WakeNet3-Europe

A network on Aircraft Wake Turbulence

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AIRBUS

Wake vortex models in real-time and fast-time flight simulation

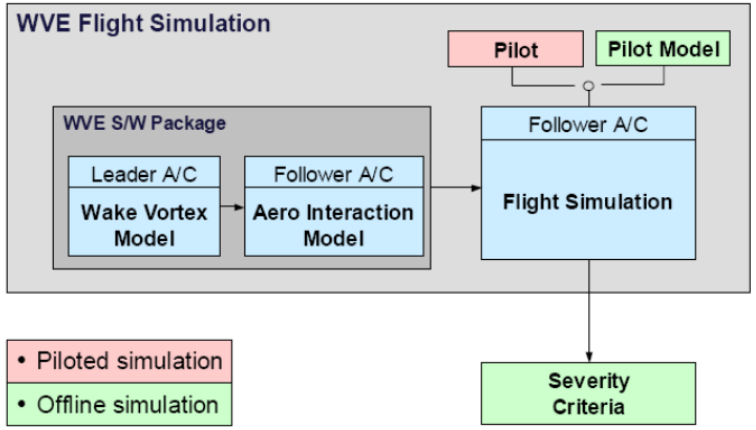
- **Introduction**
- **Flight simulation – VESA**
- **Implementation of different vortex models in VESA**
- **Application example - Demo**
- **Summary - Outlook**

Introduction

- Wake vortex encounter flight simulations require an accurate representation of the vortices the aircraft encounters
- Induced velocities and thus forces & moments depend on the relative position of the aircraft to the vortex tubes
- For real-time as well as fast-time applicability computation efficiency is required
- Therefore simplified models are usually applied
- Three model implementations in the Airbus VESA tool will be presented here:
  - Simple straight, infinite vortices
  - Simulated parametrized wavy and ring vortices
  - A method to include non-straight vortex lines

Vortex Encounter Severity Assessment – VESA

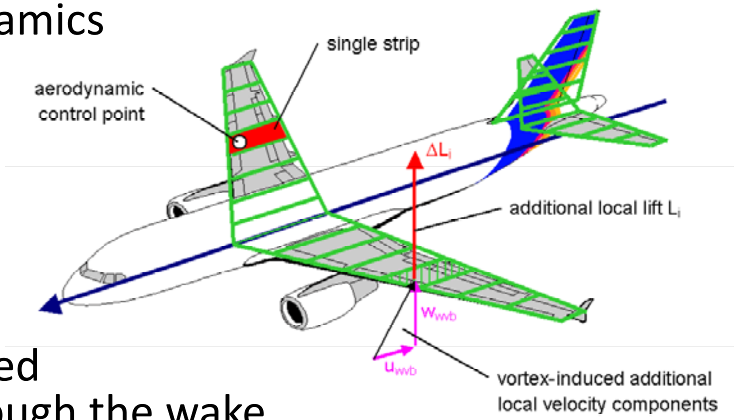
- Dynamic flight simulation including vortex-aircraft interaction
- Takes into account encounter severity
- Fast-time Monte Carlo simulation capability (stand-alone or with connection to WakeScene)
- Sub-models included:
  - Full 6 degree-of-freedom dynamic *flight simulation* (A320)
  - *Wake vortex model* to compute 3-dimensional velocity field in space
  - *Aerodynamic Interaction Model (AIM)* to compute vortex-induced forces & moments on the aircraft
  - *Pilot model* for offline control and wake encounter recovery
  - *Severity metrics* to assess severity of each encounter



Vortex Encounter Severity Assessment – VESA

- The *Aerodynamic Interaction Model* is the link between vortex induced flow field and the impact on the aircraft

- Additional vortex-induced velocities on the aerodynamic surfaces result in additional forces & moments impacting the flight dynamics



- Different models are available, e.g. strip methods (see right) or Lifting Line methods

- In any case, the induced velocities need to be evaluated at several points on the aircraft while it is moving through the wake

- Therefore a vortex model must be capable to give induced velocities at arbitrary points in space in each timestep of the simulation

