Wing Cuff Design for Cessna CJ1

AAE 415 Project
Purdue University
Saturday, December 10th, 2004

Brian Adams
Kevin Clark
Greg Davidson
Phil Spindler

Contents

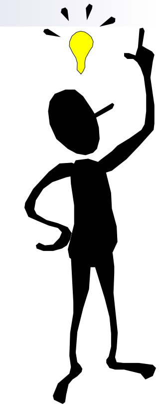
- Background of Problem
- Literature Review
- Design Process
- Design Configuration
- Analysis/Results
- Conclusions

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?

Pilot Testimony for Wing Cuff

- "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

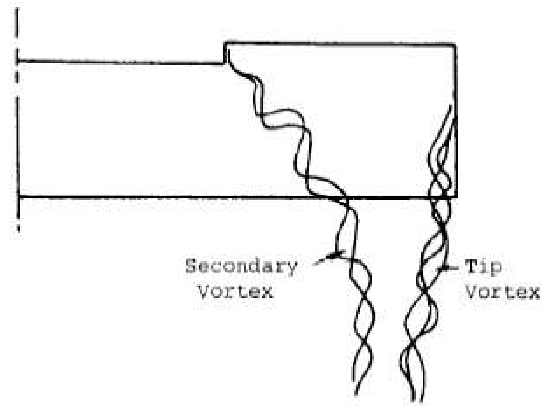
Lancair 400 Wing

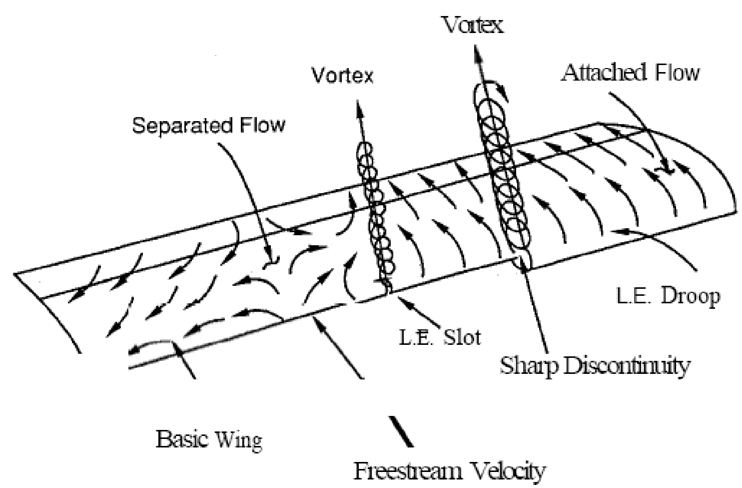
Literature Review

- Numerous papers were reviewed in order to validate theoretical models and assumptions
- Papers exhibiting substantial experimental data will be discussed in further
  - AIAA Technical Paper A88-50576 21-01 & Journal of Aircraft – Vol. 28, issue 7
  - SAE Technical Paper - 830720
  - NACA-TN-2948
  - NASA-TP-2011

AIAA Technical Paper A88-50576 21-01 & Journal of Aircraft – Vol. 28, issue 7

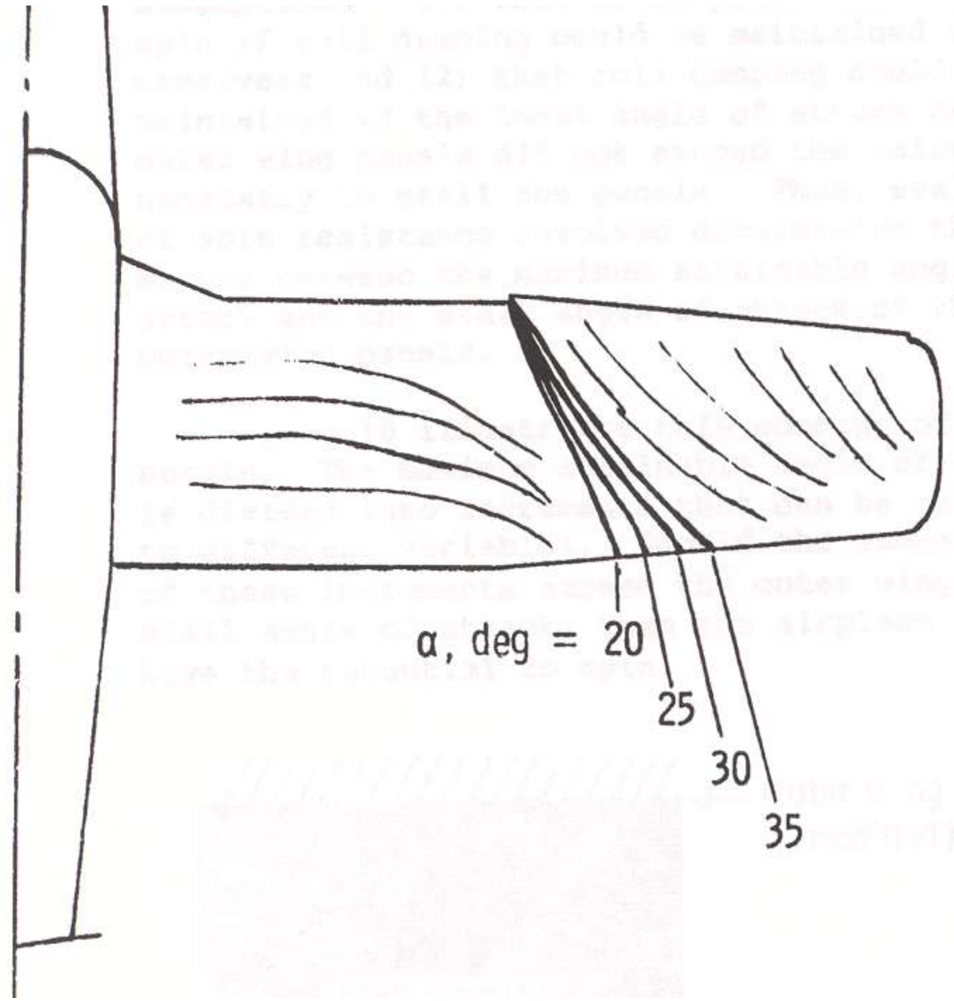
- Cuff Creates a secondary vortex over the wing
  - Prevents separated flow from propagating down the span
  - Attached flow is maintained over the tip and aileron





