CDISC Remote Design Method to Simulate Aircraft Interference Effects for the CATNLF Flight Test

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Outline

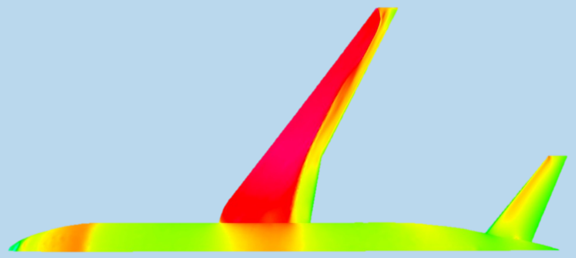
- Background / Motivation
- Method
  - Computational Tools
  - Remote Design Approach
- Results
  - Design Point
  - Off-Design Conditions
- Concluding Remarks

Research Background

- Laminar flow technology improves vehicle performance by reducing skin friction and profile drag
- Crossflow Attenuated Natural Laminar Flow (CATNLF) design method changes the shape of airfoils to obtain pressure distributions that delay transition by damping crossflow instabilities
- Current CATNLF development phase is flight testing concept
  - Wing-like test article is designed to have 52% laminar flow on suction side
  - Instrumented test article to provide data to evaluate CATNLF effectiveness in flight environment

Computational Study

2014 – 2017



Goal: To develop technology
Reference: AIAA 2016-4326

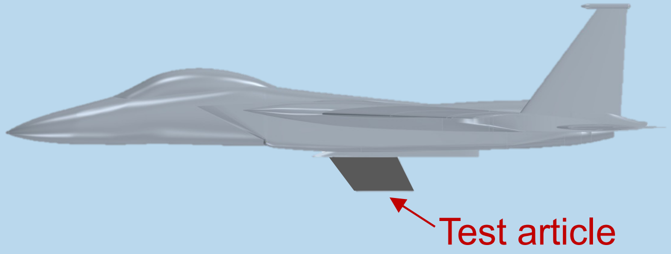
Wind Tunnel Test

2017– 2019

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

Flight Test

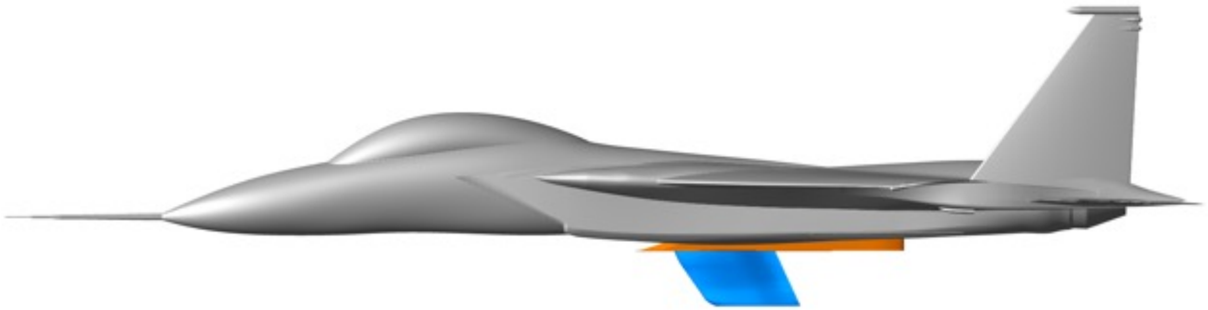
2019 – Present



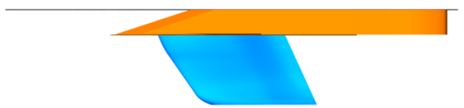
Goal: To advance technology
Reference: AIAA 2021-0173

Motivation for Present Work

- Proposed plans to release the CATNLF flight test data to community for transition studies
- CATNLF test article was designed in the Flight Configuration to account for interference from the F-15, but the F-15 is not a publicly-releasable geometry
- Aerodynamic and transition characteristics of the test article are significantly altered in the Isolated Configuration because of missing F-15 interference effects

