Revisiting wake vortex mitigation by means of passive devices – Concept and current validation status of a novel device

Contents

- Known on-board vortex mitigation techniques
- Concept of VACS: Vortex Alleviation Cone System
- Proof of concept

- Current validation in the nearfield

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Known on-board vortex mitigation techniques

Several devices, EU-projects AWIATOR and C-Wake [1], 2006

NASA [2], 1974

Blowing at the wingtip [4], 1977

Vortex generators [4], 1977

NASA [3], 1988
Concept of Vortex Alleviation Cone System

- Conceptual approach
  - Highest wv encounter during approach phase: Alleviation in this phase
    - Modest drag is acceptable
    - Device needs to be deployable, possibly retrofitted
      - Simple, light, small, passive, robust, safe, independent
- Aerodynamic approach
  - Momentum conservation: vortex widening for reduced intensity
Concept of Vortex Alleviation Cone System

- Effective approach:
  - Widening the established vortex core by $w_f = 2-3$
    using a conical tube behind the wing/flap [5]
  - Textile / inflatable device or integrated surface

Working mechanism
Retractable wing-/ flaptip device
Integrated and adaptable wing-/ flaptip feature
Concept of Vortex Alleviation Cone System

- Physical effects:

  - Conservation of mass
  - Vorticity transport equation: $\omega_x \rightarrow \omega_\vartheta$
  - Conservation of angular momentum
  - Reduced axial velocity
  - Axial velocity induction
  - Critical Swirl Numbers:
    - Vortex Breakdown
    - Turbulent diffusion
  - Reduced tangential velocity
  - Impact on pressure drag
  - Impact on induced drag

Vortex breakdown related to feedback- and induction-mechanism
Concept of Vortex Alleviation Cone System

- Realization and implementation
  - Compartment and gearing space for installation into:
    - Gap b/w aileron and flap
    - Flap cavity
    - Flap track (other a/c type)
Proof of concept

- Preliminary investigations at RWTH Aachen using generic wing-model

70% reduction of $v_{t,max}$, $w_f = 3$
15% reduction of $c_{L,ind}$, $w_f = 3$
Progressive reduction of $\omega_{x,max}$ with $w_f$
Current validation in the nearfield

- RWTH Aachen University project funded by “Innovationsfond”
  - Validation of the effectiveness and efficiency of VACS
- Project scope
  - **WP1:** Analysis of lift, drag, effectiveness, and noise (ILR)
  - **WP2:** Analysis of vortex intensity long-time development (ILR)
  - **WP 3:** Analysis of air traffic benefits and solution trade-off (VIA*)
  - **WP 4:** Joint workshop on expertise level (ILR & VIA*)

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Current validation in the nearfield

- Windtunnel and measurement configurations

  - **Low speed windtunnel**
    - \( \text{Rec} = 300.000 \) / \( V \approx 29 \text{ m/s} \)
    - Nose suction
  
  - **6C Balance**
    - DMS, temperature compensated
  
  - **3C PIV**
    - 4 MPx Cameras
    - Davis by LaVision PIV software
    - 16x16 px² with 50 % overlap

  - **Acoustic Array**
    - 32 microphones
    - Still under investigation
Current validation in the nearfield

- Wing half-model and VACS devices
  - Articulated H/L features, BAC 3-11/RES/30/21 airfoil
  - VACS devices with $w_f = 1 - 5$
  - $d_{\text{inlet}} = 10 \text{ mm} \sim d_{\text{core}}$
  - $l_{\text{VACS}} = 70 \text{ mm} = 40 \% c_{\text{mac}}$
  - Attachment:
    - Core capturing
    - Hinged flaptip mounting

Cruise

Take off
$\varphi_{\text{SLAT}} = 0^\circ$
$\varphi_{\text{FLAP}} = 10^\circ$

Landing
$\varphi_{\text{SLAT}} = 20^\circ$
$\varphi_{\text{FLAP}} = 20^\circ$
Current validation in the nearfield

- Smoke visualization, landing configuration

**Indications:**
- Increasing diffusion of vorticity with increasing $w_f$
- High $w_f$ produce circulating breakdown region behind the outlet
- Drag penalty and effectiveness?
Current validation in the nearfield

- VACS influence on drag ($c_W$) in best L/D points

Indications:
- Drag dominated by $c_{W,0}$ with increasing $w_f$
- $c_{W,D}$ increase > $c_{W,IND}$ reduction
Current validation in the nearfield

- VACS influence on L/D

L/D over $c_A$; Take-off configuration; $\alpha = 2^\circ$

L/D over $c_A$; Landing Configuration; $\alpha = 6^\circ$

\[ \Delta \text{L/D for Take-off} \quad (\alpha = 2^\circ) \quad \text{and Landing Configuration} \quad (\alpha = 6^\circ) \]

Performance degradation:
- Moderate for landing, excessive for take-off
- $w_f$ adaptation for low drag service?
Current validation in the nearfield

- **3C-PIV: Mitigation potential**

\[ v_{t,\text{max}} \text{ over } w_f ; \ x/c = 5 \]

Reduction of vortical motion:
- \( \omega_{x,\text{max}} \): 85 % (Landing), 75 % (Take-off)
- \( v_{t,\text{max}} \): 40 % (core growth ~ 3) (both)
Current validation in the nearfield

- **3C-PIV: Mitigation potential**

\[
\frac{v_{t}}{U_{\infty}} \text{ for different } w_f ; x/c = 5 ; \text{ Landing}
\]

\[
\frac{v_{t}}{U_{\infty}} \text{ for different } w_f ; x/c = 5 ; \text{ Landing}
\]

\[
\text{Swirling strength over } w_f ; x/c = 5
\]

Potential for \(C_{\text{Roll,ind}}\) reduction:
- Needs to be assessed for completely rolled-up vortex in the farfield

Potential for swirl instability:
- Enhancement of turbulent diffusion?

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Outlook

- Further analysis:
  - Comparing drag components from balance and 3C-PIV
  - Assessment of swirl and turbulence
  - Acoustic noise assessment
  - Optimization / miniaturization / adaptivity / trade-offs

- Further direct project scope
  - WP1: Analysis of lift, drag, effectiveness, and noise (ILR)
  - **WP2: Analysis of vortex intensity long-time development (ILR)**
  - WP 3: Analysis of air traffic benefits and solution trade-off (VIA*)
  - WP 4: Joint workshop on expertise level (ILR & VIA*)

- Water towing tank experiments at DST** in Duisburg, Germany, Oct. 2014
  - 2C-PIV, VACS at flap-tip and possibly wing-tip
  - Start-stop investigation / mitigation
  - 120 span vortex mitigation assessment

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Summary

- **VACS**
  - Potential for hands-on vortex mitigation
  - Generic and real-configuration tests successful

- **Vortex mitigation**
  - For take-off: high (40% \(v_{t,\text{max}}\); 75% \(\omega_{x,\text{max}}\)): promising
  - For landing: high (40% \(v_{t,\text{max}}\); 85% \(\omega_{x,\text{max}}\)): promising
  - Swirl potential for turbulent diffusion behind VACS

- **Maximum L/D penalty**
  - For take-off: high (14% @ \(w_{f} = 5\)): not ok
  - For landing: low (4% @ \(w_{f} = 5\)): ok
    - low (1% @ \(w_{f} = 2\)): ok

- **DE patent pending**
References

Thank you!
Questions?