Validation of Wake Vortex Encounter Simulation Models Using Flight Test Data

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Scope of Presentation

- flight tests, measurements, and data

- flight test data analysis performed within the S-WAKE project:
  - determination of vortex model parameters to characterize vortex flow field
  - validation of flight mechanic/aerodynamic interaction models

- summary
### Statistics of Full Scale Flight Encounter

<table>
<thead>
<tr>
<th>Date</th>
<th>Encounter A/C</th>
<th>Altitude</th>
<th>Encounter flown</th>
<th>Flap setting of wake generating A/C</th>
<th>DLC-flap setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.8.2001</td>
<td>Dornier Do128</td>
<td>FL 95</td>
<td>27</td>
<td>14°, 35°</td>
<td>const.</td>
</tr>
<tr>
<td>21.8.2001</td>
<td>Dornier Do128</td>
<td>FL 95</td>
<td>15</td>
<td>14°, 1°</td>
<td>split, oscillating</td>
</tr>
<tr>
<td>15.3.2002</td>
<td>Cessna Citation</td>
<td>FL 150</td>
<td>25</td>
<td>14°</td>
<td>const.</td>
</tr>
<tr>
<td>22.3.2002</td>
<td>Dornier Do128</td>
<td>FL 100</td>
<td>25</td>
<td>14°, 35°</td>
<td>const.</td>
</tr>
</tbody>
</table>

**total 116**
Wake Generating Aircraft ATTAS

ATTAS with extended flaps

smoke generator in action

smoke trace, constant DLC flaps

smoke trace, oscillating DLC flaps
Encounter Aircraft

Dornier Do 128 (TU-BS)
4 flow probes (5 hole probes)

Cessna Citation II (NLR)
1 flow probe (vanes)
Encounter Maneuver

- wake generation
- smoke trace
- 0.5 nm
- 1.5 nm
- 3.0 nm
Flight Test Encounter Scenario
Do128 Typical Encounter Flow Sensor Measurements

horizontal velocity, wake system

vertical velocity, wake system

m/s

noseboom
right wing
left wing
vertical tail

time, s
The 2 Steps of Encounter Flight Test Data Evaluation

**Step 1: Flow Field Characterization**
- **Vortex Model**
- **Flight Path Reconstruction (FPR)**
- Flow measurements

**Step 2: Encounter Model Validation**
- Basic A/C aero model
- Aerodynamic interaction model
- Pilot's control inputs
- Forces, moments
- ∆ forces, ∆ moments
- Outputs

**Outputs:**
- Accelerations, rates, attitude, altitude, velocity

**Model Accuracy**

**Flow Measurements:**
- Accelerations, rates, attitude, altitude, velocity
Validation Basic Do128 Model - no Wake Vortex Influence

- Lateral acceleration
- Vertical acceleration
- Roll rate
- Pitch rate
- Yaw rate
- Bank angle
- Pitch angle
- Yaw angle

measured vs. model output
Determination of Vortex Model Parameters: \textit{Rosenhead - B \& H}

- Identified:
  - $\Gamma = 115.3 \text{ m}^2/\text{s}$
  - $r_c = 0.90 \text{ m}$
  (=4.2\% wing span)

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Horizontal velocity measurements vs. model output for:
- Noseboom sensor
- Right wing sensor
- Left wing sensor
- Vertical tail sensor

Vertical velocity measurements vs. model output for:
- Noseboom sensor
- Right wing sensor
- Left wing sensor
- Vertical tail sensor

Distance: 0.8 nm
Determination of Vortex Model Parameters: *Winckelmans*

- horizontal velocity
- vertical velocity
- measured
- model output

*Identified:*
- \( \Gamma = 152 \text{ m}^2/\text{s} \)
- \( r_c = 0.22 \text{ m} \)
  (=1% wing span)

**distance:** 0.6 nm
Do128: Comparison of Different Vortex Models

Circulation

Core Radius
- Rosenhead - Burnham & Hallock
- Lamb-Oseen
- Proctor - Winckelmans

Vortex Separation

Max. Tangential Velocity
Aerodynamic Interaction Models

Strip Method (SM)
ONERA

Lifting Surface Method (LSM)
TU Berlin
Validation of *Strip Method (SM)*: Simulation of ATTAS/Do128 Wake Vortex Encounters

**Encounter 1:** right → left

**Encounter 2:** left → right

<table>
<thead>
<tr>
<th></th>
<th>measured</th>
<th>simulation model output</th>
</tr>
</thead>
<tbody>
<tr>
<td>lateral accel.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>vertical accel.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>roll rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pitch rate</td>
<td></td>
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**Encounter 1:** right → left

**Encounter 2:** left → right

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<th>simulation model output</th>
</tr>
</thead>
<tbody>
<tr>
<td>yaw rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bank angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pitch angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>yaw angle</td>
<td></td>
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Validation of *Lifting Surface Method (LSM)*: Simulation of ATTAS/Do128 Wake Vortex Encounter

**Encounter 1:** right ➔ left

**Encounter 2:** left ➔ right

### Measured vs Simulation Model Output

- **Lateral Acceleration**
  - Measured: **3 M/s²**
  - Simulation Model Output: **3 M/s²**

- **Vertical Acceleration**
  - Measured: **20 M/s²**
  - Simulation Model Output: **20 M/s²**

- **Roll Rate**
  - Measured: **-50 DEG/S**
  - Simulation Model Output: **-50 DEG/S**

- **Pitch Rate**
  - Measured: **10 DEG/S**
  - Simulation Model Output: **10 DEG/S**

- **Yaw Rate**
  - Measured: **15 DEG/S**
  - Simulation Model Output: **15 DEG/S**

- **Bank Angle**
  - Measured: **-15 DEG**
  - Simulation Model Output: **-15 DEG**

- **Pitch Angle**
  - Measured: **50 DEG**
  - Simulation Model Output: **50 DEG**

- **Yaw Angle**
  - Measured: **-20 DEG**
  - Simulation Model Output: **-20 DEG**

- **Time, s**
  - Start: **0 s**
  - End: **20 s**

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Summary

- S-WAKE flight test measurements (116 encounter) are a valuable high quality data base

- Flight test data were successfully evaluated with parameter identification and flight path reconstruction techniques to determine parameters of wake vortex models (Rosenhead & Burnham-Hallock, Lamb-Oseen, Winckelmans)

- Flight test data were successfully evaluated to validate aerodynamic interaction models (AIMs) for near parallel encounter cases (strip method, lifting surface method)

- In general, both AIMs are suitable to simulate wake vortex encounters (especially roll and vertical axes). Overall, both methods show equally good results.