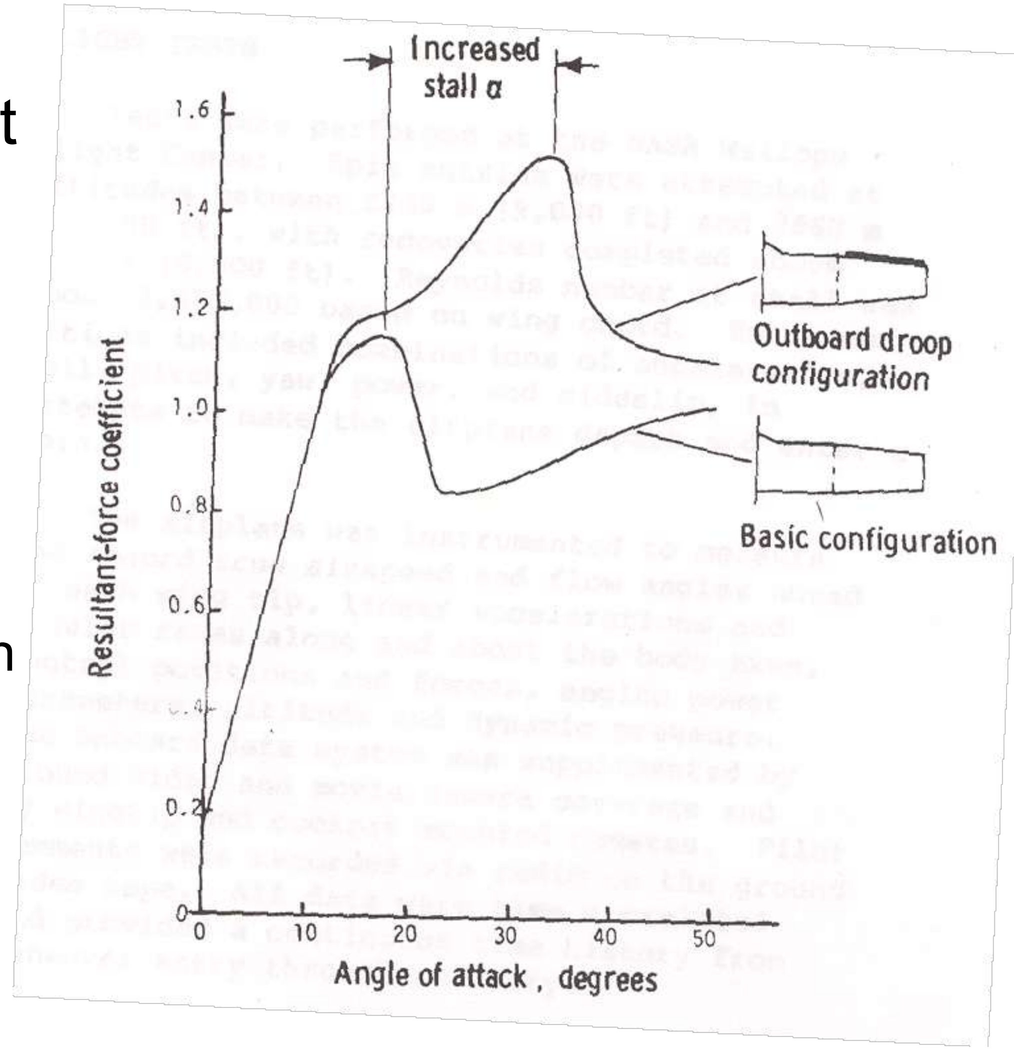
SAE Technical Paper - 830720

- Figure shows boundary between attached and separated flow at various angles of attack
  - Addition of cuff creates vortex, delaying stall