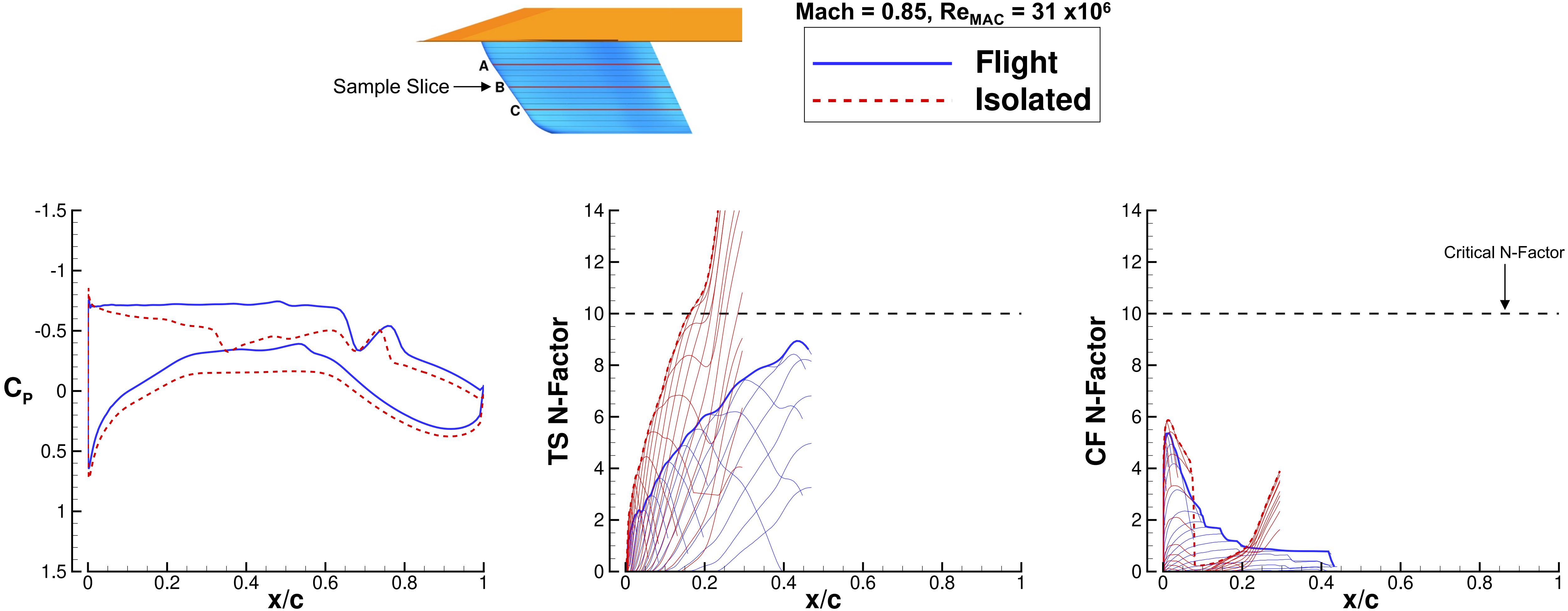


CATNLF Test Article in Flight Configuration



CATNLF Test Article in Isolated Configuration

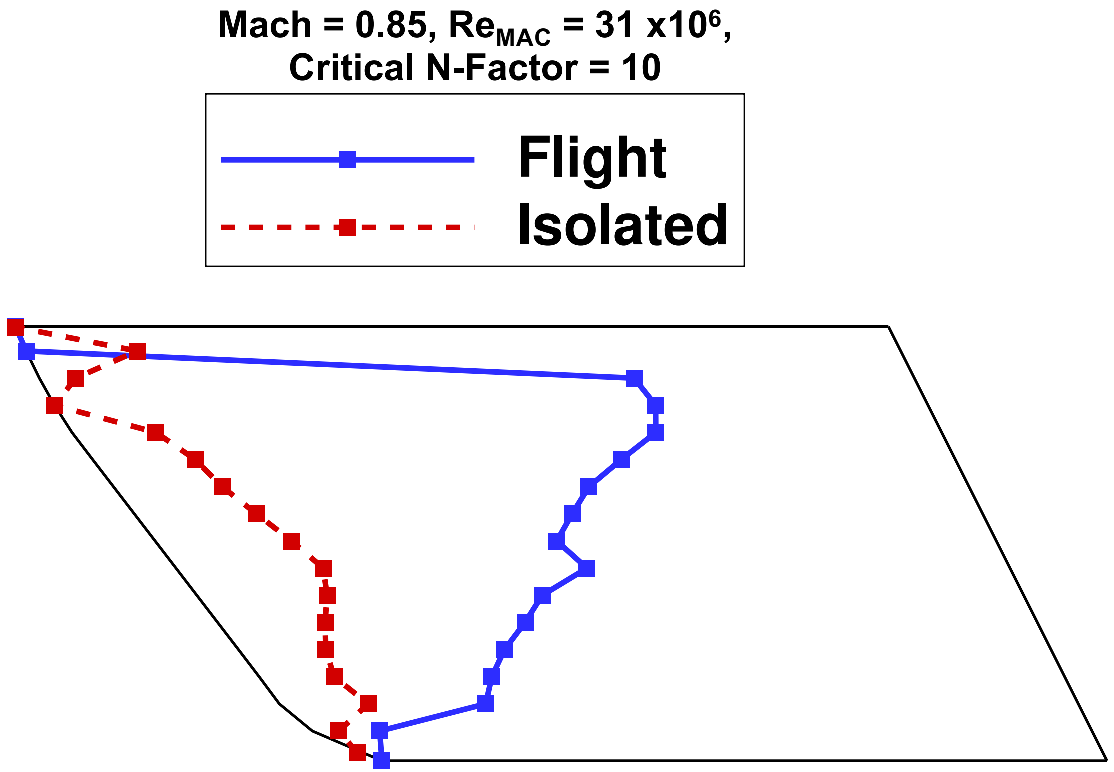
Influence of Aircraft on CATNLF Test Article



TS = Tollmien-Schlicting; CF = Crossflow

Influence of Aircraft on CATNLF Test Article

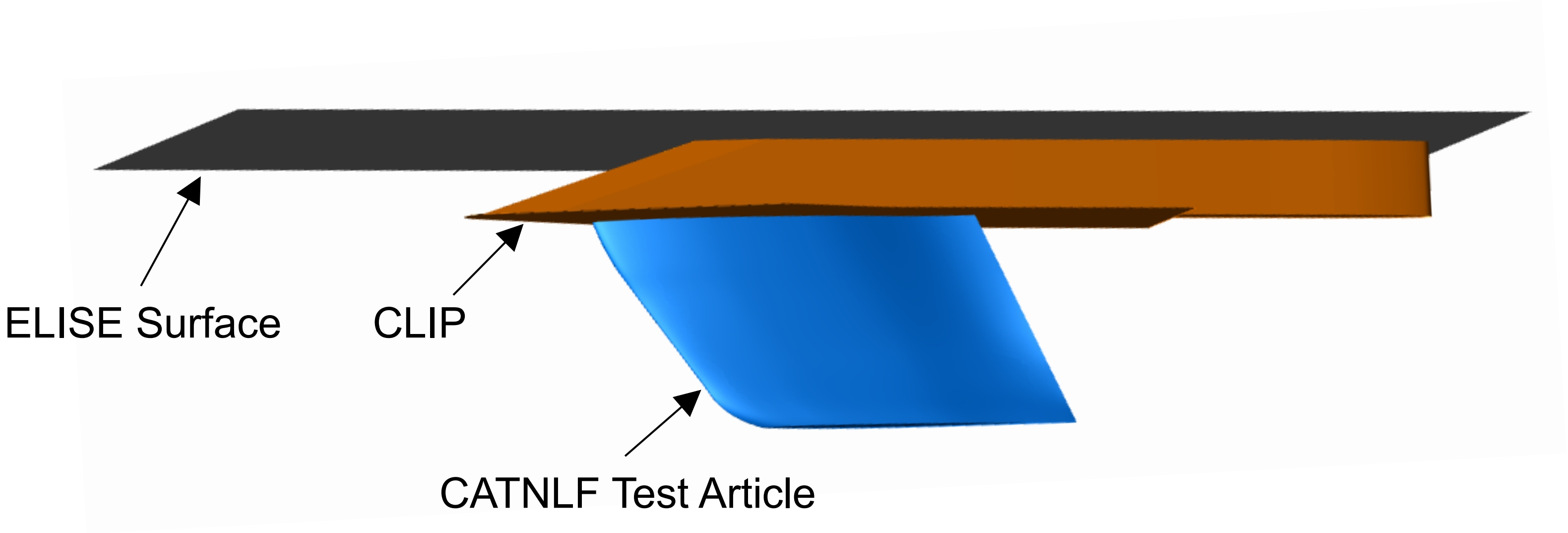
Goals of releasing flight test data include evaluating computational transition methods, but changes in CATNLF test article character without the F-15 complicate that objective



