Force Measurement Improvements to the National Transonic Facility Sidewall Model Support System

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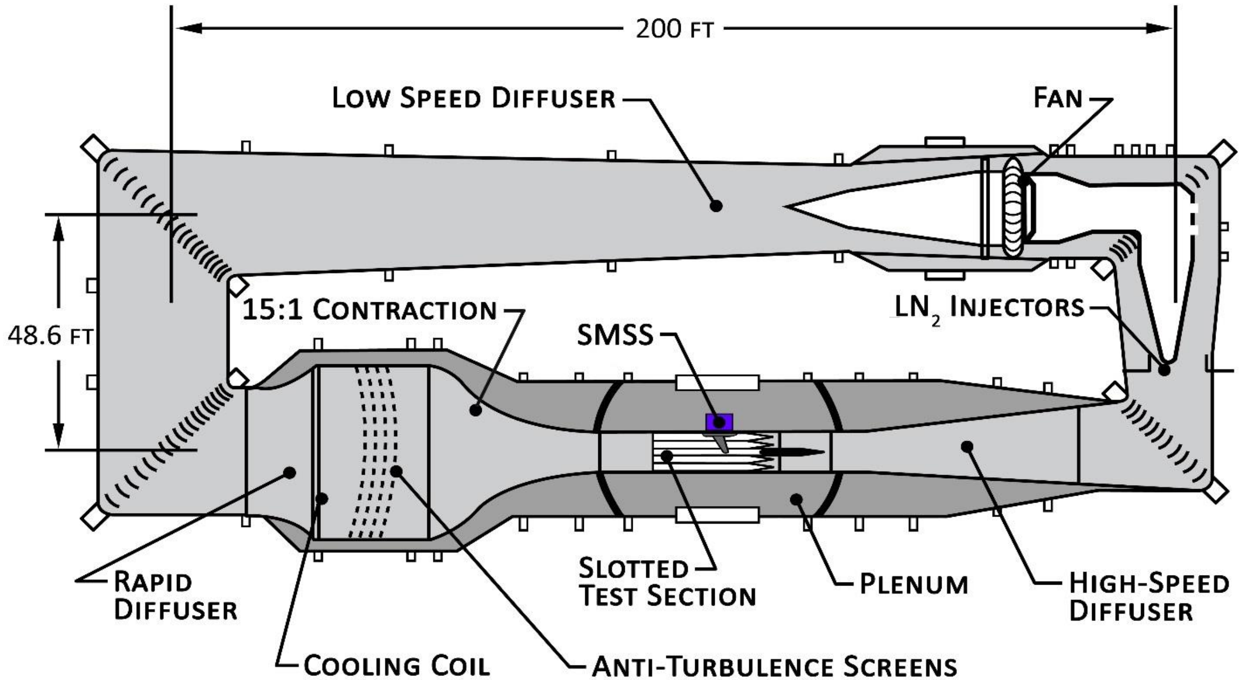
Outline

- The National Transonic Facility
- Introduction and Problem Statements
  - challenges with powered semi-span testing in a transonic cryogenic environment
- The FAST-MAC Model
  - primary testing platform
- Calibration of the NTF-117S Balance
- Balance Cavity Recirculation System (BCRS) Description and Modifications
- Sidewall Model Support System (SMSS) Description and Modifications
- Test Results
  - repeatability results, thermal stability data, wind-off zero data
- Concluding Remarks
- Questions

The National Transonic Facility

- Closed circuit, transonic, wind-tunnel at NASA Langley Research Center
- Flight Reynolds numbers achievable through cryogenics and pressurization
- Capable of supporting both full-span and semi-span test articles