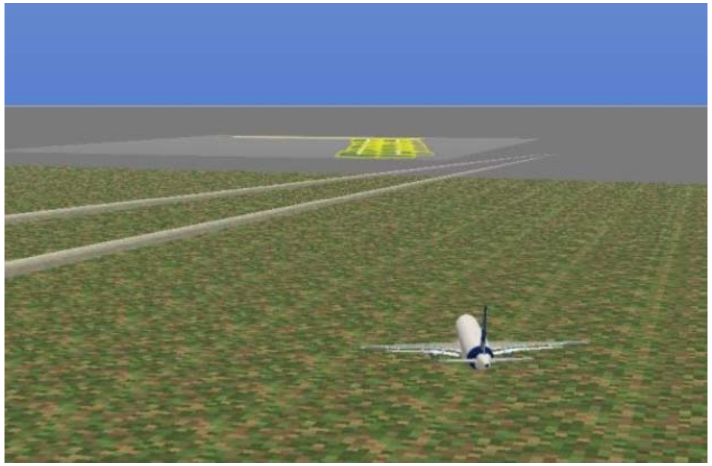
Implementation of vortex models in VESA

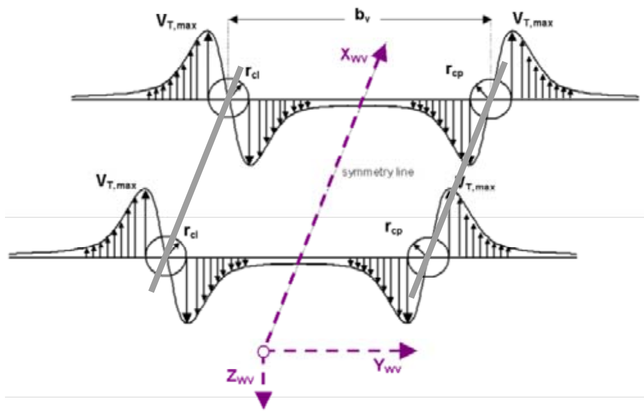
Several models of different level of detail are implemented in VESA:

- Straight, infite vortices
  - Most simple implementation, used for investigating influence of general parameters (vortex strength, position, intercept angles …) on encounter severity
- Parametrized wavy vortices and ring vortices
  - Useful for investigating influence of vortex waviness and breakup into vortex rings on encounter severity
- Curved, segmented vortices
  - Increasing realism of vortex representation along a flight path without undue computational effort (developed within CREDOS)

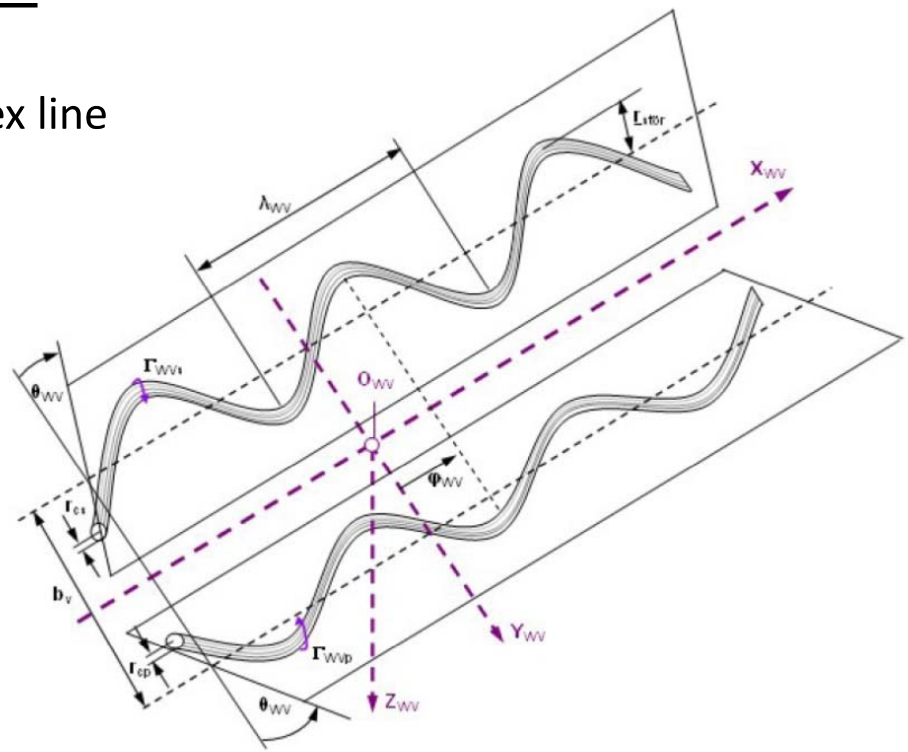
Straight vortices

- Infinitely long, straight and parallel vortex tubes
- Alignment using two angles + offset to define encounter geometry
- Velocity distribution using Biot-Savart law + vortex velocity model, e.g.:
    - Rosenhead / Burnham-Hallock
    - Winckelmans
    - Lamb-Oseen
- Determination of induced velocities at arbitrary points with very little computational effort





