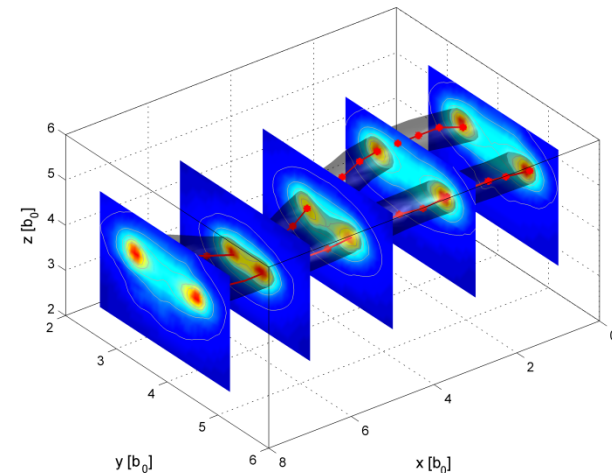
- Limited accuracy
- Low computational effort
- Quick variation of parameters

Numerical Simulation Data

e.g. LES Data

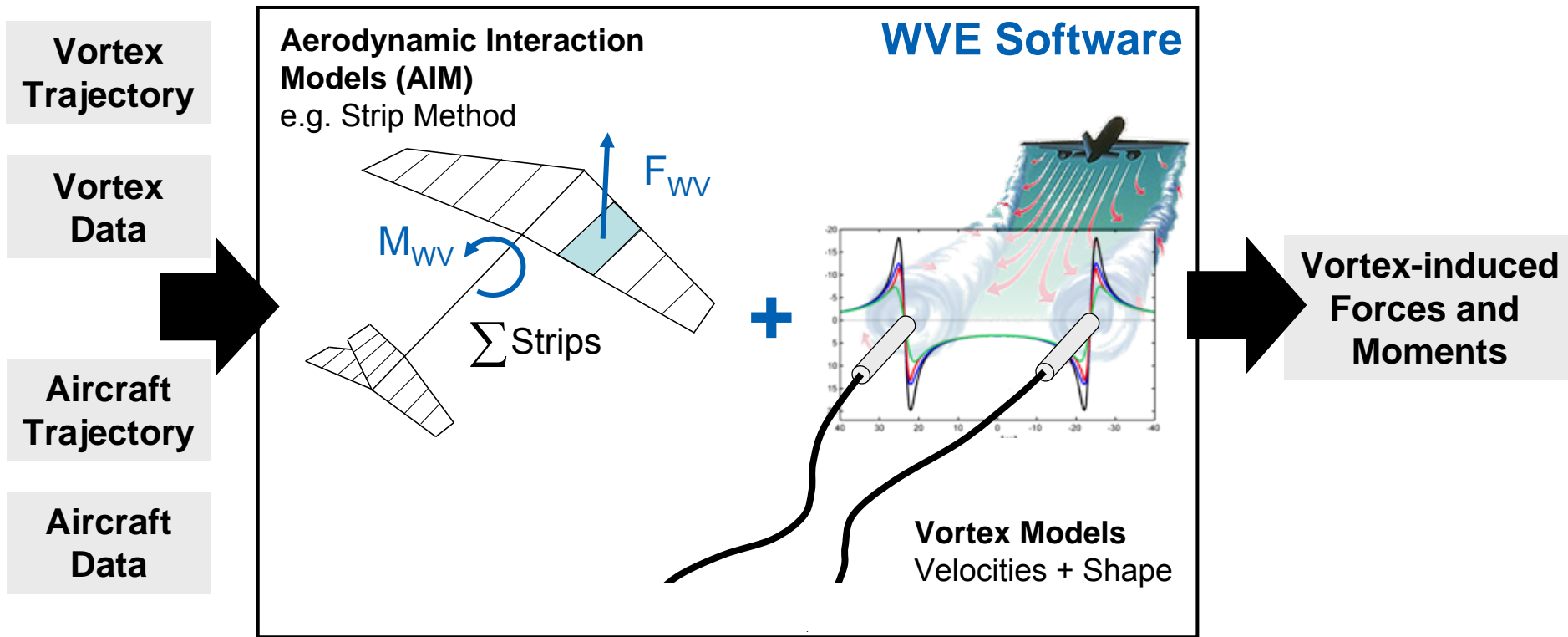


Source: I. De Visscher et al. (UCL)