ELISE Remote Design Method

Equivalent Loading via Interference Surface Effects (ELISE)

Remote design method that creates a surface that produces the same interference effects seen on the CATNLF test article in flight



Computational Tools

- **Design Module: *CDISC***

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

- **Flow Solver: *USM3D-ME***

  Solves Navier-Stokes equations on unstructured mixed-element grids

- **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

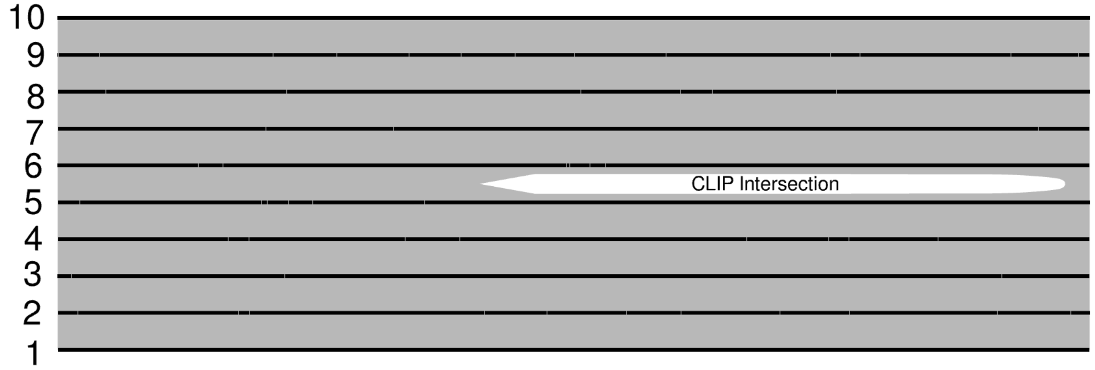
ELISE Remote Design Method

Key Difference with Remote Design:

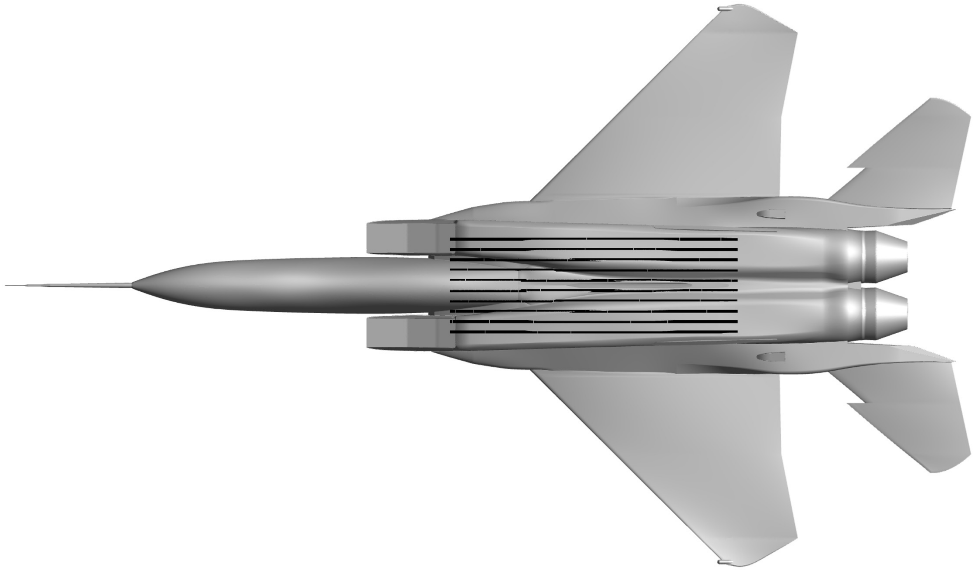
- Primary surface of interest is not the surface being designed with CDISC

Design Setup:

- Test article and CLIP geometry are fixed
- ELISE surface is an inviscid flat box around base of CLIP
- CDISC is used to alter the shape of the ELISE surface to match target pressures
- Target pressures are extracted from the underside surface of the F-15 in the Flight Configuration grid
- Target pressures and design region adjusted during design to improve agreement

