



Meeting the Challenges of Propulsion and Active Flow Control Testing in the National Transonic Facility

Gregory S. Jones

William E. Milholen II

Christopher M. Cagle

**NASA Langley Research Center
Subsonic Fixed Wing Project
Fundamental Aeronautics Program**

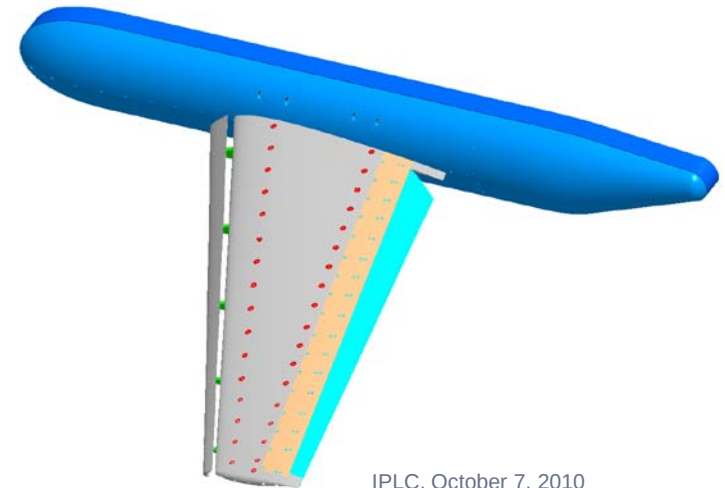
***IPLC
Philadelphia, Pennsylvania
October 7, 2010***



OUTLINE



- Background
- Measurement Issues Associated w/ SMSS
- Air Station Checkout
- Circulation Control Semi-Span Model
- Concluding Remarks



NASA Subsonic Transport System Level Metrics

.... technology for dramatically improving noise, emissions, & performance



CORNERS OF THE TRADE SPACE	N+1 (2015)*** Technology Benefits Relative to a Single Aisle Reference Configuration	N+2 (2020)*** Technology Benefits Relative to a Large Twin Aisle Reference Configuration	N+3 (2025)*** Technology Benefits
Noise (cum below Stage 4)	- 32 dB	- 42 dB	- 71 dB
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-50%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metroplex* concepts

*** Technology Readiness Level for key technologies = 4-6

** Additional gains may be possible through operational improvements

* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

N+1 "Conventional"



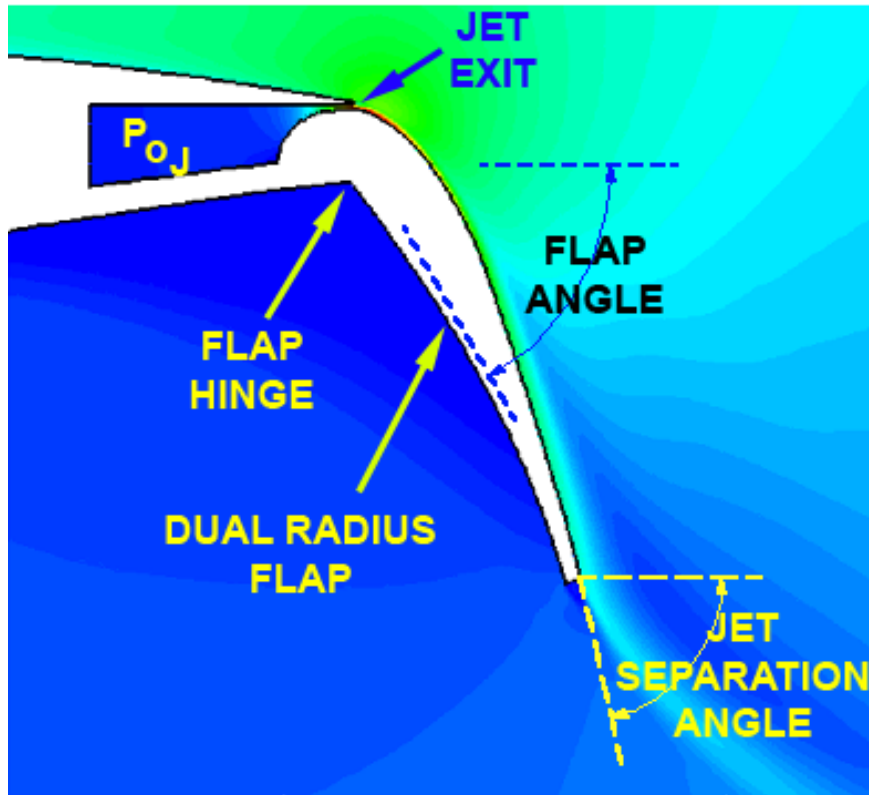
N+2 Hybrid Wing/Body



N+3 Generation



Circulation Control Aerodynamics



Technology/Physics

High momentum blowing slot

- direct augmentation of lift and drag
- steady or unsteady blowing

Benefits

Simplified low-speed high-lift system

- significant reduction in flap chord
- replacement of complex fowler system

High-speed applications

- transonic drag reduction
- buffet boundary modification
- maneuvering

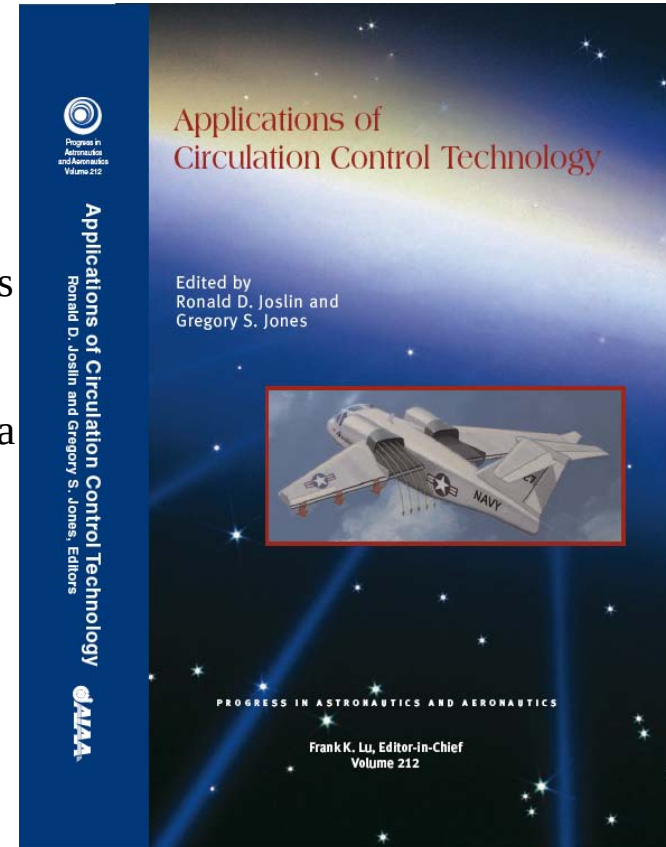
New design trade studies

- field length (CTOL,STOL,ESTOL), noise, cruise efficiency, maneuver

2004 NASA/ONR CIRCULATION CONTROL WORKSHOP



- **Experiments**
 - Long history that includes small scale to flight demonstrations
 - Limited data sets available for modern CFD validation for fixed wing aircraft
- **CFD**
 - Comparisons of different techniques resulted in inconsistencies of performance prediction (turbulence models, grid generation related to jets and wakes, etc)
 - Need better prediction tools and high-quality experimental data bases to quantify and optimize performance
- **Workshop conclusions related to fixed wing applications**
 - Circulation control has not been implemented on production aircraft (Why?)
 - Low confidence in prediction capability
 - Lack of need on conventional mission profiles
- **Next workshop in 2012 time frame**
 - NASA ARC, LaRC



