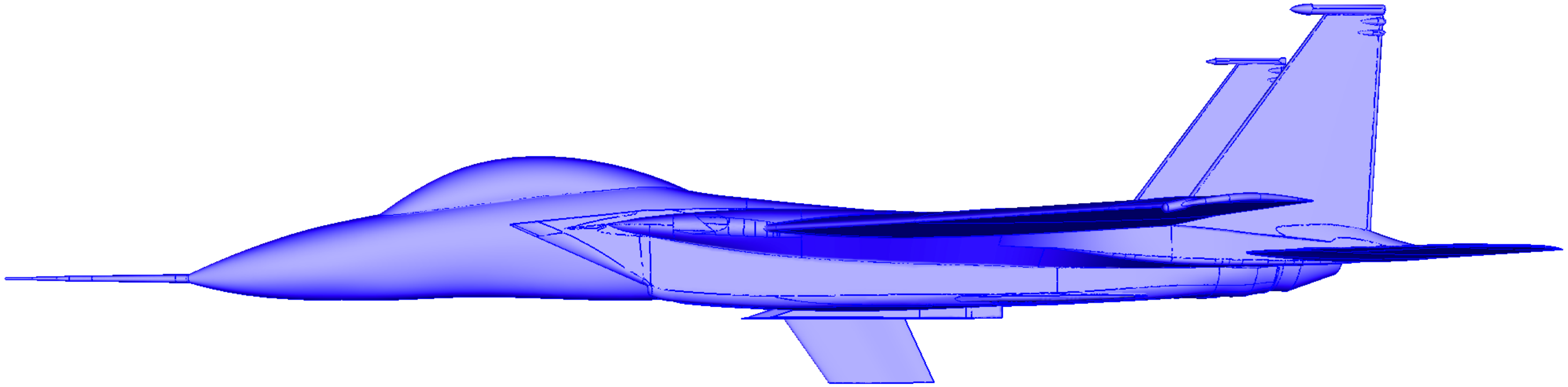
Design of a Crossflow Attenuated Natural Laminar Flow Flight Test Article



Michelle Lynde, Richard Campbell, Brett Hiller, and Lewis Owens
NASA Langley Research Center

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Outline

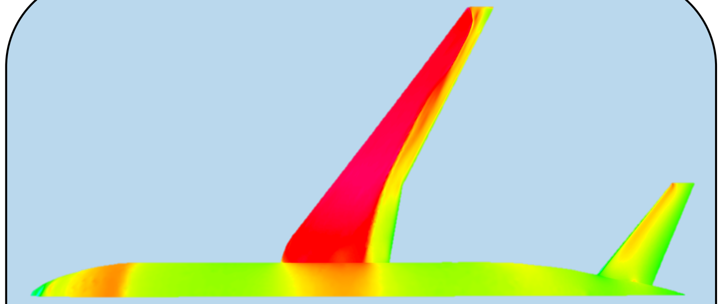
- Introduction
- Design Results
- Testing Strategy
- Concluding Remarks

CATNLF Concept Development

NASA Laminar Flow Design Method

Crossflow Attenuated Natural Laminar Flow (CATNLF) design method changes the shape of airfoils to obtain pressure distributions that delay transition by damping crossflow instabilities

