Flow Separation Control for Civil Transport Aircraft: some insight

J. Reneaux, Applied Aerodynamics Department

Orléans, 24-25 November 2009
Outline of the presentation

Introduction

Actuators

Modelling of the actuator effects

Flow control strategy

Applications

Conclusions
Drag reduction

Drag breakdown for a long range aircraft

Wave drag
- Bump
- Trailing edge devices

Lift-induced drag
- Winglets

Viscous drag
- Riblets
- Laminar flow

⇒ New approach with Control of flow separation
Control of flow separation

Objectives: to introduce flow control in the design loop in order to come up with more efficient novel configurations

Flow control techniques:
- Passive vortex generators
- Active, air-jet vortex generators
- Active, Pulsed and synthetic jets
- Plasma actuators (DBD, Synthetic jet)
Development of micro valves allowing pulsed jet to be generated

Air velocity above the micro valve for various frequencies d=1 mm

Pulsed supersonic jet d=0.5 mm
Schlieren visualization (DAAP/MMHD)
Micro-valve 100 Hz Film 1,000 Pictures/s

Marc Deschamps, Frédéric Ternoy, ONERA-DERM
Plasma Synthetic Jet (micro-jet by plasma)

**Principle**

- **Stage 1:** Energy Deposition
- **Stage 2:** Discharge
- **Stage 3:** Recovery

**CEDRE computation**

**Schlieren visualisations**

→ velocity measurement

- V\(_{\text{jet}} \rightarrow 300 \text{ m/s}\)
- T\(_{\text{jet}} \sim 600 \text{ K}\)
- F\(_{\text{jet}} \rightarrow 4000 \text{ Hz}\)

Φ orifice = 1mm

→ *Presentation 24 November*

P. Harcy, P. Barricau, D. Caruana, C. Gleyzes

Daniel Caruana, Philippe Barricau, Pierrick Hardy, ONERA-DMAE
Flow control actuators

Needs for comparison in the power & mass costs for the different actuators:

Actuator efficiency

<table>
<thead>
<tr>
<th>Actuator Type</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>PJAs (direct bleed)</td>
<td>40%</td>
</tr>
<tr>
<td>PJAs (electrical)</td>
<td>10% → 20%</td>
</tr>
<tr>
<td>SJAs</td>
<td>1% (DBD)</td>
</tr>
</tbody>
</table>

Aerodynamic efficiency?

M. Jabbal, S.C. Liddle, W.J. Crowther, University of Manchester

Modelling the Costs of Implementing Active Flow Control Systems on Civil Trans. Aircraft, KATnet2, 2009

Active Flow Control Systems Architectures for Civil Transport Aircraft, CEAS, Manchester, 2009
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Vorticity distribution at 5δ downstream of VGs

Counter rotating VGs

7.2 \times 10^6 nodes

5.7 \times 10^6 nodes

Bender, Anderson, Yagle

Vincent Brunet, ONERA-DAAP
Air jet simulation using the overset grid technique and the elsA software

Meshes

RANS simulation

Julien Dandois, Mickael Meunier, ONERA - DAAP
Air jet simulation with a jet model

Air jet (30° - 60°) at $M_j = 2$

Over-set grid

Jet model

Velocity $V_x$ at $X=014$ m

$\mu t/\mu V_x$ at $X=014$ m

Christian Gleyzes, ONERA-DMAE
Separation control by synthetic jet LES simulations

Separation control over a ramp with a synthetic jet slot

LES without control

LES with control at $F^+=1$, $C_\mu=1.9\%$
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Optimisation of a slotless flap configuration: continuously blowing slot

**Objective:** to recover the reference CL

3 design variables

SA RANS Simulations
Coupling between genetic algorithm and a surrogate model (Kriging)

Mickael Meunier, ONERA - DAAP
Closed loop control with reduced model based upon non-linearised approach \((POD)\)
Buffet phenomenon in 2D flow
OAT15A airfoil

