



Curved wake vortices encounter simulations with pilots-in-the-loop

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WakeNet3-Europe Workshop on

Models and Methods for Wake Vortex Encounter Simulations



Content

- Introduction
- Simulator Campaign in ZFB A330 Simulator
- Flight Test with ATTAS
- Conclusions





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Introduction

Why simulate encounters with curved wake vortices?

- Matured wake vortices are never straight in reality
 - Evolution of vortex shape depends on atmospheric conditions
 - During decay process vortex shape alters significantly
- Vortex curvature has influence on encounter characteristics
 - To gain simulation outputs applicable to reality necessary to take vortex curvature into account
- For realistic feel of wake encounter in simulators straight vortices are insufficient
 - Pilots' reaction only representative if impression is realistic



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A330 Simulator Campaign

Introduction

- Simulator campaign in A330 full-flight simulator (ZFB) in June 2009
 - Comparison of encounters with straight and curved vortices
 - Investigation on autopilot behaviour during wake encounter
- A330 simulator certified for training
- Separate simulation host for research
- Campaign conducted with airline pilots and test pilots



[Fotos: ZFB]

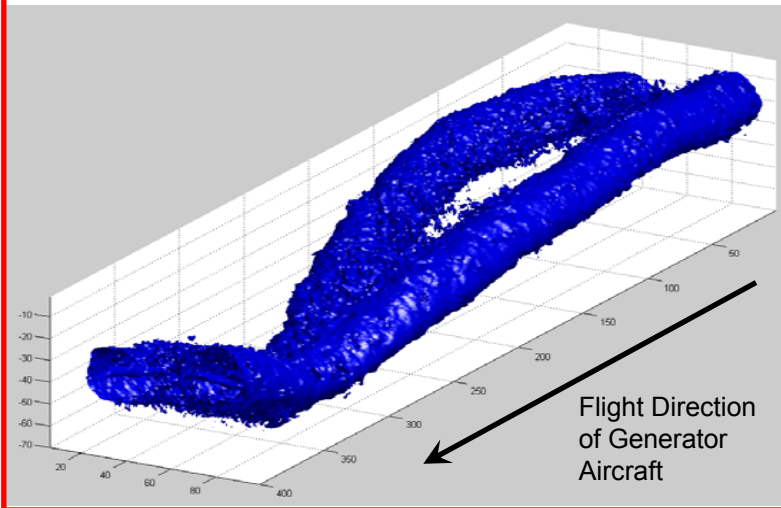


Vortex Flow Fields and Simulation

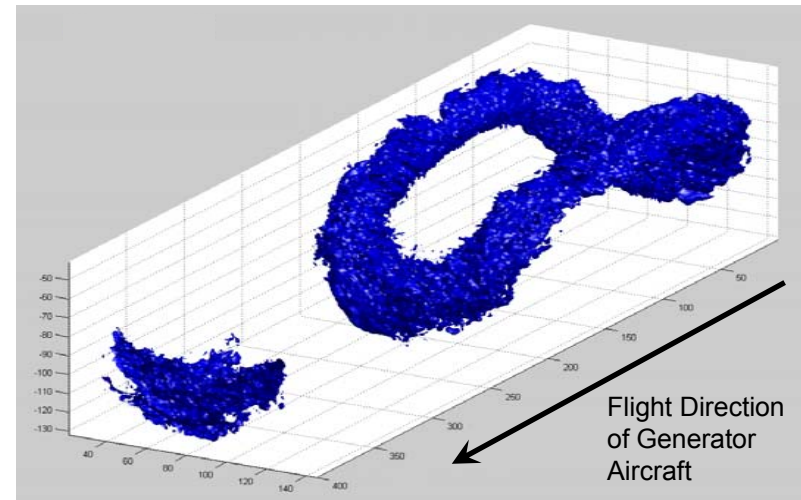
Large-Eddy-Simulations

- LES performed by DLR Institute of Atmospheric Physics
- Generator aircraft A340-300
- 3-D flow fields in 4 seconds steps $[u,v,w] = f[x,y,z,t]$