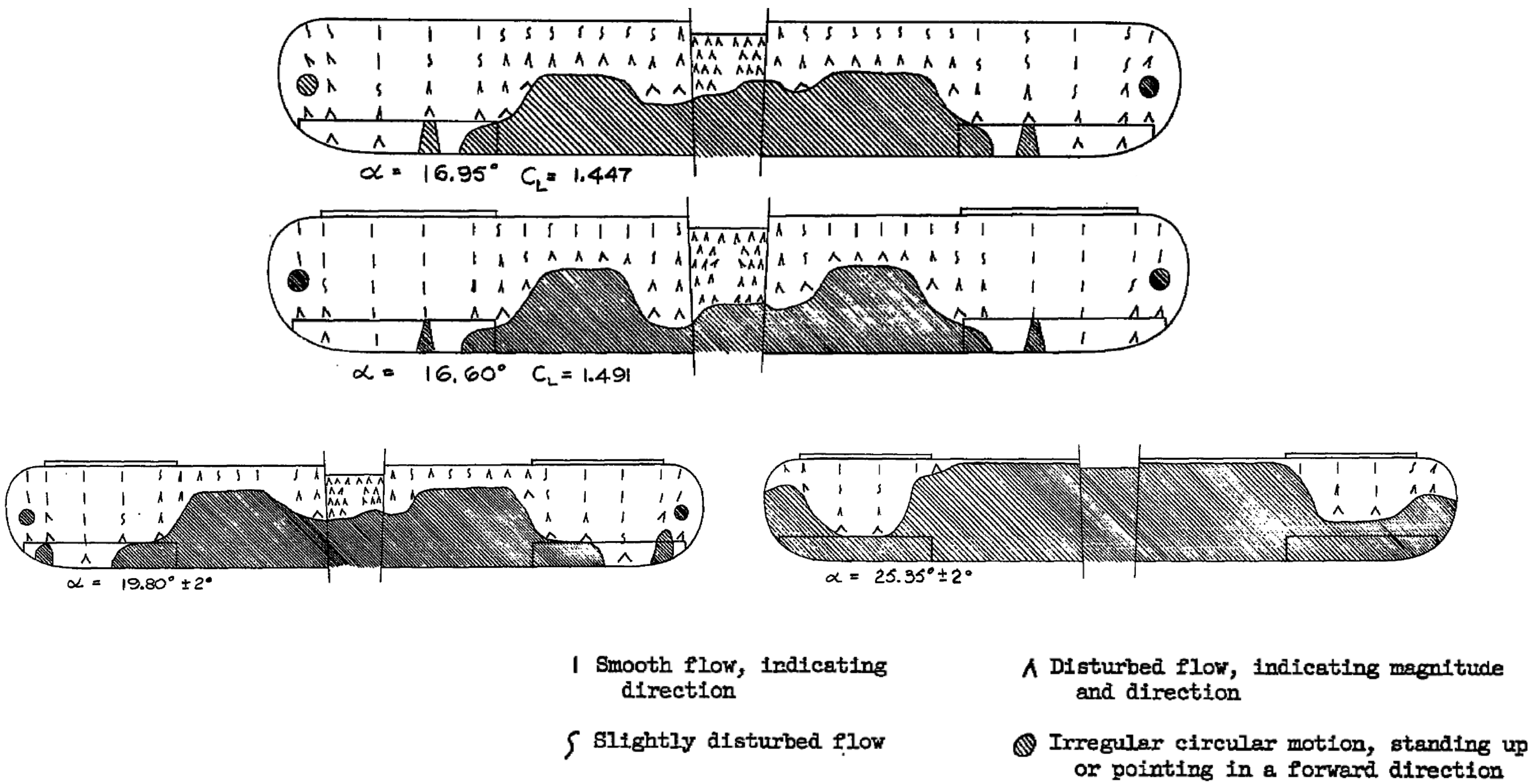
SAE Technical Paper - 830720

- 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



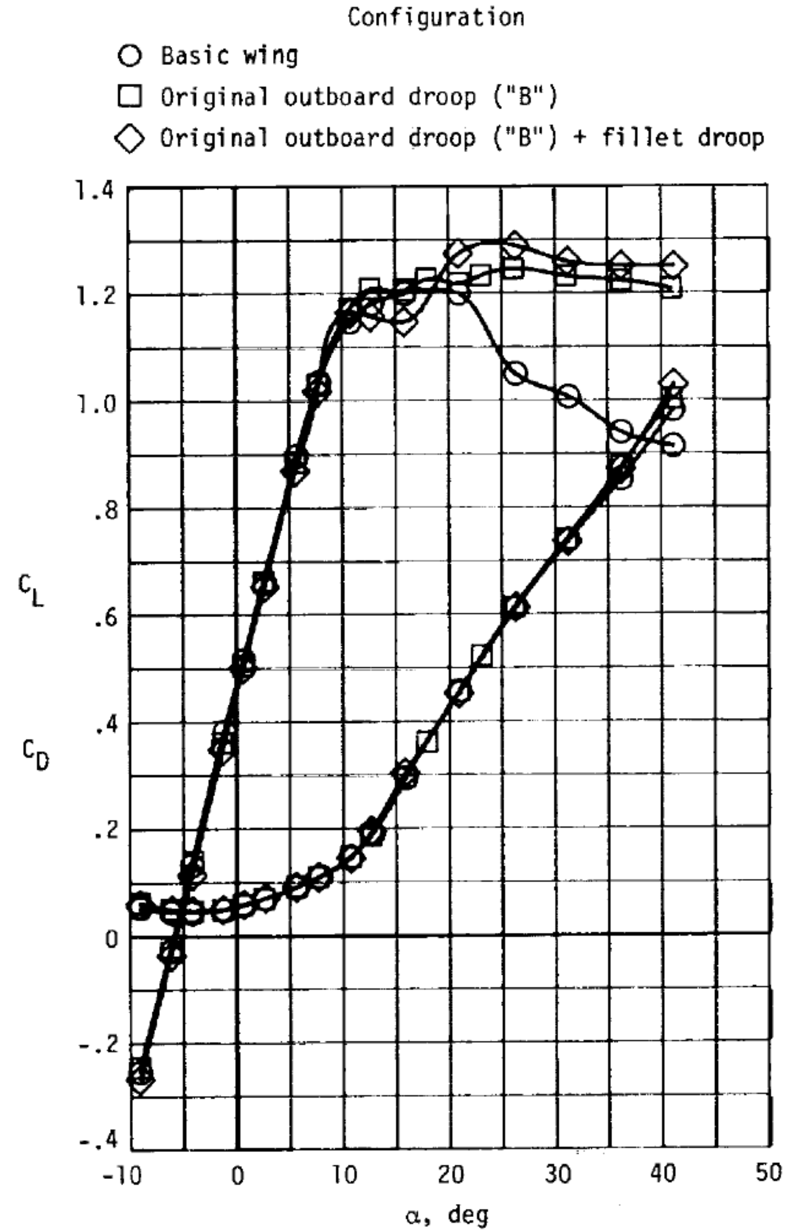
NACA-TN-2948

- Investigation of Lateral Control Near Stall



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?

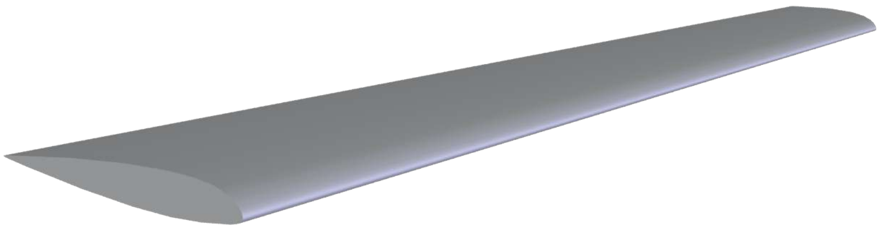
- Light Jets are popular among rich, 'inexperienced' pilots as an upgrade from their Cirrus or Lancair
- Can we design a wing cuff to prevent spin resistance on a Light Jet?
  - Cessna CJ1 smallest available Light Jet on the market today
    - Many emerging companies are designing smaller 'Very Light Jets'
      - So far, none have incorporated wing cuffs

Design Process

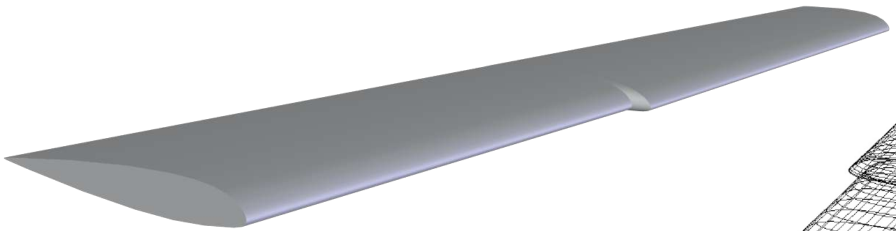
- Objective: Design Wing Cuff for Cessna CJ1 to increase stall and roll characteristics
  - Wing cuff to be approximately same dimensions as aileron
  - Analyzed different wing configurations at various angles of attack
    - Stock wing – NACA 23014
    - Wing with Cuff Addition – Cuff dimensions iterated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

