Wing Cuff Design for Cessna CJ1

AAE 415 Project
Purdue University
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Background of Problem

- Low experienced, rich pilots buy new airplane
- Airplane goes into stall and spins
  - Pilot can’t get out of spin
    - “Dr. Killers”
  - How can we design a wing to prevent this?

Mooney: Known for high performance but poor stall characteristics
Note: Unmodified leading edge
The Answer: A WING CUFF

- Leading edge modification
  - Creates vortex
  - ‘Stops’ propagation of separated air across the span
  - Able to maintain roll authority while the inboard section is stalled
    - Aiding in spin prevention
- Cosmetically appealing
Current Use of Wing Cuff

- **Cirrus & Lancair**
  - Integrate wing cuff on every single-engine airplane they sell
    - Cirrus is the #1 producer of GA aircraft
  - Aircraft are nearly spin resistant

- Marketing gimmick, or does it actually work?
“I rode with the Lancair company pilot when they had the prototype Columbia 400 here in Willmar about 3 years ago. I flew the airplane from take off to landing except when he took over to show me how the stall works. We eased back on the power and went into a stall and he held it in and did banks while in stall going down and had FULL aileron control. I was amazed!"

- Gene Underland, Pilot
Literature Review

- Numerous papers were reviewed in order to validate theoretical models and assumptions.
- Papers exhibiting substantial experimental data will be discussed in further detail.
  - SAE Technical Paper - 830720
  - NACA-TN-2948
  - NASA-TP-2011
Cuff Creates a secondary vortex over the wing
- Prevents separated flow from propagating down the span
- Attached flow is maintained over the tip and aileron
Figure shows boundary between attached and separated flow at various angles of attack.

- Addition of cuff creates vortex, delaying stall.
Resultant force coefficient (combination of lift and drag) increased significantly with droop addition.

- Droop comparable to wing cuff
- Paper notes the increase in resultant force coeff. Due to increase in lift rather than increase in drag
  - Results in better stall/roll characteristics
NACA-TN-2948

- Investigation of Lateral Control Near Stall

\[ \alpha = 16.95^\circ \quad C_L = 1.447 \]

\[ \alpha = 16.60^\circ \quad C_L = 1.491 \]

\[ \alpha = 19.80^\circ \pm 2^\circ \]

\[ \alpha = 25.55^\circ \pm 2^\circ \]

- Smooth flow, indicating direction
- Slightly disturbed flow
- Disturbed flow, indicating magnitude and direction
- Irregular circular motion, standing up or pointing in a forward direction
NASA-TP-2011

• Effects of Wing-Leading Edge Modifications on a Full-Scale, Low-Wing General Aviation Airplane
• Cuffed wing $C_l$ does not rapidly drop
• Insignificant change in drag polar
So it works… Now what?

- Light Jets are popular among rich, ‘inexperienced’ pilots as an upgrade from their Cirrus or Lancair.

- Can we design a wing cuff to prevent spin resistance on a Light Jet?
  - Cessna CJ1 smallest available Light Jet on the market today
    - Many emerging companies are designing smaller ‘Very Light Jets’
      - So far, none have incorporated wing cuffs.
Design Process

- **Objective:** Design Wing Cuff for Cessna CJ1 to increase stall and roll characteristics
  - Wing cuff to be approximately same dimensions as aileron
  - Analyzed different wing configurations at various angles of attack
    - Stock wing – NACA 23014
    - Wing with Cuff Addition – Cuff dimensions iterated

- **Design Tools**
  - CMARC
  - FLUENT
  - XFOil
  - MatLab
Design Configuration

- Stock Wing
- Wing Cuff Addition
CMARC Analysis

- Demonstrated vortex generation at cuff
  - Also showed vortex at wing tip
- Software was not able to show separation
  - Limited use for project design
Fluent Grid Creation

- Grid creation for Cuffed Airfoil
- Grid creation for Stock Airfoil

Symmetric Boundary Wall
FLUENT Analysis

Cp Distribution

Mach Number Contour
Contour of Turbulent Kinetic Energy

Vortex creation along the cuff
Vortex creation along the cuff

Velocity Vectors of the Cuff
Xfoil/MatLab Analysis

- Analyzed both stock wing and wing cuff airfoil sections at various angles of attack
  - Aileron Up, Aileron Down, and Aileron Neutral configurations
- Assumptions
  - Wing cuff section to have completely attached flow and wing root section to be completely separated
    - Attached flow $C_l$ obtained from Xfoil
    - Separated flow $C_l$ $\sim$ 40% drop from $C_l$ max
### Xfoil Cl Prediction – 14.5°

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Cl Value</th>
</tr>
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<tbody>
<tr>
<td>C_i Root - Separated</td>
<td>1.0 (Abbott &amp; von Doenhoff)</td>
</tr>
<tr>
<td>C_i Cuff - Aileron Nominal - Attached</td>
<td>1.69</td>
</tr>
<tr>
<td>C_i Cuff - Aileron Nominal - Separated</td>
<td>1.02</td>
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<tr>
<td>C_i Cuff - Aileron Up - Attached</td>
<td>0.81</td>
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<tr>
<td>C_i Cuff - Aileron Up - Separated</td>
<td>0.49</td>
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<tr>
<td>C_i Cuff - Aileron Down - Attached</td>
<td>1.96</td>
</tr>
<tr>
<td>C_i Cuff - Aileron Down - Separated</td>
<td>1.18</td>
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</table>
MatLab Results
Design Case – CJ1 Wing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Increase (%)</th>
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<tbody>
<tr>
<td>Platform Area Increase</td>
<td>1</td>
</tr>
<tr>
<td>Cuff Span</td>
<td>40</td>
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<tr>
<td>Cuff Chord Increase</td>
<td>3</td>
</tr>
<tr>
<td>Aileron Up $M_{\text{root}}$ Increase</td>
<td>33</td>
</tr>
<tr>
<td>Aileron Down $M_{\text{root}}$ Increase</td>
<td>48</td>
</tr>
</tbody>
</table>
Conclusions

- Cuff improves Cessna CJ1 stall/roll characteristics
  - Flow remains attached over the aileron
- Cuff does not increase drag
- Increase in $C_L$ due to increase in platform area could be prevented with wing taper