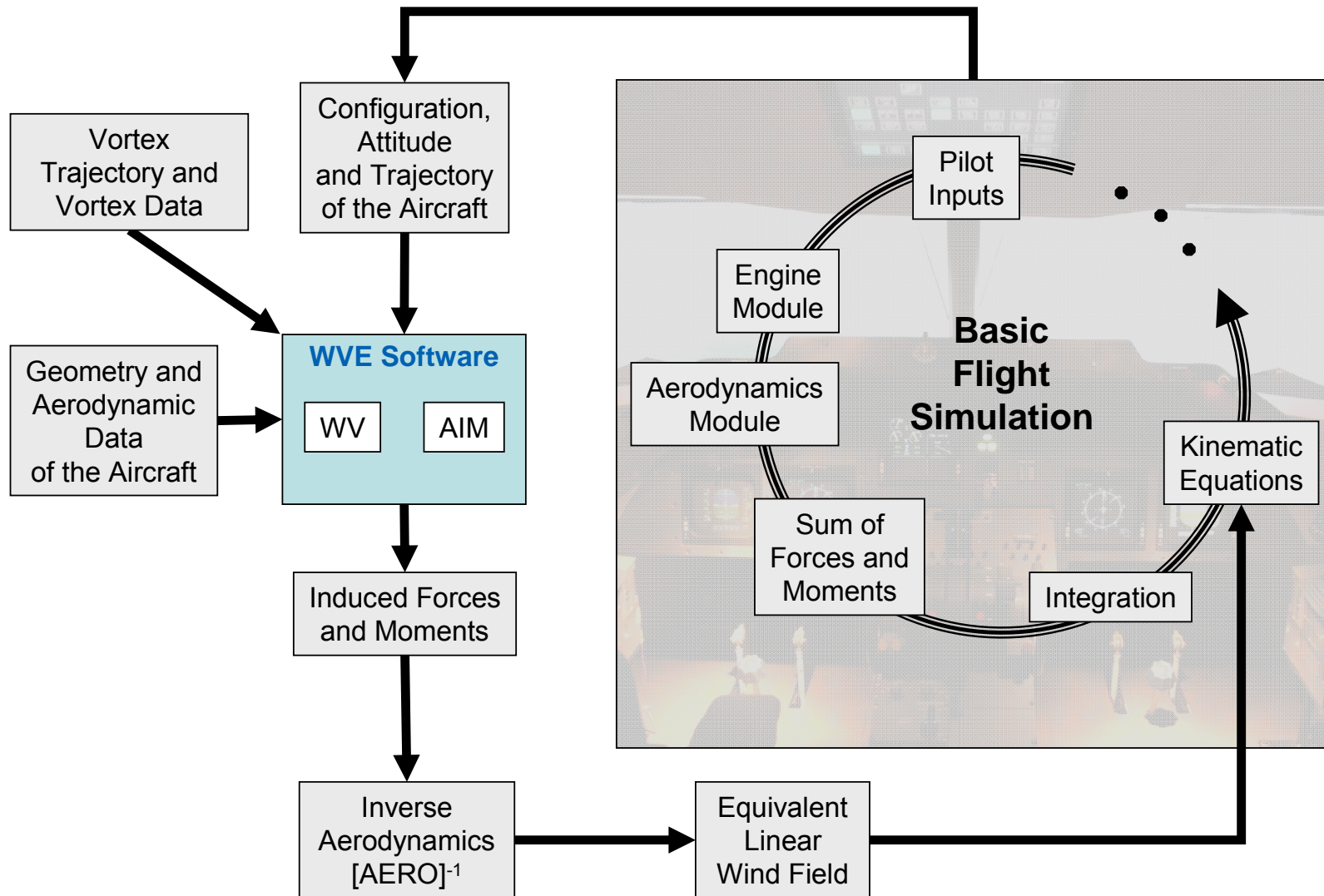


- Accurate data
- High computational effort
- Variation of parameters requires time consuming simulation

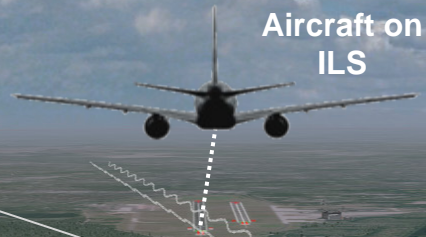
Integration of Operational WV Models into WV Encounter Simulation



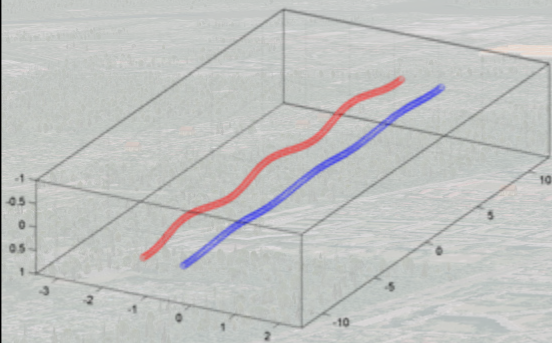
Wake encounter software package from S-WAKE
is being improved continuously



Combination of parametric models
Flow field and deformation fixed in
space and time during encounter

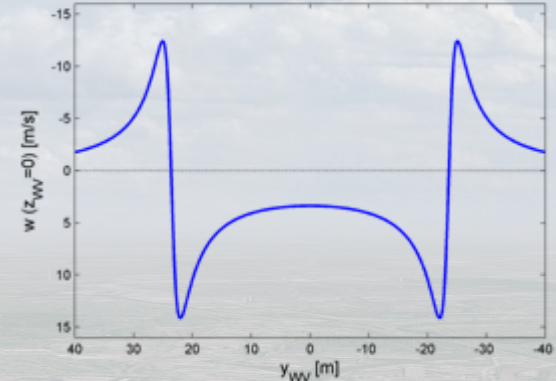


Analytical Model for Deformation



Source: Loucel, Crouch, AIAA 2004

Model for Flow Field



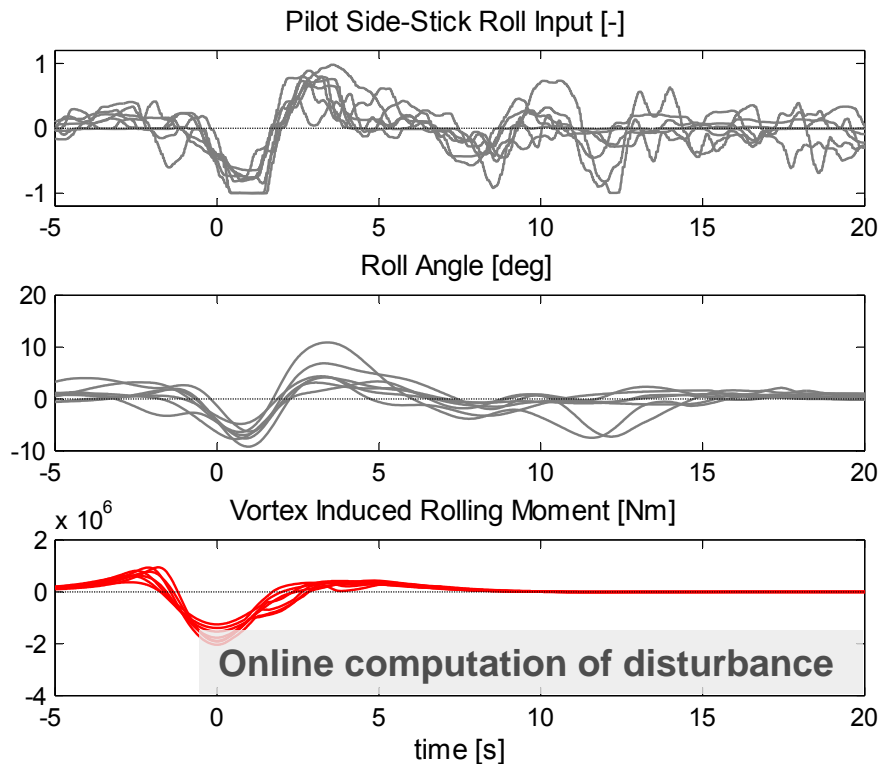
Screenshot from SEPHIR Simulator at TU Berlin