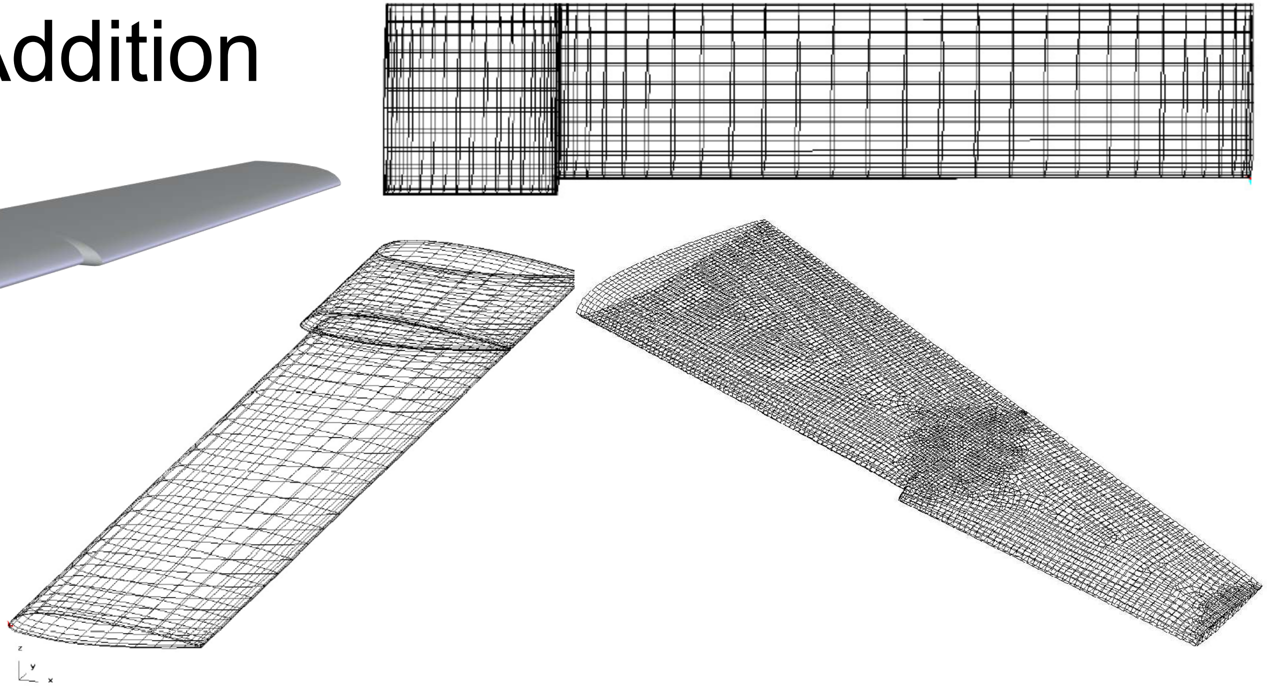
Design Configuration

- Stock Wing



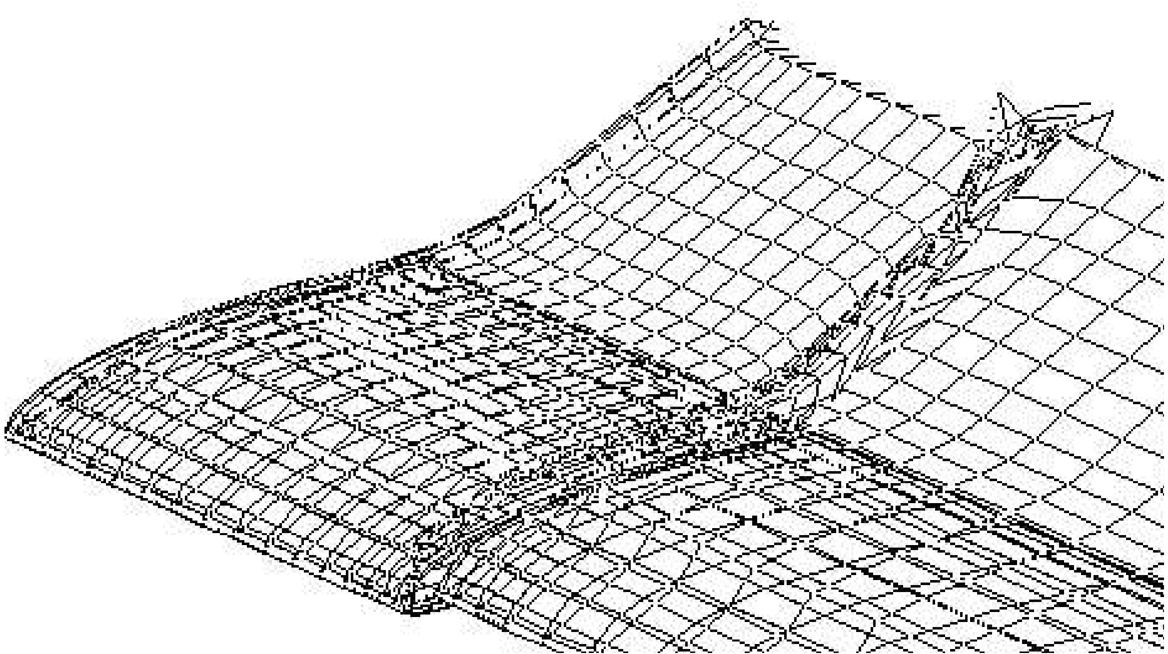
- Wing Cuff Addition



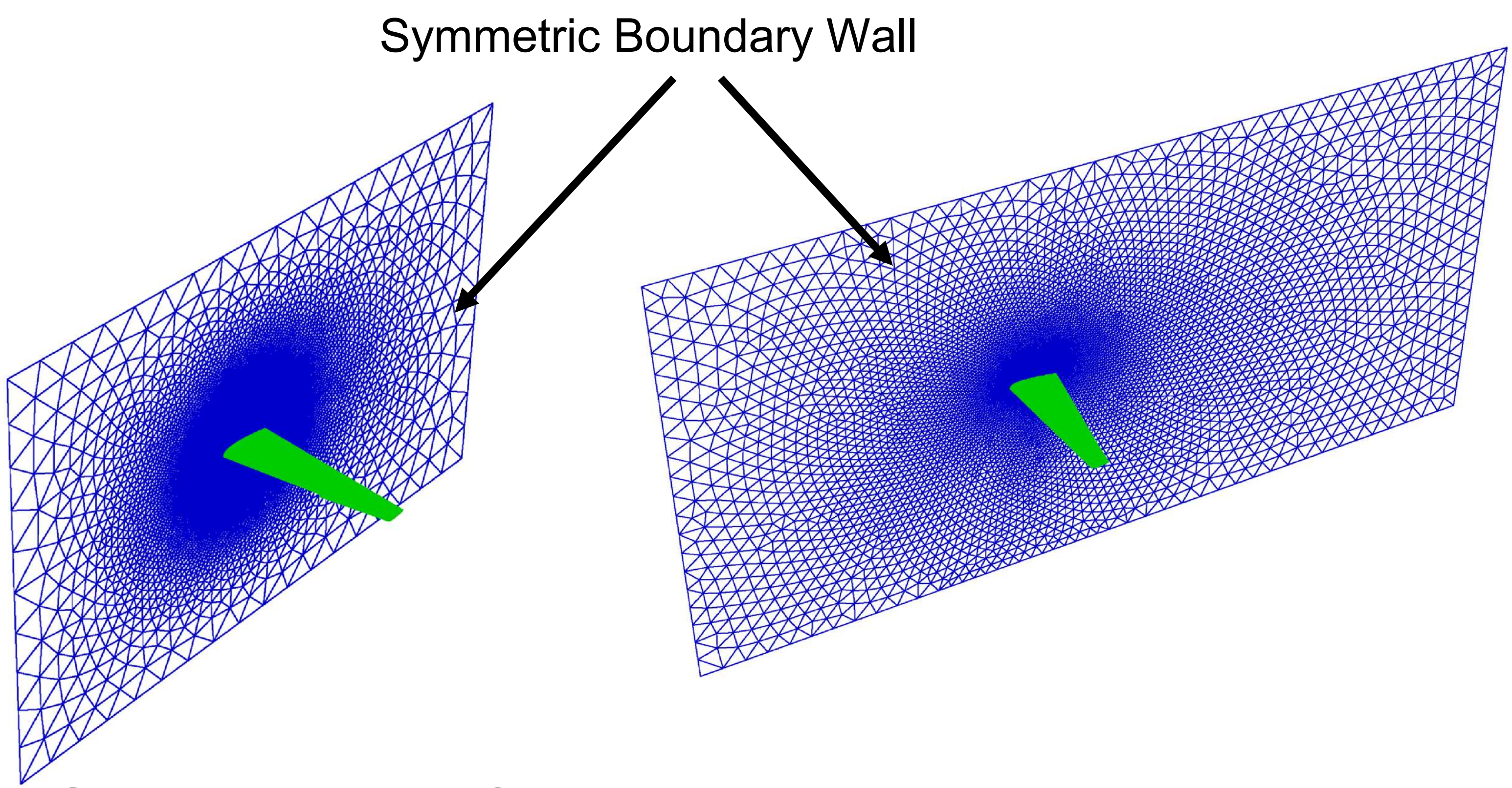


CMARC Analysis

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



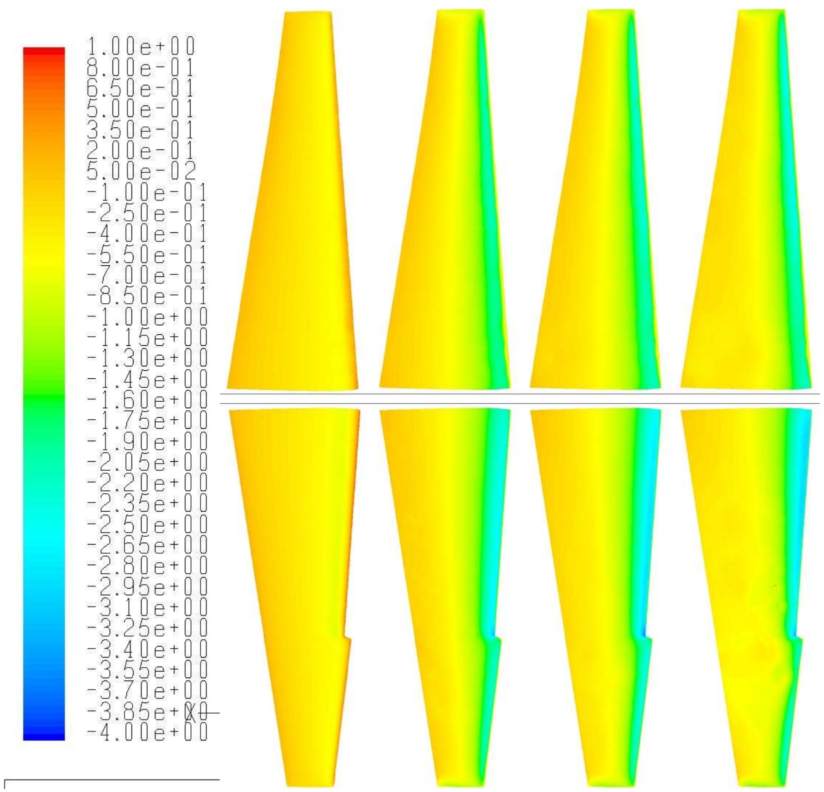
Fluent Grid Creation



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