t = 108s (~4nm)
moderate turbulence



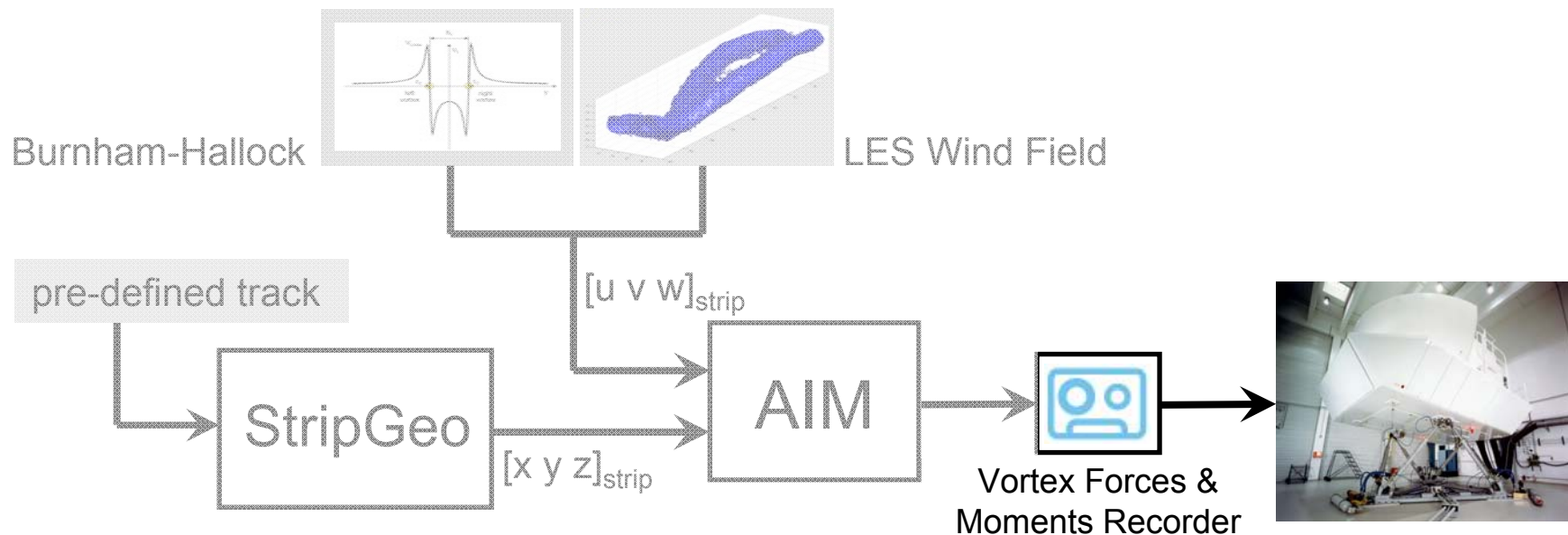
t = 288s
no turbulence



A330 Simulator Campaign

Vortex Data

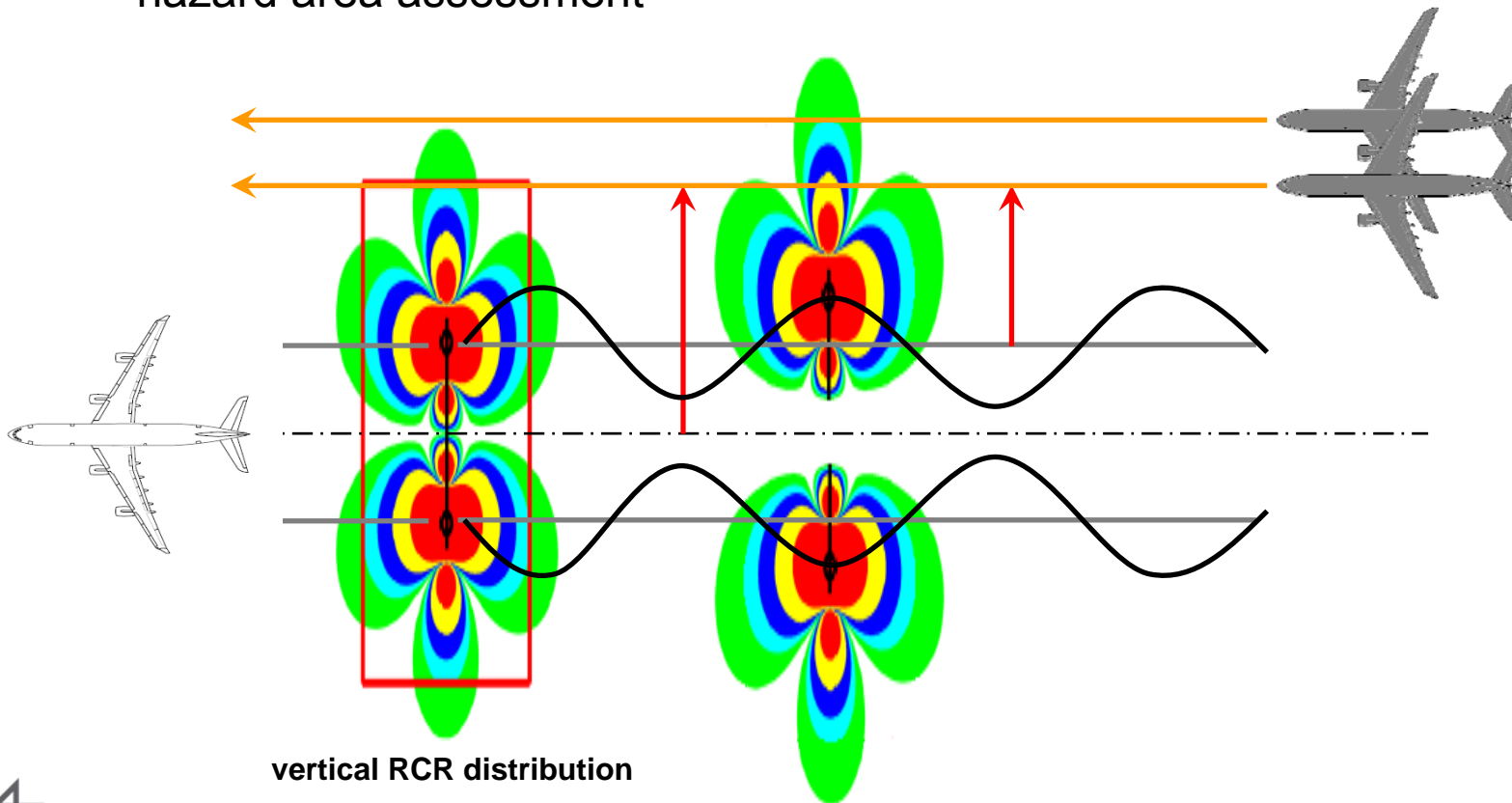
- Encounter-Simulations performed using time-fixed, pre-recorded vortex force and moment histories
- Straight vortices with Burnham-Hallock radial velocity distribution
- Curved vortices from Large-Eddy-Simulations