Computational Study

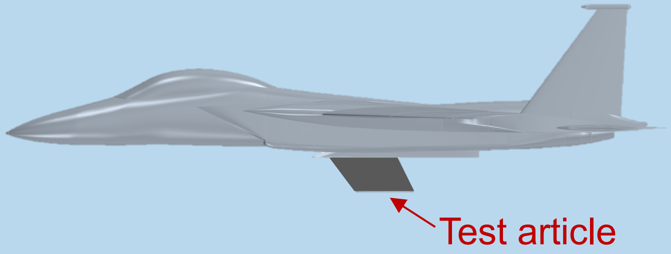


Goal: To develop technology
Reference: AIAA 2016-4326

Wind Tunnel Test

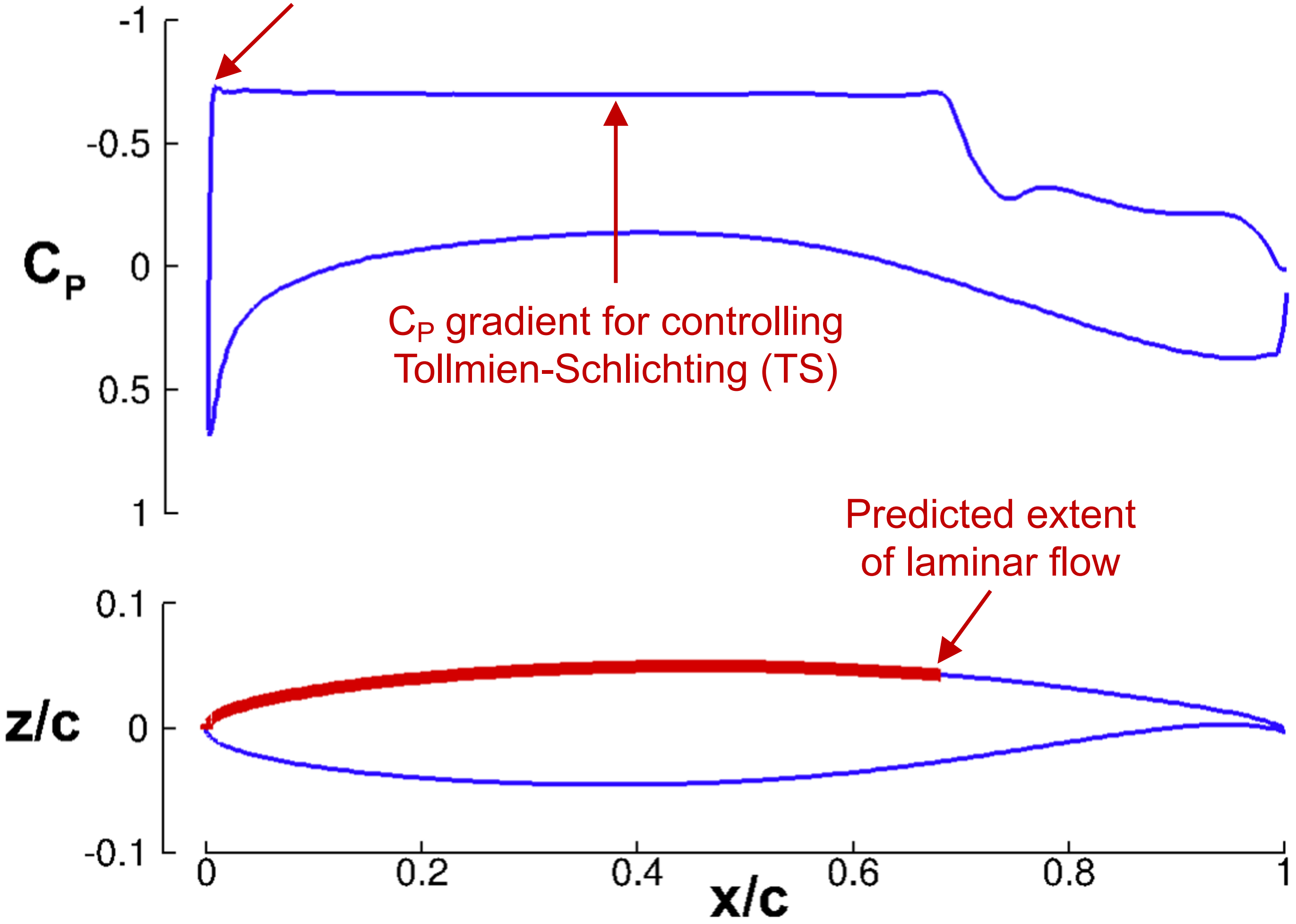
Goal: To confirm computations
References: AIAA 2017-3058, AIAA 2019-3292

Flight Test



Goal: To advance technology
Reference: Current paper

Example CATNLF Pressure Distribution



Rapid acceleration for crossflow (CF) attenuation

C_P gradient for controlling Tollmien-Schlichting (TS)

Predicted extent of laminar flow

CATNLF Analysis Tools

- **Design Module: *CDISC***

  Applies knowledge-based design rules to change geometry to match target pressure distributions

