WakeNet3-Europe
A network on Aircraft Wake Turbulence

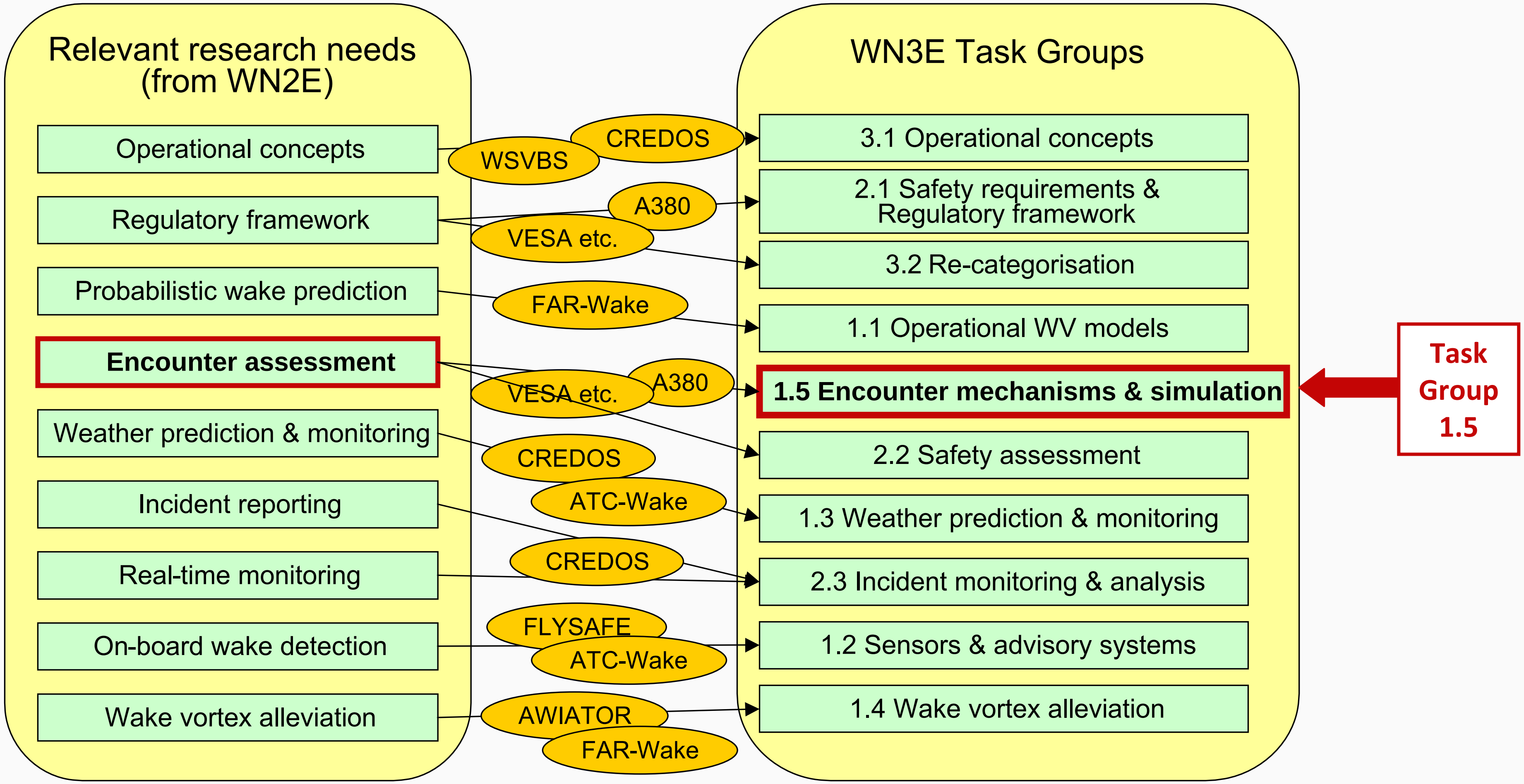
Specific Workshop
organised by
Task Group 1.5 Encounter Mechanisms & Simulation

Models and Methods for Wake Vortex Encounter Simulations

TU Berlin, June 1-2, 2010

Invited participants from
Industrie, Research, Universities
and
Authorities

European Coordination Action for Aircraft Wake Turbulence



Day 1
Wake Vortex Models for Encounter simulations

Day 2
Models of Pilot Behaviour and Severity Assessment

Wake generating aircraft

Wake creation

Initial rolled-up vortex

Wake evolution

Evolved & aged vortex

Wake encounter

vortex impact on follower aircraft

Aircraft reaction

Reaction of follower aircraft

Encounter hazard

Hazard

Source: Airbus

The models are needed for safety and risk assessments of new separation standards

Near-field

- discrete vortices
- vorticity sheets

x/b < 0.5

Mid-field

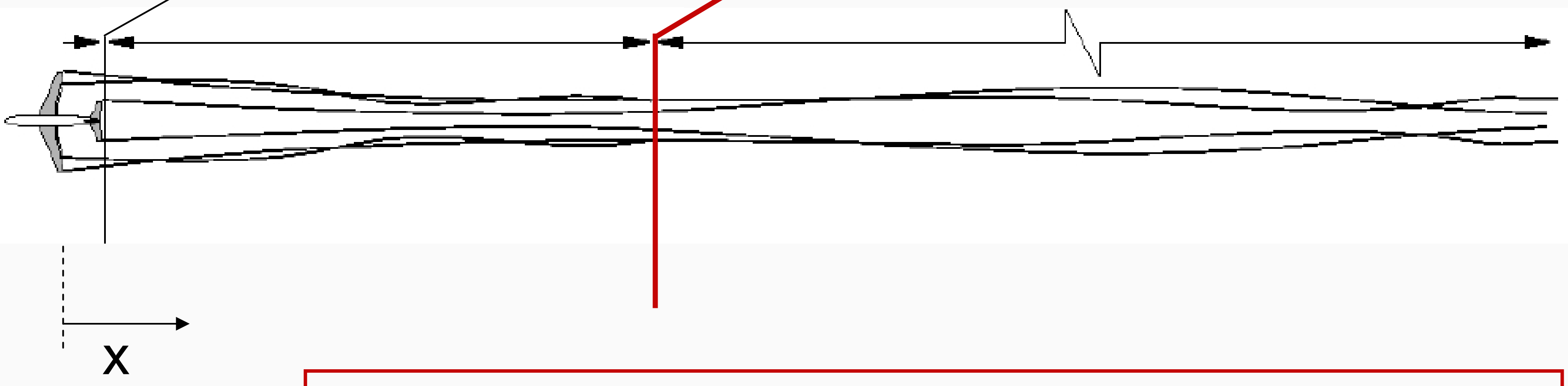
- roll-up of vortex sheets
- merging of vortices