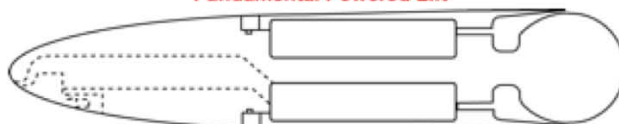
ISBN-10: 1-56347-789-0

CFD VALIDATION



Benchmark Cases

Fundamental Powered Lift



2-D CC Airfoil w/ Upper and Lower Blowing

GTRI/NASA LaRC – MTF/BART

Complete System

Integrated Powered Lift

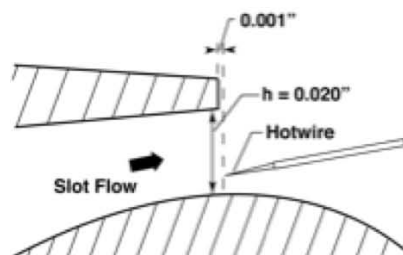


3-D Hybrid Wing Body w/ USB augmented w/ CC Wing

Cal Poly/NASA ARC - NFAC

Unit Problems

Fundamental Wall Bounded Jet

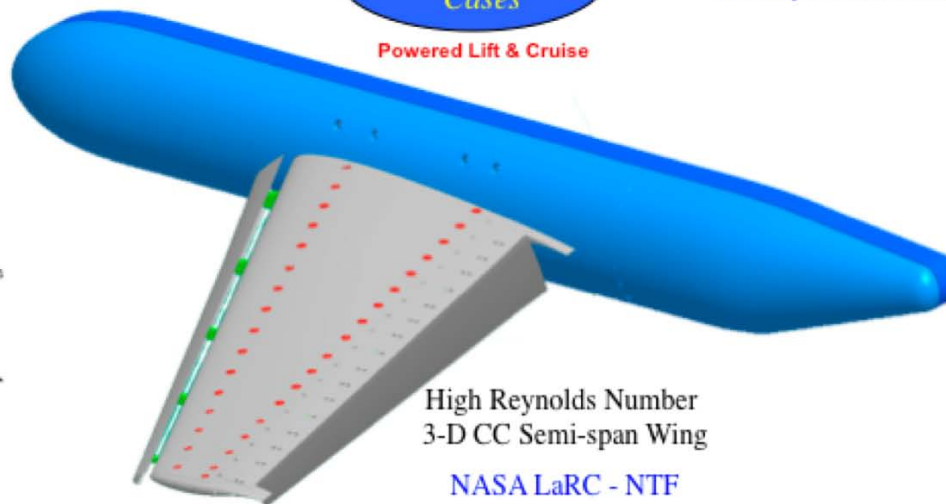


Jet Exit Velocity Profile

NASA LaRC – CC Lab

Subsystem Cases

Powered Lift & Cruise



High Reynolds Number
3-D CC Semi-span Wing

NASA LaRC - NTF

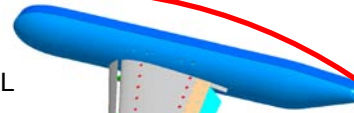
Increasing Geometric And Flow Complexity

PARTNERSHIPS FOR ADVANCING CIRCULATION CONTROL AERODYNAMICS



NASA (ARC,LaRC,DFRC)