- **Flow Solver: *USM3D***

  Solves Navier-Stokes equations on unstructured tetrahedral grid

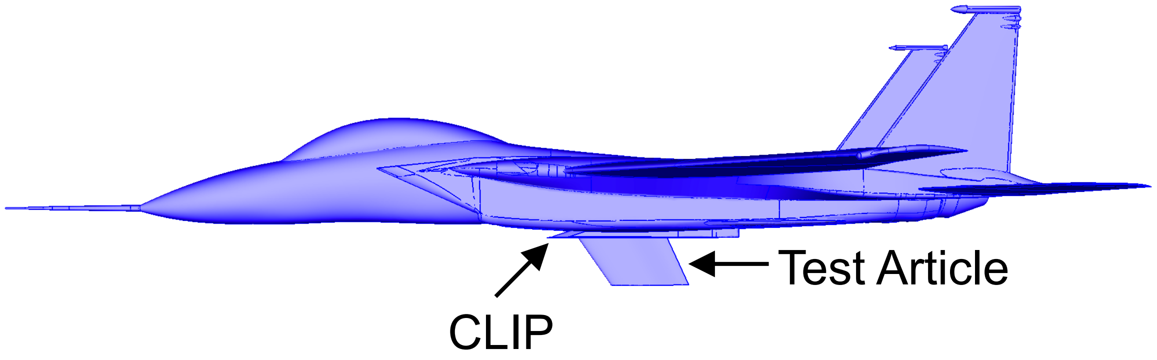
- **Boundary Layer Profile Solver: *BLSTA3D***

  Calculates boundary layer velocity and temperature profiles based on chordwise pressure distribution assuming conical flow

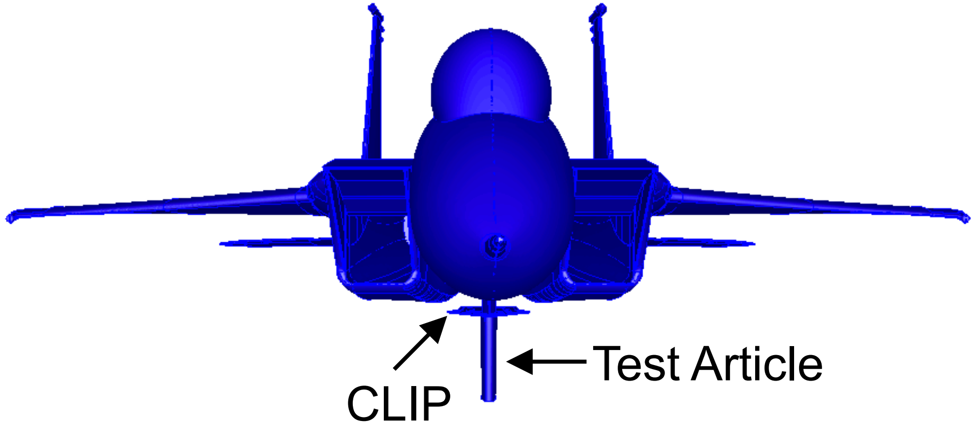
- **Boundary Layer Stability Analysis: *LASTRAC***

  Stability analysis and transition prediction using e^N Linear Stability Theory method with compressibility effects