0.5 < x/b < 10

Far-field

- persistence
- decay

x/b > 10



➡ Task Group 1.5 addresses only the Far-field

FMRA
Fachgebiet Flugmechanik, Flugregelung und Aeroelastizität

Berlin Institute of Technology

Overview on wake vortex models for encounter simulations

Robert Luckner

WakeNet3-Europe, Specific Workshop
“Models and Methods for Wake Vortex Encounter Simulations”
Berlin, 1-2 July 2010

Objectives and expected outcome of day 1:

1) Summary of existing, state-of-the-art wake vortex models
   a) for flight simulator investigations (real-time models)
   b) for fast-time Monte Carlo simulations (fast-time models)

2) Evaluation of these state-of-the-art models and identification of research needs

3) Contribution to the WakeNet3-Europe report on Research Needs

   regarding “Wake vortex models for encounter simulations in real-time piloted simulator tests and for fast-time flight simulations for risk assessment”.

Motivation

Day 1
Wake Vortex Models for Encounter simulations

Wake generating aircraft

Wake creation

Initial rolled-up vortex

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vortex impact on follower aircraft

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The models are needed for safety and risk assessments of new separation standards

Source: Airbus

National Research Council (NRC), US:

Wake Turbulence - An Obstacle to Increased Air Traffic Capacity, pp 41 (2008)

On "Wake Vortex Modeling":

- **Definition:**

  Wake vortex modeling attempts to predict the basic characteristics of the vortices from the near field into the far field as a function of the generating aircraft and the ambient atmospheric conditions.

- **Finding**

  3.10 Wake vortex modeling is an essential element for most concepts aimed at reducing Instrument Flight Rules (IFR) spacing requirements

  3.11 NASA's aeronautics program is well-aligned to conduct medium- to long-term foundational wake vortex modeling

- **Recommendation**

  none

National Research Council (NRC), US:

Wake Turbulence - An Obstacle to Increased Air Traffic Capacity (2008)

- **Milestones for Wake Vortex Modeling**

Time Horizon	Milestone
1) Short term	a) Flight test requirements defined based on **modeling needs** b) **Probabilistic model** development based on the state of the art c) Vortex uncertainties predicted for different weather conditions
2) Medium term	a) Flight test conducted (as necessary) to support/ **validate modeling** b) Wake vortex evaluated using flight data c) **Range of applicability** estimated for models d) Models applied to support recategorization efforts
3) Long term	a) Models applied to support dynamic spacing

WakeNet2-Europe in Collaboration with WakeNet-USA:

Wake Vortex Research Needs for Improved Wake Vortex Separation Ruling and Reduced Vortex Signatures (March 2006)

- **Recommendation (Part 2, pp 48)**

  It is important that all sub models of the simulations are validated so that they are acceptable for all stakeholders, …

  …, a sub model validation in conjunction with plausibility checks that ensure correct interaction between sub models is the only suitable means to validate such a methodology.

WV models for flight simulations

WVE investigations in flight simulators (real time)

- during manual flight
- during automatic flight (autopilot / auto throttle)

WVE risk assessments based on flight simulations (fast time)

- probabilistic investigations (Monte Carlo Simulation, MCS)
- sensitivity analysis
- worst case search

Development of Detection, Warning and Avoidance Systems

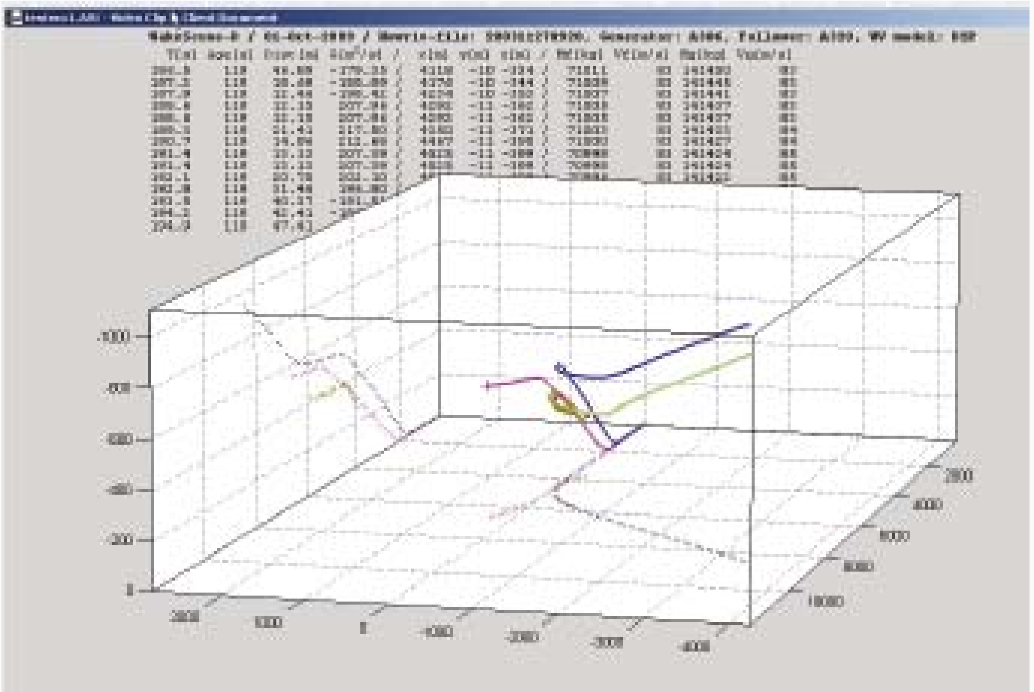
S-Wake Flight Simulators

Flugzeug / ICAO-Kategorie		Simulatortyp	Standort
Airbus 330-300 **HEAVY**		<u>Certified Airline Training Simulator (FAA level D)</u> 6 DoF motion system, visual system, side-stick control, fly-by-wire control system, and autopilot supplemented by research facilities	TU Berlin
Fokker 100 **MEDIUM**		<u>Research Flight Simulator of NLR</u> 4 DoF motion system, visual system, control column	NLR, Amsterdam
VFW614-ATD **MEDIUM**		<u>Development Flight Simulator THOR of Airbus</u> Fixed base, high-fidelity daylight visual system and a generic cockpit equipped with side-stick controls and programmable displays, fly-by-wire functions, etc.	Airbus, Hamburg
Cessna Citation **SMALL**		<u>Research Flight Simulator of NLR</u> 4 DoF motion system, visual system, control column	NLR, Amsterdam
Dornier Do 228-200 **SMALL**		<u>Certified Training Simulator (JAR level B)</u> 6 DoF motion system, visual system, control column	Simtec GmbH, Braunschweig

