WAKE VORTEX ALLEVIATION by MEANS of PASSIVE VORTEX DEVICES

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Outline

- Wake vortex hazard
- Models and measurement technique used
- Wake vortex devices
- Wake alleviation potential
- Conclusions and outlook
Wake Vortex Hazard

The Effect of Trailing Vortices on Following Aircraft:

- **Induced Rolling moment**
- **Downwash**
- **Upwash: Structural Loading**

Airports operate a **minimum trailing distance** to approach aircraft, which is the biggest cause of airport congestion.
Wake Vortex Hazard

The Effect of Trailing Vortices on Following Aircraft:

- **Induced Rolling moment**
- **Downwash**
- **Upwash: Structural Loading**
- **Zero Vertical Velocity Line**

The goal of *wake vortex devices* is to **reduce trailing vortex strength** and **life time** to improve airport capacity and flying safety.
Experimental Setup: Half Model 1

**Half-Model Characteristics:**
- Model scale: 1:22.5
- Wingspan b/2: 1.301 m
- Wing mean aerod. chord $l_\mu$: 0.323 m
- Aspect ratio $A_R$: 9.302
- Fuselage length $L_B$: 2.605 m

**Baseline Configuration:**
- In-board slat: 19.6°
- In-board flap: 26°
- Mid-board slat: 23.0°
- Out-board flap: 26°
- Out-board slat: 26°
- Aileron: 10°
- Horizontal stabilizer: -9.5°
- Angle of attack: 9.5°

**Freestream velocity**

<table>
<thead>
<tr>
<th>Freestream velocity</th>
<th>$U_\infty$</th>
<th>25.0</th>
<th>[m/s]</th>
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<tr>
<td>Reynolds number*10^6</td>
<td>0.471</td>
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</table>

The wing is equipped with transition strip

Half model 1 tests: same AoA

Toulouse, 9-10 Feb. 2005

Lehrstuhl fuer Aerodynamik
Experimental Setup: Half Model 2

Half-Model Characteristics:
- Model scale: 1:19.25
- Wingspan b/2: 1.491 m
- Wing mean aerod. chord $l_{\mu}$: 0.3569 m
- Aspect ratio $A_R$: 9.5
- Fuselage length $L_B$: 2.90687 m

Baseline Configuration:
- In-board slat: 19.6°
- Mid-board slat: 23.0°
- Out-board slat: 23°
- In-board flap: 26°
- Out-board flap: 23°
- Aileron: 5°
- Horizontal stabilizer: -6°
- Angle of attack: 7°

Freestream velocity
- $U_\infty$: 25.0 [m/s]
- Reynolds number $\times 10^6$: 0.520 [-]

The wing is equipped with transition strip.

Half Model 2 tests: same lift coefficient, $C_L=1.44$
**Experimental Setup: the wind tunnel**

- **Fan:** 180 kW
- **0...30 m/s**

**Honeycomb Section**
- Nozzle: Type Börger, 2.12 : 1
  - Turbulence Level < 0.5 %

**LTA-E4 Half-Model**
- 0.37

**Corner Blades**
- x* = 5.6

**Test Section:**
- 21 x 1.8 x 2.7 m

**Hot-Wire Probe Traversing System**

**Adjustable Ceiling:**
- Pressure Gradient Control

**Half model 01**
- x* = 5.6

**Half model 02**
- x* = 4.5

**WakeNet2-Europe**
**Hot-wire Anemometry**

- Miniature triple-wire probes
- Computer-aided fully-automated calibration
- Multi-dimensional look-up table

Surfaces for anemometer output voltages at constant velocity and probe angle, resp.

\[ <|u|, \alpha, \beta> = f(E_1, E_2, E_3) \]

\[ <u, v, w> \iff <|u|, \alpha, \beta> \]
**Vortex Devices: Flap-Plate**

*Tested on Half model 1*

- **Flap Plate vortex**
- **Plate wingspan** = \( \frac{1}{4} \) of the outboard flap wingspan
- **Plate chord** = \( \frac{1}{2} \) of the outboard flap chord
Vortex Devices: Turbulence generators

Tested on Half model 1 and 2

Introduction of additional turbulence in the region of the outboard flap

Three design types:
(denomination is valid for the starboard wing)

Left swept plate
Double swept plate
Right swept plate
Bluff body fixed to the pylon extension fairing (PEF) introducing disturbances in the region of the outer edge of the outboard flap.
Vortex Devices: Differential Flap Setting (DFS)

Two DFS configurations:

- **Inboard loading 26/8**
  - AoA = 9.3°
  - Inboard flap: 8°
  - Outboard flap: 26°

- **Outboard loading 8/26**
  - AoA = 9.6°
  - Inboard flap: 26°
  - Outboard flap: 8°

Lift coefficient: $C_L = 1.44$

Tested on Half model 2
Extended Near Field Vortex Topology – Device off configuration