OPERATING PARAMETERS

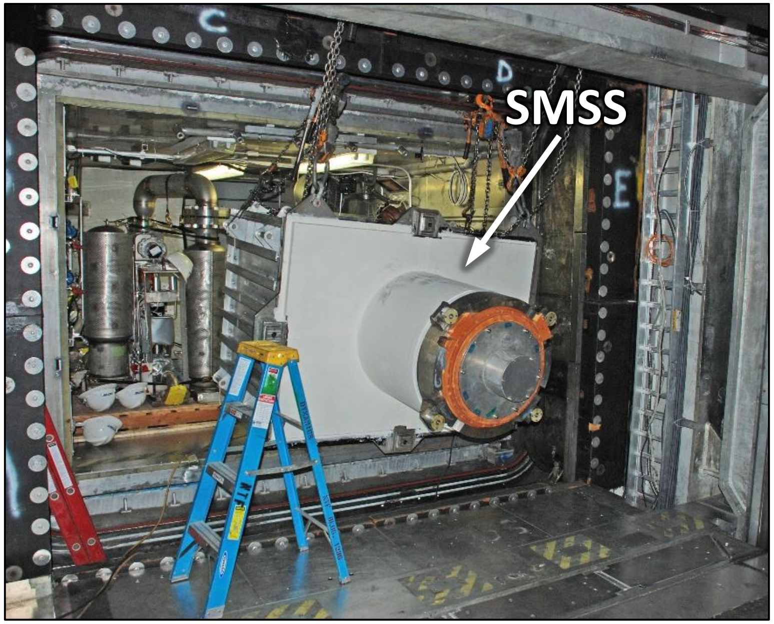
Mach Number:	**0.1 to 1.2**	*Test Gas:*	**Air, Nitrogen, Mix**
Test Temperature:	**-250°F to 120°F** (116 K to 322 K)	*Reynolds Number:*	**$146\text{x}10^6$ per foot (max)**
Total Pressure:	**15 psia to 120 psia** (1 atm to 8.2 atm)	*Fan Power:*	**101 MW**

Introduction

- SMSS used for semi-span testing
  - originally designed for cryogenic low-speed high-lift applications
  - internal components and balance kept warm
- Flow control system (FCS) recently integrated into SMSS to provide 2 concentric flow paths of high-pressure air (up to 20 lbm/sec)

ENABLES
- *active flow control*
- *engine simulation*
- *propulsion airframe integration*

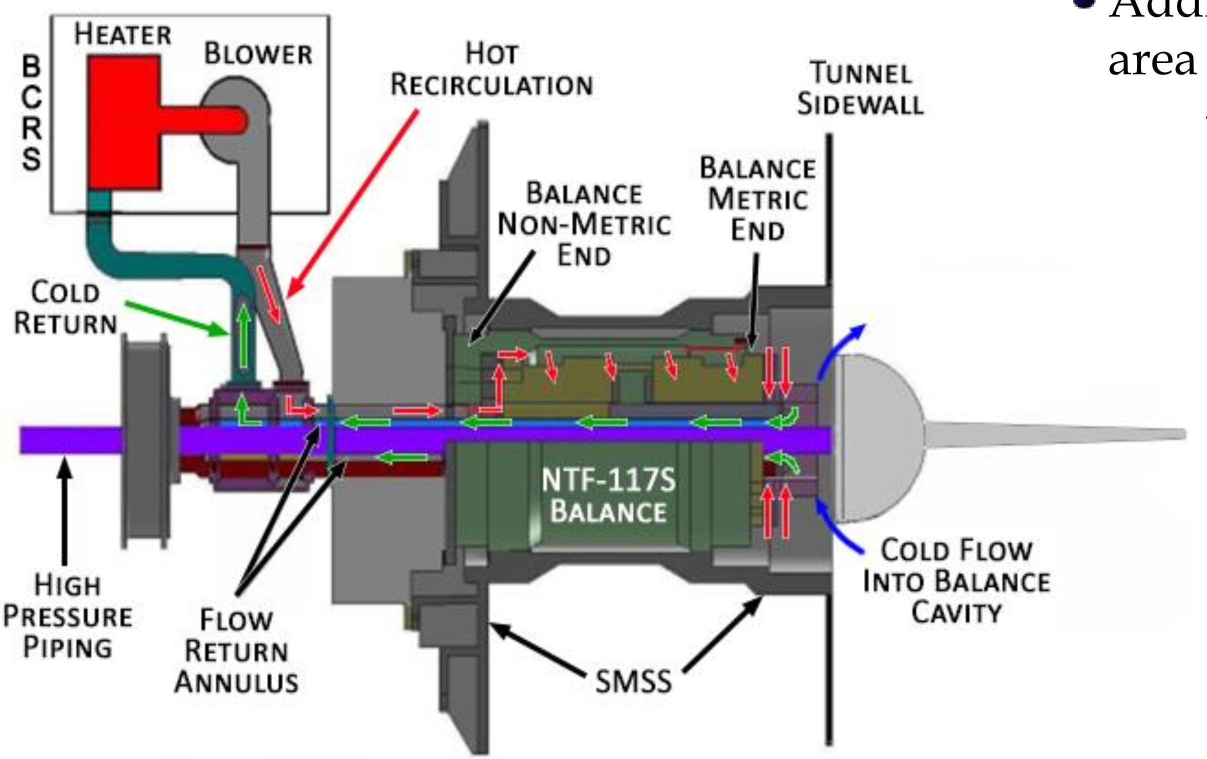
- Transonic cryogenic test environment coupled with high-pressure air delivery system presented force measurement challenges