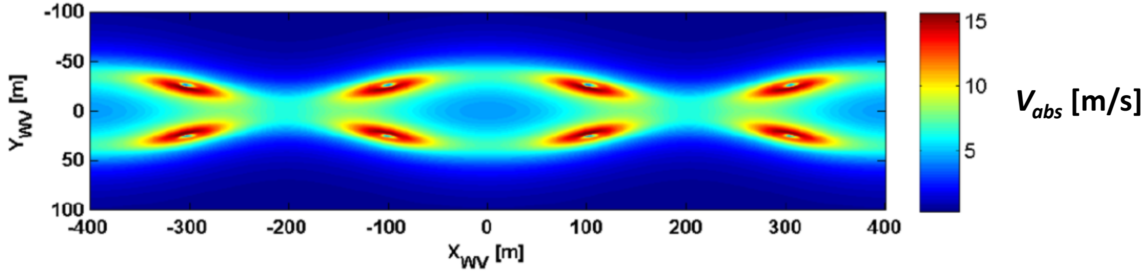
Parametrized Crow instability and ring vortices

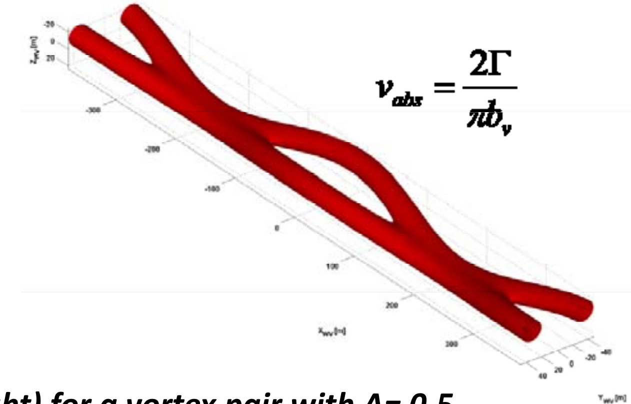


- Crow instability modeled as sinusoidal vortex line
- Variable parameters are
  - Amplitude factor $A = r/r_{max}$ (A=1: vortex lines are touching)
  - Wavelength λ_{WV}
  - Vortex span b_v
  - Inclination Θ_{WV}
  - Circulation Γ_{WV} and core radius r_c
- Integration of induced velocities over small, finite (straight) vortex segments ds, using Biot-Savart law
- Integration region (number of periods considered) and step size ds need to be balanced between computational effort and accuracy

Parametrized Crow instability and ring vortices

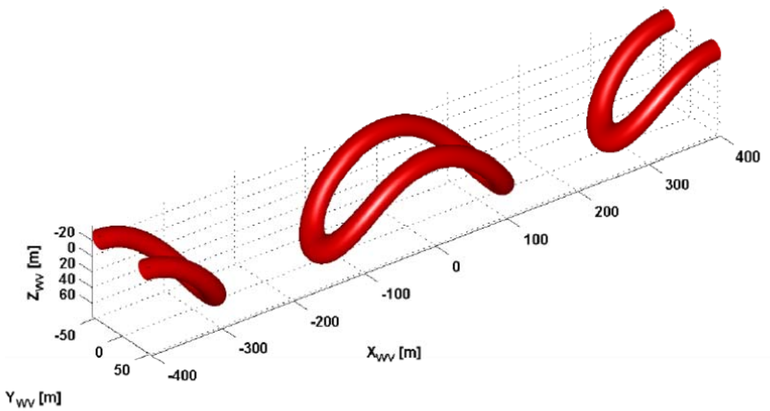
- Implementation of wavy vortices in VESA simulation





Distribution of absolute induced velocity v_{abs} (left) and isosurfaces (right) for a vortex pair with A= 0.5

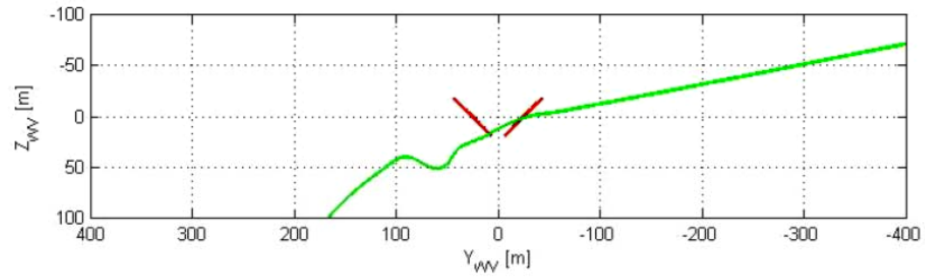
- Similar implementation for ring vortices (after *Loucel & Crouch,* 2005):