WakeScene – Wake Vortex Scenario Simulation Package,

Jan Kladetzke, DLR

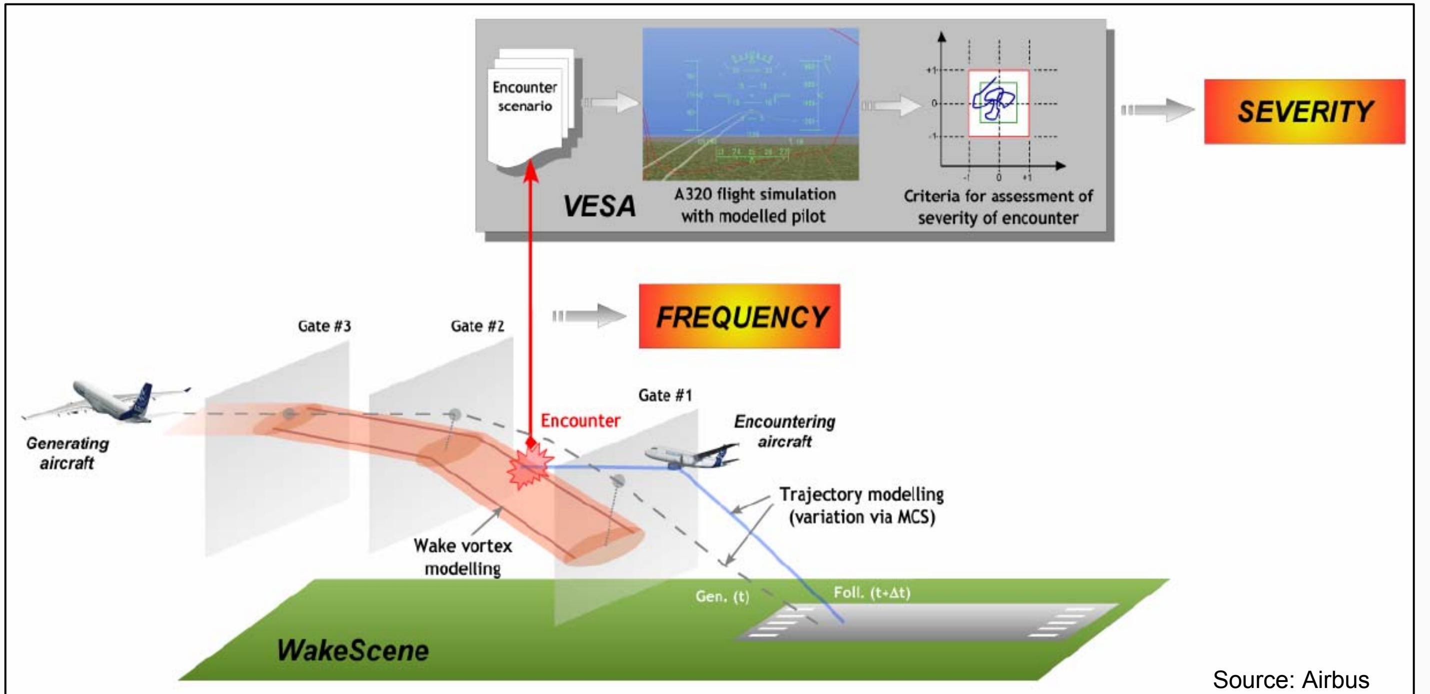
- Airspace simulation to compute wake encounter probability (Fast-time Monte Carlo Simulations)
- Models trajectories of leading and following aircraft and the evolution of the generated vortices
- Takes into account weather, a/c performance, wake decay, but not encounter severity
- Identifies potential encounters, to be considered in severity assessment (interface to VESA)



VESA – Vortex Encounter Severity assessment

Sebastian Kauertz, Airbus

- WakeScene
- Dynamic flight simulation including vortex-aircraft interaction
- Assess encounter severity



Source: Airbus

widat / ASAT – Wake Interactive Development & Analysis Tools

ATSI, FAA

Air Traffic Simulation, Inc.
3317 Deer Valley • Edmond, Oklahoma 73034 • USA
info@atsi.aero • www.atsi.aero

widat™

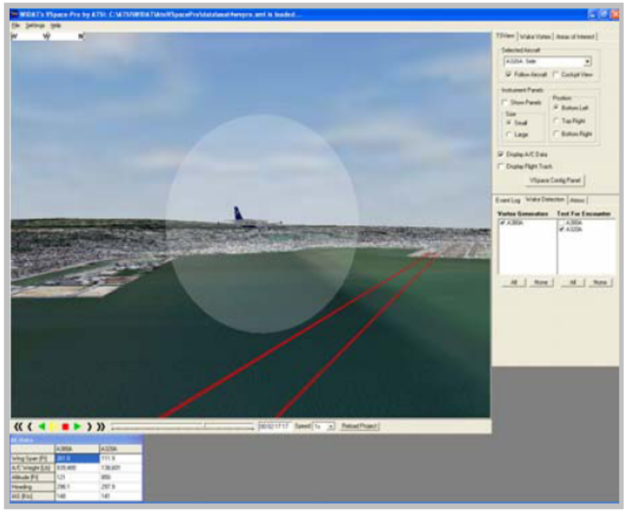
Wake Interactive Development & Display Analysis Tools
on the Cutting Edge of Wake Turbulence Evaluations

Source: http://www.atsi.aero/pdf/WIDAT.pdf

As the need to enhance the utilization of existing airspace and supporting infrastructure increases, so does the need for computer tools to allow designers to optimize airspace for efficiency while maintaining the desired level of safety.

WIDAT™ fulfills the long existing need for a highly interactive computer automation system capable of providing airspace designers with quick answers to critical and complex wind turbulence related questions.