SUPERCRITICAL GACC AIRFOIL



TE BLOWING

TE BLOWING & PULSED

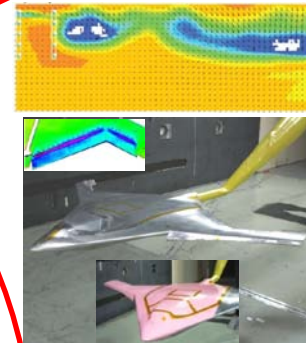
SUPERCRITICAL TMA0712 AIRFOIL



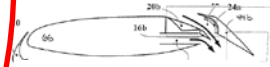
TE BLOWING

TE BLOWING & PULSED

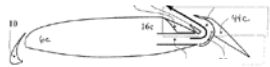
University of Florida



Cruise Mode



High Lift Mode



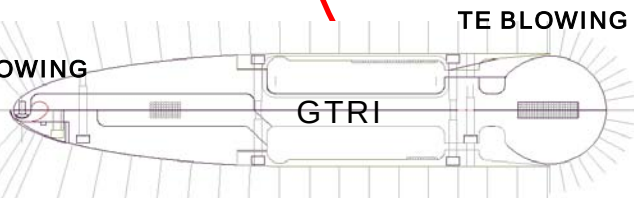
Reversing Mode

CFD

TE BLOWING

LE BLOWING

GTRI



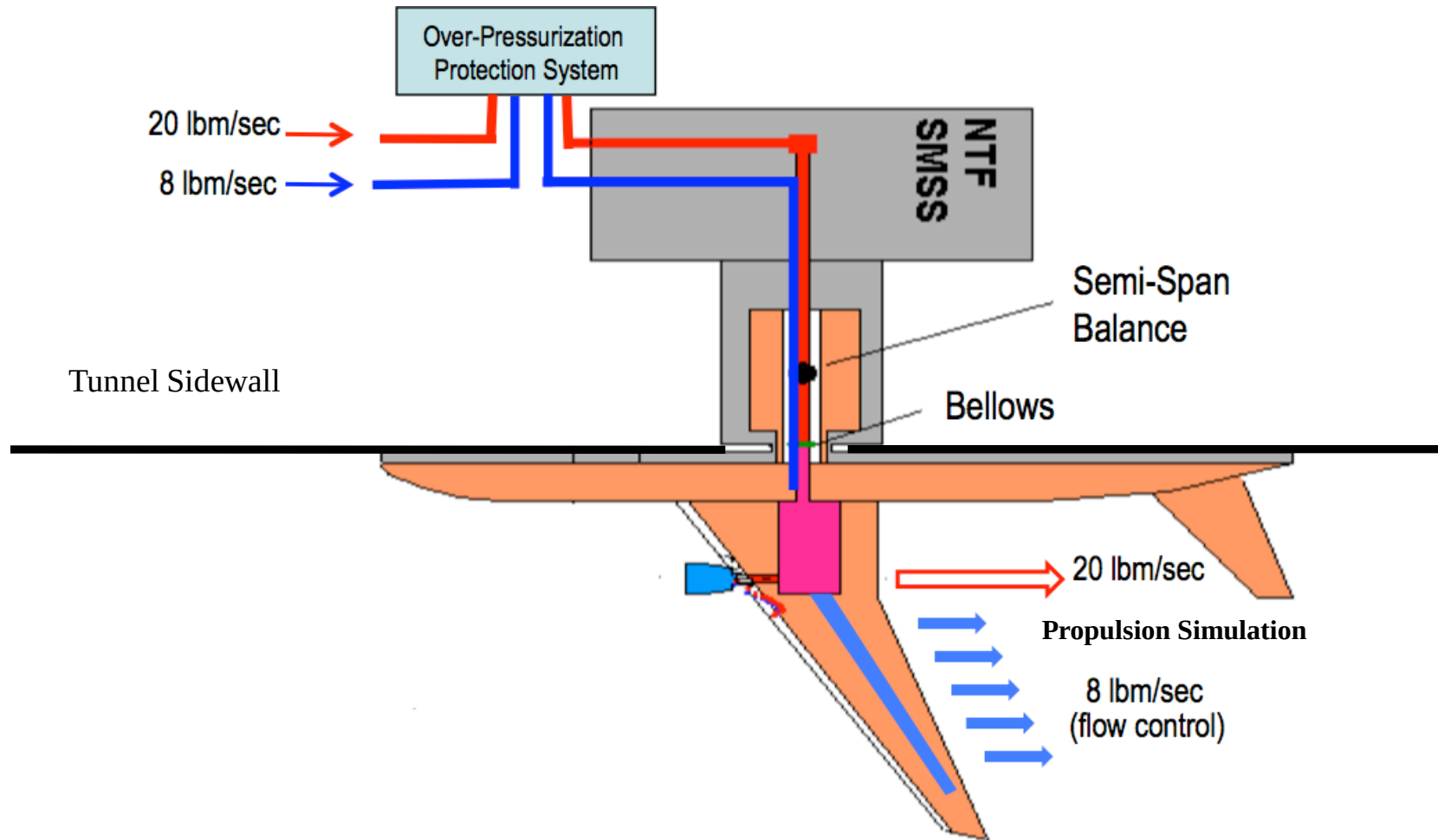
CAL POLY



DOD & Industry

University

Simplified Schematic of High Pressure Air Delivery for Semi-Span Models in the NTF

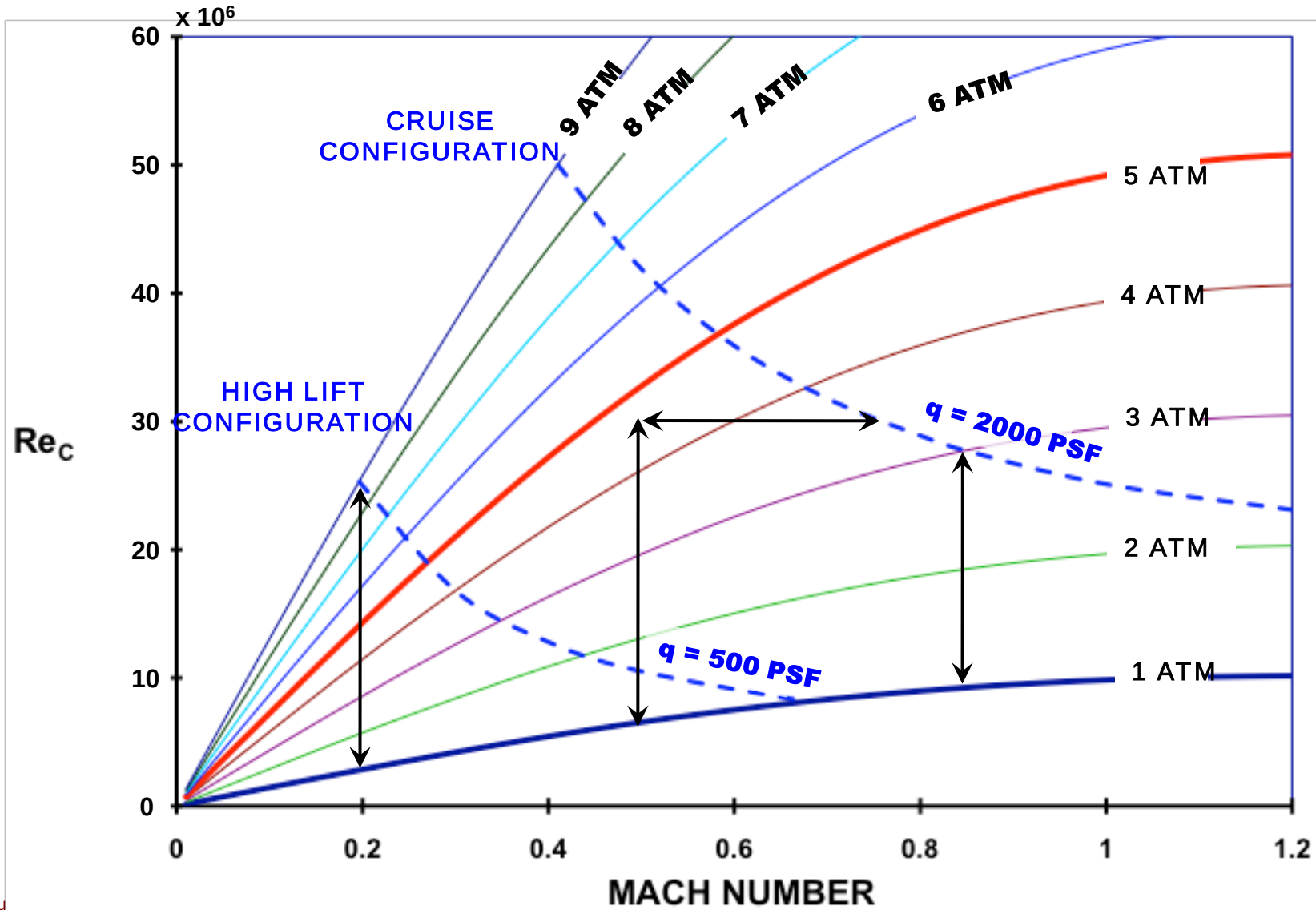


Testing in air (120 °F) to mild cryogenic conditions (-50°F)

NTF Operating Envelope Using SMSS



$S_{REF} = 6.06 \text{ ft}^2$ $MAC = 18.1 \text{ inches}$ $T_o = -50^\circ\text{F}$



SPECIAL CHALLENGES ASSOCIATED W NTF



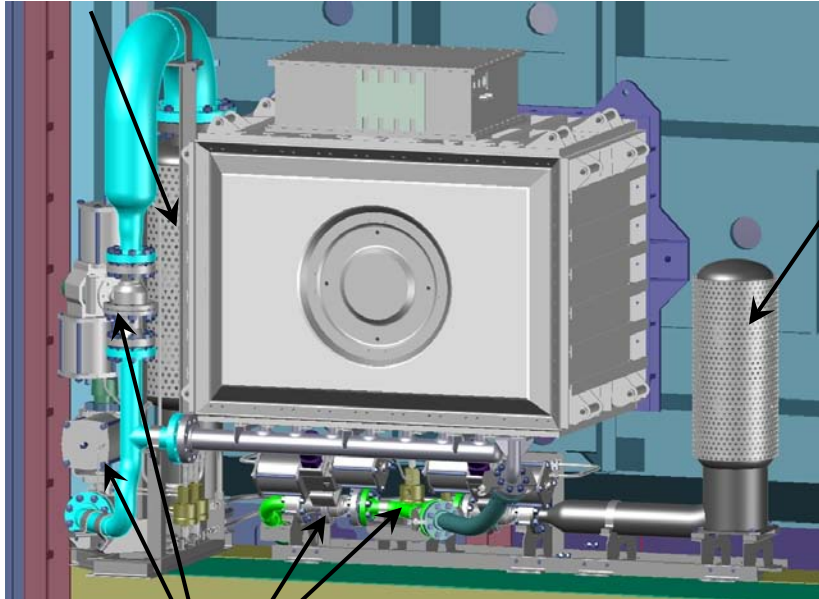
- BALANCE STABILITY AT COLD CONDITIONS
 - HEATED ENCLOSURE (SMSS)
- PRESSURE TARES ASSOCIATED WITH BELLOWS
 - POST TEST 195
- TEMPERATURE EFFECTS ON INSTRUMENTATION
 - MOTOR CONTROL VALVES IN MODEL
 - MODEL SAFETY SYSTEM SENSITIVE TO TEMPERATURE
 - PRESSURE TRANSDUCERS
 - HEATED ENCLOSURES FOR ESP SYSTEMS
 - CALIBRATION FOR PRESSURE AND TEMPERATURE
- MASS FLOW REQUIREMENTS AT ELEVEATED PRESSURES
 - FLOW METER CALIBRATION FOR 0.3% READING