Movie 1

Movie 2

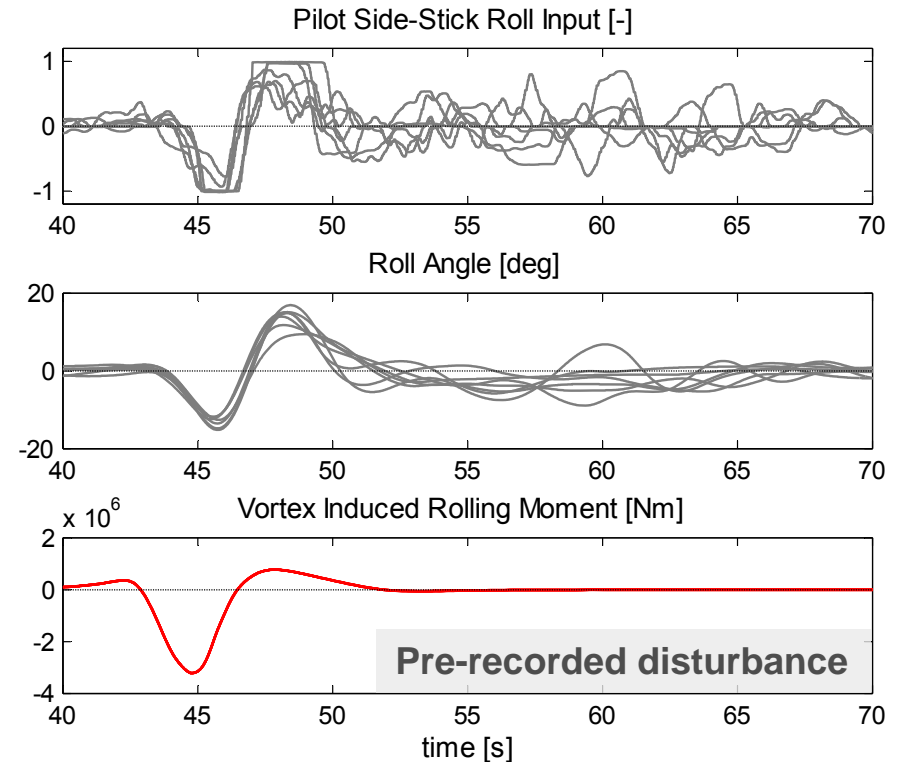
“Free” Encounters

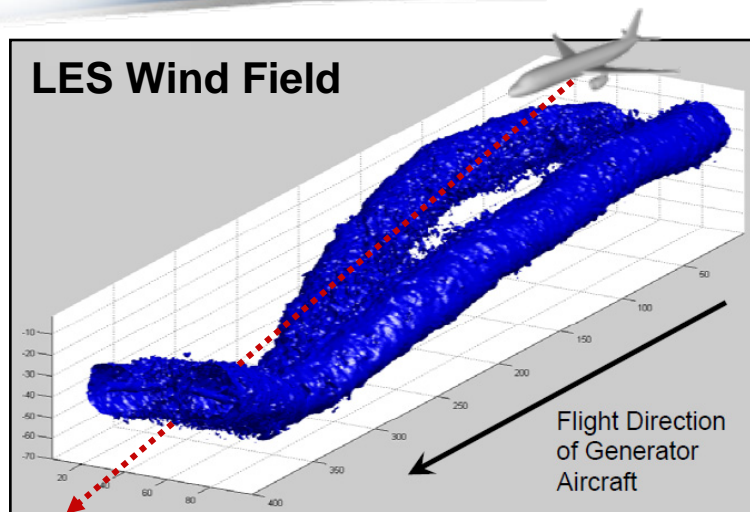
- Complete simulation of encounter
- Multiple comparable encounters



“Fixed” Encounters

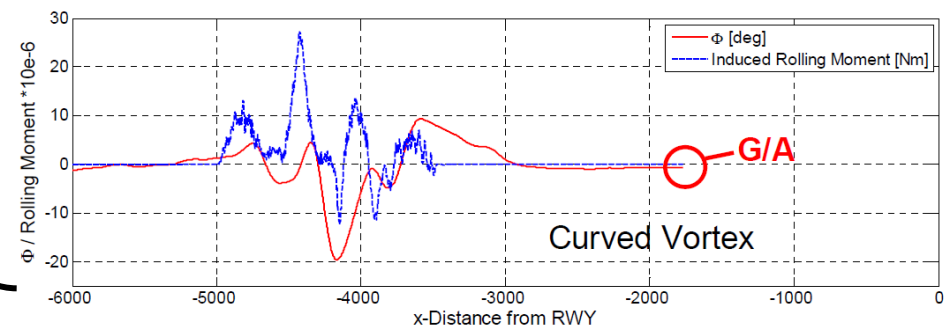
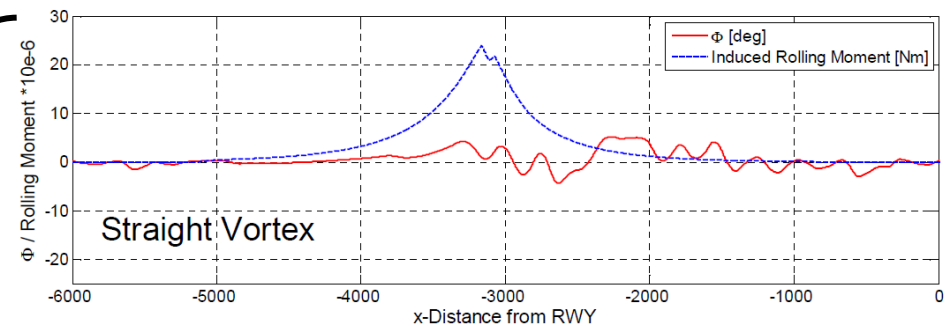
- Fixed vortex disturbance
- Multiple identical encounters