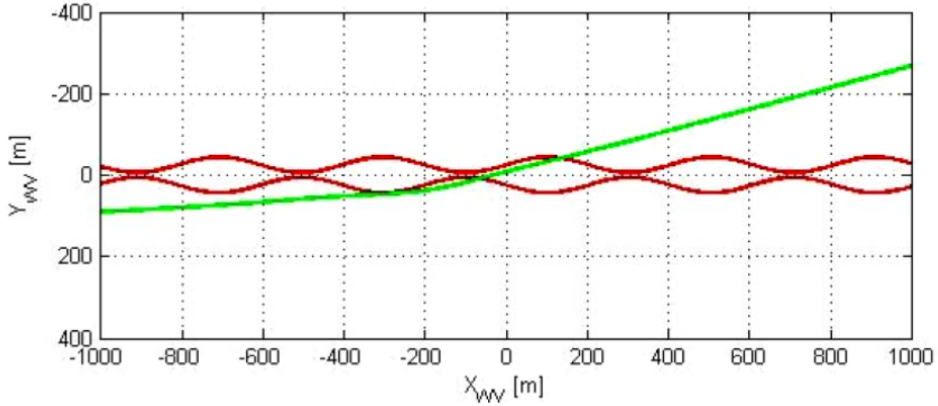


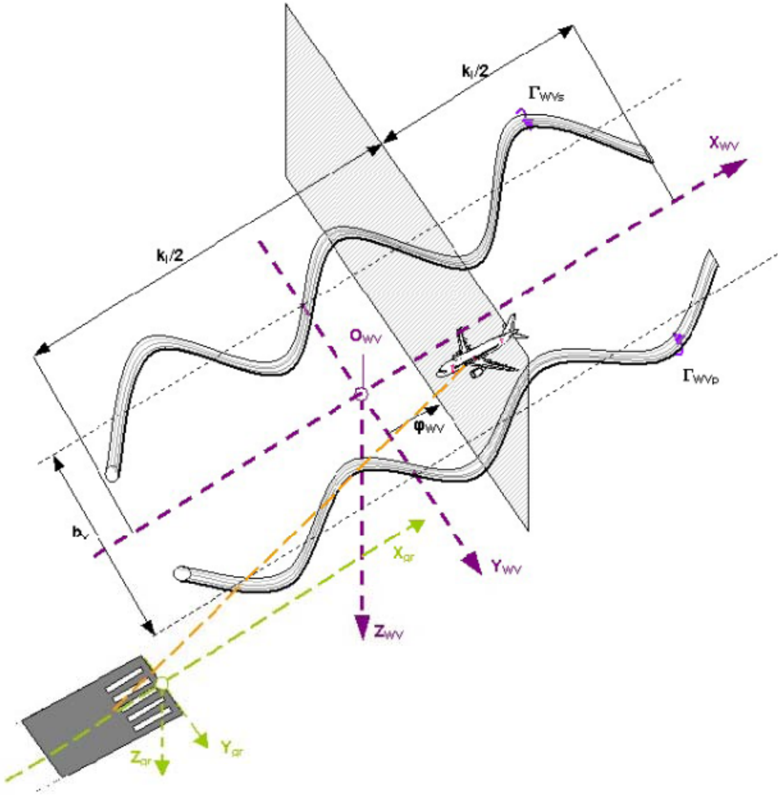
Isosurfaces for vortex rings (T_v= 0.2)

Parametrized Crow instability and ring vortices

- Model has been applied for investigating influence of vortex curvature on aircraft reaction in dynamic encounter simulation