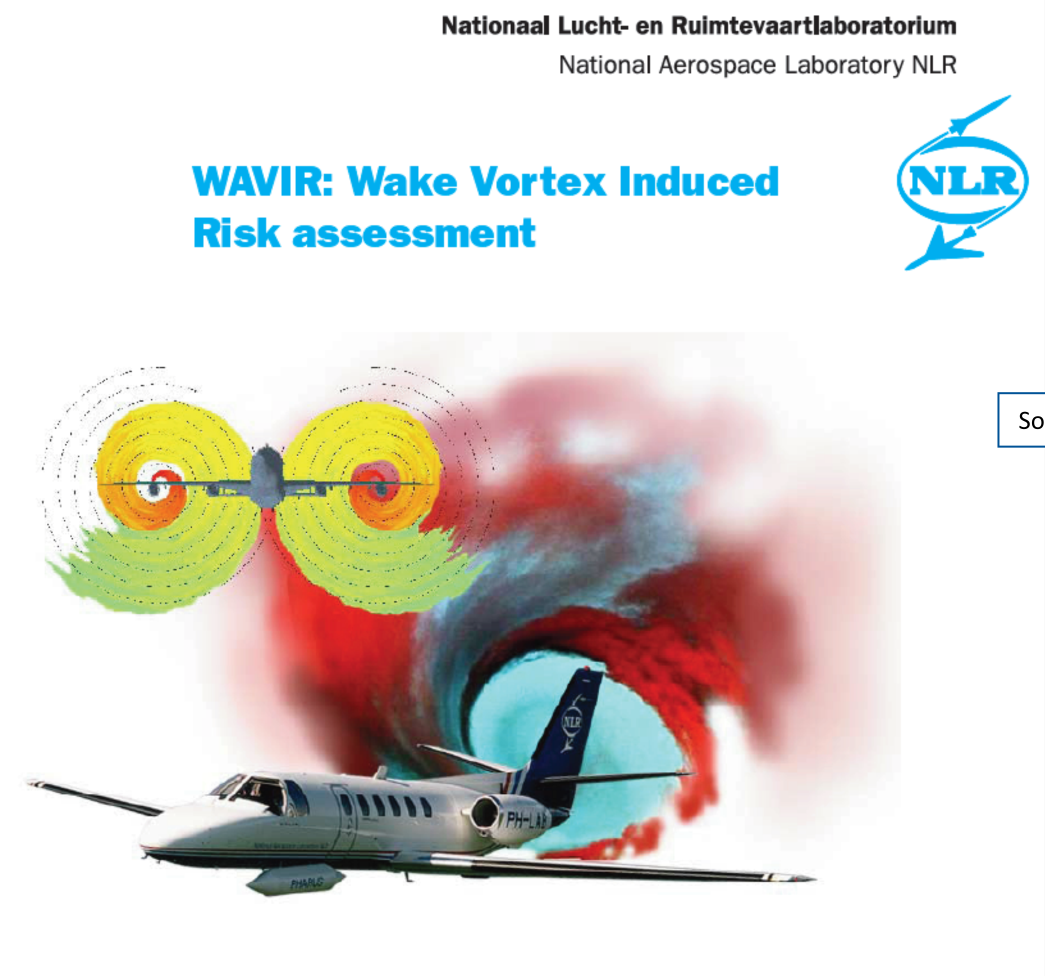
In many studies, the spatial relation between aircraft, wakes, terrain, and other objects is highly complex and critical to the



WIDAT's Vspace-Pro™ Visualization of *ASAT4WV--Pro*™ Simulation Engine Operational Scenario

WAVIR – Wake Vortex Induced Risk Assessment

NLR



Source: http://www.nlr.nl/documents/flyers/f203-03.pdf

Applications and Model Requirements

For discussion

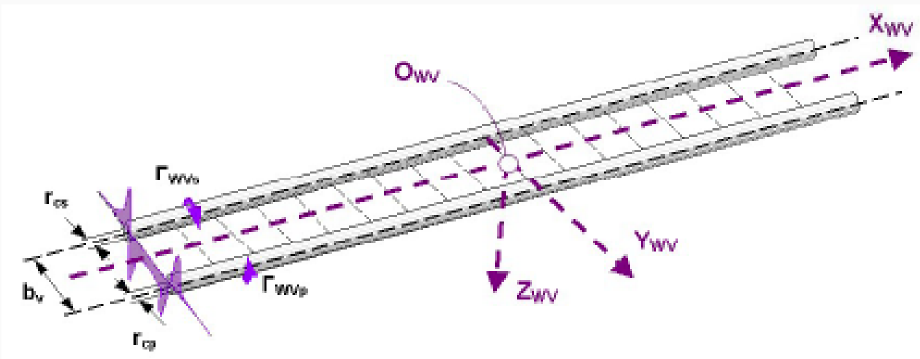
Draft

Applications	**Wake Vortex Model Requirements**
Flight simulator (real time) • manual control • autopilot control	High-fidelity of vortex-induced velocities Reproducibility of tests Parametric models Real-time capable Robust Vortex evolution (Detection Warning and Avoidance System)
Risk assessment (fast time) • MCS • sensitivity analysis • worst-case search	High-fidelity of vortex-induced velocities and vortex evolution (transport and decay) Reproducibility of tests Parametric models Fast-time capable Statistical distribution of parameters Conservative

Type 1: Straight wake vortex pairs
S-Wake (Airbus, TU Berlin, Cerfacs, DLR, NLR), NASA, FAA, etc.

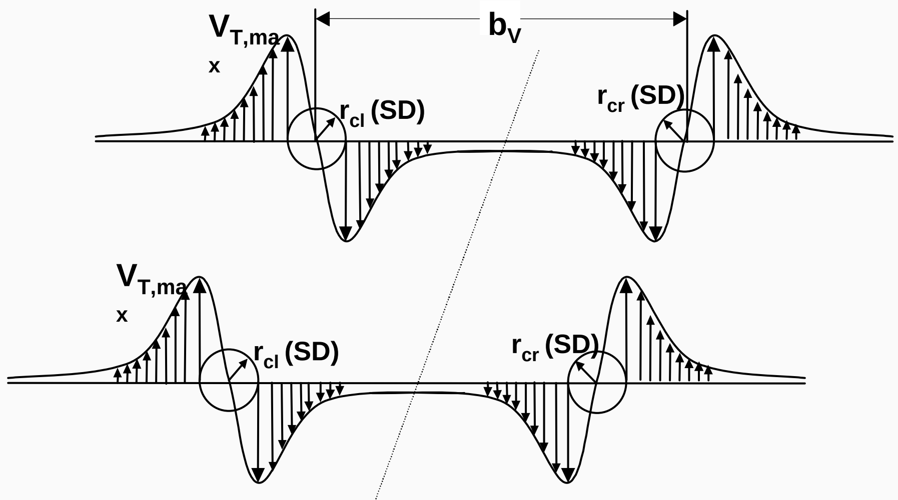
- Analytical description of wake vortex axes
- straight, no decay, no transport
- constant circulation, constant spacing