Piloted encounters with curved vortices

- Use of LES data to acquire vortex wind field
- Pre-defined flight tracks
- Comparison of straight and curved vortices



AIM

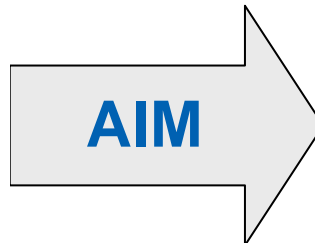
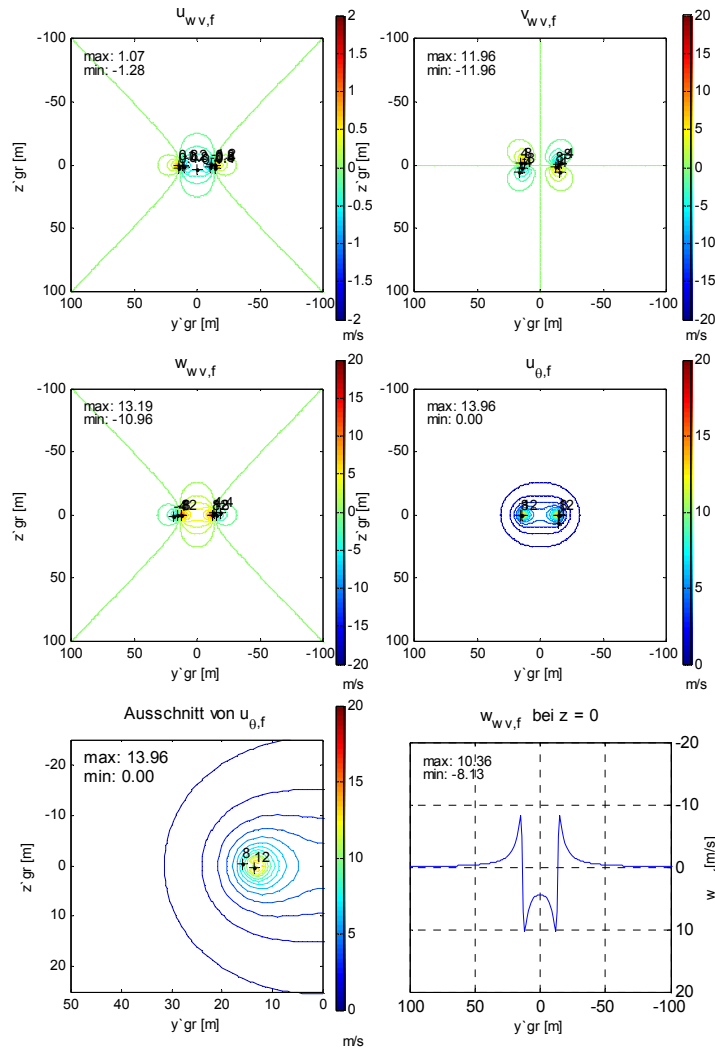
F_{wv}