Test Title	Test Completion Date
Flow Control Acceptance	December 2010
FAST-MAC 1	April 2011
FAST-MAC 2	December 2012
FAST-MAC 2.5	June 2015
RCEE	September 2015

Balance Thermal Stability Problems

- Balance temperature stability is critical for high data quality
  - balance cavity recirculation system (BCRS) uses heater/blower combination to maintain balance temperature of 100°F



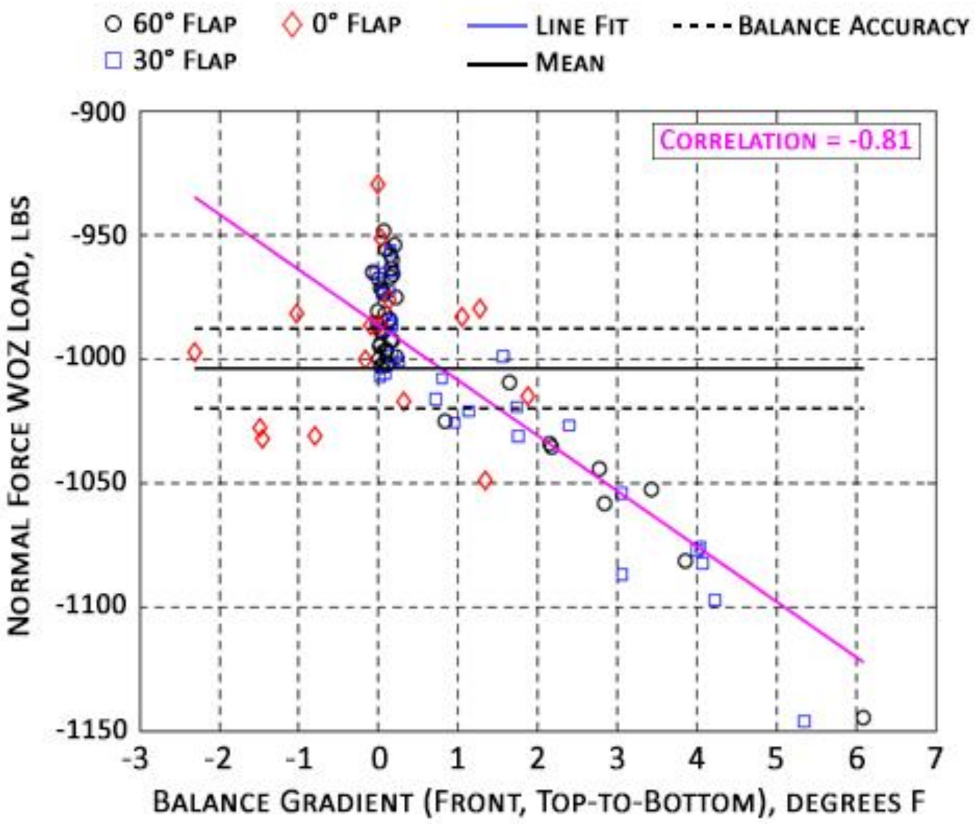
- Addition of FCS restricted flow area through center of balance
  - system became thermally anemic, could not maintain balance temperature

- Ingestion of cold gas into balance cavity could not be overcome by convection of heated air around the balance

Correlation of Thermal Gradient to WOZ Data

- Wind-off zero (WOZ) data from early testing provided evidence of thermal deficiencies on force data
- Strong correlation found between temperature gradient and load
- Thermal gradients also apparent between front and back of balance