Application: Flight simulation
- flight simulators,
- risk assessment

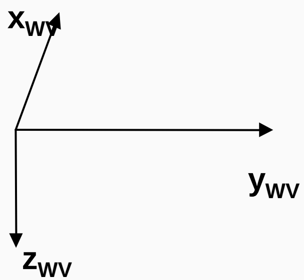


Source:S-WAKE

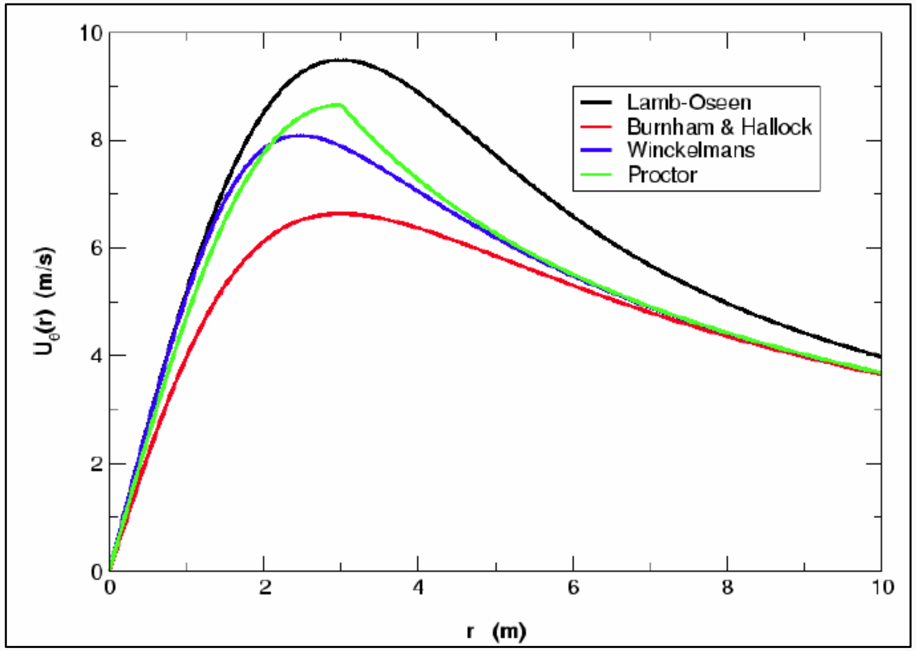
Analytical tangential velocity flow field