Test Article Dimensions and Design Conditions



Side View

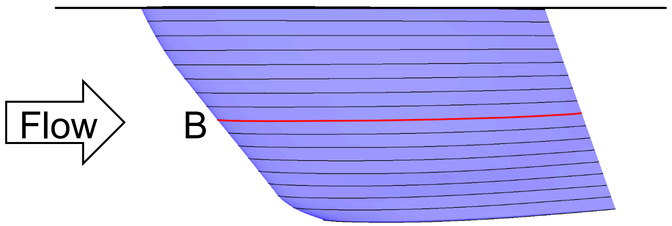


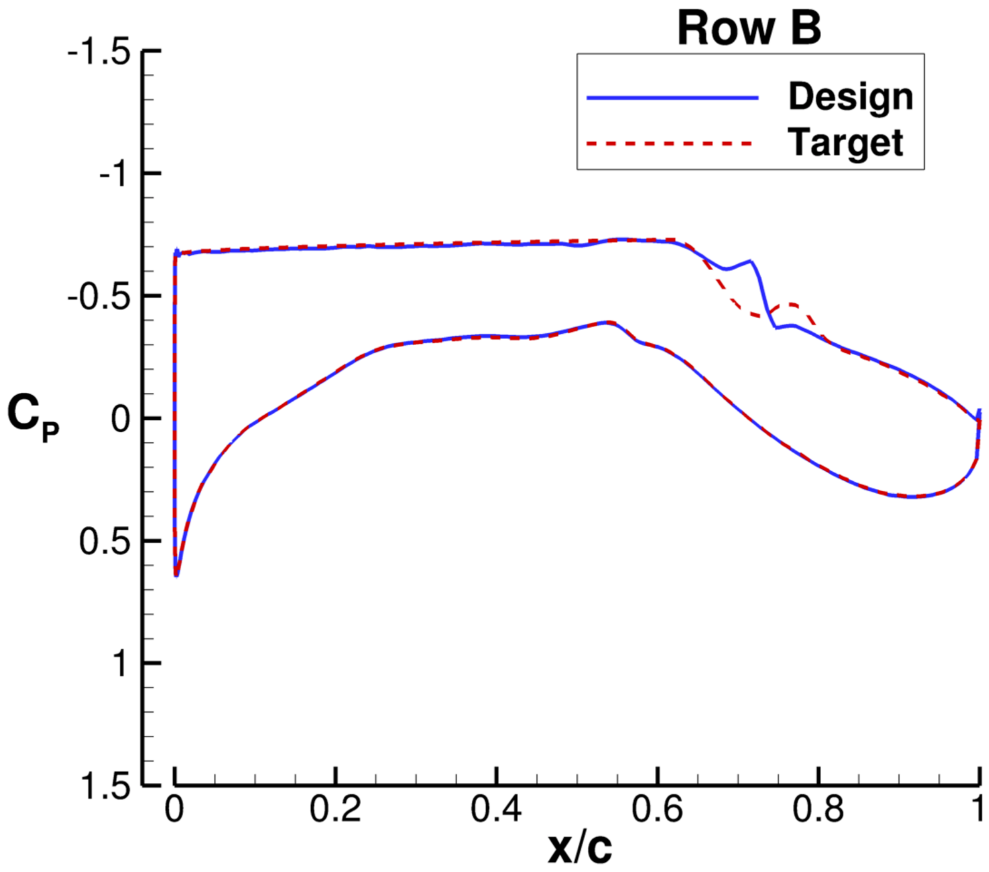
Front View

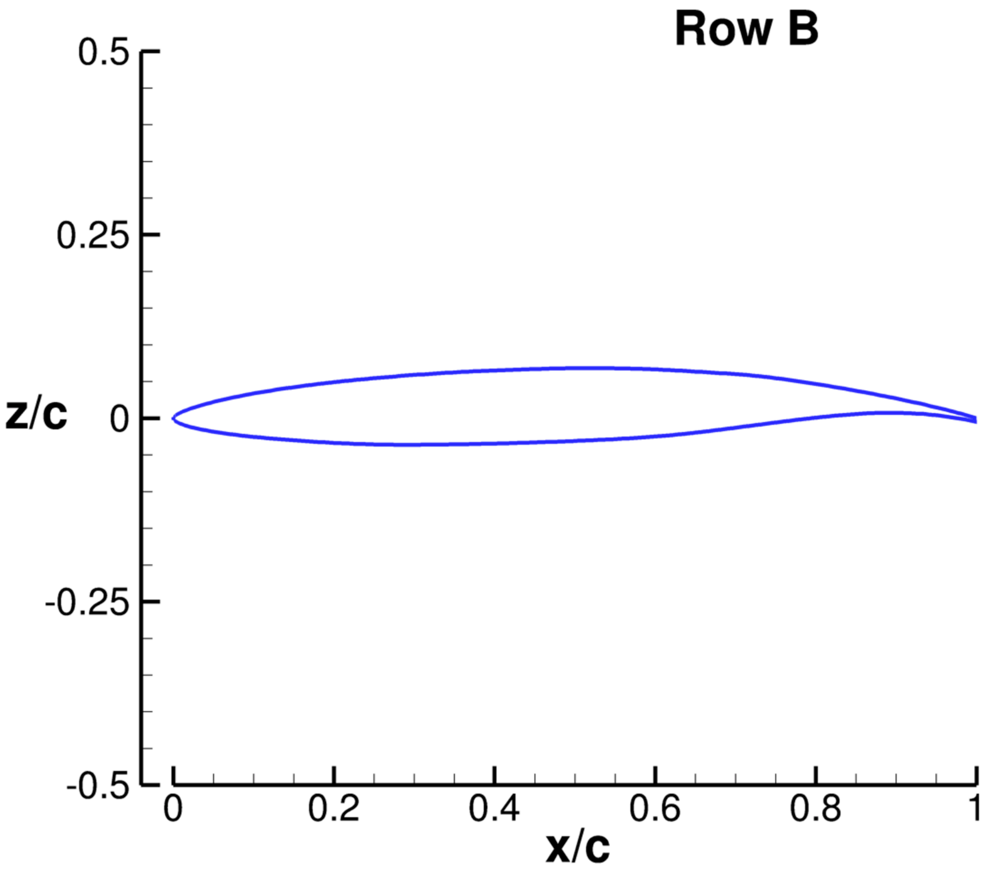
Geometry Parameters	
Mean Aerodynamic Chord (MAC)	5.9 ft
Span	3.3 ft
Reference Area	19.7 ft^2
Leading-Edge Sweep	35 deg
Max Thickness	10% chord