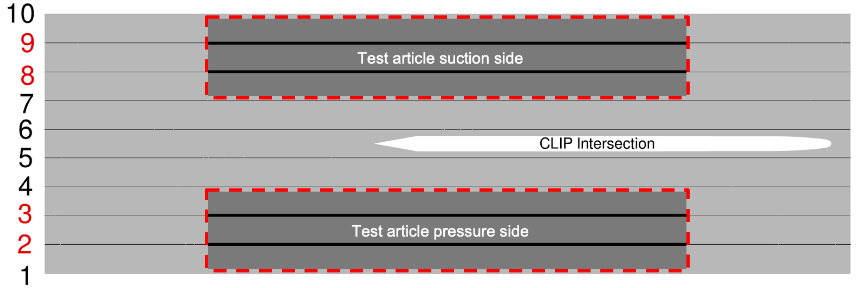


Design stations on ELISE surface

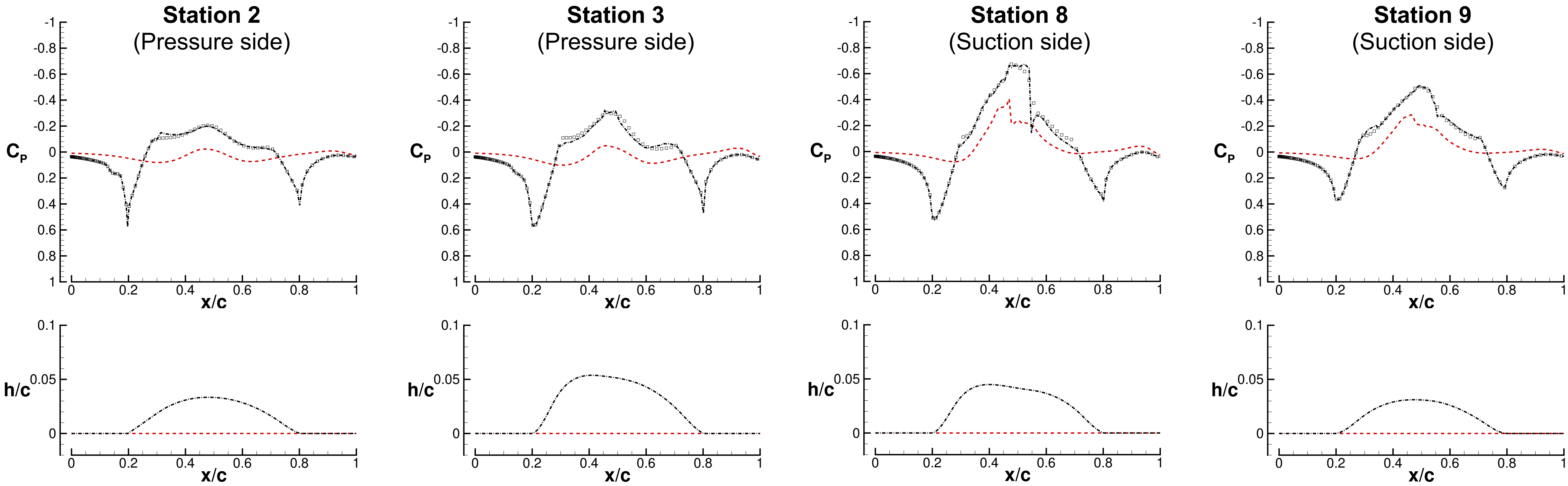


Target pressures extracted from F-15 surface

ELISE Remote Design Results: Design Stations

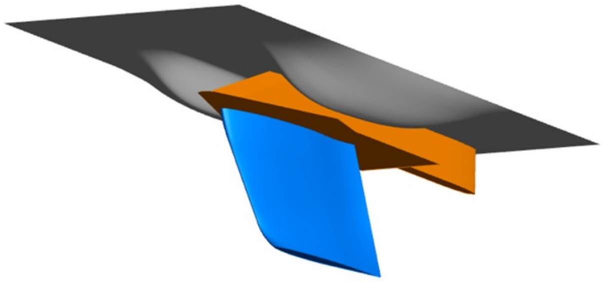


Original
Design
Targets

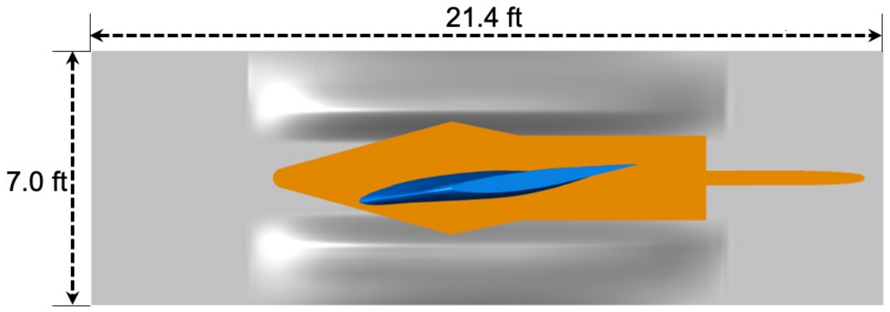


ELISE Remote Design Results: Surface Geometry

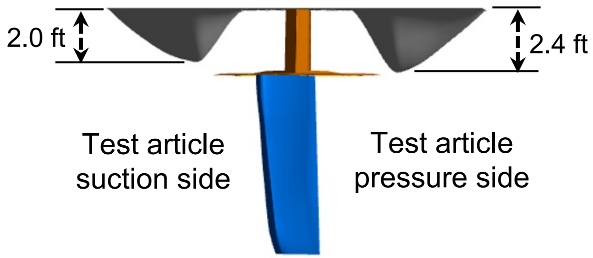
CDISC creates asymmetric bumps on either side of test article to match target pressures