M_{wv}

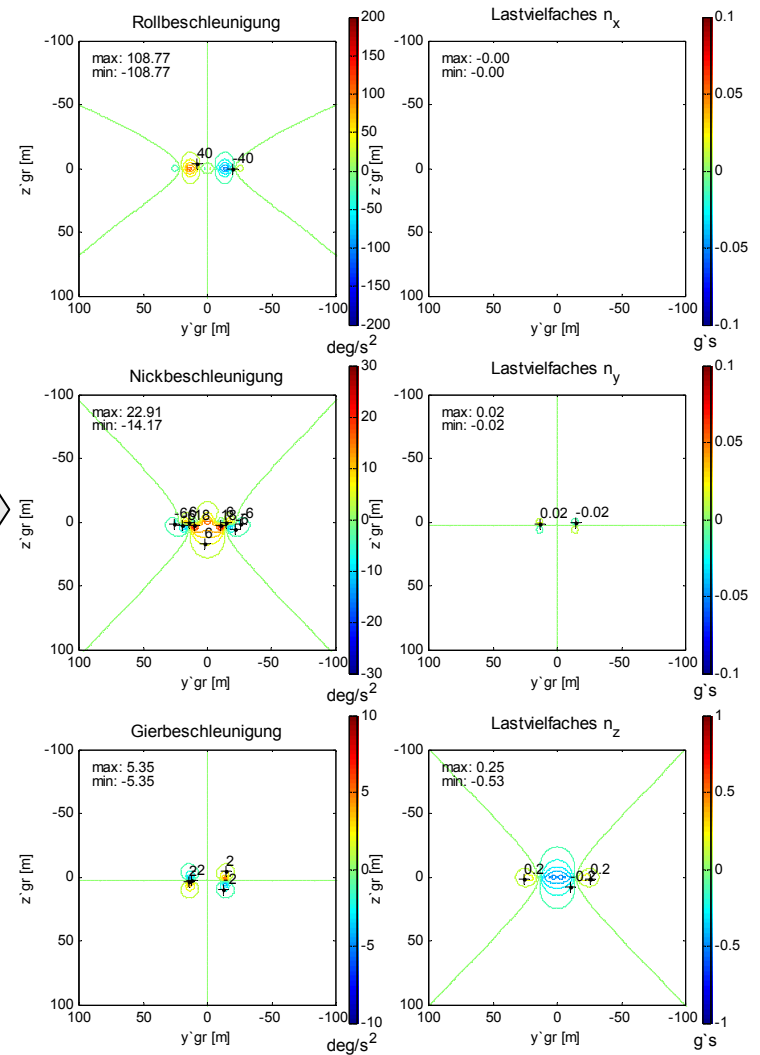


Simulator Campaign in ZFB A330 full-flight simulator at TU Berlin in 2009

Vortex-induced Velocities

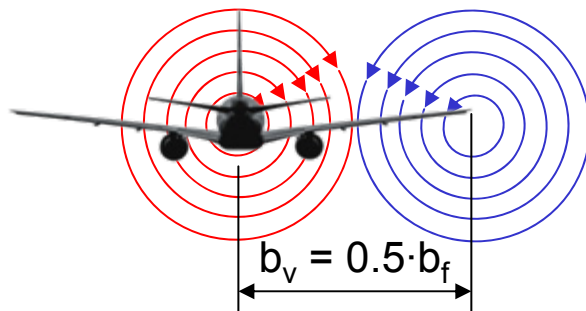


Vortex-induced A/C Accelerations



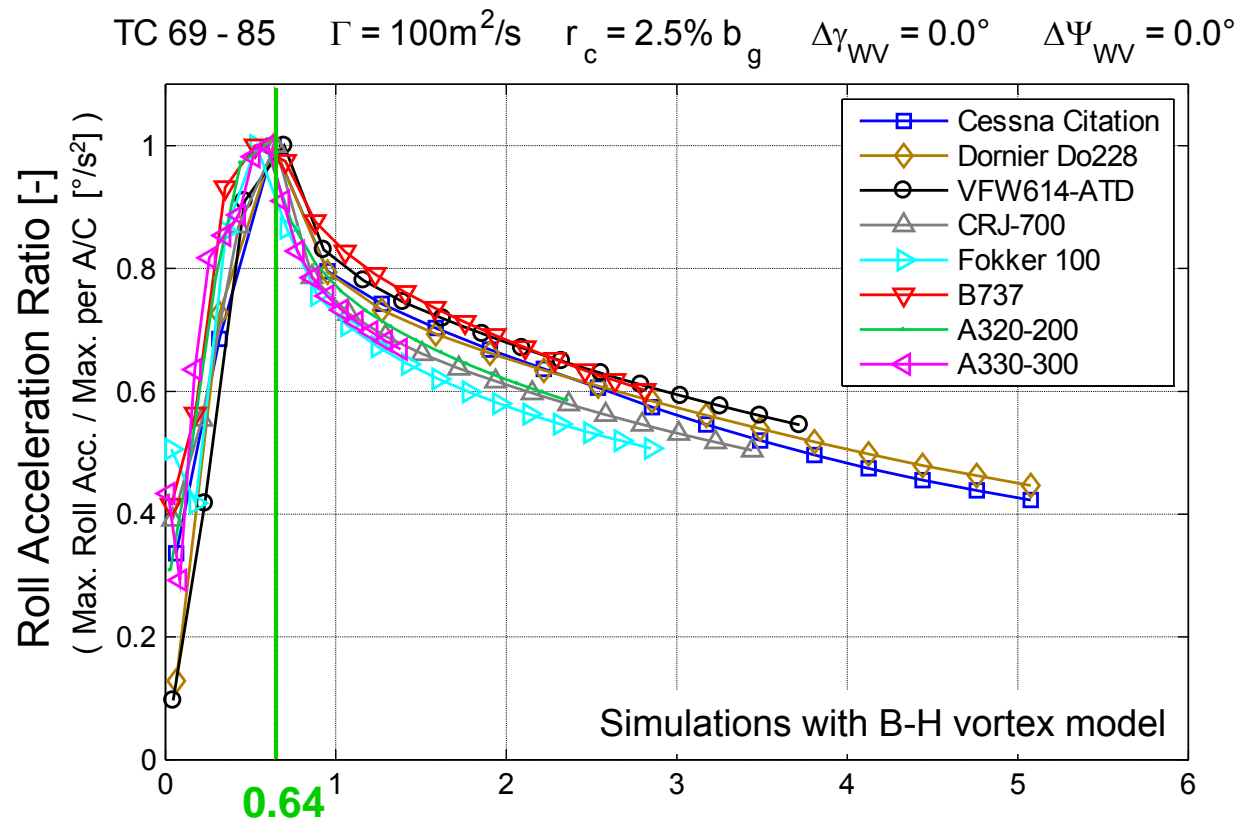
Example: Wing Span Ratio Effects

Theoretical Worst Case

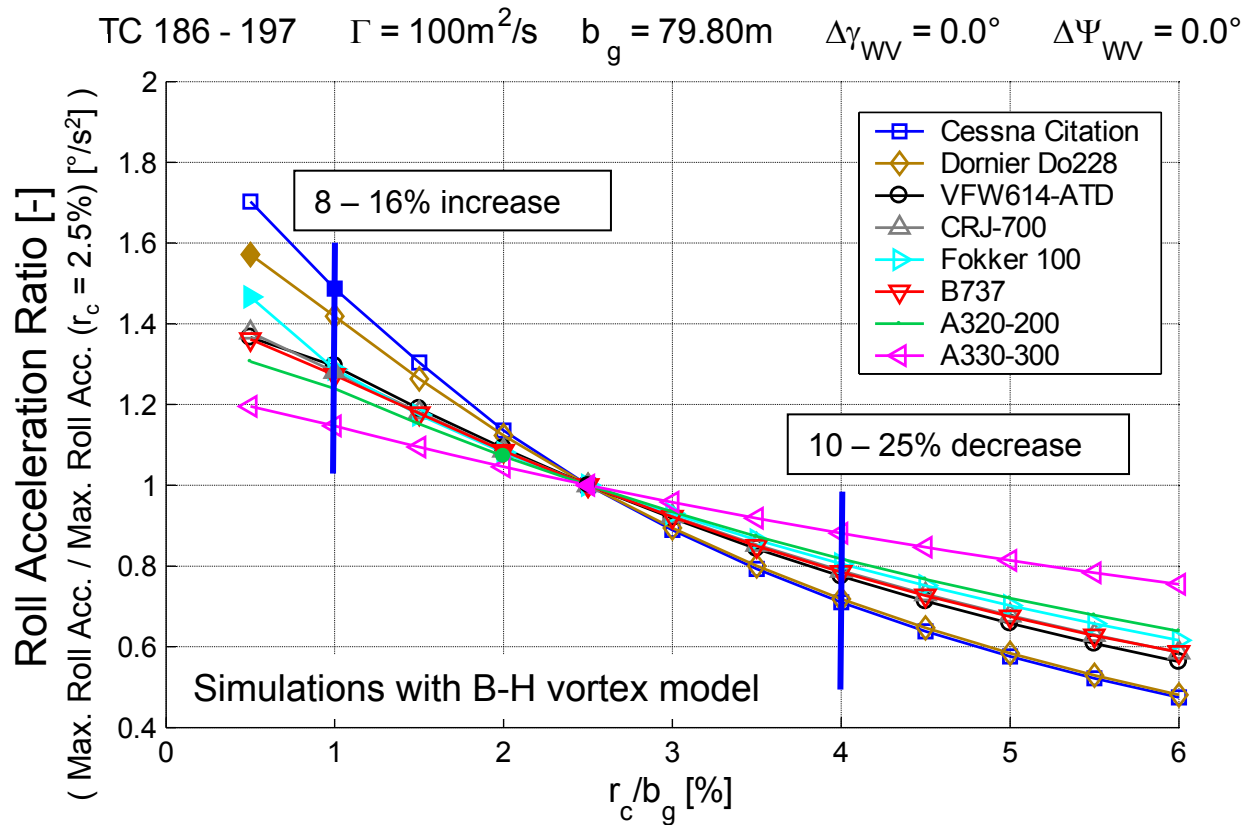


$$0.5 \cdot b_f = b_v = \pi/4 \cdot b_g$$

$$b_g/b_f \approx 0.64$$