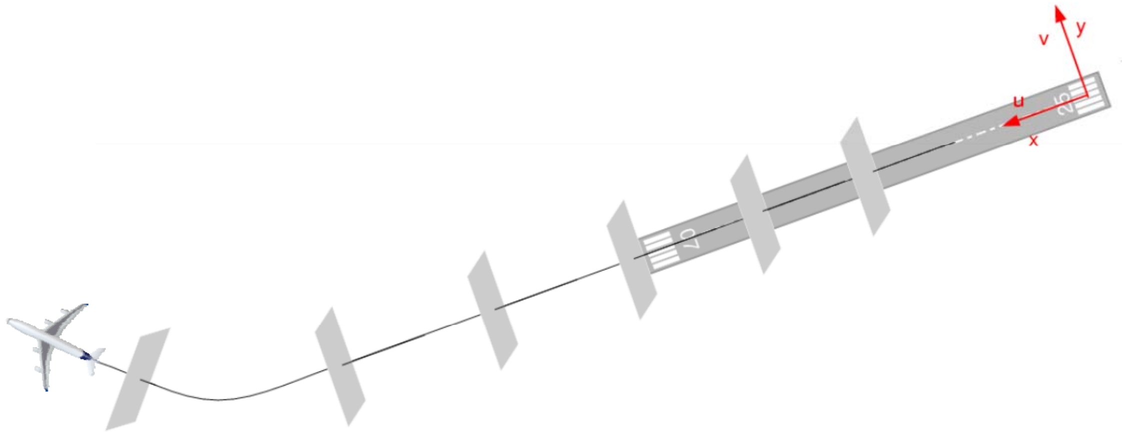


Curved vortices

- Input: Wake vortex circulation & position from wake prediction model in several *gates* along generator flight path (see below)
  - Vortex decay is calculated individually in each gate
  - Typical distance between gates: 5 s ≅ 350 m (variable)

- Wind components in gate plane considered by wake prediction model – wind component perpendicular to plane is moving the gate

- Data can be used time-dependent (*vortices moving*) or fixed at a specific time instant (*vortices frozen*)



Curved vortices

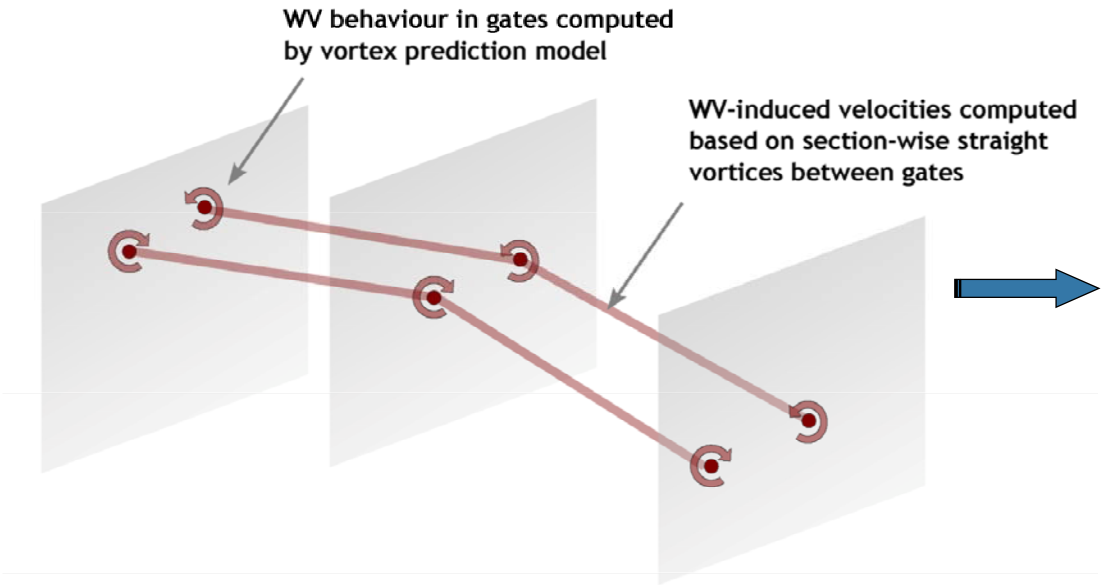
- Advantage: More accurate representation of vortex wake in terms of:
  - Curvature along flight path
  - Variable circulation along flight path
  - Consideration of ground effect

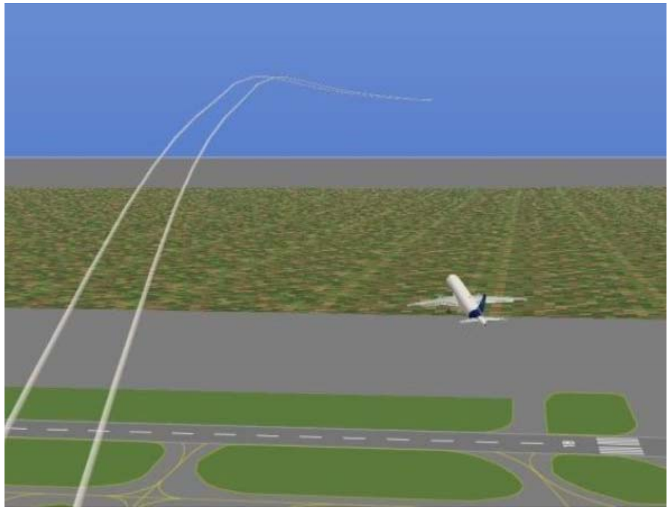
- Difficulty: Vortices are harder to hit
  - Encounters cannot be „planned“ as easily in parameter or simulator studies (especially when vortices are moving)
  - A method to correctly place the vortices relative to the aircraft is needed (see application example later)