Schlieren visualisation

LDV measurement
PRF BUFET’N Co: OAT15A Airfoil

URANS 2.5D Hypothesis

Entry signal  POD analysis (8638 snapshots)

Slot at 21%  Mode 1  Mode 2

Mode 3  Mode 4

Julien Dandois, ONERA - DAAP
Optimal control with non linear-type reduced model for identification: "NARMA: Non-Linear Auto-Regressive Moving Average" model"

\[
\tilde{x}(n) = \sum_{i=1}^{N_x} a_i \tilde{x}(n-i) + \sum_{i=0}^{N_u-1} b_i u(n-i) + \sum_{i=0}^{N_x^2-1} c_{ij} \tilde{x}^2(n-i) + \sum_{i=1}^{N_x} \sum_{j=0}^{N_u-1} d_{ij} u^2(n-i) + \sum_{i=1}^{N_x} \sum_{j=0}^{N_u-1} e_{ij} \tilde{x}(n-i) u(n-j) + \sum_{i=1}^{N_x^3} f_i \tilde{x}^3(n-i) + \sum_{i=1}^{N_x^4} g_i \tilde{x}^4(n-i)
\]

\(\text{Good prediction of reduced model w/o and with control}\)

Julien Dandois, ONERA-DAAP, Philippe Mouyon ONERA-DCSD
PRF BUFET’N Co: OAT15A Airfoil
Closed loop tuning on the reduced order model

On-going activities on the closed loop control in URANS

Julien Dandois, ONERA-DAAP, Philippe Mouyon ONERA-DCSD
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Applications
  ➢ High-lift devices
  ➢ Buffet phenomenon
  ➢ Engine installation
  ➢ S-Duct

Conclusions
Application of flow control to high-lift configurations

Objectives
To develop new high-lift configurations in order to:
- Reduce the geometric complexity & the weight (slat & flap tracks,...)
- Improve the lift-to-drag ratio in take-off
- Reduce the aerodynamic noise in take-off and landing (slat noise)

\[ \delta_{\text{slat}} = 24.4^\circ - \delta_{\text{flap}} = 32.4^\circ \]

- **Slot-less flap**
  - Conf. 1
  - \[ \delta_{\text{flap}} = 25^\circ \]
  - Lower lift due to massive separation on the flap

- **Droop nose**
  - Conf. 3
  - \[ \delta_{\text{slat}} = 35^\circ \]
  - Earlier stall due to massive separation from the knee

- **Slat-less**
  - Conf. 2
  - Very earlier stall due to massive separation from the leading edge

Cooperation with Dassault-Aviation
Application of flow control to the Buffet phenomenon

Objectives: To delay the buffet phenomenon which limits the aircraft flight envelope

Perspectives: drag reduction due to a wing surface area decrease
Use of VGs to delay the buffet onset

elsA EARSM-SZL, T2 experiment, Re=5 \times 10^6
Control with a trailing edge deflector
M=0.73 Re=4×10^6

Closed-loop approach
\[ \delta(t) = \delta_0 + \delta'(t) \]
with \( \delta'(t) = A \ P(t-\tau) \) and \( P \) the unsteady pressure in the shock region

Evolution of shock location versus time
PRF BUFET’NCo: reference configuration
\( \alpha = 3.5^\circ, M = 0.815 \)

- Friction lines parallel to the trailing edge Y/b \( \sim 15\% \)
- Oil coming from the pressure side Y/b \( \sim 20\% \) \( \Rightarrow 90\% \)
PRF BUFET’NCo: Flow control by mechanical VGs
\( \alpha = 3.5^\circ, M = 0.815, \text{Re}=2.5 \times 10^6 \)
Wall pressure distribution at $Y/b = 50; 70; 80\%$

- with control, shock location further downstream since flow separation has been reduced
- $Y/b = 50\%$: separation at the trailing edge
- $Y/b = 70$ et $80\%$: separation suppressed