Modified Side Mounted Support System



high flow
vent

low flow
vent



model isolation
& vent valves

coaxial
supply
lines

heater/blower

bellows

model
turntable

manifolds

pitch
drive

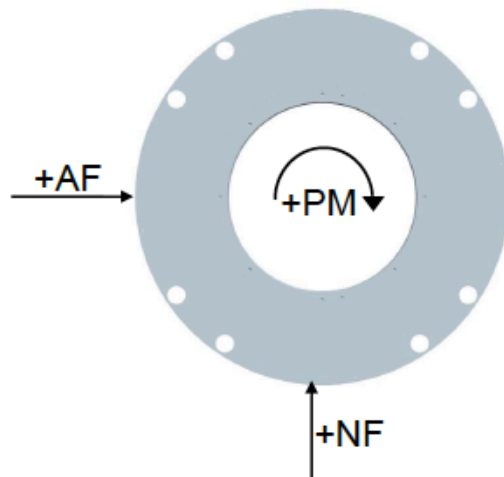
Balance

Characteristics of the New NTF-117S Balance



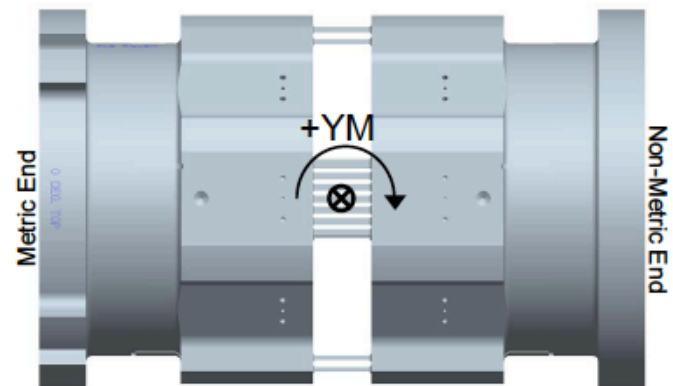
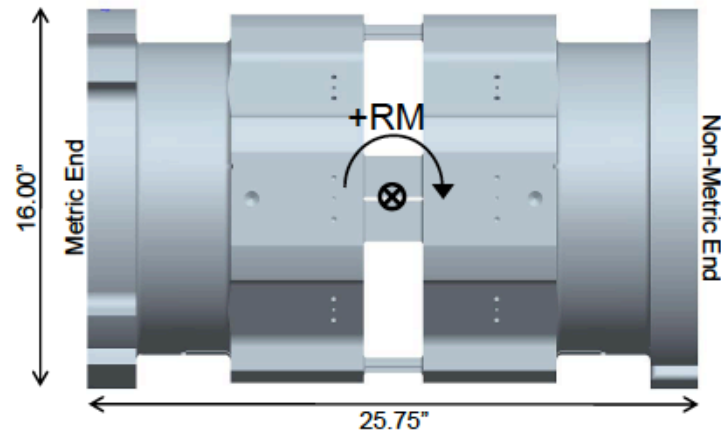
Balance completion/calibration funded by ATP

- enables transonic semi-span testing
- initial fabrication in 1990s during AST
- parallel effort for in situ calibration at NTF (winter 2010)



Full Scale Design Loads*:

Normal Force:	12,000 lbs
Axial Force:	1,800 lbs
Pitch Moment:	90,000 in-lbs
Roll Moment:	669,000 in-lbs
Yaw Moment:	100,350 in-lbs

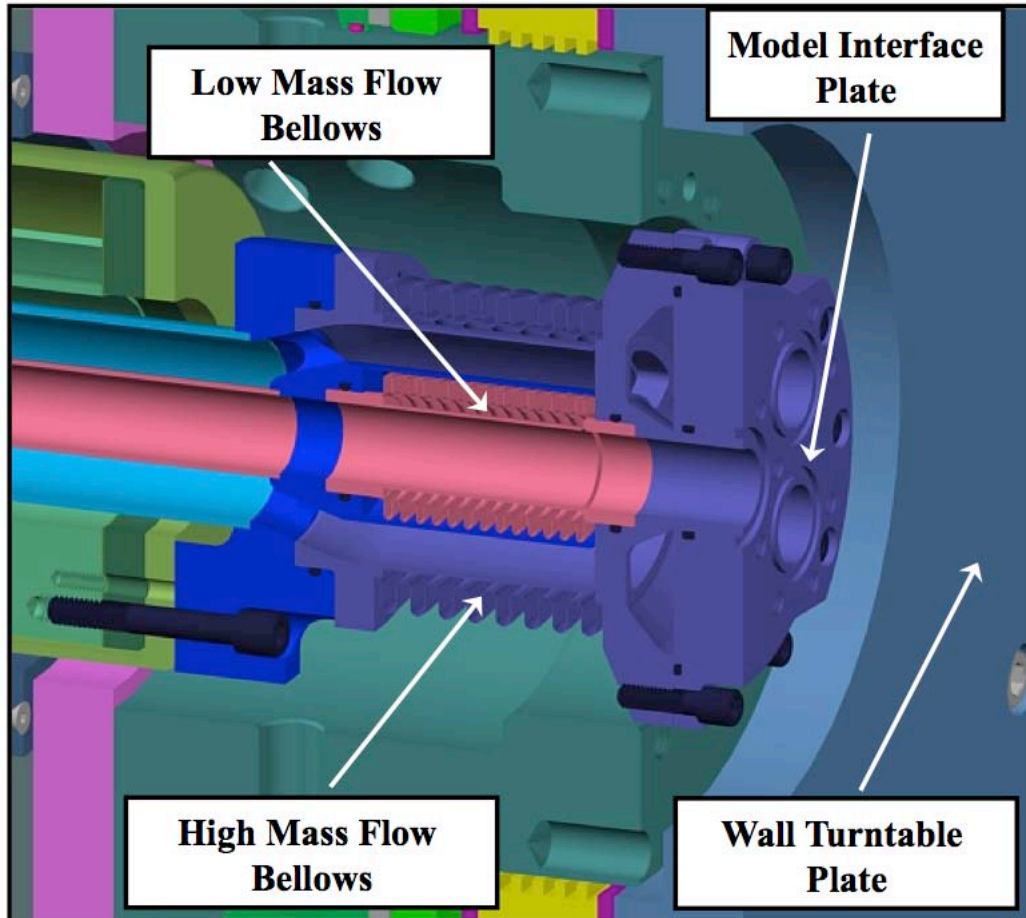


⊗ = Balance Moment Center (BMC)