Design Conditions	
Mach	0.85
Altitude	5,000 ft
Re_{MAC}	31 million
Sectional Lift Coefficient	0.50
Critical N-Factor	10
Laminar Flow Target	Suction side only

Test Article Airfoil Pressures and Geometry

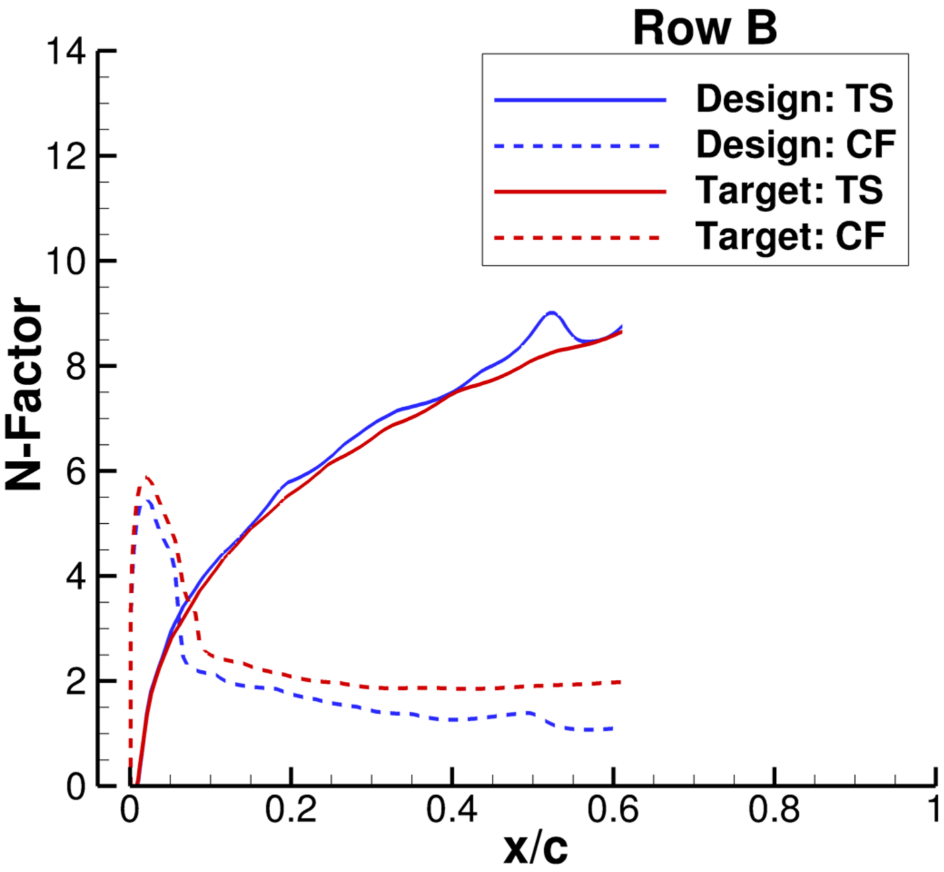