Curved vortices - Example: D2P

Step 1: Reconstruction of vortex lines in space (OGE)

- Two vortices contribute to induced velocities out of ground effect

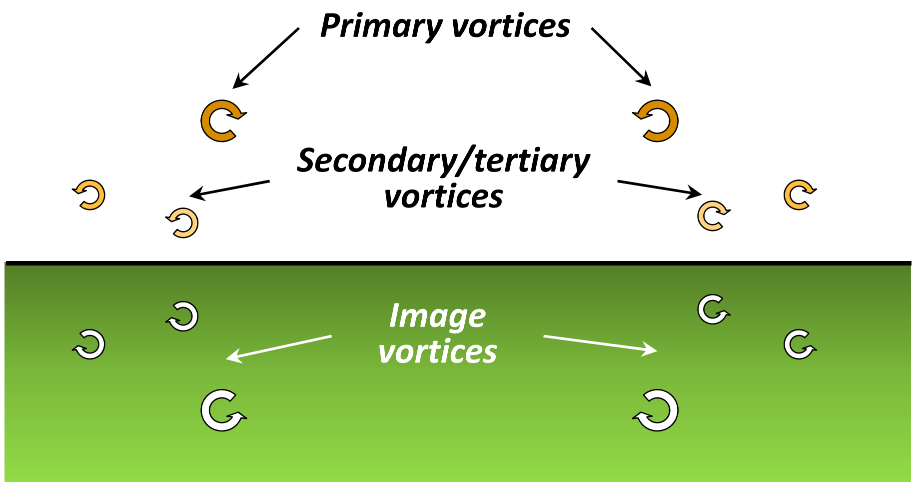


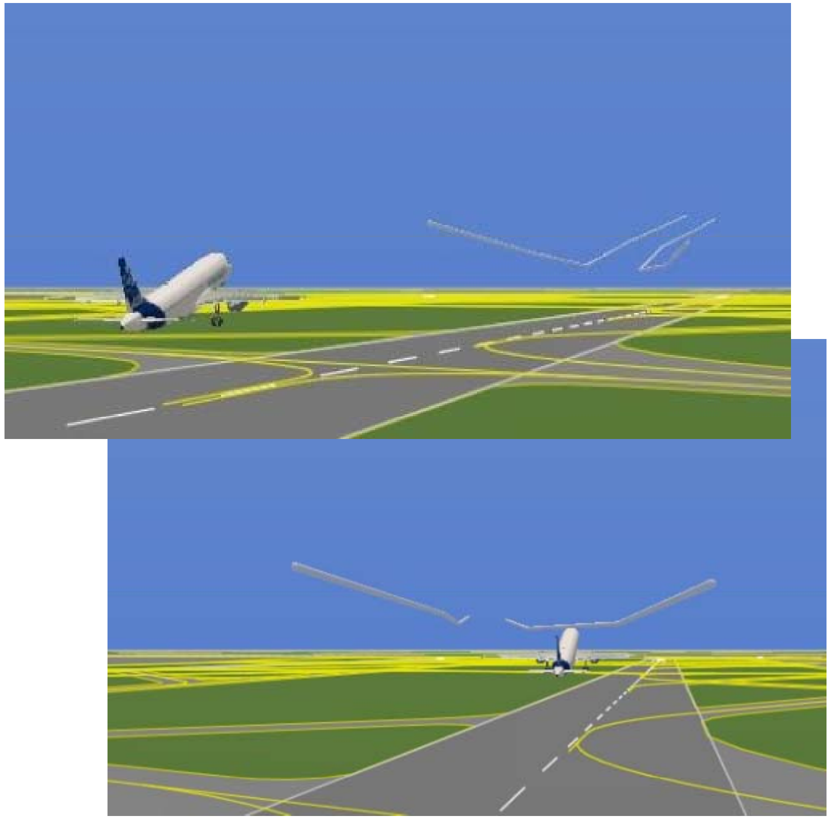


Curved vortices - Example: D2P

Step 1: Reconstruction of vortex lines in space (IGE)