8/14/2009

* All loads are about BMC

Cross-Sectional View of Bellows Attachment



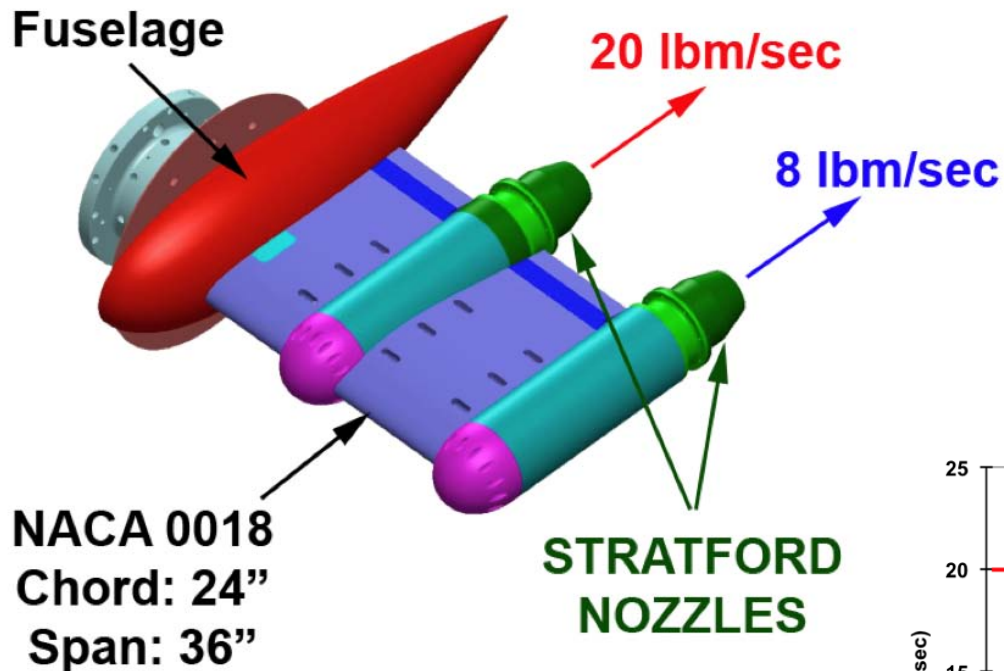
Static pressure tares estimated to be small

- low stiffness compared to balance
- lack of sideforce measurement

Second balance calibration being planned to access effect of bellows

Momentum tares to be evaluated using calibration nozzles

Verification of Air Station Performance

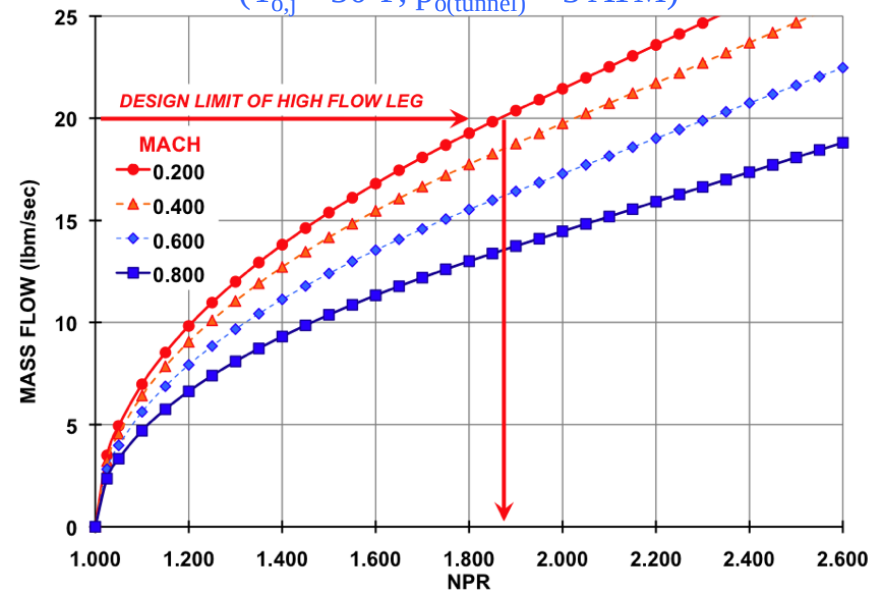


Initial Runs are with
NO External flow (i.e. tunnel off)

OBJECTIVES

- 1.) Determine the boundaries of the new Air Station
 - Mass Flow
 - Temperature
- 2.) Evaluate Balance tares associated with bellows

Predicted Nozzle Performance
($T_{o,j} = -50^{\circ}\text{F}$, $p_{o(\text{tunnel})} = 5 \text{ ATM}$)