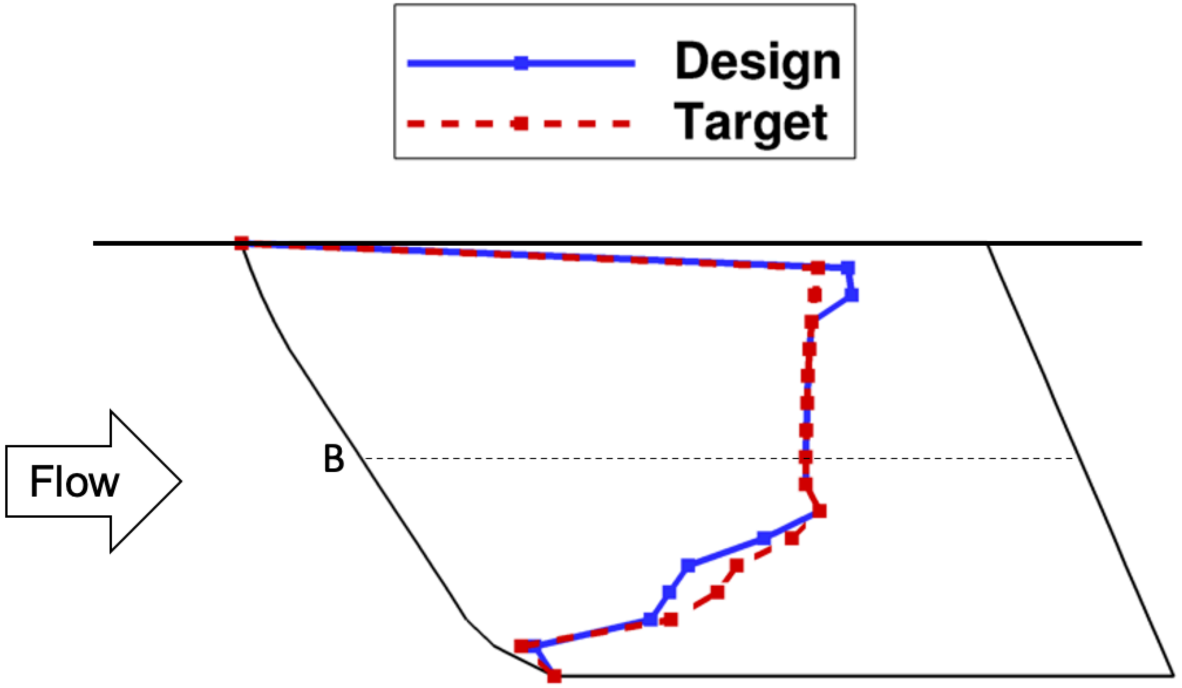




Test Article Laminar Flow Characteristics

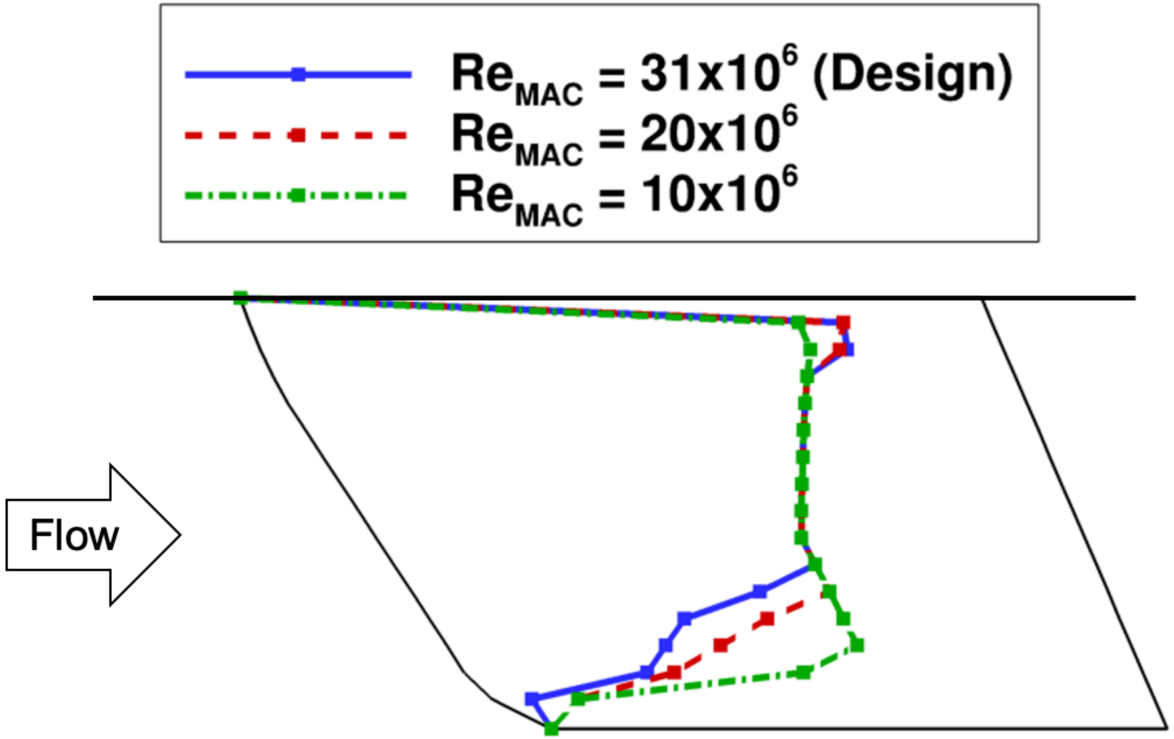
Designed test article is predicted to support laminar flow on approximately 53% of the suction side surface area in a flight environment