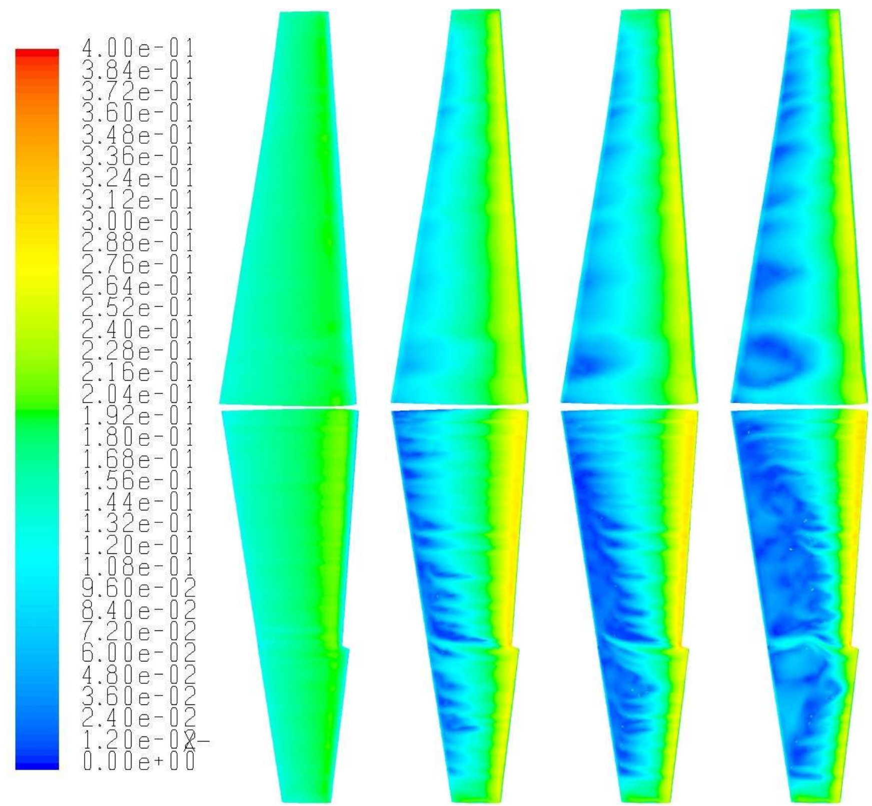
FLUENT Analysis

AoA 0° 13° 15° 17°



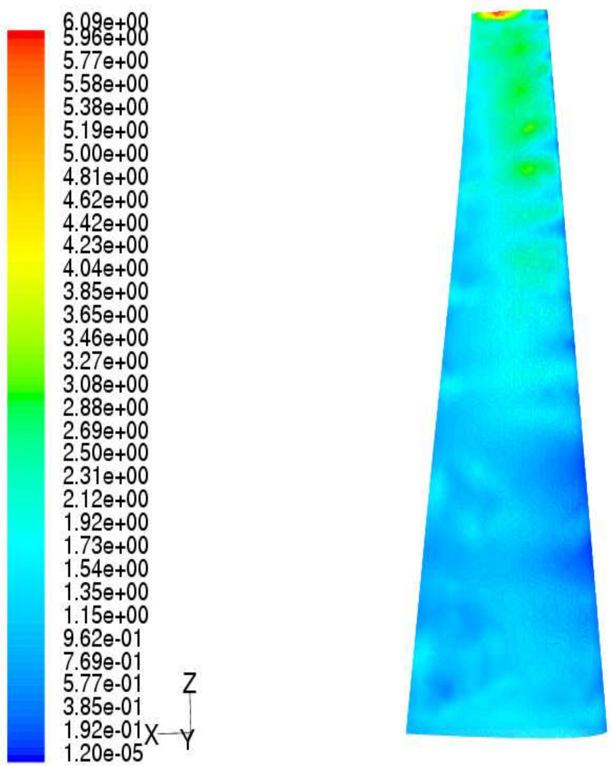
Cp Distribution

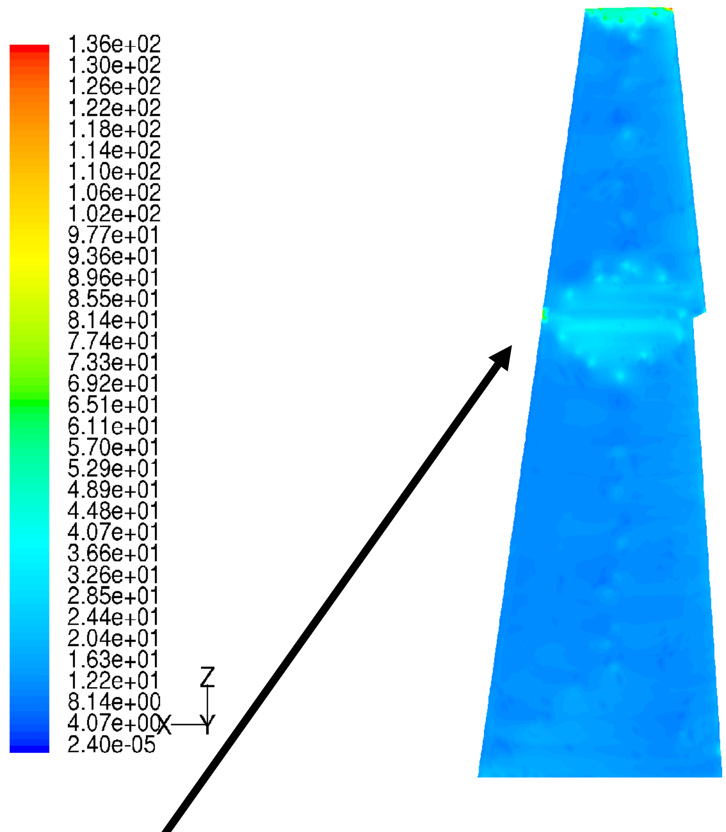
AoA 0° 13° 15° 17°



Mach Number Contour

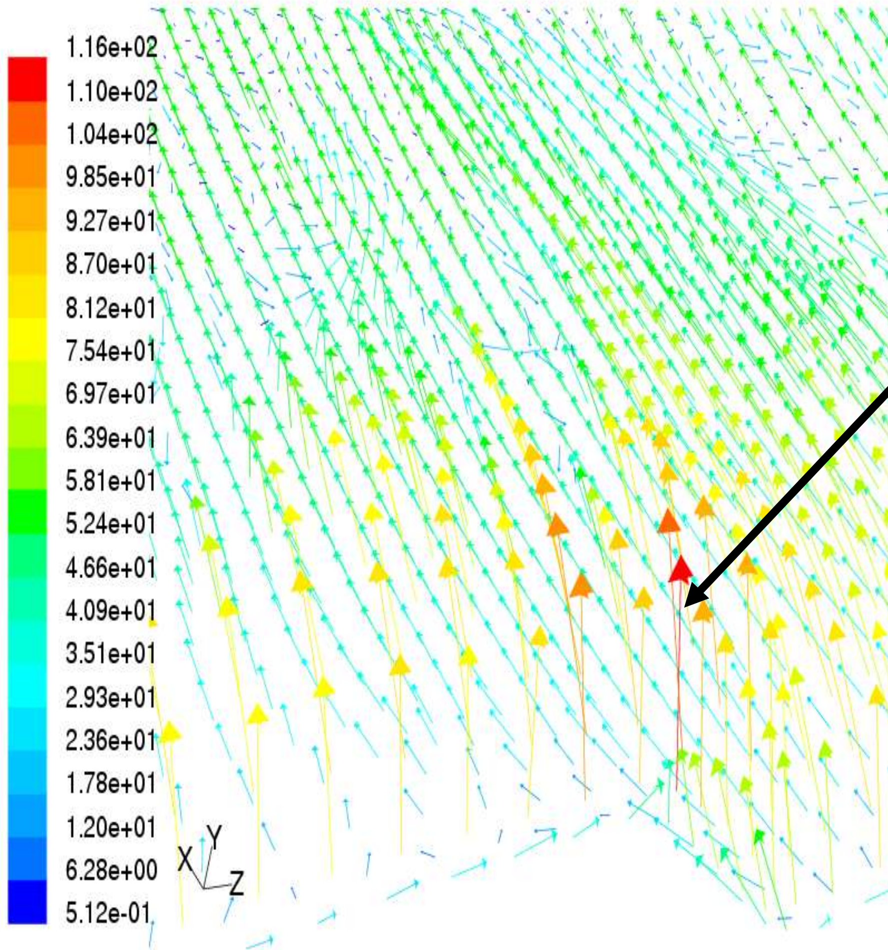
Contour of Turbulent Kinetic Energy



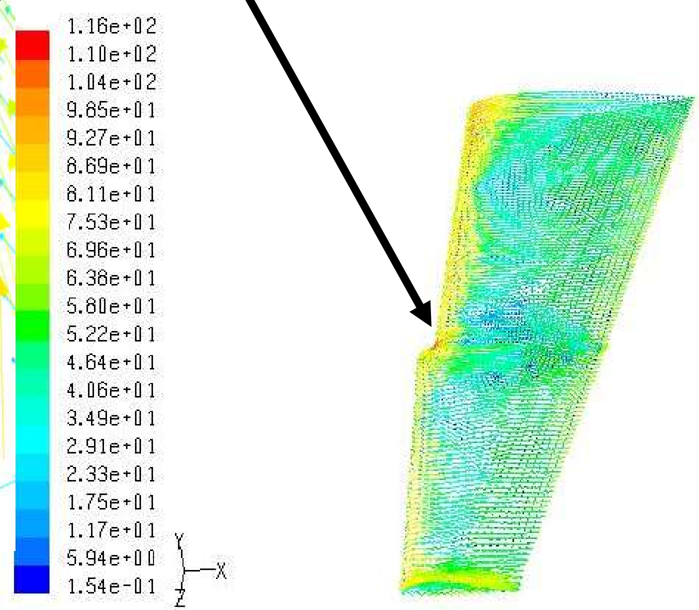