- Up to 12 vortices contribute to induced velocities in ground effect





Curved vortices - Example: D2P

Step 2: Computation of induced velocities

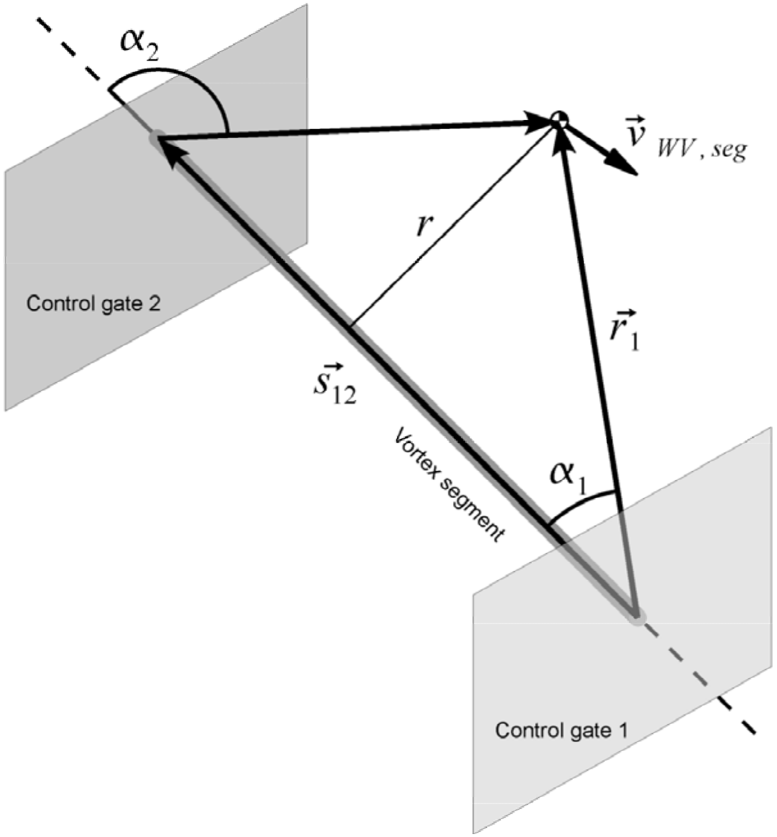
- For each vortex segment between two gates the ind. velocity is computed, e.g.:

Biot-Savart + Rosenhead:

$$\vec{V}_{wv,seg} = \frac{\Gamma_{seg}}{4\pi} \frac{r}{r_c^2 + r^2} (\cos\alpha_1 - \cos\alpha_2) \frac{\vec{s}_{12} \times \vec{r}_1}{\|\vec{s}_{12} \times \vec{r}_1\|}$$

$$\vec{V}_{wv,tot} = \sum_i \vec{V}_{wv,seg,i}$$

(Γ_{seg}, r_c: averaged between gates)



