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To cite this version:
Dinh Hung Truong, Abderahmane Marouf, Jan. B Vos, Dominique Charbonnier, Alain Gehri, et al.. Unsteady CFD simulations of a synthetic jet for flow control around a high lift wing flap system. 56th 3AF International Conference on Applied Aerodynamics, 28 30 March 2022, Toulouse France, Mar 2022, Toulouse, France. hal-03926470

HAL Id: hal-03926470
https://hal.science/hal-03926470
Submitted on 6 Jan 2023

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Unsteady CFD simulations of a synthetic jet for flow control around a high-lift wing-flap system

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56th 3AF International Conference on Applied Aerodynamics
28 – 30 March 2022, Toulouse - France
Introduction

Numerical methods
- NSMB solver, Chimera grid
- Modeling of ZNMF devices

Results
- Validation
- AFC with ZNMF in 2D
- AFC with ZNMF in 3D

Conclusion and Perspectives
Unsteady CFD simulations for Active Flow Control

➢ Introduction

➢ Numerical methods
  ➢ NSMB solver, Chimera grid
  ➢ Modeling of ZNMF devices

➢ Results
  ➢ Validation
  ➢ AFC with ZNMF in 2D
  ➢ AFC with ZNMF in 3D

➢ Conclusion and Perspectives
Smart Morphing & Sensing
for aeronautical configurations

Active Flow Control 4
Tilt Rotor aircraft

Leonardo Helicopters
Unsteady CFD simulations for Active Flow Control

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Conclusion and Perspectives
Numerical methods

- **NSMB solver: Navier Stokes Multi-Block code [Hoarau et al. 2016]**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
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<td>$U_\infty$</td>
<td>$68 \text{ m/s}$</td>
</tr>
<tr>
<td>$Ma$</td>
<td>$0.2$</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>$0^\circ - 8^\circ$</td>
</tr>
<tr>
<td>$\delta$</td>
<td>$10^\circ - 40^\circ$</td>
</tr>
</tbody>
</table>

- **Turbulence models:** URANS (SA) and DDES-SA

2D computational domain

3D computational domain
Modelling of Zero-Net-Mass-Flux (ZNMF) devices

ASPIE synthetic jet actuator

Slot dimensions: 1x150 mm²
Peak exit velocity during suction: 135 m.s⁻¹
Peak exit velocity during blowing: 150 m.s⁻¹
Optimal actuation frequency bandwidth: between 200 and 300 Hz
Actuator volume: 164x94x57 mm³
Numerical methods

➢ Modelling of ZNMF devices

ASPIC mass flux

\[ q_{0}^{ref} = V_{0} \times d = 150 \times 10^{-3} = 0.15 \, m^{2}/s \]

ZNMF devices’ mass flux

\[ q = V_{0} \times w = V_{0} \times d \times \sin \beta \]

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Diameter (mm)</th>
<th>Height (mm)</th>
<th>Inclined angle (degree)</th>
<th>Dimensionless velocity [ V_{jet}/U_{inf} ]</th>
<th>Mass flow [ (m^{2}/s) ]</th>
<th>Dimensionless frequency [ F^{+} ]</th>
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<td>8.363</td>
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Velocity is adjusted to get the same mass flux for all cases.
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Validation with experimental data

- Experimental PIV
  - AOA = 4°
  - AOA = 8°

- Numerical simulation

Mach=0.15 (U_\infty = 51.5 m/s)
Active Flow Control with ZNMF in 2D

➢ Baseline and morphing with cambering (10cm)
Active Flow Control with ZNMF in 2D

➢ Baseline and morphing with cambering (10cm)
Active Flow Control with ZNMF in 2D
Active Flow Control by ZNMF in 2D

The effect of the ZNMF characterized by the variation of the drag (left) and the lift (right).

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<th>Mass flow ($m^2 \cdot s^{-1}$)</th>
<th>Dimensionless frequency $F^+$</th>
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Time history of forces in the baseline, the best case and the worst case.

1mm-15deg ⇒ 6.78% increase in lift
5mm-45deg ⇒ 0.7% decrease in lift

The effect of the ZNMF characterized by the variation of the drag (left) and the lift (right).
Active Flow Control by ZNMF in 2D

Control strategy for using ZNMF:
- small size with high velocity is better than large size with small velocity
- the orientation should be tangential to the wing surface
Active Flow Control by ZNMF in 3D

- **Studied configuration**

(A) Small span

(B) ZNMF location

(C) ZNMF orientation
Active Flow Control by ZNMF in 3D

- Hybrid turbulence modelling DDES-SA with ZNMF
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Conclusion and Perspectives
➢ The Active Flow Control using ZNMF with blowing-suction and morphing with a cambering flap: a lift increase with a refrain of the drag increase are achieved;

➢ Strategy for using ZNMF: small size with high velocity is better than large size with small velocity;

➢ The orientation of ZNMF devices should be tangential to the wing surface;

➢ 3D hybrid modeling was performed: interaction of shear-layers, reattachment of the BL, wake thinning;

➢ The position of the jet is an essential factor;
Examine the flow control around a Tilt-Rotor Aircraft using ZNMF

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Thank You!