Vortex creation along the cuff

Velocity Vectors of the Cuff

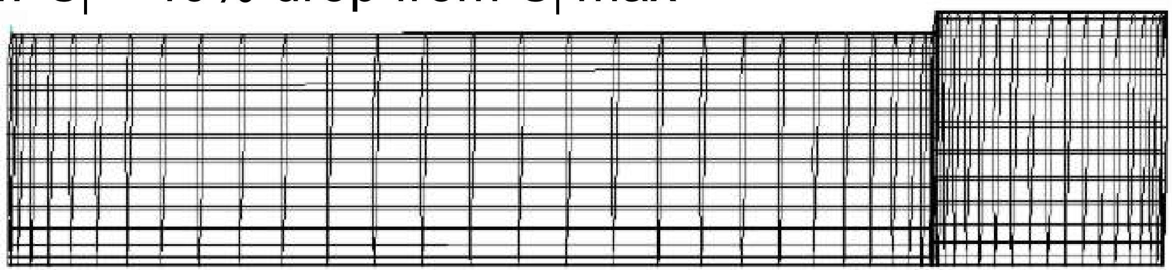


Vortex creation along the cuff



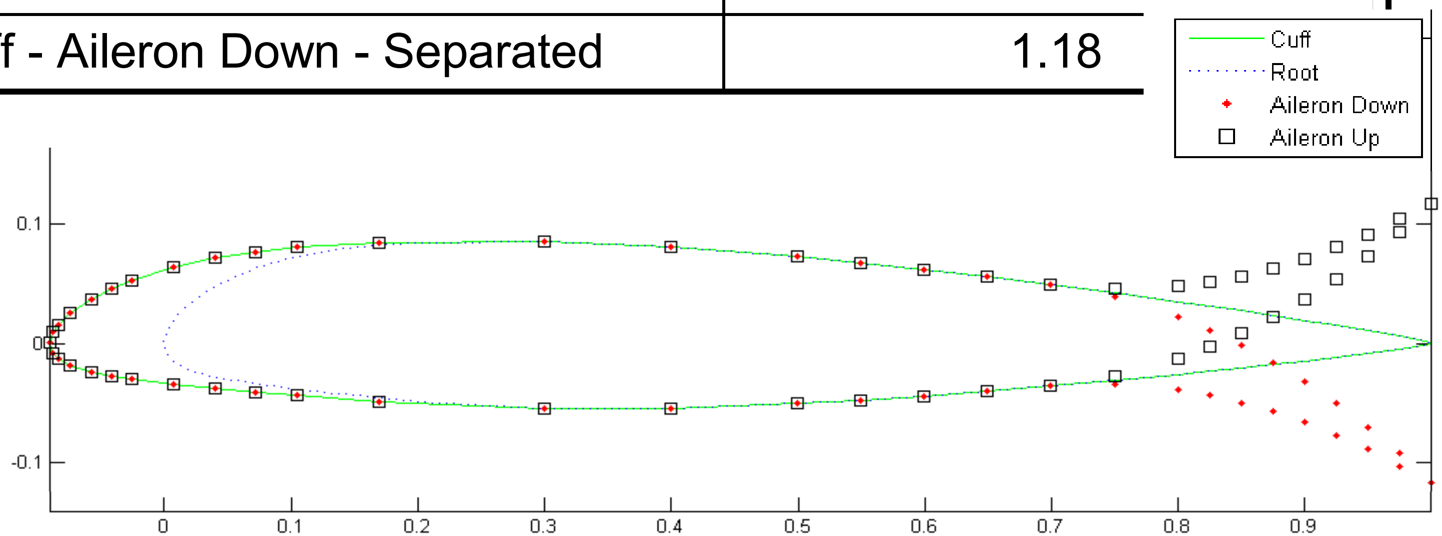
XFoil/MatLab Analysis

- 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 ~ 40% drop from C_l max

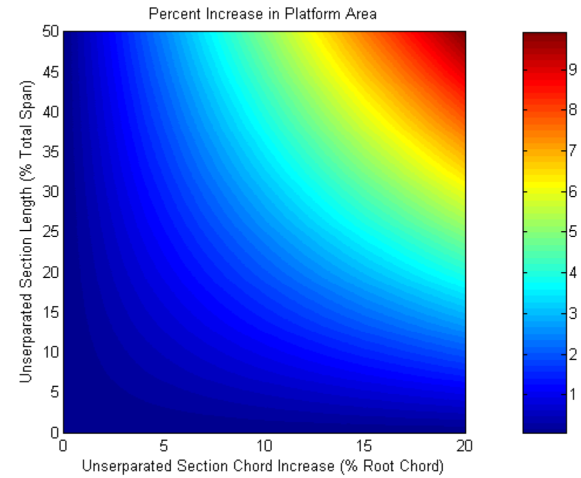