Example: Core Radius Effects

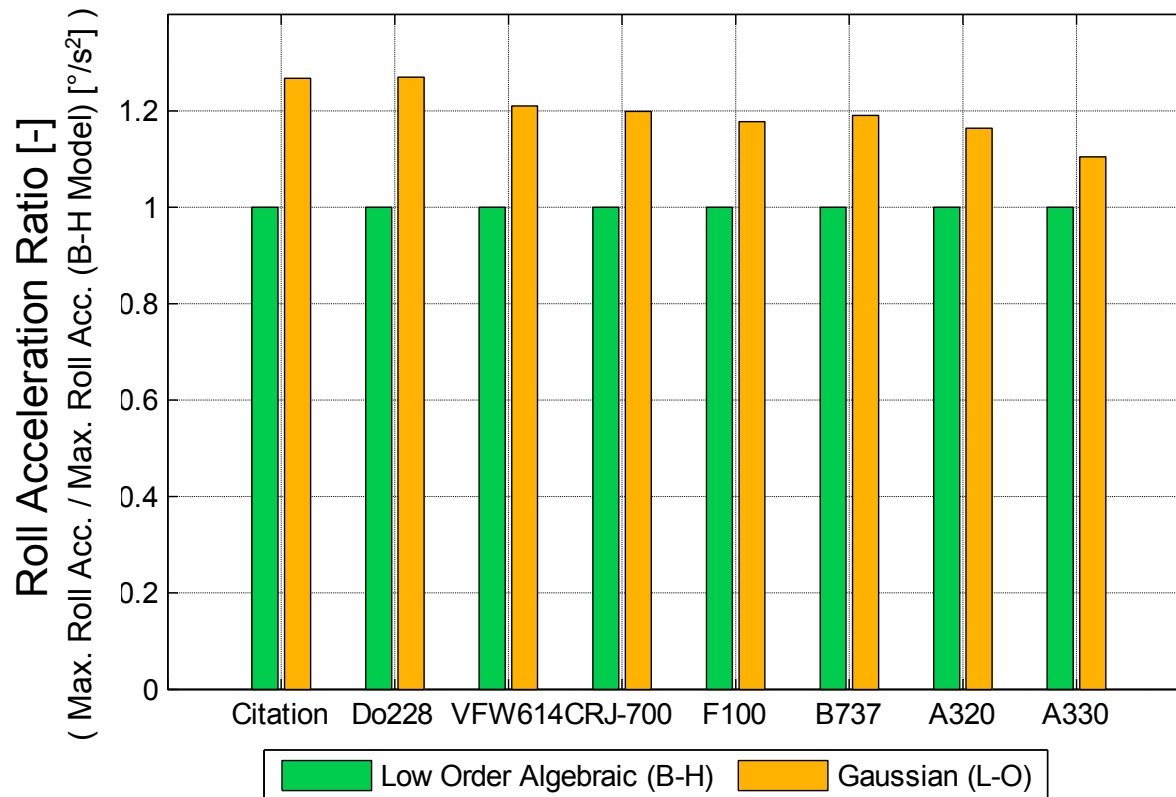


Size of follower aircraft (mainly wingspan, moment of inertia) has significant impact on Roll Acceleration Ratio versus r_c/b_g

Research need to identify core radius size

Example: Vortex Model

$$\Gamma = 100 \text{m}^2/\text{s} \quad r_c = 2.5\% b_g \quad b_g = 79.80 \text{m} \quad \Delta\gamma_{\text{wv}} = 0.0^\circ \quad \Delta\Psi_{\text{wv}} = 0.0^\circ$$