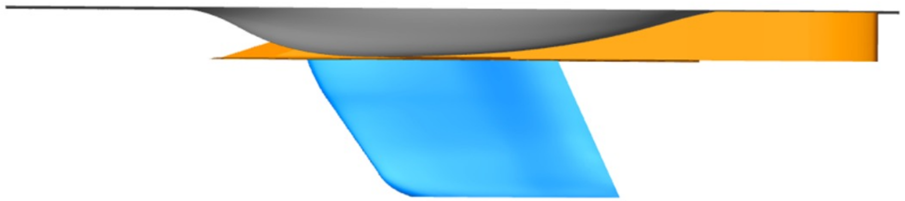
Isometric View



Bottom View



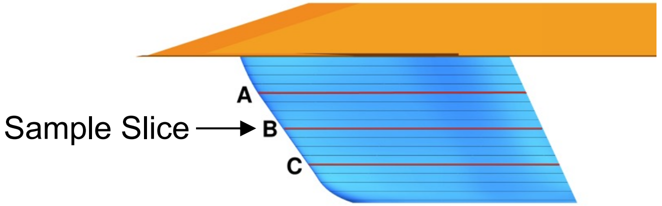
Front View



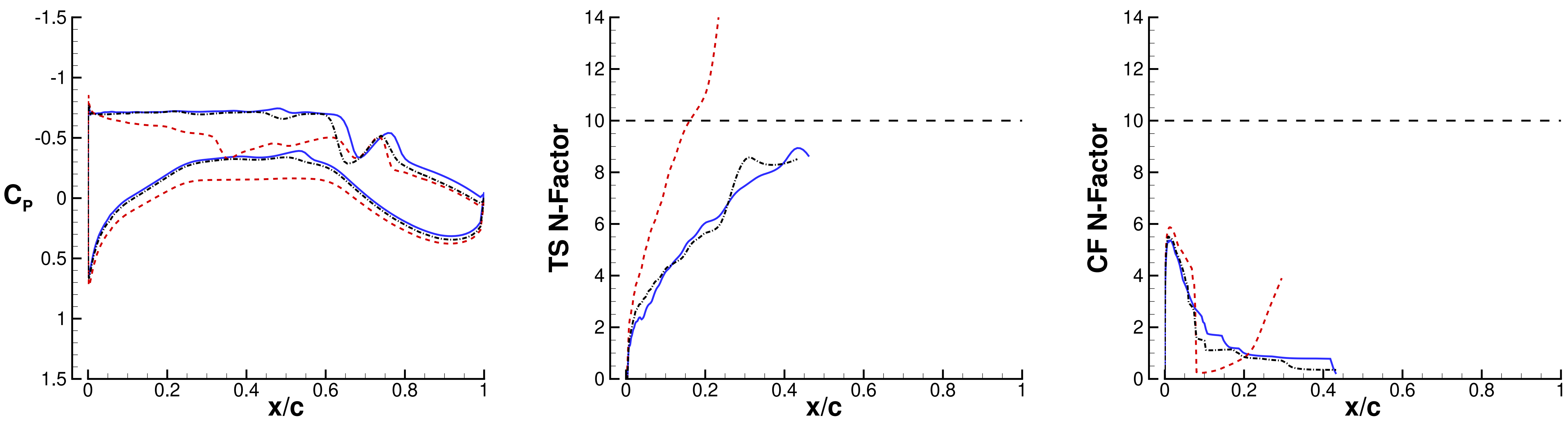
Side View

ELISE Remote Design Results: Test Article Influence

Results suggest the ELISE method is successful at replicating the interference effects of the F-15 on the CATNLF test article in flight