A330 Simulator Campaign

Encounter Scenario

- Wider lateral spread of curved vortices must be taken into account for hazard area assessment



vertical RCR distribution

A330 Simulator Campaign

Experimentation

➤ Scenario

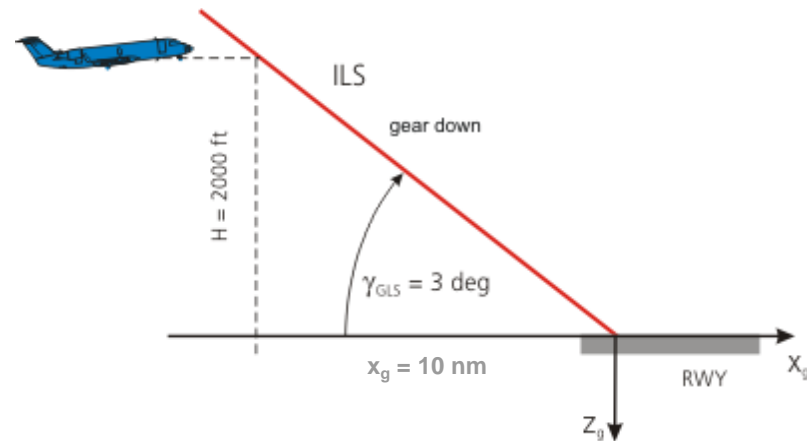
- Height above Ground: 2000ft
- Position: 10-Miles-Final (on LOC. / below G/S)

➤ Pilot Task

- Perform ILS approach on FRA ILS25R under VMC
- Act as if in real flight (callouts, procedures, G/A decisions etc.)

➤ Rating

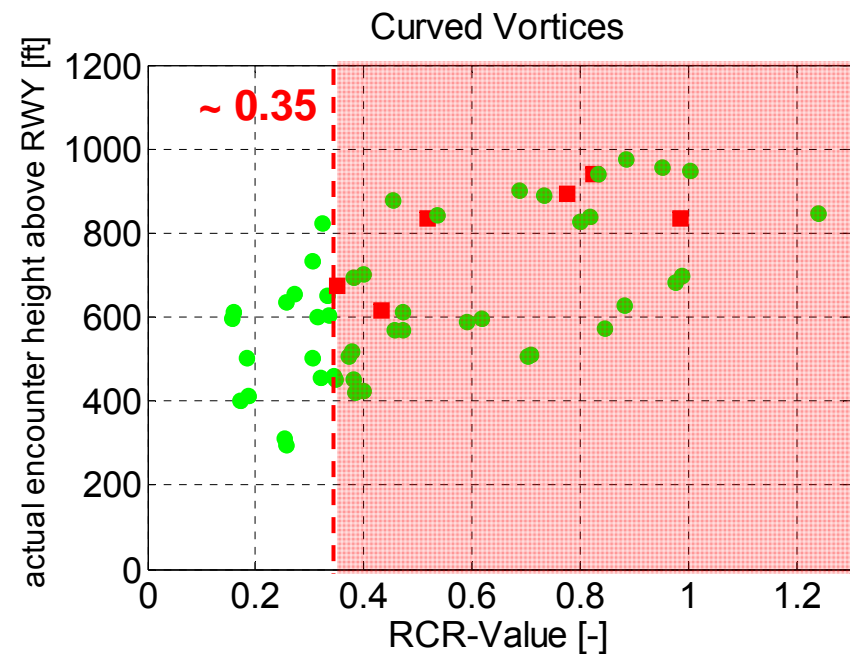
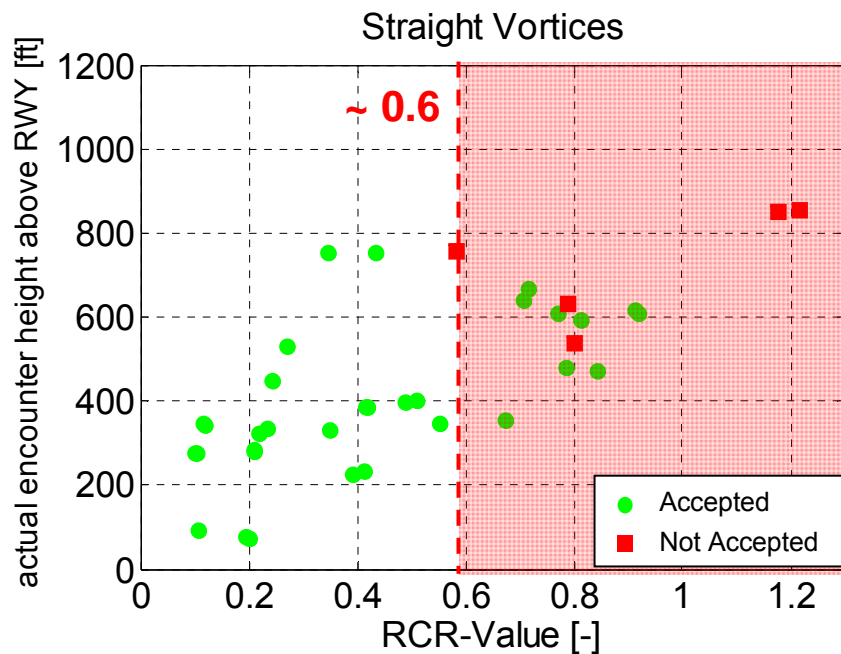
- A/C Control
- Demands on Pilot
- A/C Excursions
- Hazard