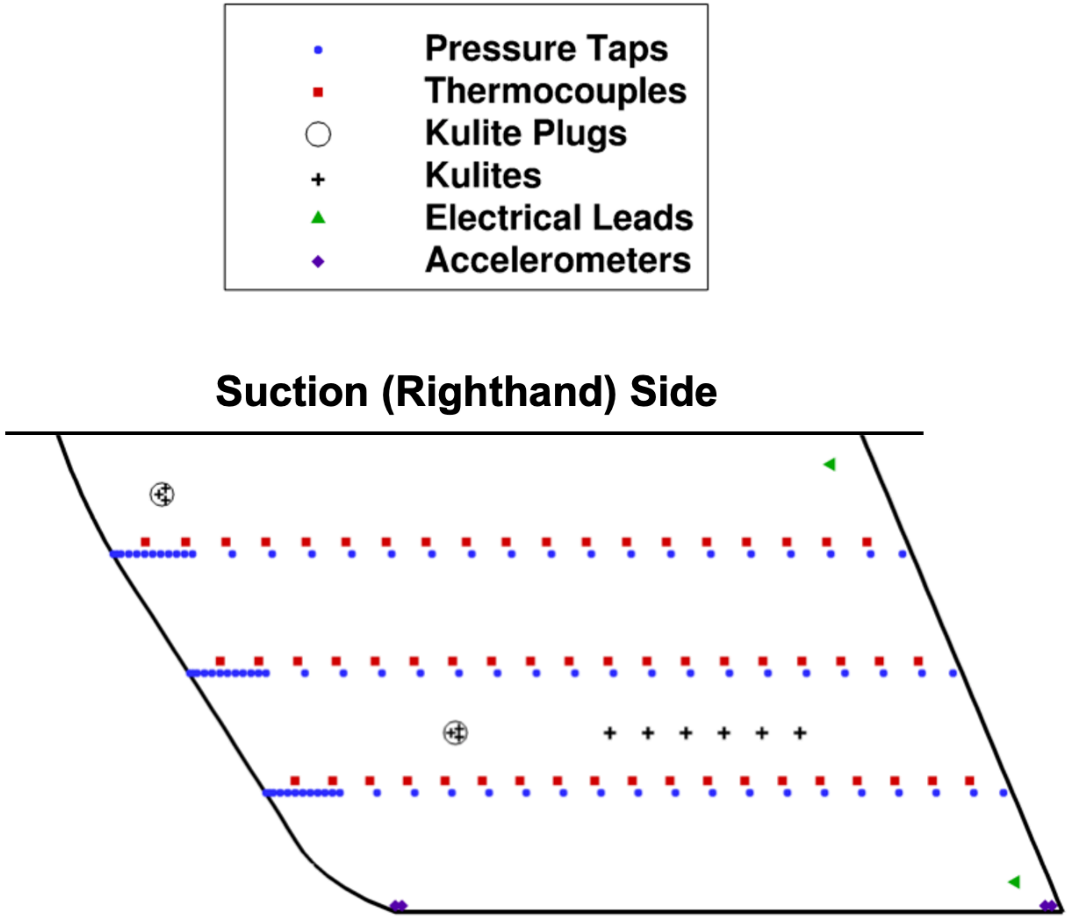
Test Article Laminar Flow Design Strategy

Laminar flow extent is shock-limited inboard for maximizing transition Re and TS transition outboard for critical N-factor characterization



Data and Instrumentation

- Transition images from IR camera mounted to F-15
- Static pressure sensors
- Flight conditions from F-15
- Subsurface thermocouples
- Unsteady pressure sensors
- Electrical leads for resistive heating paint layer
- Wingtip accelerometers