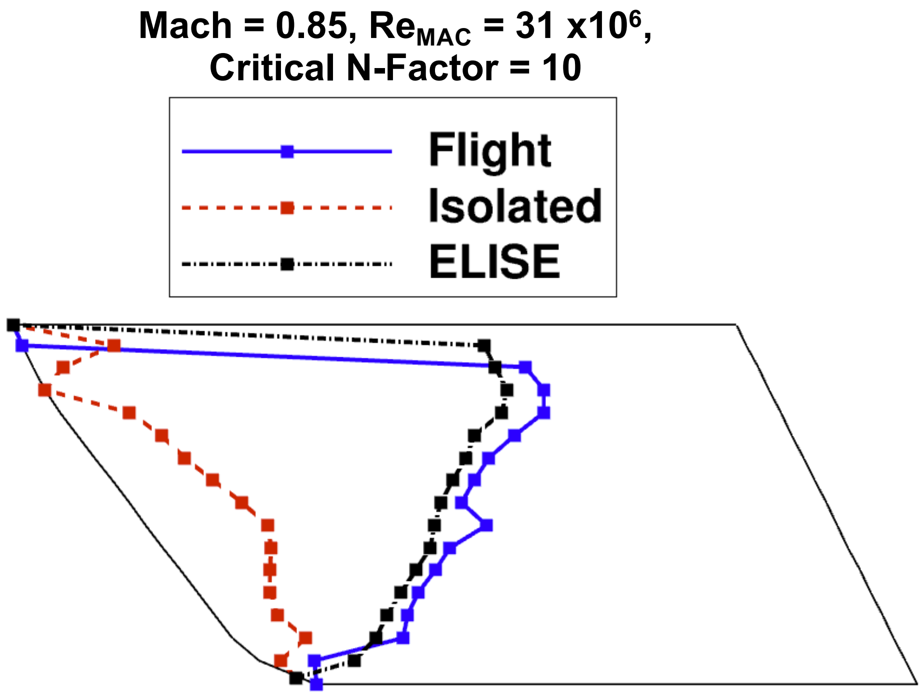


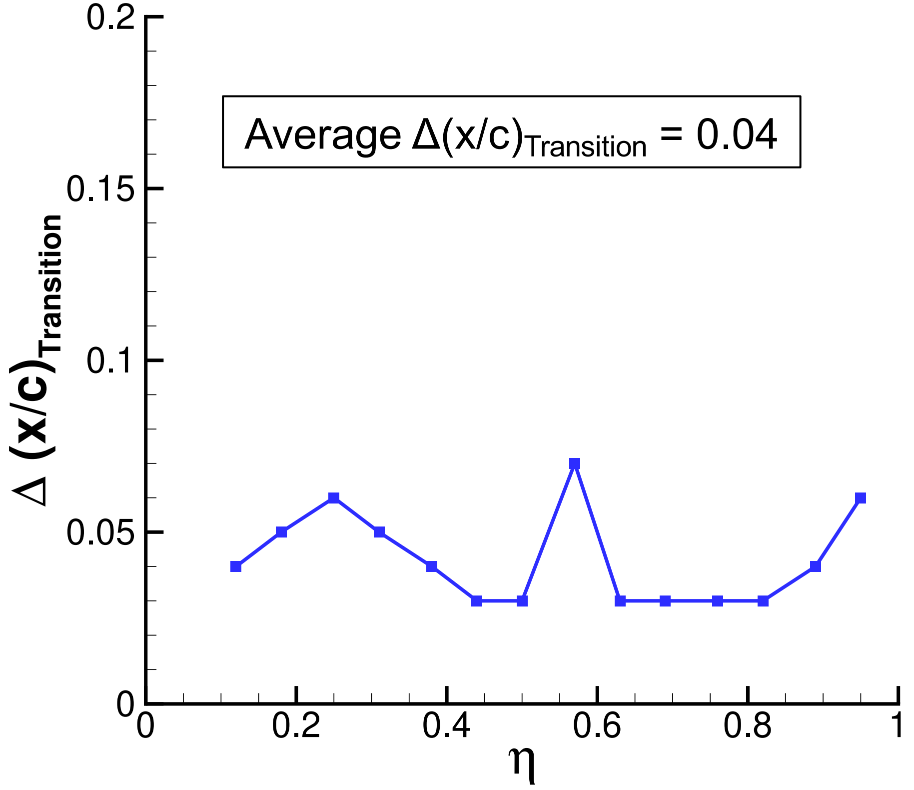
Mach = 0.85, Re_{MAC} = 31 x10^6



ELISE Remote Design Results: Test Article Transition

ELISE surface replicates the predicted transition characteristics of the Flight Configuration within reasonable accuracy





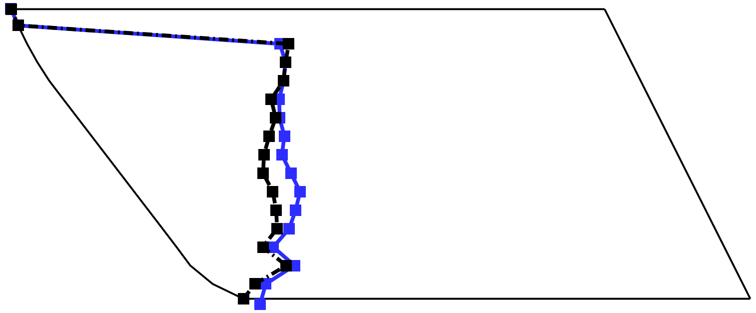
Off-Design Results: Mach Changes

Transition characteristics between the F-15 and ELISE surface configurations are reasonably maintained over expected Mach tolerance range (±0.02) in flight test

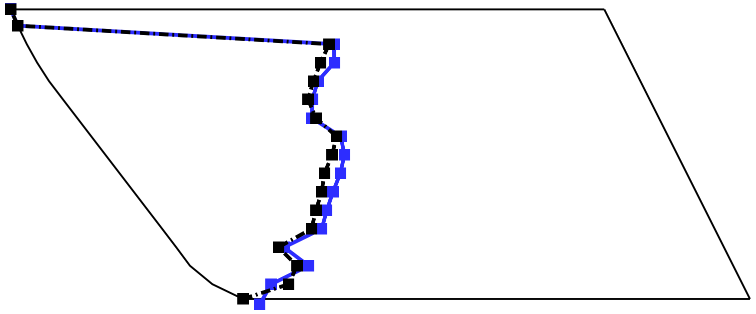
Design Mach = 0.85,
Critical N-Factor = 10

Flight	**Flight**
ELISE	**ELISE**

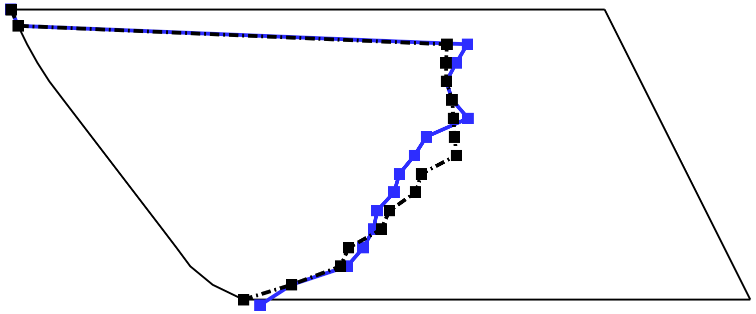
Mach = 0.83
Average $\Delta(x/c)_{Transition}$ = 0.02



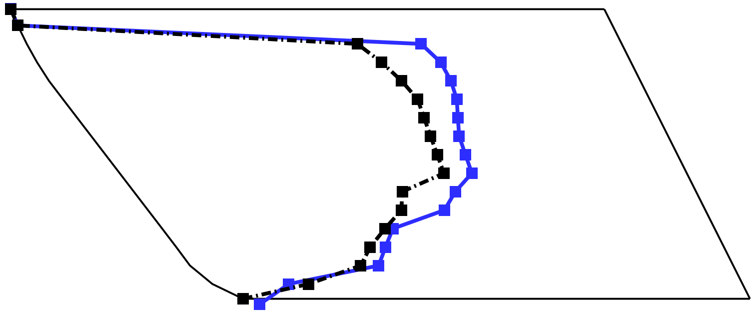
Mach = 0.84
Average $\Delta(x/c)_{Transition}$ = 0.02



Mach = 0.86
Average $\Delta(x/c)_{Transition}$ = 0.03



Mach = 0.87
Average $\Delta(x/c)_{Transition}$ = 0.06



Suggested range of use:
0.83 ≤ Mach ≤ 0.86

Based on maximum average $\Delta(x/c)_{Transition}$ limit of 0.05

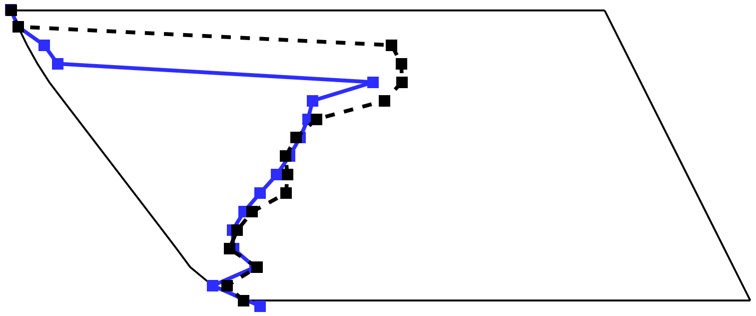
Off-Design Results: F-15 Sideslip Angle Changes

F-15 sideslip angle (β) has larger impact on agreement of transition characteristics between F-15 and ELISE surface configurations