A330 Simulator Campaign

Encounter Matrix

➤ Only 11.6% (11 of 95) unaccepted encounter

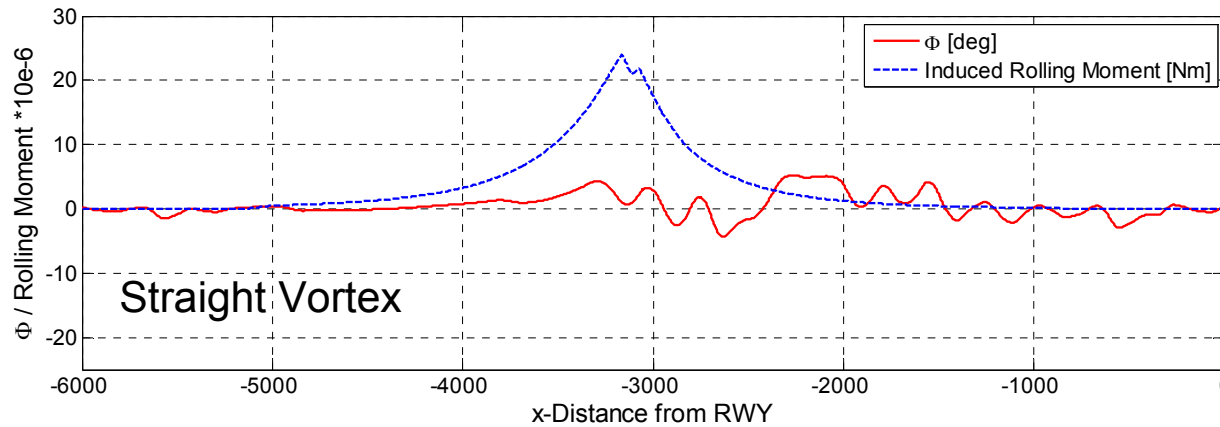


➤ Previous investigations revealed acceptance threshold of $RCR = 0.2$ (conventional controls, straight vortices)



