AFLONEXT FINAL CONFERENCE
Active Buffet Flow Control on Wing Trailing Edge

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ACTIVE BUFFET FLOW CONTROL ON WING TRAILING EDGE

Outline

\ Motivation / Objectives

\ Benchmark of CFD Simulation Capabilities

\ Design of Mini-TED devices for Buffet Control

\ Evaluation at Aircraft Level

\ Lessons Learnt
Motivation

Potential of Buffet Control

Trimmed $C_L$  
(Weight / Altitude)

Aircraft Buffet Boundary  
(measured at flight test measured at pilots seat +- 0.25g)

Allowable operational envelope  
(0.3g buffet margin)

Mach Flex

$C_L$ vs Mach
Potential of Buffet Control

Trimmed $C_L$ (Weight / Altitude)

Aircraft Buffet Boundary with control on

Aircraft Buffet Boundary control off

Buffet suppression activated when close to buffet restoring 0.3g buffet boundary

ToC Cruise condition
With relaxed buffet margin

Manoeuvre
Objectives

Predict the performance of different control devices

Identify the most promising application (buffet control?)

Perform parametric study to find more efficient configurations

Optimisation w.r.t. a specific objective (max lift/efficiency?)
Benchmark of CFD Simulation Capabilities

Prerequisite for design:
\ validated design environment
\ common baseline

Validation process:
\ definition of benchmark experiments for comparison
\ case studies by contributors
\ cross-comparison of results
\ derivation of lessons learnt
Benchmark of CFD Simulation Capabilities

Benchmark Experiments used AFLoNext:

- buffet flow control experiments conducted within the AVERT project (EU 5th Framework)
  - 2D airfoil experiments performed at VZLU
  - 3D half-model experiments performed at ONERA
- selected test case
  - transonic flow with/without buffet
- data for comparison
  - steady/unsteady pressure and aerodynamic coefficients
Benchmark of CFD Simulation Capabilities

2D CFD simulation validation

high AoA, no AFC

med AoA, with AFC
Benchmark of CFD Simulation Capabilities

3D CFD simulation validation

no AFC

with AFC
Design of Mini-TED devices for Buffet Control

Design problem

- **Design parameters object of investigation:**
  1. Jet mass-flow rate coefficient: \(0.2\% \leq C_{\dot{m}} \leq 0.8\%\) (ref. = 0.43%)
  2. Jet inclination angle: \(10^\circ \leq \varphi \leq 170^\circ\) (ref. = 90°)
  3. Slot position: \(90\% \leq \left(\frac{x}{c}\right)_{\text{T.E.}}^{\text{slot}} \leq 98\%\) (ref. = 94.5%)
  4. Slot size: \(0.1\% \leq \frac{l_{\text{slot}}}{c} \leq 0.5\%\) (ref. = 0.25%)

- **BASELINE** configuration has no blowing
- **REFERENCE** AFC is fluidic Gurney with reference (AVERT) values of design parameters, and \(C_{\mu} = 1.12\%\).

1. **Optimizations for maximum lift:** objective = \(C_l(\alpha=0.9^\circ) + C_l(\alpha=3.4^\circ)\)

2. **Optimization for maximum lift-over-drag** ratio (\(E\)): objective = \(E(\alpha=0.9^\circ) + E(\alpha=3.4^\circ)\)
**Design of Mini-TED devices for Buffet Control**

**Optimization result**

<table>
<thead>
<tr>
<th></th>
<th>REF-AFC</th>
<th>OPT-AFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MASS-FLOW RATE COEFFICIENT</td>
<td>0.43</td>
<td>0.37</td>
</tr>
<tr>
<td>JET INCLINATION ANGLE</td>
<td>90</td>
<td>124.5</td>
</tr>
<tr>
<td>SLOT T.E. POSITION</td>
<td>94.5</td>
<td>97.7</td>
</tr>
<tr>
<td>SLOT SIZE</td>
<td>0.25</td>
<td>0.24</td>
</tr>
</tbody>
</table>

**AoA = 1.9°**
Evaluation at Aircraft Level

Scope of assessment study

\ Wing design space investigated with AvIATE (rapid low order methodology)
\ Single aisle use case.
\ Wing planform constants: sweep, thickness, crank
\ Wing planform variables: span, taper
\ Study limited to aerodynamic buffet onset
\ Wing span loadings are calculated assuming that the Centre of Lift remains constant for $C_L$ range of interest*.
\ Assumes buffet is initiated when local sectional $C_l$ exceeds a specified value (function of Mach, sweep, thickness & design philosophy)

*Wing deformations tend to bring CoL inboard for increased CL, but for rigid wing analysis CoL migrates outboard for increased CL
Evaluation at Aircraft Level

Process methodology

Flow control effectiveness from 2D simulations allows $C_{l\text{buffet}}$ to be increased. Average $C_{l\text{buffet}}$ and area of wing requiring buffet suppression calculated to determine the mass flow the system must deliver.
Evaluation at Aircraft Level

Potential of buffet onset AFC with const. wing area

Single aisle use case.

Mission fuel:

“(a)” 0.3g buffet margin
“(b)” min. MTOW
“(c)” min. mission fuel

\ 4.7% fuel saving if we can recover 0.15g÷0.2g margin to buffet
Evaluation at Aircraft Level

Buffet control mass flow requirements
\ Data received from 2D CFD simulations scaled to aircraft conditions
\ Wing planforms assessed need buffet delay up to DCI 0.15

Flow control mass flow scaled to aircraft conditions

Example:
\ $\Delta C_{lave}$ buffet delay $\approx 0.08$
\ $S_{FlowControl} \approx 40m^2$
\ Mass flow $\approx 6.5 \text{ kg/s}$
\ Pressure Ratio $\approx 2.1$
Evaluation at Aircraft Level

Potential benefits of buffet suppression flow control

- Mass flow & systems mass estimates integrated with AvIATE to derive mass ‘snowball’ effects
- Accounting for system mass system reduces the fuel benefit to 4.2% for the design wing area.
- Largest flow control benefit from small highly loaded wings
- Benefit decreases rapidly with increased wing area
- Benefit of high span wings largely achieved with increased wing area

Evaluation at Aircraft Level

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Lessons Learnt

Benchmark of CFD Simulation Capabilities

- CFD methods capable to predict buffet onset
- CFD methods capable to predict effect of AFC on buffet onset
- AFloNext experience: deviations in CFD smaller than uncertainties from experiment

Design of Mini-TED devices for Buffet Control

- **lift increases** are obtained with a smaller slot closer to the trailing edge; a lower mass-flow rate can be used if the jet inclination is increased beyond 90°
- **efficiency increases** are obtained with a larger slot more distant from the trailing edge, blowing with a lower mass-flow rate almost normally to the wing surface

Evaluation at Aircraft Level

- **4.2% mission fuel reduction** by extending buffet margin on single-aisle aircraft size wing
- fuel reduction potential decreases with wing size
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