Suction (Righthand) Side

Flight Test Goals

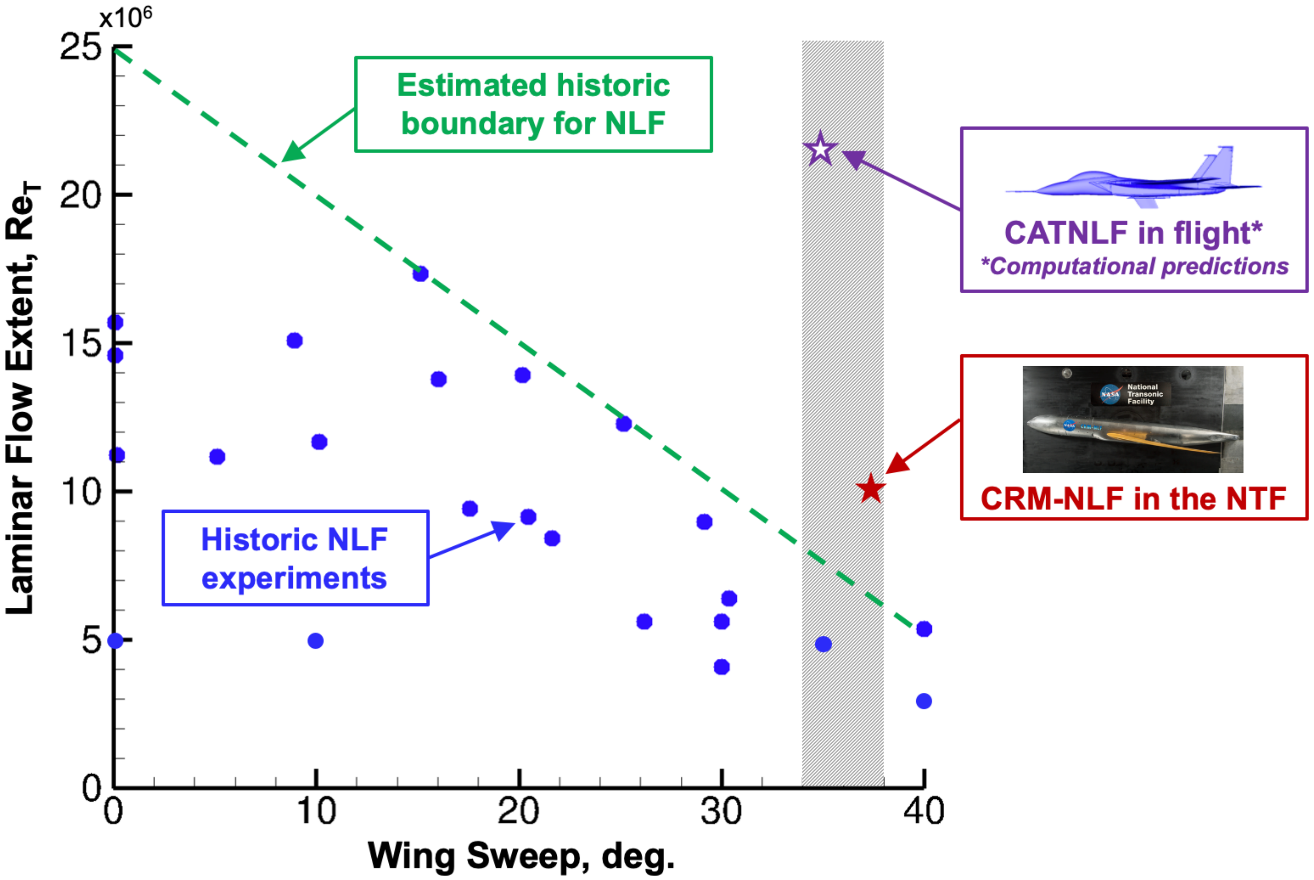
- **Primary Goal:** To confirm the effectiveness of the CATNLF method in attenuating crossflow growth at conditions representative of a modern transonic transport wing
- **Secondary Goal:** To investigate the surface requirements for laminar flow applications on transonic transport wings

Flight Conditions for Goals		
Goal	1	2
Altitude (ft)	5,000* – 28,500	19,600 – 49,500
Re_{MAC} (million)	31* – 15	20 – 6
Unit Re (million/ft)	5.3* – 2.6	3.4 – 1.0

**Design condition*

Test Article Design Results in Perspective

Computational predictions of the CATNLF test article show a significant increase in laminar flow extent at transport-relevant sweeps compared to historic experiments



Concluding Remarks

- Test article has been designed using the CATNLF method to support laminar flow at transport-relevant conditions
- Test article will be mounted underneath an F-15 and is currently scheduled to be flown in 2022 at Armstrong Flight Research Center
- Computational predictions show laminar flow on 53% of the surface area on the suction side and double laminar flow extents seen on previous experiments at comparable wing sweep
- Test article instrumentation and flight test conditions are selected to support 2 goals:
  - Primary Goal: To confirm the effectiveness of the CATNLF method in attenuating crossflow growth at conditions representative of a modern transonic transport wing
  - Secondary Goal: To investigate the surface requirements for laminar flow applications on transonic transport wings

Contact: Michelle Lynde <michelle.n.lynde@nasa.gov>