A330 Simulator Campaign

Straight ↔ Curved Vortices



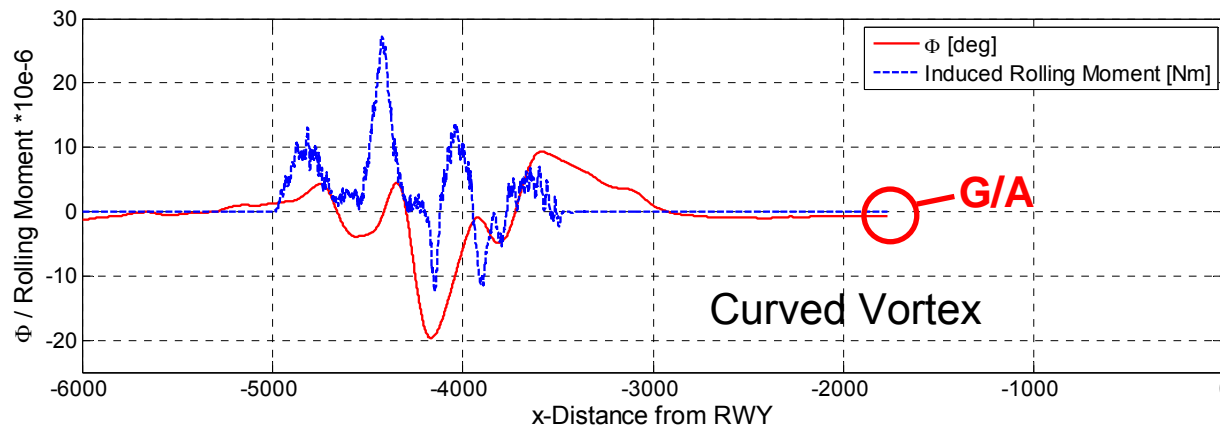
nominal RCR = 1.0

Playback Height = 900ft agl.

Encounter Situation:

$\Delta\gamma = -3^\circ$ / $\Delta\Psi = 0^\circ$ (left)