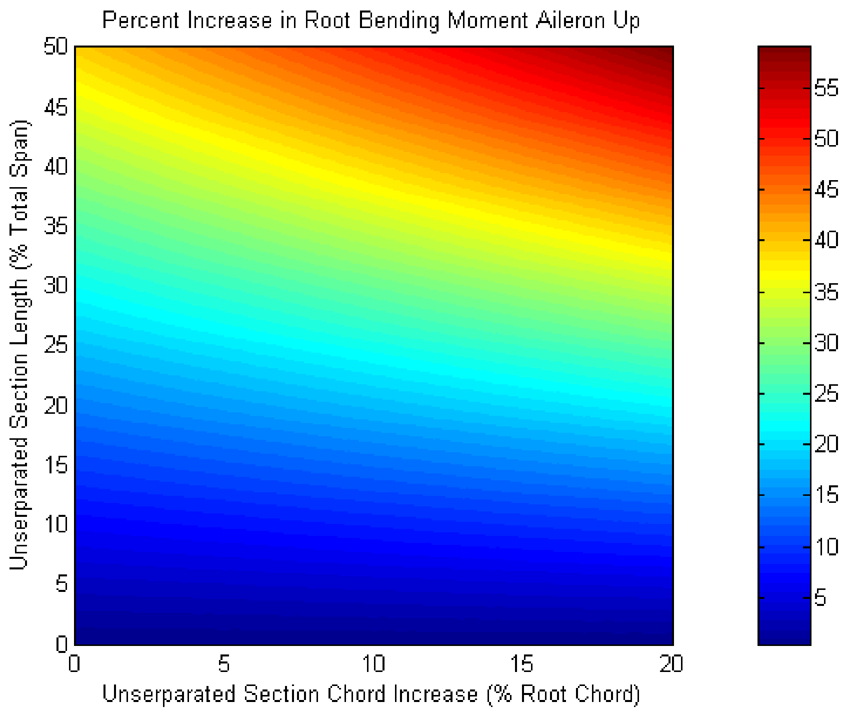
XFoil Cl Prediction – 14.5°

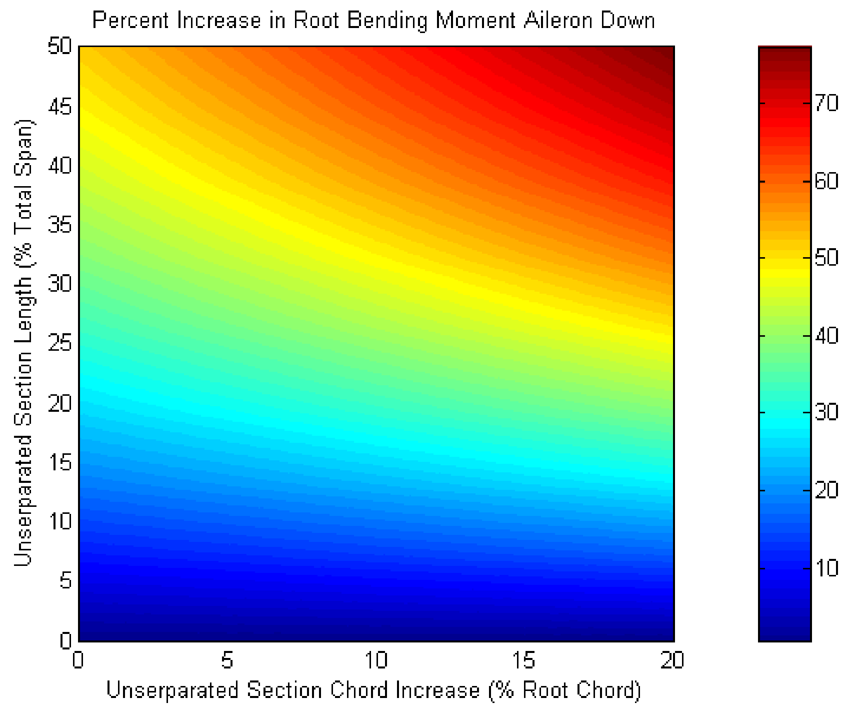
C_l Root - Separated	1.0 (Abbott & von Doenhoff)
C_l Cuff - Aileron Nominal - Attached	1.69
C_l Cuff - Aileron Nominal - Separated	1.02
C_l Cuff - Aileron Up - Attached	0.81
C_l Cuff - Aileron Up - Separated	0.49
C_l Cuff - Aileron Down - Attached	1.96