Non-dimensional axial vorticity distributions $\xi$
for cross-flow planes $x^* = 0.37$ to $x^* = 5.6$

Levels of $\xi$

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<tr>
<th>Value</th>
<th>Color</th>
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<td>Orange</td>
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<td>Yellow</td>
</tr>
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<td>Green</td>
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<td>Blue</td>
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<tr>
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<td>Magenta</td>
</tr>
<tr>
<td>2.60</td>
<td>Gray</td>
</tr>
<tr>
<td>1.20</td>
<td>Black</td>
</tr>
<tr>
<td>0.00</td>
<td>White</td>
</tr>
</tbody>
</table>

$WTV = $ Wing Tip Vortex
$OFV = $ Outboard Flap Vortex
$ONV = $ Outboard Nacelle Vortex
$INV = $ Inboard Nacelle Vortex
$HTV = $ Horizontal Tailplane Vortex
$WFV = $ Wing Fuselage Vortex

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**Flap-Plate**

Non-dimensional axial vorticity peak $\xi$ of the Outboard Flap Vortex (OFV)

Circulation of the Outboard Flap Vortex at $x^* = 5.6$

Tangential velocity of the Outboard Flap Vortex, $x^* = 5.6$
Flap-Plate – Induced rolling moment

\( b = 11 \text{ m} \Rightarrow \frac{b_f}{b_g} \approx 0.2 \)

\( A = 16.2 \text{ m}^2 \)

\( \text{Chord} = 1.454 \text{ m} \)

\( C_{l\alpha} = 6.2831 \)

\( U_{oo} = 25 \text{ m/s} \)

**Baseline Flap-plate**

Maximum induced rolling moment coefficient, \( x^* = 5.6 \)

**Induced rolling moment coefficient, \( x^* = 5.6 \)**
Double swept plate – Additional turbulence

Baseline ➔

Device on ➔

Lateral turbulence intensity distribution at \( x^* = 0.37 \)

Non-dimensional axial vorticity at \( x^* = 5.6 \)
Double swept plate – Induced rolling moment

Circulation of the Outboard Flap Vortex at $x^* = 5.6$

Tangential velocity of the OFV at $x^* = 5.6$

Induced rolling moment coefficient, $x^* = 5.6$

Approximately -25%
**Cylinder – Induced rolling moment**

Non-dimensional axial vorticity at $x^* = 5.6$

Circulation and tangential velocity of the OFV at $x^* = 5.6$

Induced rolling moment coefficient and maximum at $x^* = 5.6$

- OFV, 13
- WTV, 0.9
- Baseline
- OFV, 14.9
- WTV, 2
- Cylinder

**Baseline Cylinder**

**WakeNet2-Europe**

**Toulouse, 9-10 Feb. 2005**
HWA measurement at 1, 2 and 4 diameters downstream of the cylinder reveal two peaks:

1. \( f_1 = 242.17 \text{ Hz } (k = 3.45), \) attributed to the cylinder vortex street

2. \( f_2 = 78.476 \text{ Hz } (k = 1.12), \)
The frequency \( f_j = 242.17 \) Hz has been observed at plane \( x^* = 0.02 \) in the region of the outboard nacelle vortex (ONV).
The frequency $f_i = 242.17$ Hz has been observed at plane $x^* = 0.02$ in the region of the outboard nacelle vortex (ONV).

No significant peaks for the cylinder frequency $f_i = 242.17$ Hz have been observed further downstream (plane $x^* = 0.37, 3.0$ and $4.5$).
Differential flap setting

Generating aircraft: Half Model 02

Non-dimensional axial vorticity at the most downstream station, $x^* = 4.5$

Baseline

Inboard loading 26/8

Outboard loading 8/26
**Differential flap setting – Induced rolling moment**

Generating aircraft: **Half Model 02**

The maximum induced rolling moment coefficient at $x^* = 4.5$ is reduced in the wake of both DFS configurations. **but the roll up process is not completed......**
Conclusion & Outlook

Several passive alleviation devices have been tested:
- by installing external bodies like swept plates, cylinder and the flap-plate
- by changing the setting of wing high lift surfaces.

Swept plates and cylinder enhance the diffusion of the wake vorticity and produce a reduction of the maximum induced rolling moment coefficient:
- the double swept plate shows a 25% reduction of the maximum induced rolling moment coefficient;
- the perturbation introduced by the cylinder could not be observed further downstream of $x^* = 0.02$

The flap-plate produces an increase of the maximum induced rolling moment.

Differential flap setting effects significantly the evolution of the wake:
- DFS 26/8 → the wing tip vortex is the dominant vortex
- both DFS configurations produce a decrease of the maximum induced rolling moment
Core Radius

- Baseline: 0.056
- Double swept plate: 0.101
- Flap-plate: 0.073
- Cylinder: 0.067