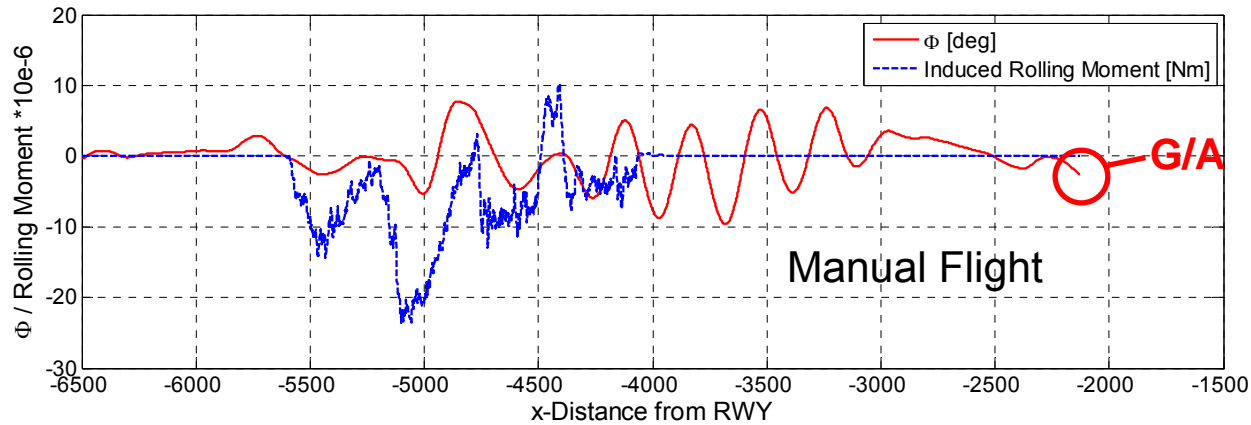
manual flight





A330 Simulator Campaign

Manual Flight ↔ A/P Engaged



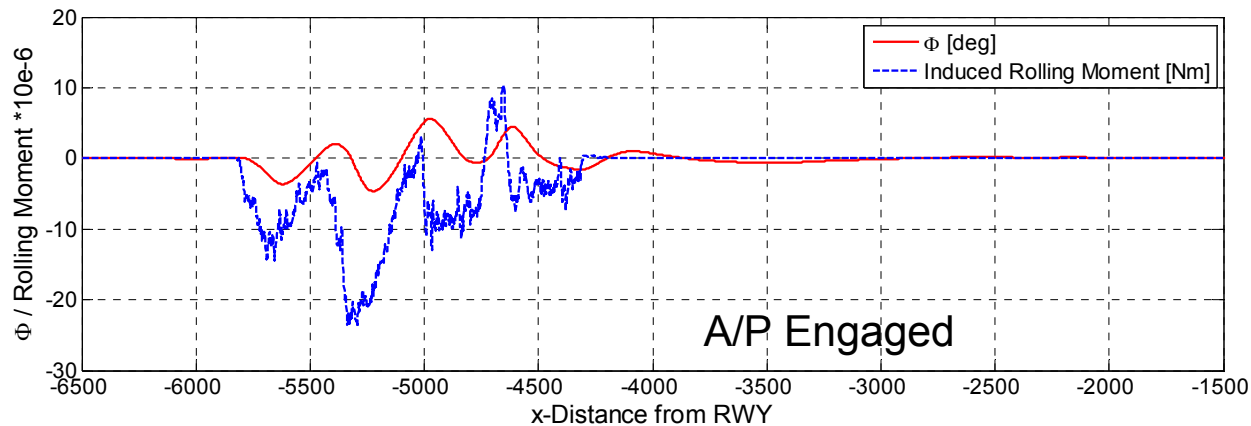
nominal RCR = 0.9

Playback Height = 1040ft agl.

Encounter Situation:

$\Delta\gamma = -3^\circ / \Delta\Psi = 0^\circ$ (right)

curved vortices





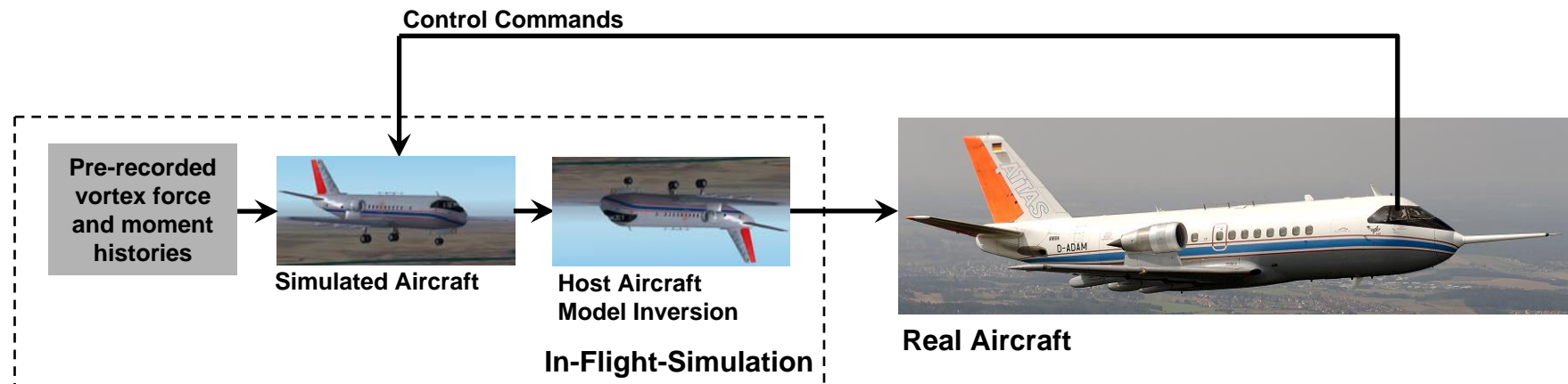
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ATTAS Flight Test

- Worldwide first-time wake encounter with curved vortices simulated in flight test
- Encounter performed during approach
- Vortex data from LES
- Time-fixed encounters using pre-recorded force and moment histories





ATTAS Flight Test





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Conclusions

- Forces and moments histories of curved and straight vortices significantly different
 - Curved vortices forces and moments histories show higher frequency
 - Time evolution of curved vortices more rapid
- Aircraft response and average pilot ratings in the same range for curved and straight vortices
- Wider lateral spread of curved vortices must be taken into account for hazard area assessment
- Under manual control curved vortices seem to be more hazardous
- Vortex curvature seems to increase the risk of PIO
- Campaign with A330 showed that FCS is able to cope with the applied vortices



[Foto: DLR]

Thanks...

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