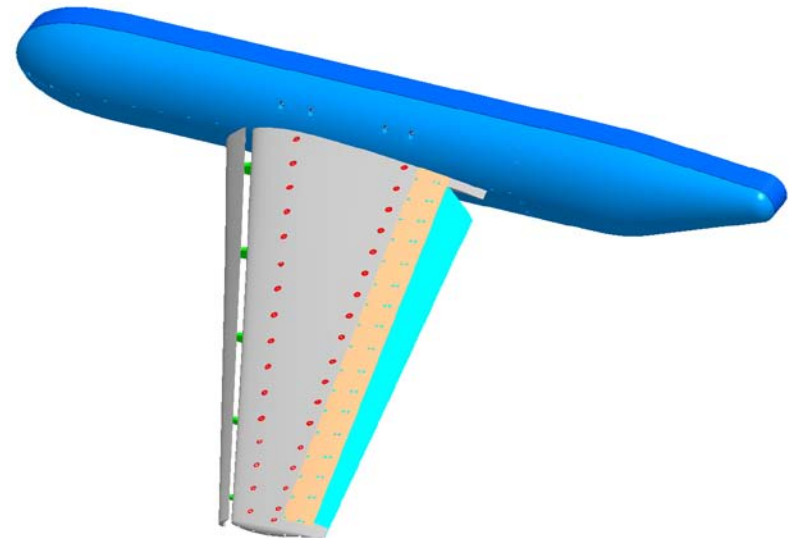


3D Aerodynamic Scale Effects for CC

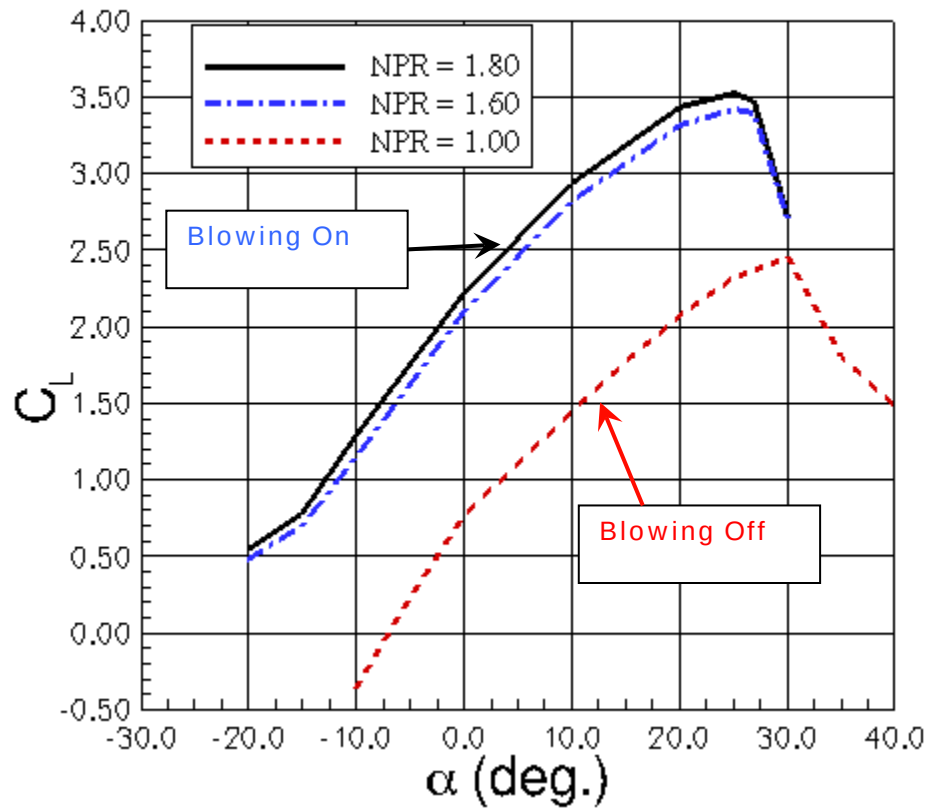
the FAST-MAC activity



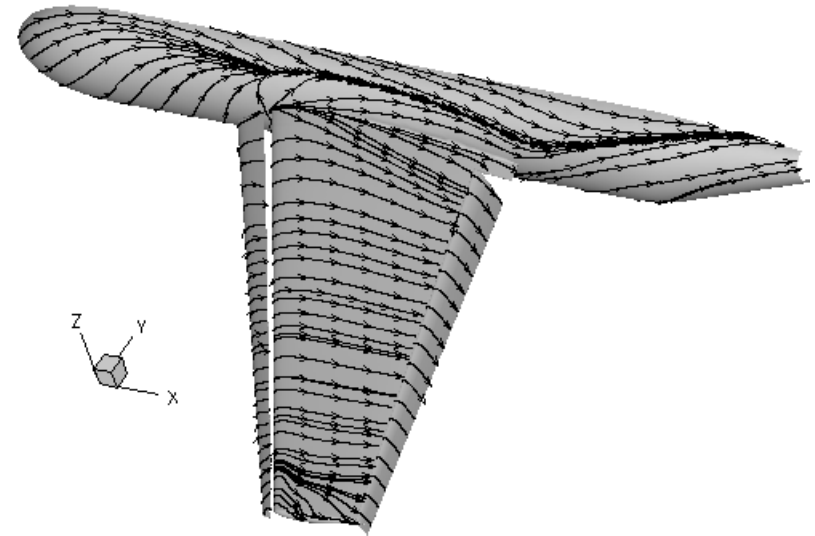
- Flow Control/Propulsion Simulation Upgrade at the National Transonic Facility
 - High-pressure air delivery station
 - Larger capacity force and moment balance
- Modular Research Model
 - Fundamental Aerodynamics Subsonic Transonic - Modular Active Control
 - Low-speed high-lift & transonic cruise
 - State-of-art aerodynamic design
 - Open geometry
 - Modular for future flow control concepts
 - Significant interest by industry/OGA to leverage model in future



Predicted Aerodynamic Characteristics of FAST-MAC High-Lift Design with Blowing using USM3D



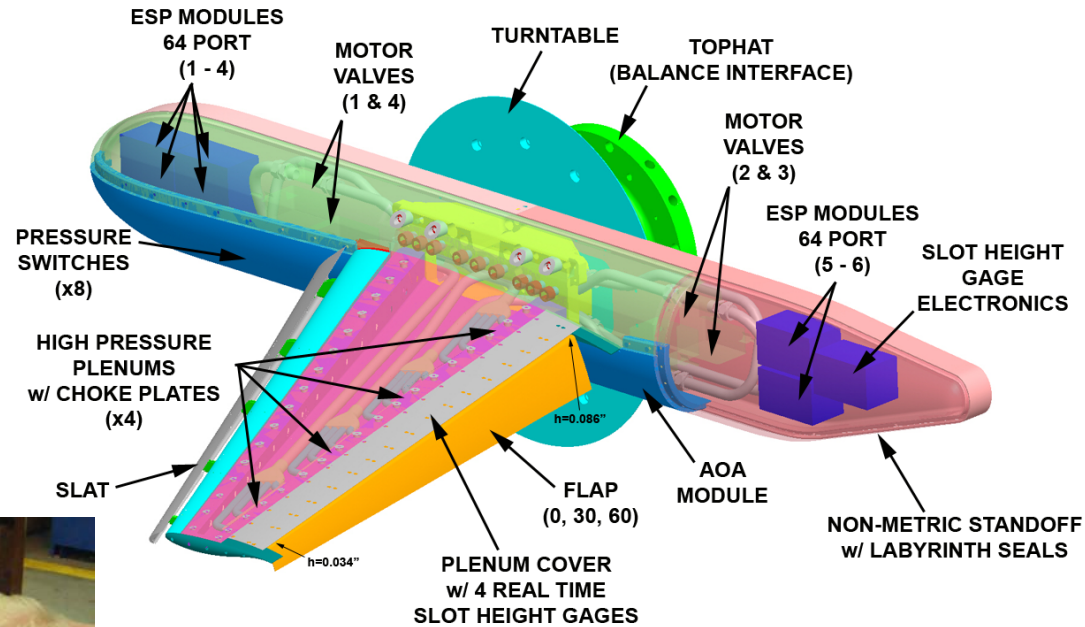
$M=0.20, Re=20 \times 10^6$



$M=0.20, \alpha=25^\circ, NPR=1.80, Re=20 \times 10^6$

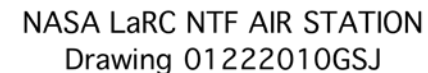
Predicted Streamlines at
Maximum Lift Coefficient