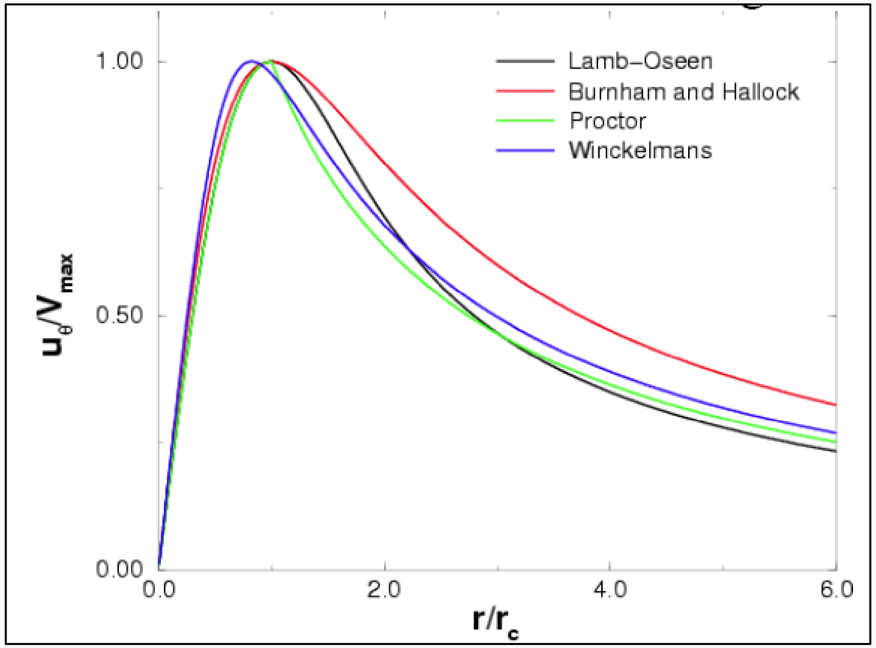


symmetry line



Tangential velocity profiles





Source:S-WAKE

r_C = const

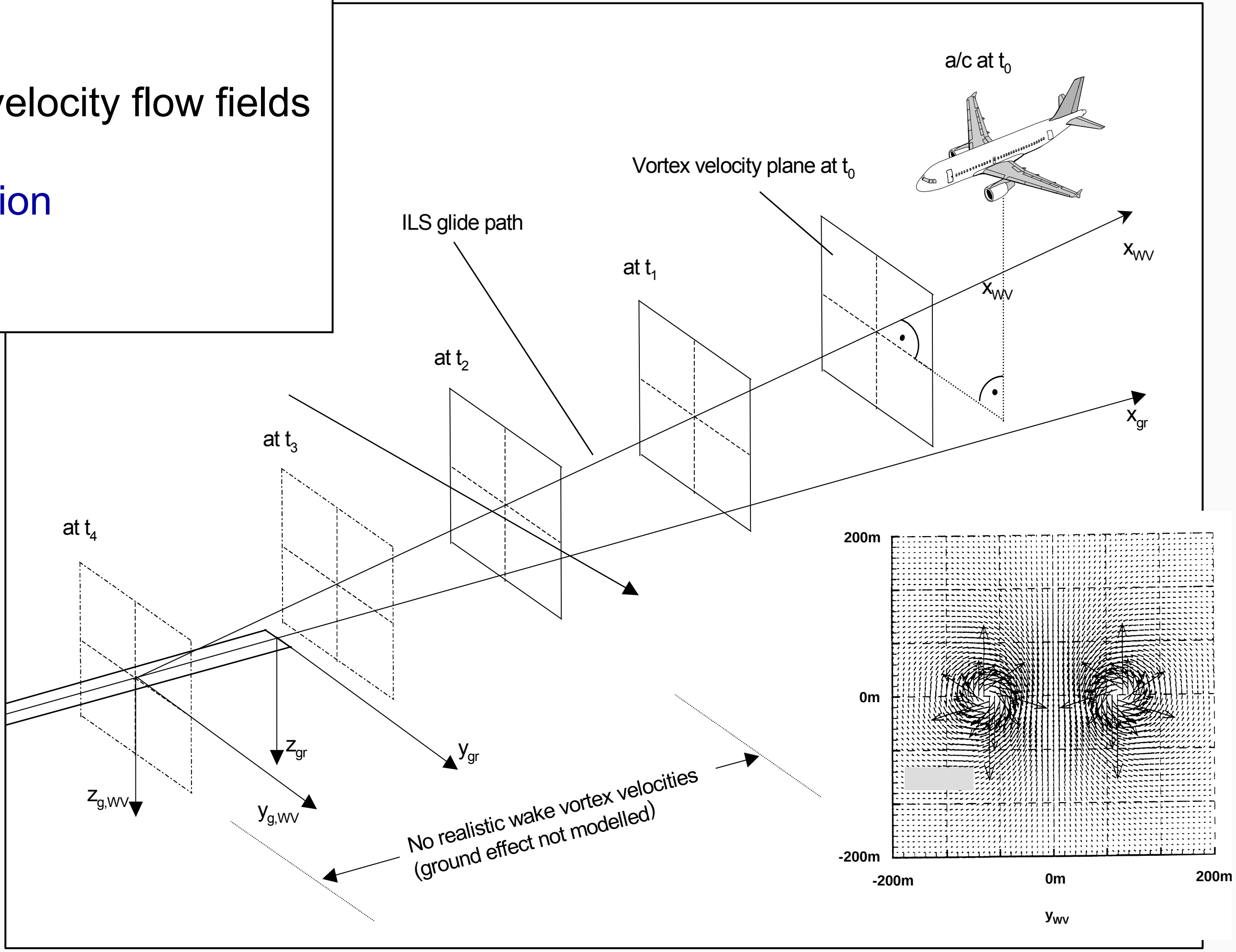
$u_{\theta max}$ = const

Type 2: Numerical wake vortex model
S-Wake (Airbus, TU Berlin, Cerfacs, DLR, NLR)
I-Wake CREDOS (UCL) etc.

- Precompiled 2D or 3D velocity flow fields

Application: Flight simulation

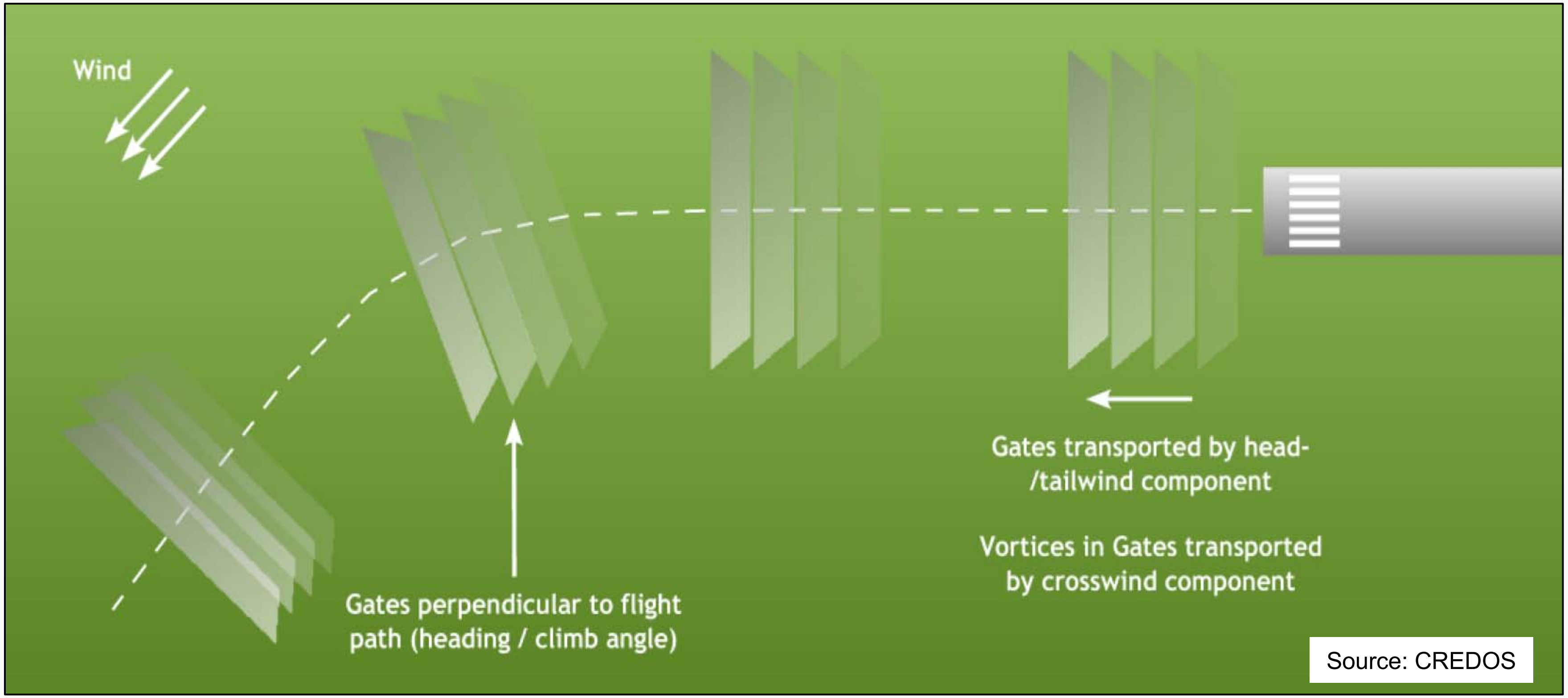
- flight simulators,
- risk assessment



Source: S-WAKE

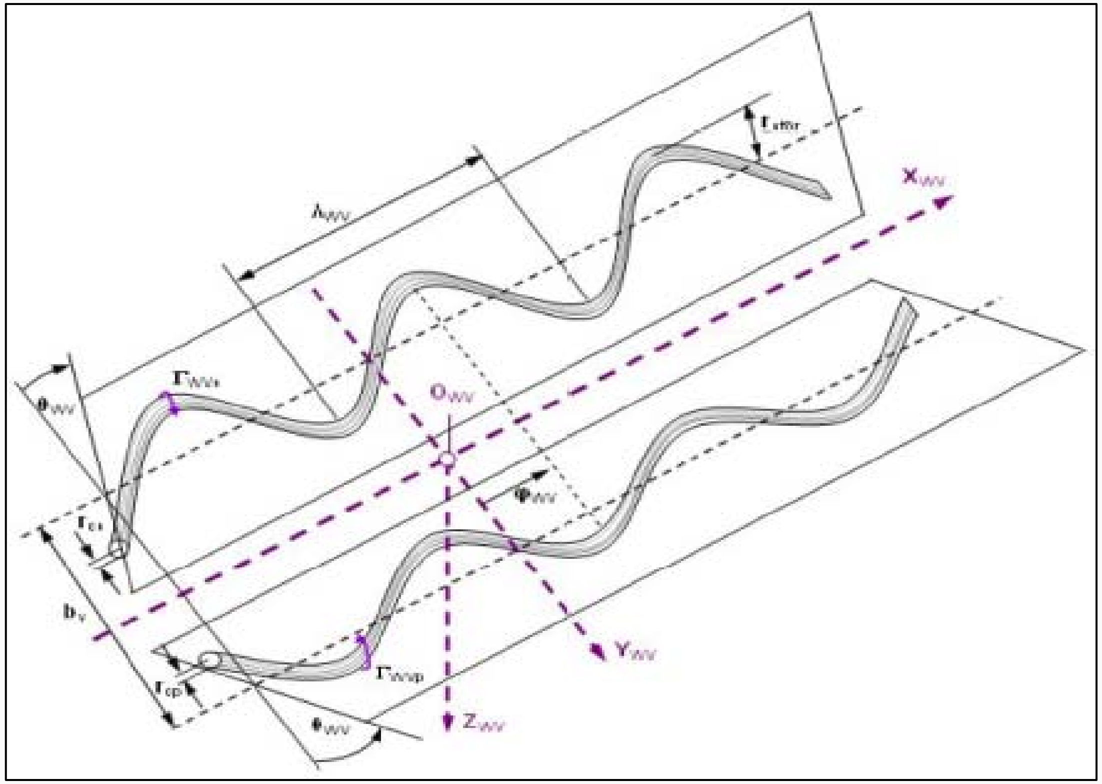
Type 2: Numerical wake vortex model
S-Wake (Airbus, TU Berlin, Cerfacs, DLR, NLR)
I-Wake CREDOS (UCL) etc.