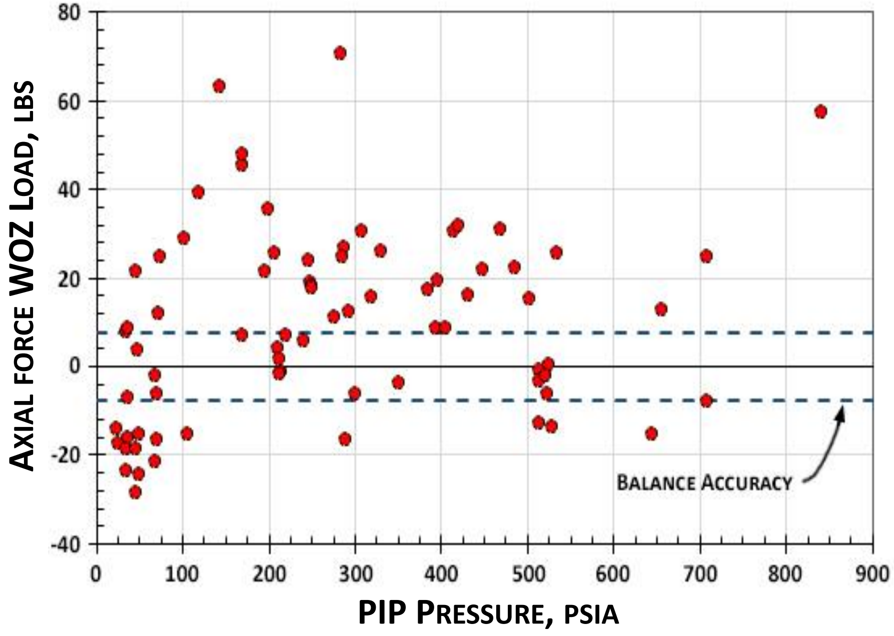
➡ **Improvements needed to BCRS to offset enthalpy loss, reduce gradients, and improve mass flow**

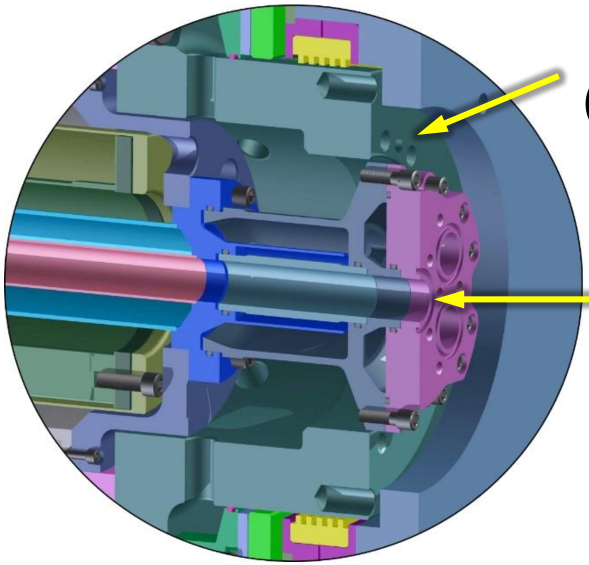


Balance Data Sensitivity to Non-Repeatable Load Path

- Load path between metric/non-metric hardware was found to be non-repeatable
  - PIP (pressure interface part) bridged metric model components
  - pre-load on balance changed from assembly to assembly, captured in WOZ data

Mechanical modifications needed to ensure load path repeatability





Hardware Bolted to Model

The FAST-MAC Model

- The FAST-MAC model is the primary blowing testbed used in recent SMSS tests
  (Fundamental Aerodynamic Subsonic Transonic Modular Active Control)
- Uses flow control system to direct high-pressure air over the flap
  - slot at 85% chord, four individual plenums for tailored blowing, configurable slot height