Internal Features of Semi-span Model Assembly

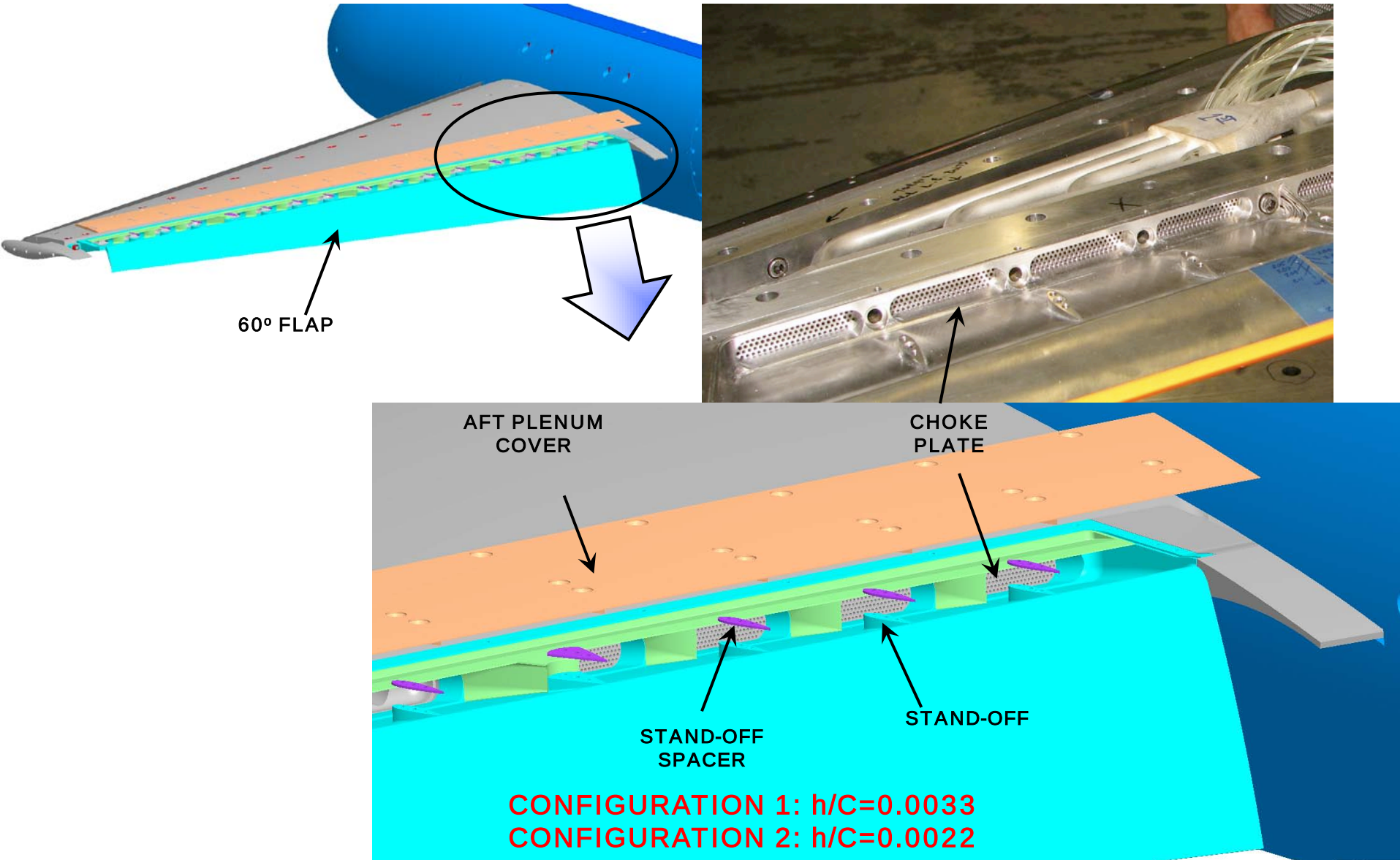


Subsonic Fixed Wing Project

- Characterize CC High Lift
- Characterize CC Cruise
- Operational Checkout Fall 2010.



SLOT HEIGHT SETTINGS



Concluding Remarks



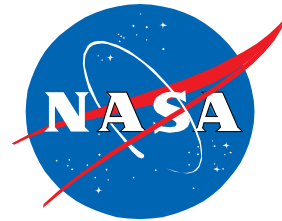
Unique high-Reynolds number testing capability for flow control and propulsion simulations is being established in the NTF using semi-span models

Unique data providing insight in to scaling laws to flight

Air station check-out/verification: now – 11/01/10

FAST-MAC model pre-test cryo-cycle: 10/20/10

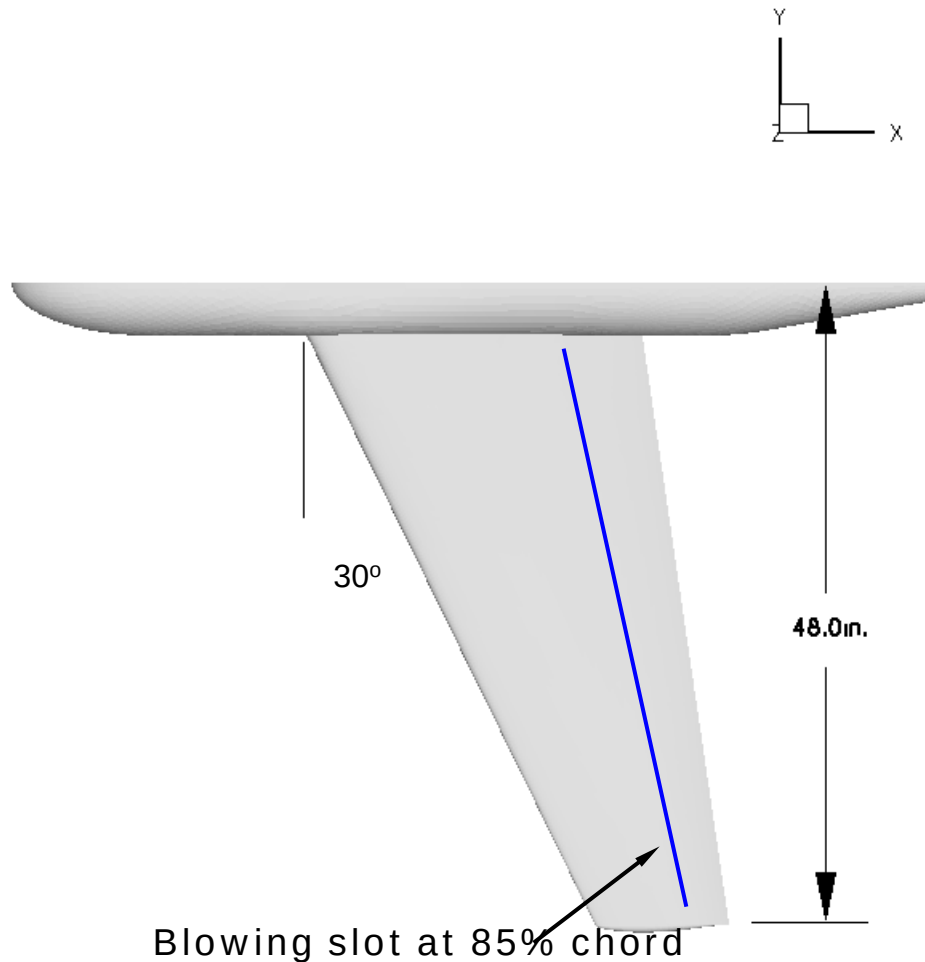
FAST-MAC model testing complete (round 1) 12/18/10