C_l Cuff - Aileron Down - Separated	1.18



MatLab Results

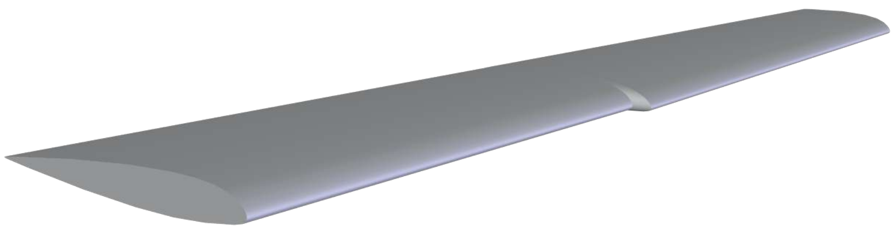


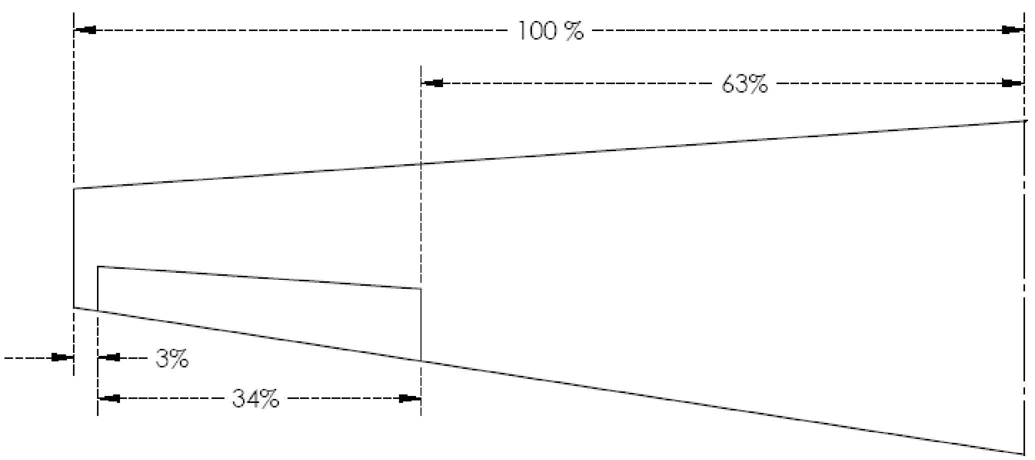




Design Case – CJ1 Wing

Platform Area Increase	1 %
Cuff Span	40 %
Cuff Chord Increase	3 %
Aileron Up M_{root} Increase	33 %
Aileron Down M_{root} Increase	48 %





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