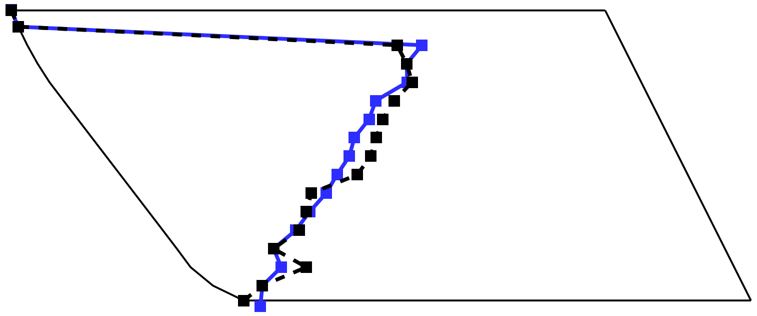
Design β = 0.0 deg,
Critical N-Factor = 10

(blue solid line, square markers)	**Flight**
(black dash-dot line, square markers)	**ELISE**

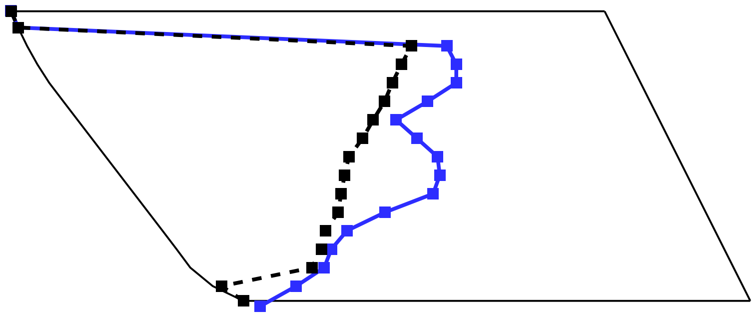
β = -1.0 deg
Average $\Delta(x/c)_{Transition}$ = 0.11



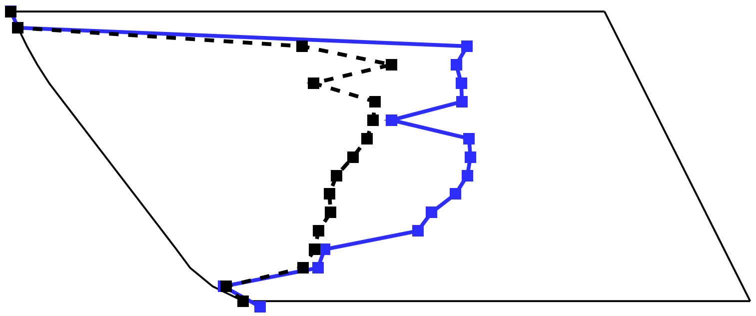
β = -0.5 deg
Average $\Delta(x/c)_{Transition}$ = 0.02



β = +0.5 deg
Average $\Delta(x/c)_{Transition}$ = 0.09



β = +1.0 deg
Average $\Delta(x/c)_{Transition}$ = 0.15

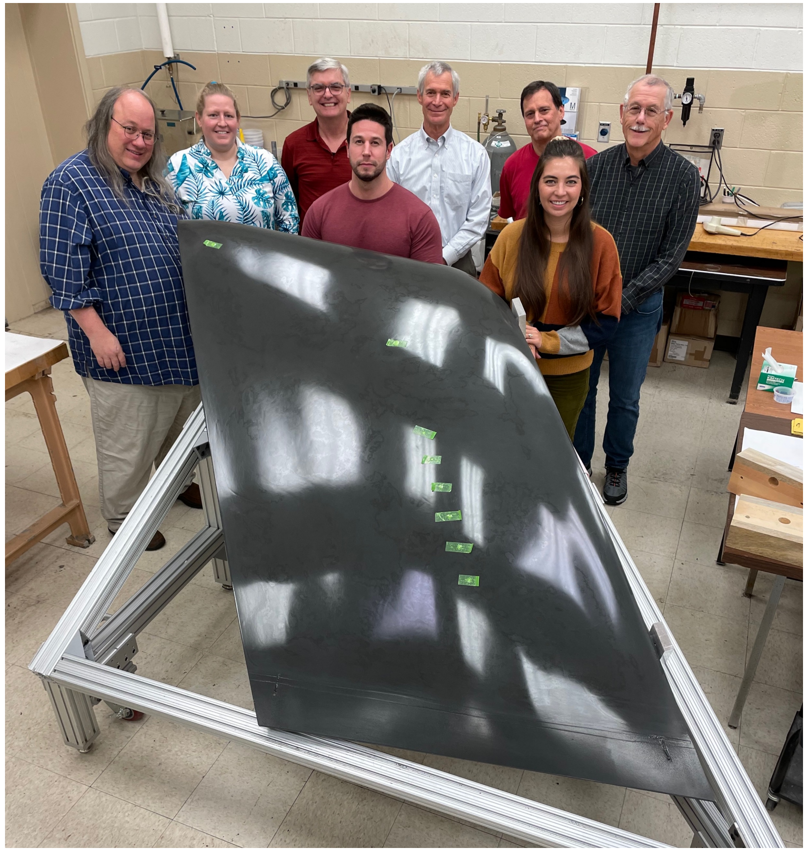


Suggested range of use:
-0.5 deg ≤ β ≤ 0.0 deg

Based on maximum average $\Delta(x/c)_{Transition}$ limit of 0.05

Concluding Remarks

- ELISE remote design method proven effective at reproducing the interference effects of the F-15 on the CATNLF flight test article
- Off-design results suggest there is a range of Mach and sideslip angles that the ELISE geometry is effective
- Final ELISE geometry would be redesigned according to flight test data
- Programmatic interest in a follow-on wind tunnel test of the CATNLF test article to evaluate influence of environment on laminar flow characteristics
  - Viscous effects on ELISE surface
  - Tunnel wall effects on CATNLF test article
  - Limitations on size due to blockage concerns



CATNLF flight test article after painting and instrumentation

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Backup Slides

Design Applications Using the NASA CDISC Design Method

9:30 History and Status of the CDISC Aerodynamic Design Method
Richard Campbell

9:50 Progress Towards the Design of a Natural Laminar Flow Wing for a Low-Boom Concept Using CDISC
Michael Bozeman