- Drifting gates



Type 3: Wavy vortices
Jeffrey Crouch, Boeing
Dennis Vechtel, DLR

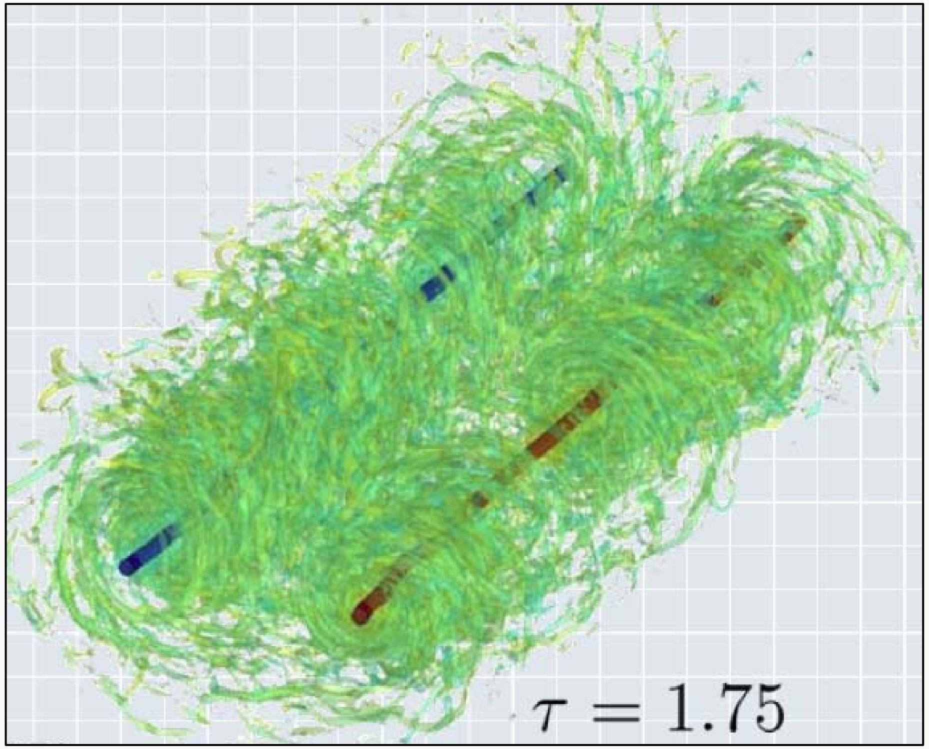
- Analytical description of wake vortex.
- Straight vortices → wavy vortex filaments → vortex rings



Type 4: Large eddy simulation

Ingo Hennemann, DLR; Dave Allerton, Graham Spence, University of Sheffield

- LES is a technique for simulating turbulent flows
- Solves numerical the incompressible Navier-Stokes equation
- Physically the best description of wake vortex behaviour, transport and decay
- Extremely high computing time requirements
- Not directly suited for real or fast time simulation
- Pre-processed velocity fields suited for real or fast time simulation



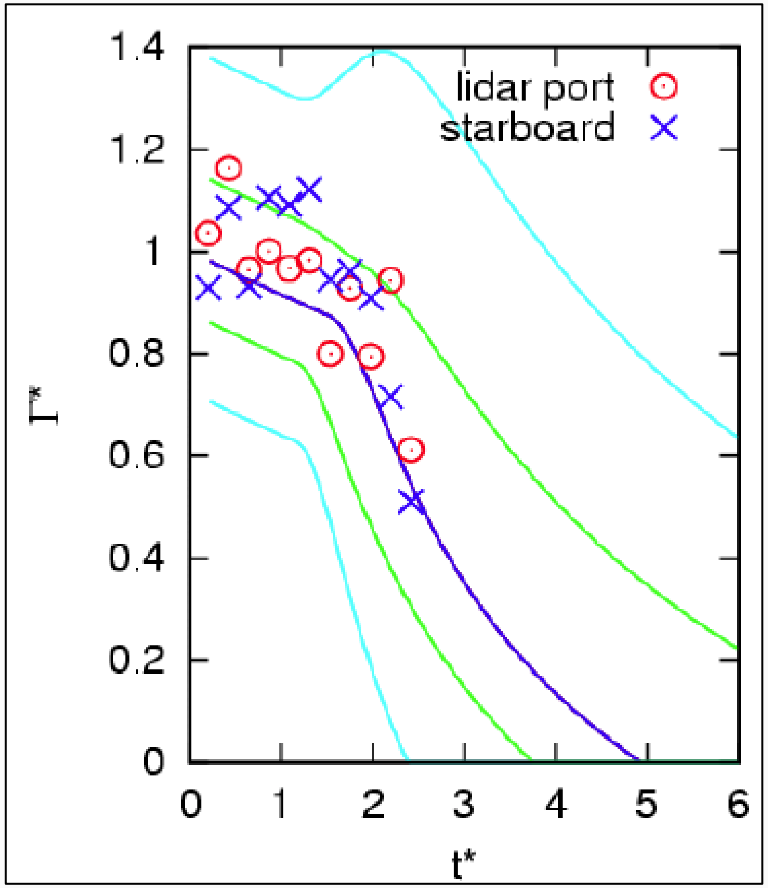
Source: CREDOS

Type 5: Mid- to far-field WV model

a) D2P - Deterministic 2-Phase wake vortex model

Frank Holzäpfel, DLR

- A parametric wake vortex transport and decay model
- Combines experimental and numerical knowledge
- Vortex decay processes in two-phases, a diffusion phase followed by rapid decay.