Pressure fluctuations at $Y/b = 60\%$
PRF BUFET’NCo: Flow control by fluidic VGs
\[ \alpha = 3.5^\circ, \quad M_p = 0.815, \quad Re=2.5 \times 10^6, \quad C_\mu=3 \times 10^{-4} \]

- Flow separation suppressed between \( Y_b = 60 \) and 80%
- Results similar to mechanical VGs

P. Molton ONERA - DAFE, V. Brunet, DAAP, A. Lepage DADS
PRF BUFET’NCo: Flow control by fluidic VGs

$\alpha = 3.5^\circ$, $M = 0.815$, $Re=2.5 \times 10^6$, $C_\mu=3 \times 10^{-4}$

Wall pressure distribution at $Y/b = 50$ ; $70$ ; $80$

- with control, shock location further downstream since flow separation has been reduced
- $Y/b = 50%$ : separation at the trailing edge
- $Y/b = 70$ et $80%$ : separation suppressed

Pressure fluctuations at $Y/b = 60$

P. Molton ONERA - DAFE, V. Brunet, DAAP, A. Lepage DADS
PRF BUFET’NCo: Flow control by pulsed jet
\( \alpha = 3^\circ, M = 0.815, \text{Re}=2.5 \times 10^6 \)

PSD Spectrum

Frequency effects

- Ref - \( Y/b = 70\% - M_p = 0.815, \alpha = 3.0^\circ \)
- VGFp - \( Y/b = 70\% - M_p = 0.815, \alpha = 3.0^\circ, f = 100\text{Hz} \)
- VGFp - \( Y/b = 70\% - M_p = 0.815, \alpha = 3.0^\circ, f = 300\text{Hz} \)
- VGFp - \( Y/b = 70\% - M_p = 0.815, \alpha = 3.0^\circ, f = 400\text{Hz} \)
- VGFp - \( Y/b = 70\% - M_p = 0.815, \alpha = 3.0^\circ, f = 500\text{Hz} \)
- VGFp - \( Y/b = 70\% - M_p = 0.815, \alpha = 3.0^\circ, f = 750\text{Hz} \)
Application of flow control to transonic configuration

Objectives
To adapt & apply flow control technologies on transonic configurations in order to reduce drag & increase separation margins

Different steps
- Application of passive flow control (VGs) to delay separation
- Application of passive & active flow control to reduce the drag (by introducing the flow control in the design loop)
- Reduction of thermal issues through flow control (power plant configuration)

ZDES jet simulation

Vincent Brunet, ONERA-DAAP
Improvement of off-design characteristics by the use of VGs – M=0.82 Re=6 $10^6$

**Objectives:** To increase separation margin for engine installation using passive boundary layer Vortex Generators

RANS Mesh of 8$10^6$ nodes - $k\omega$

Velocity near the inner part of the pylon versus the angle of attack

- Capacity of flow control techniques (passive VGs) to postpone unfavourable phenomena for engine installation
- On-going activities with the introduction of flow control in the design loop

Vincent Brunet, DAAP, Meudon
Flow control application to S-duct engine air-intake R4MA wind tunnel tests – rake measurements

Configuration

Mach M=0.6

Without control
DC60=0.33

Control with 10 VGs
DC60=0.18

Control with 14 AirjetVGs
DC60=0.24

On-going activities on RANS & URANS simulations

Anne-Laure Delot-Vuilerme, DAAP, Meudon
Concluding remarks

Thanks to European & national projects, dramatic progresses have been obtained for both the actuators (VGs, pulsed jets, synthetic jet by plasma) & the numerical approach (model development & method assessment, numerical optimisation)

Main applications are oriented towards the high-lift configurations, the buffet phenomenon, the power plant configuration & the air intake

Strong needs for:
- developing the closed loop approach in order to minimize the control energy to be supplied
- modelling the costs of implementing flow control systems
- investigating the distributed flow control

Extended integration of control concept will lead to innovative designs

Maturation of flow control concepts in JTI SFWA project