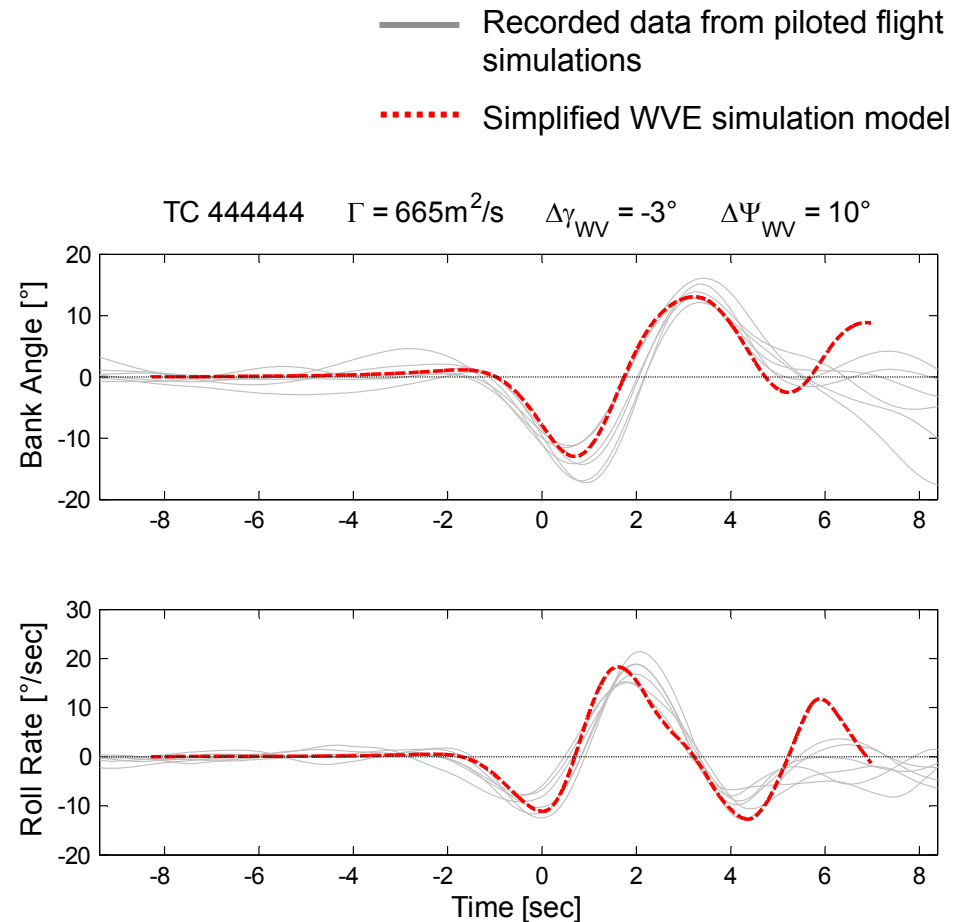
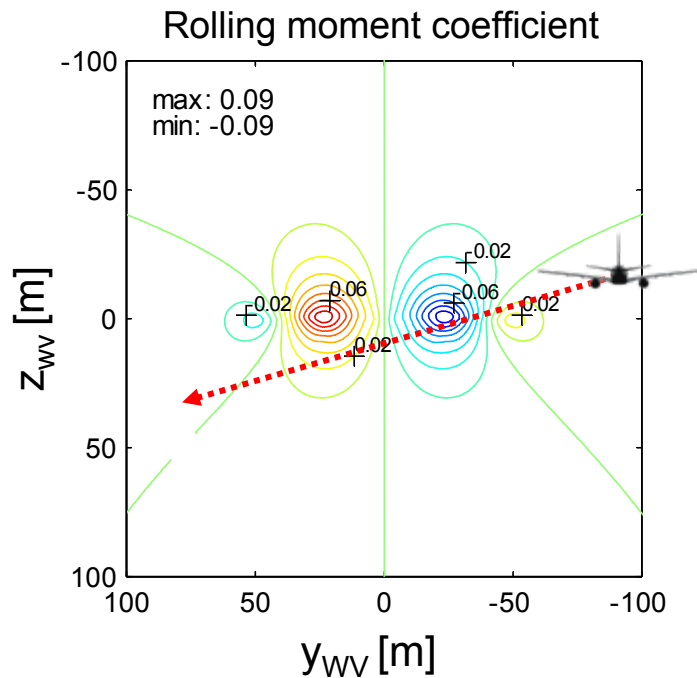


Vortex model selection has a significant impact on Roll Acceleration Ratio

Effect varies with size of follower aircraft

Validated parametric vortex velocity field models are needed

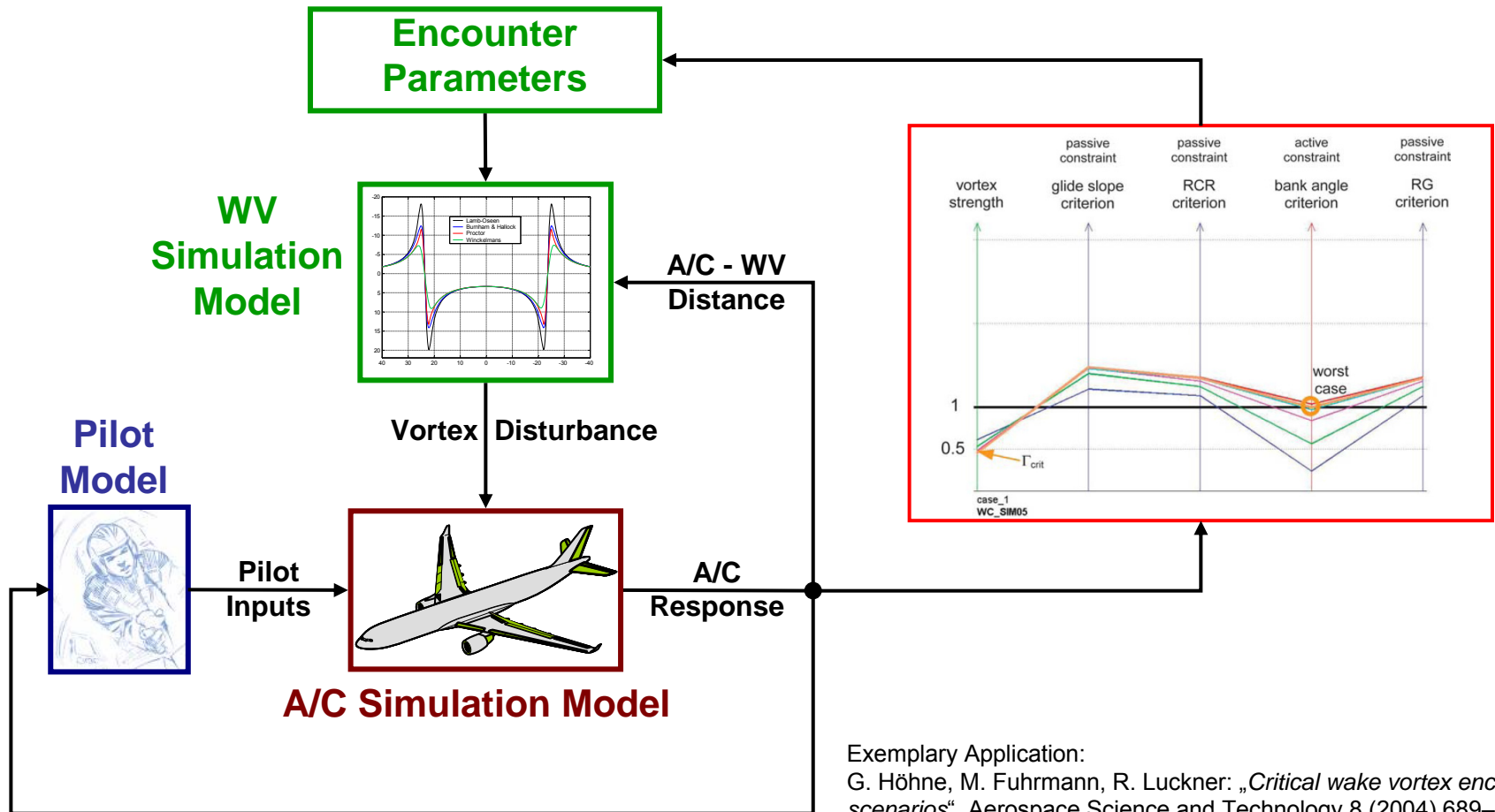
- Straight flight path to compute vortex disturbance
- Linear 1DoF model for aircraft roll motion
- Generic control surface deflections (Pilot model + FCS model)