Source: CREDOS

Application: Risk assessment (WakeScene)

P2P (Probabilistic 2-Phase wake vortex model)

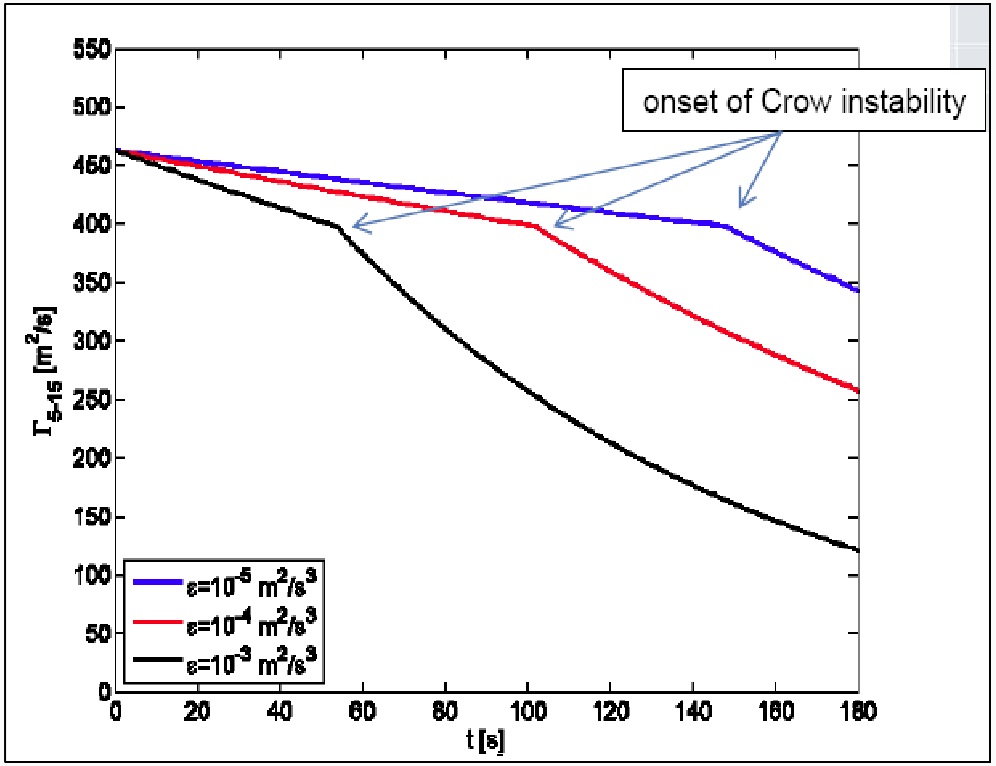
- Predicts probabilistic wake vortex behaviour as a function of aircraft and environmental parameters.

Type 5: Mid- to far-field WV model

b) DVM (Deterministic Wake Vortex Model)

Ivan de Visscher, Gregoire Winckelmans, UCL

- Operational modelling of WV behaviour
- Including transport and decay
- Integrates, in time, various physical models so far as to forecast, in real-time, the transport and decay of the wake vortices in one computational gate (i.e., one slice of space along the flight path)



Source: CREDOS

Application: Flight simulation
- flight simulators,
- risk assessment

PVM (**Probabilistic** wake **Vortex Model)**
- using DVM as a subtool (based on MCS)

Type 5: Mid- to far-field WV model

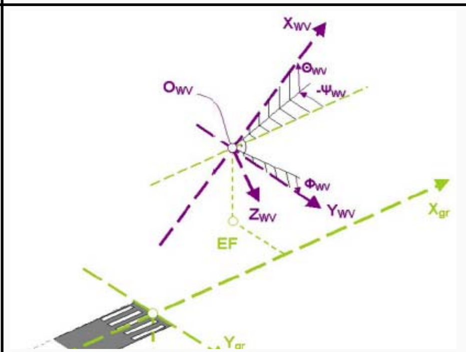
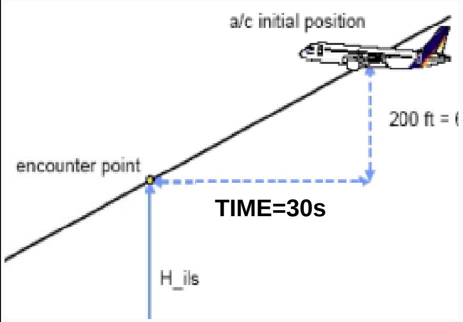
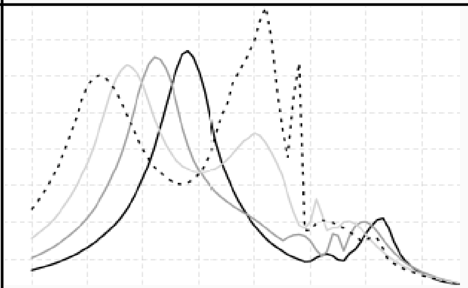
c) APA model

NASA Langley Research Centre, North West Research

- Predicts wake vortex trajectories and circulation
- The initial wake vortex consists of two vortices whose initial strength and position dependent on input conditions
- Out of ground effect: APA model utilizes a decay and transport model (Sarpkaya)
- In ground effect: APA model introduces secondary vortices that causes vortex rebound
- Has been used in NASA's AVOSS and in ASAT

Source: NASA

Integration of wake vortices into the flight simulation

Method	Figure	Description	Advantage	Disadvantage	Application
Free Enc.		Geodetically fixed wake vortex. Defined flight trajectory required (ILS approach)	Realistic variation of encounter geometries	Encounters are not reproducible. Small encounter hit rate	Investigation on diversities of a/c reaction
Forced Enc.		Time fixed wake vortex	See *Free Enc.* Encounter hit rate is much better than for fixed encounter	Not reproducible.	See *Fixed Enc.*
Fixed Enc.		Pre-recorded incremental, vortex-induced forces and moments	Reproducible disturbance for the a/c.	No statistical variations	Pilot model development

Questions

1. What are

   a) the strengths and

   b) the weaknesses

   of current **Vortex Models** for risk assessment?

2. Is the achieved fidelity sufficient (ref. slide 2 and 3) or is there further research required?

2. How can validation and credibility of models be achieved

Fidelity issues for discussion

1) **Tangential velocity distribution**
   - ► **Are existing analytical and numerically-calculated distributions sufficient?**

2) **Vortex shape (straight, curved)**
   - ► **Would wavy vortices significantly change the encounter geometry?**

3) **Vortex strength (circulation) and decay (also addressed by Task Group 1.1)**
   - ► **Are 2-phase models sufficient to describe vortex decay? - Do we need 3 Phase models?**
   - ► **Are in-ground and near ground models sufficient for risk assessment in ground level?**

4) **Wake transport**
   - ► **Is wake transport modelling always needed or only for departure and landing?**