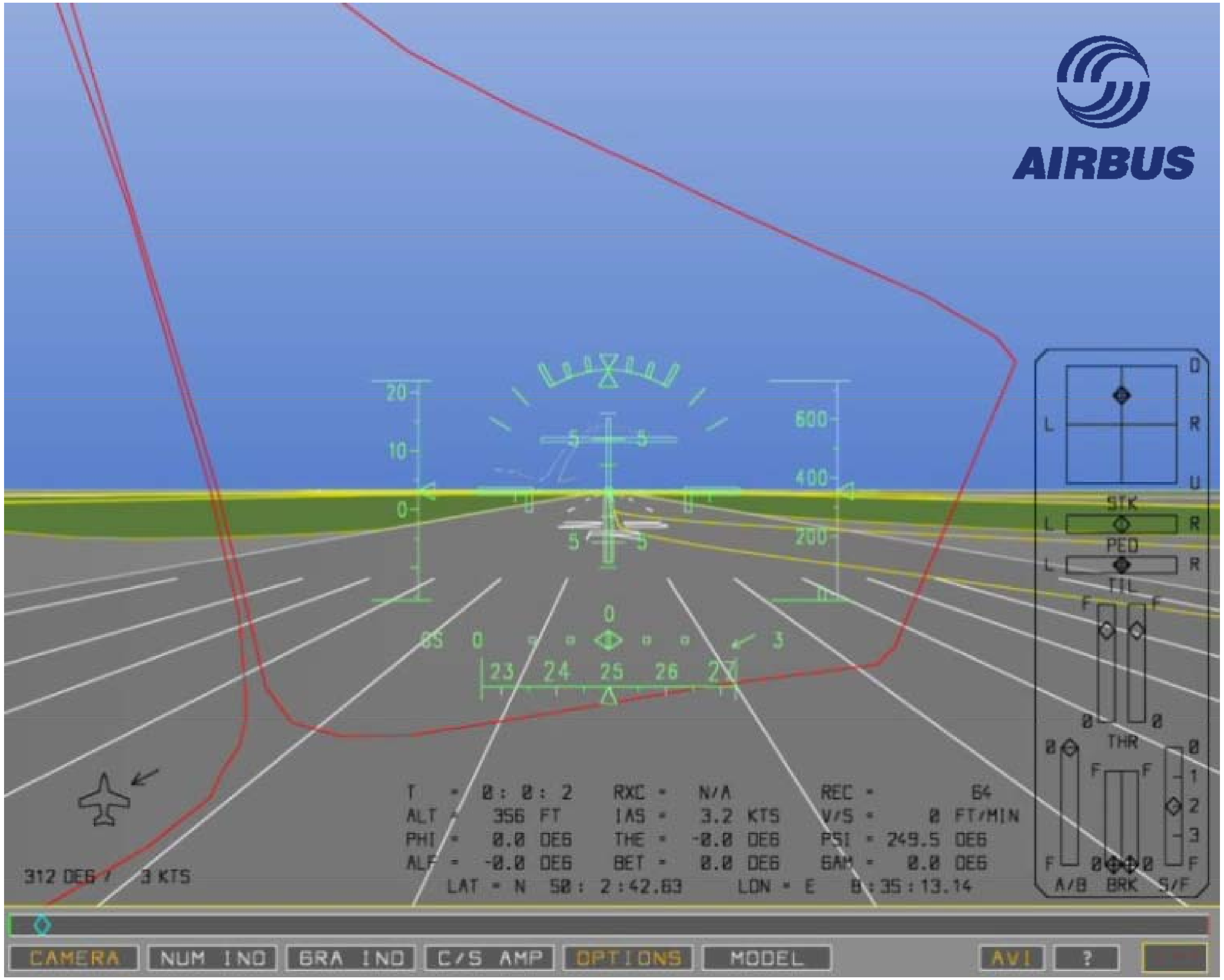
Summary – curved vortices

- Implementation of curved wake vortices in wake encounter simulations considers
  - Curvature along flight path
  - Variable circulation along flight path
  - Motion of vortices with time (if needed)
- A similar implementation exists for the DVM wake prediction model
- Vortex prediction models, vortex velocity models and AIM have been validated with data from numerous measurement campaigns
- Full validation of 3-dimensional velocity fields (esp. IGE) difficult to impossible due to lack of sufficient real-life data – but for the envisaged application the superposition of several vortex flow fields is assumed to be sufficient
- Not considered in this type of modeling is curvature due to instabilities (Crow…)

Application example

- Curved vortex model has been used in the CREDOS project for simulations in combination with WakeScene (DLR), using the D2P wake prediction model
  - Fast-time simulation (Monte Carlo)
  - Once an encounter is identified in WakeScene, the necessary data is transferred to VESA:
    - Position, circulation, core radius of each vortex from wake prediction model
    - Follower aircraft performance parameters
    - Weather data (wind profile)
    - Vortices are placed in same position relative to the aircraft in WakeScene and in VESA
    - Vortices remain fixed in space and time in VESA
  - The encounter is simulated in VESA, with the aircraft controlled by a pilot model (take-off & encounter recovery)
  - Severity of encounter determined by a dedicated severity model, taking into account the dynamic reaction of the aircraft

Demo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ALF = -0.0 DEG
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Summary

- Implementation of different wake vortex models in wake encounter simulations has been demonstrated, considering
  - Vortex circulation, span, core radius, intercept angles
  - Curvature and variable circulation of vortices along the flight path
  - Motion of vortices with time
  - Sinusoidal instabilities and ring vortices in a parametric form
- The approaches described are in general applicable to all flight phases and have been successfully applied already for specific investigations (e.g. S-WAKE, CREDOS)
- The maturity of the models is assumed to be good and adequate for the application, especially for the OGE case
- A combination of the different models into one (e.g. curved vortices + waviness) is not envisaged

Outlook

- Models are available for different types of applications – from simple parametric studies to wake encounter risk assessments of a specific airspace volume for different phases of flight (e.g. approach or departure corridor)
- Some of these tools will be applied in future projects (e.g. SESAR) to support definition of new separation schemes
- For the IGE case a sensitivity study of the influence of secondary and image vortices on the induced forces & moments on the aircraft is envisaged