Simplified dynamic WVE model: option for RECAT Phase II or III methodology

Worst-Case Search

Anti-optimization to identify worst-case encounter conditions

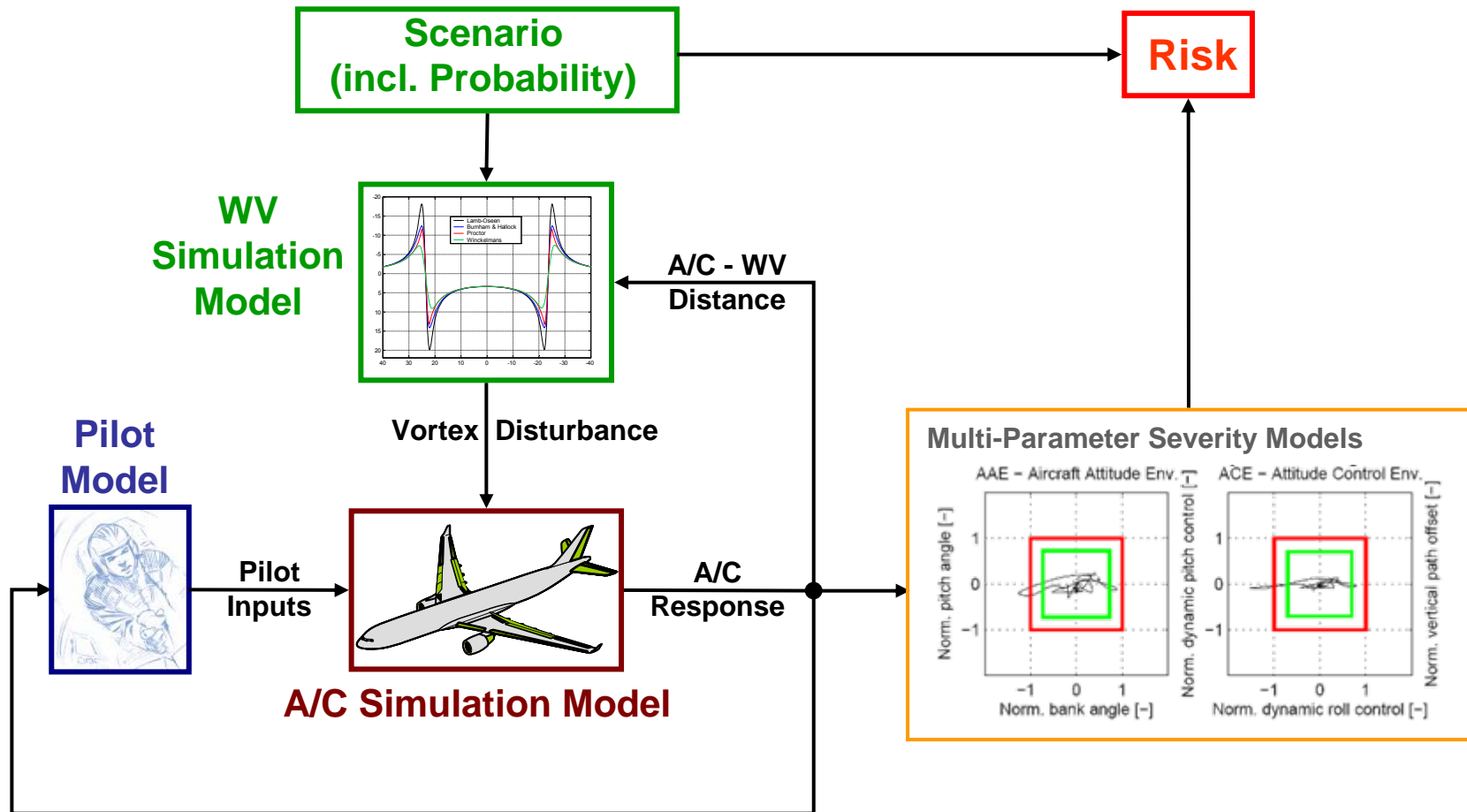


Exemplary Application:

G. Höhne, M. Fuhrmann, R. Luckner: „Critical wake vortex encounter scenarios“, Aerospace Science and Technology 8 (2004) 689–701, 2004

Risk Analysis

Monte-Carlo Simulations with tools such as VESA / WakeScene



- **Criteria and data for WV model validation are needed.**
- **Uncertainties regarding values of important parameters have to be addressed (e.g. core radius, vortex span).**
- **Interaction of aircraft surfaces and wake vortex flow field is not considered in current encounter simulations.**
→ **How strong are the effects?**

- **Interdisciplinary cooperation between vortex modeling (fluid dynamics) and encounter simulation (flight dynamics) is important for model development (fit for purpose).**
- **WVE simulation provides results on parameter sensitivities and importance of model parameters.**
- **WV models in WVE simulations directly affect aircraft upsets (e.g. max. bank angle) and consequently pilot's severity rating.**
- **For severity assessments and safety analysis, validated WV (and WVE) models are essential.**

Thank you for your attention!

Questions?

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