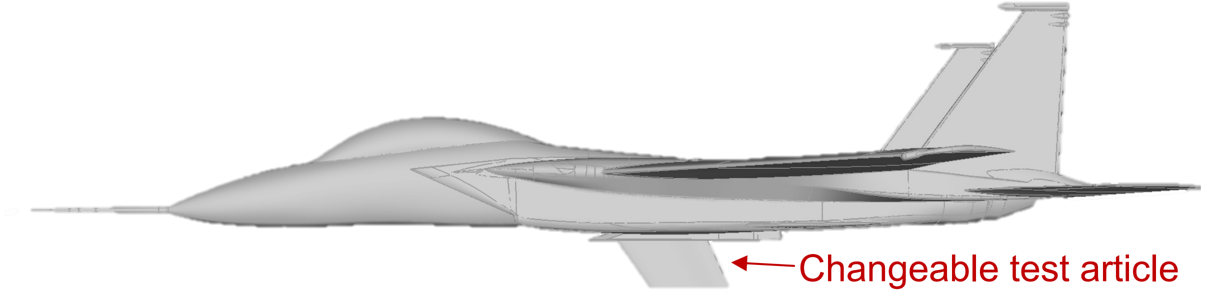
10:10 Application of the CATNLF Design Method to a Transonic Transport Empennage Using CDISC
Brent Pomeroy

10:30 Transonic Cruise Slotted Wing Design for Commercial Transport Aircraft Using CDISC
Brett Hiller

10:50 CDISC Remote Design Method to Simulate Aircraft Interference Effects for the CATNLF Flight Test
Michelle Banchy

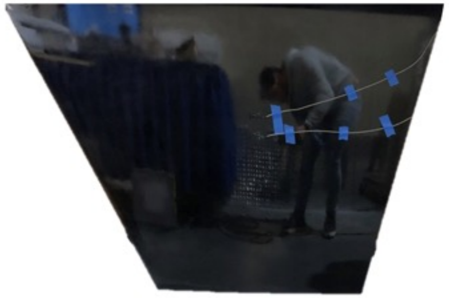
CATNLF Flight Test Series

Series of flight tests under an F-15 using the Centerline Instrumented Pylon (CLIP)



AFRC F-15 CLIP Flight Test Bed

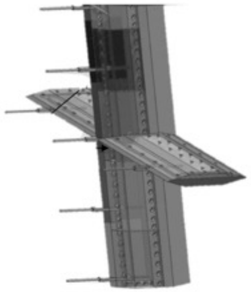
Flight 1: ReHEAT Experiment



Goal: Test carbon-based heating layer for improved flow visualization
Status: Successfully completed 2020*

*Reference: AIAA 2020-3089

Flight 2: Flow Rake Experiment

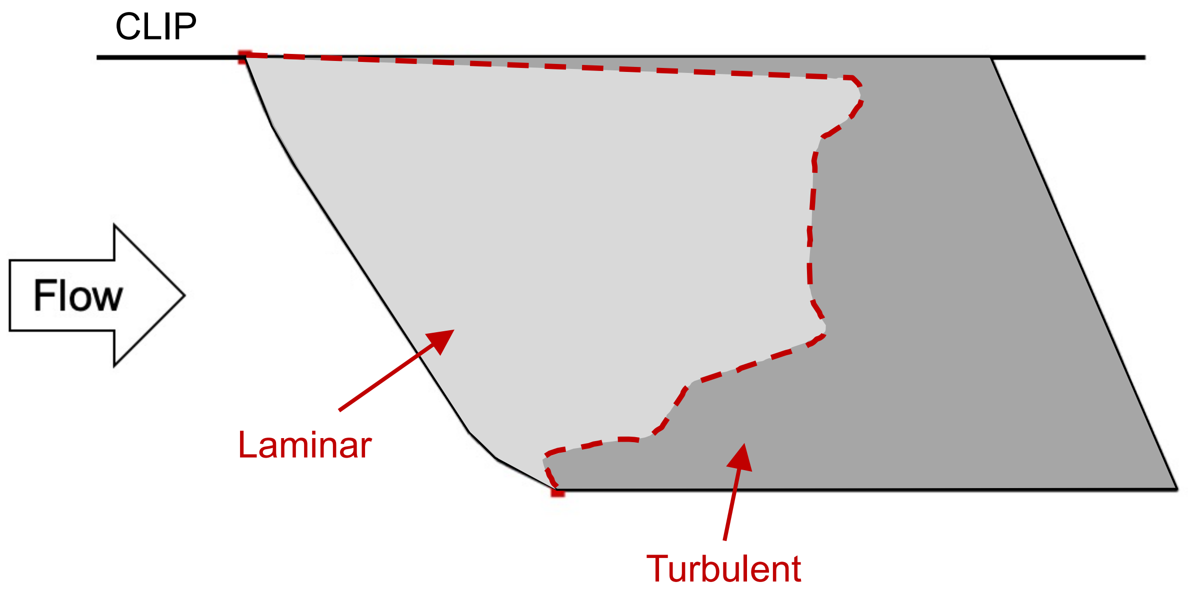


Goal: Quantify flow environment underneath F-15
Status: First flight January 2024

Flight 3: CATNLF Experiment

Goal: Test CATNLF concept in flight environment
Status: First flight May 2024

CATNLF Test Article Design



Key Geometry Parameters and Design Conditions	
Mean Aerodynamic Chord (MAC)	5.9 ft
Span	3.3 ft
Leading-Edge Sweep	35 deg
Mach	0.85
Re_{MAC}	31 million
Section Lift Coefficient	0.50

- Approx. 52% of surface area has laminar flow at design condition with maximum transition Reynolds number of approximately 24 million
- Laminar flow inboard is shock-limited transition and outboard is Tollmien-Schlicting transition
- Test article instrumented with static and dynamic pressure ports, thermocouples, accelerometers, and internal electrical wires for resistive heating layer