Temperature Sensitivity on Pressure Gage



FAST-MAC Transonic Wing Design



Wing planform parameters:

$$AR=5.0, \lambda=0.40$$

$$cbar = 18.1 \text{ in.}$$

Design conditions:

$$M=0.85, Re = 30 \times 10^6$$

$$C_L = 0.50$$

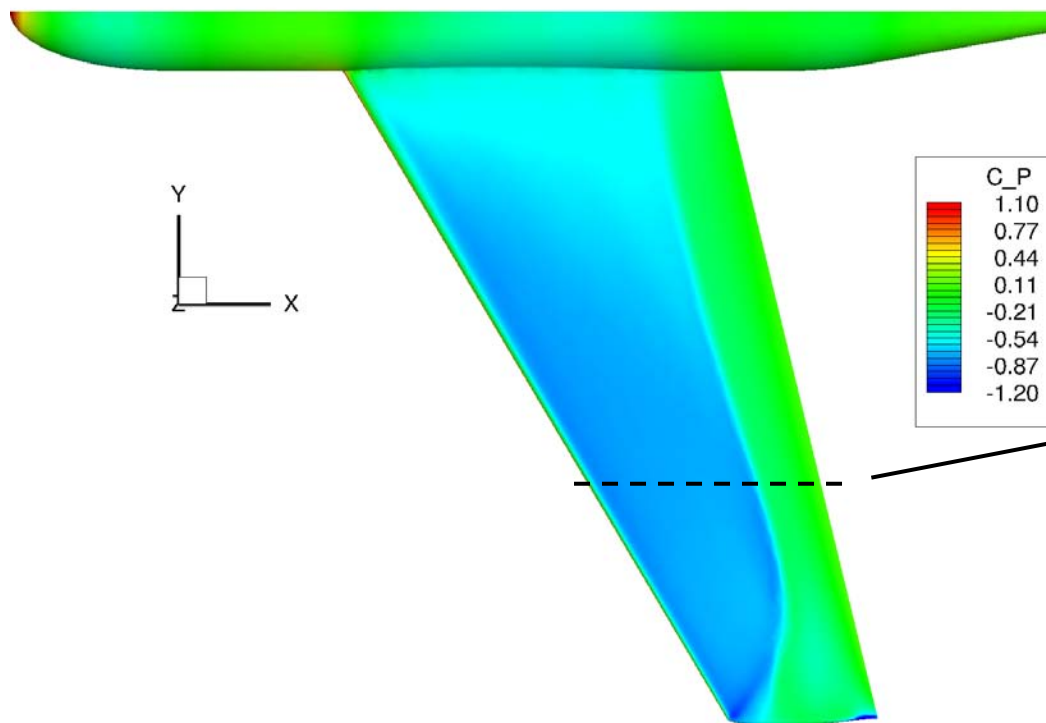
Flow solver:

USM3D, fully turbulent,
S-A turb model with wall
functions,
~5 million cells

Inverse design using CDISC

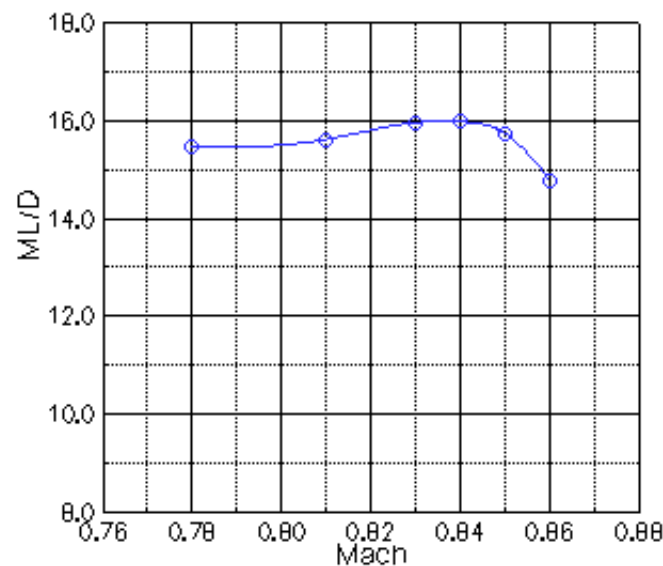
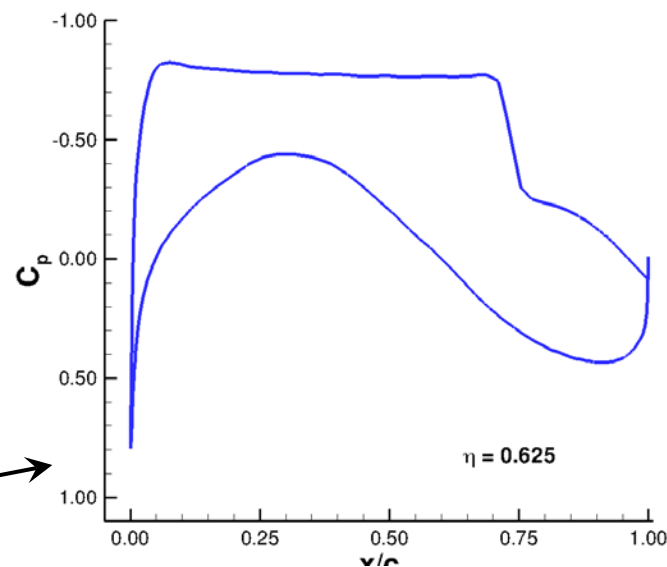
- no blowing slot included

Predicted Aerodynamic Characteristics of FAST-MAC Wing Design (no blowing) using USM3D

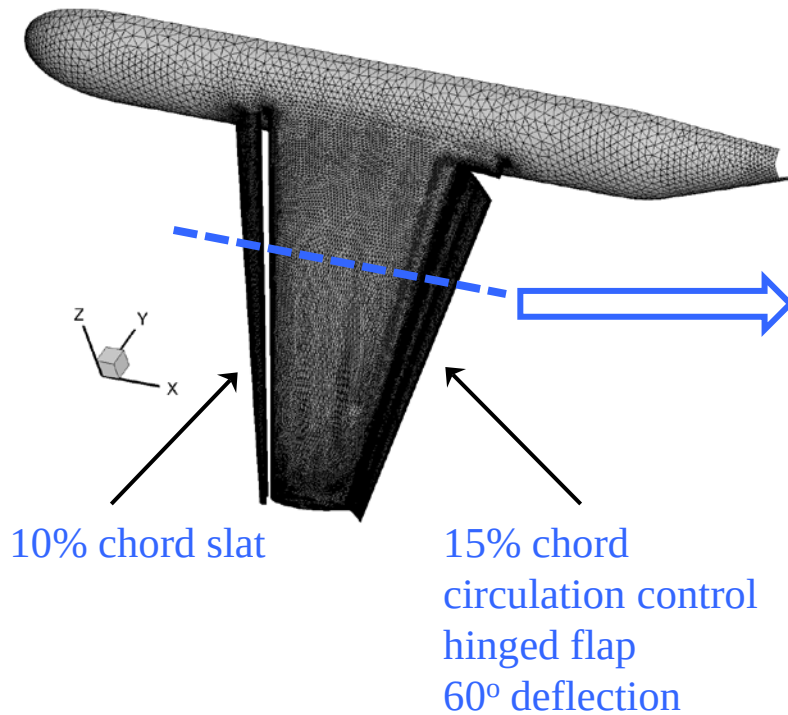


$M=0.85$, $C_L=0.50$, $Re = 30 \times 10^6$

Wing Designed using CDISC



FAST-MAC High-Lift Design with Blowing



USM3D, full-viscous simulation, S-A turbulence model (35 million cells)