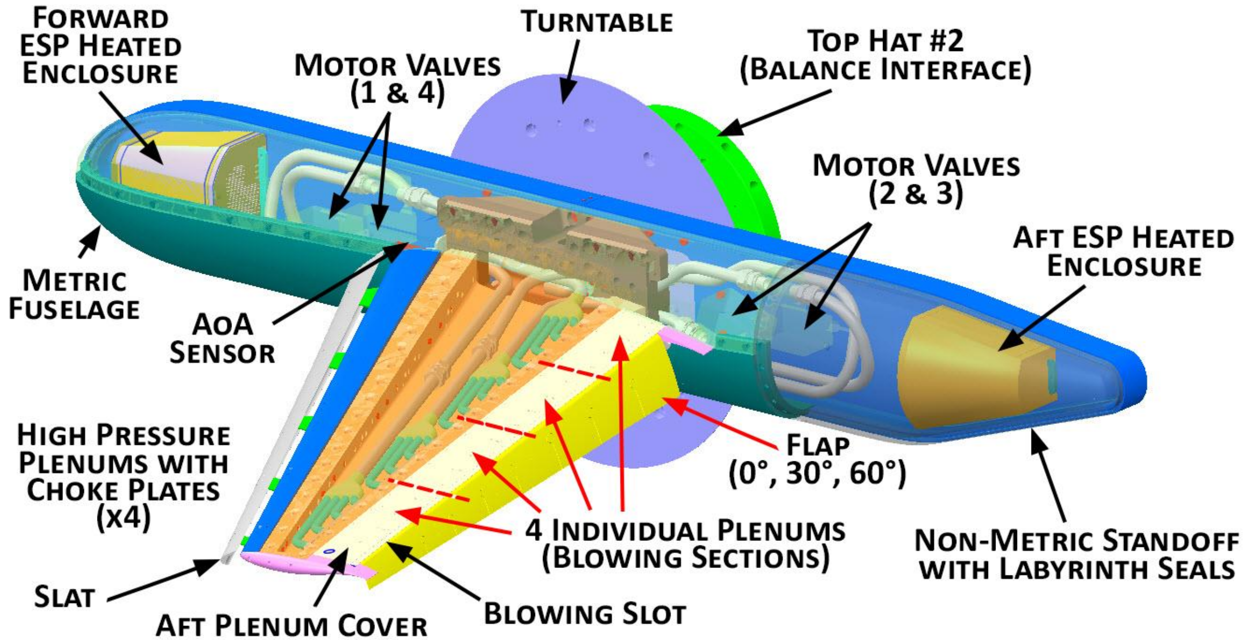
FAST-MAC VITALS

Mean Aerodynamic Chord
19.4 inches

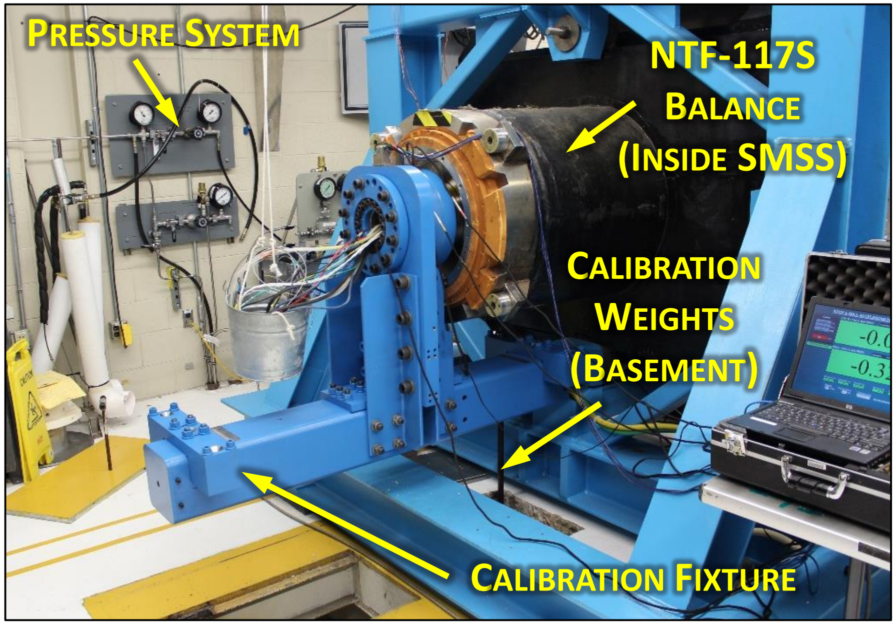
Design Cruise Mach
0.85

Wing Span
48 inches

Stand-Off Width
2 inches



Calibration of the NTF-117S Balance

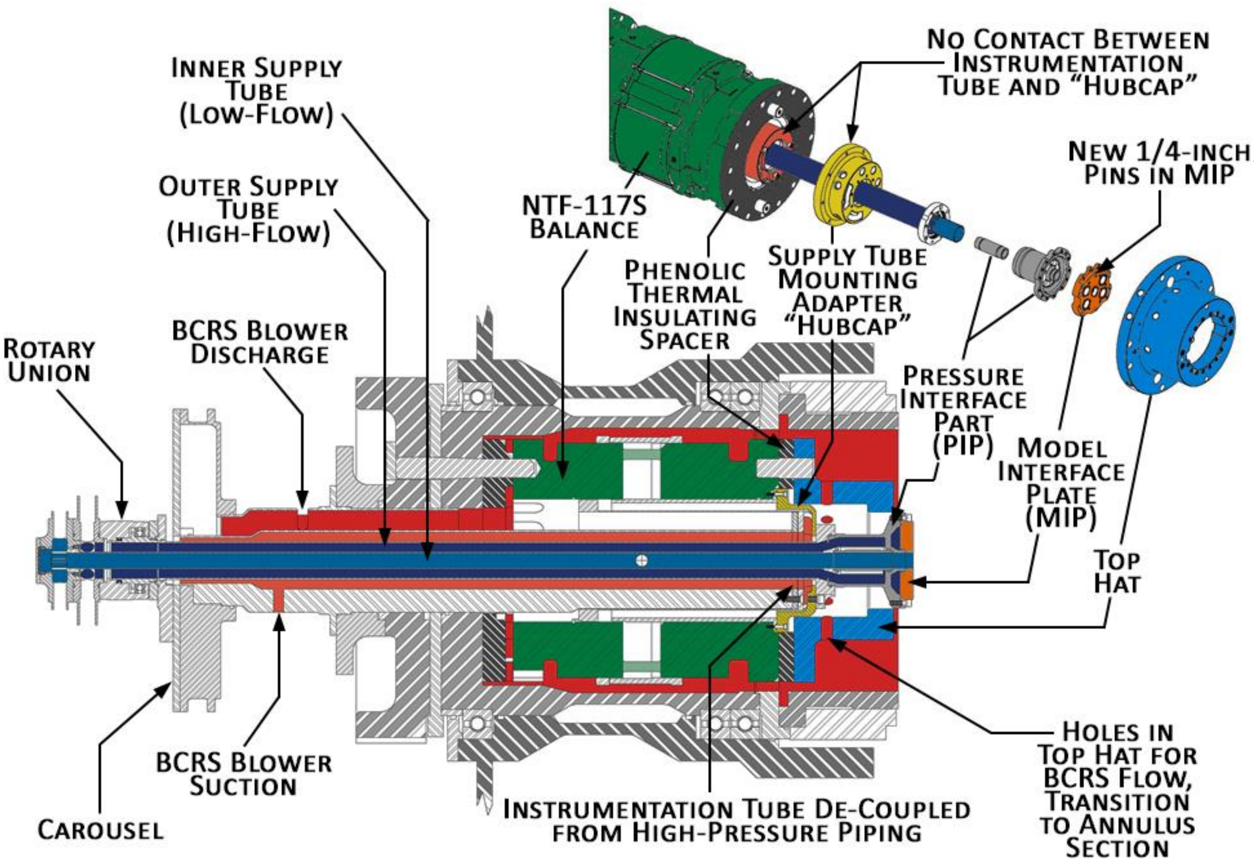


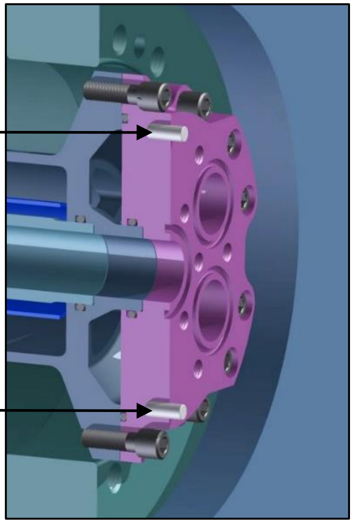
- All force and moment measurements made with NTF-117S balance
- Flow control hardware bridging balance requires a system calibration that includes PIP pressure and temperature
- Recent modifications to mechanical assembly required new calibration

Component	Max Load	Calibration Accuracies (95% Confidence): 2009 Balance Alone	T213 System Calibration	T222 System Calibration
Normal Force	12,000 lbs	+/- 6.00 lbs	+/- 16.3 lbs	+/- 24.8 lbs
Axial Force	1,800 lbs	+/- 2.52 lbs	+/- 7.78 lbs	+/- 4.64 lbs
Pitching Moment	90,000 in-lbs	+/- 144 in-lbs	+/- 64.8 in-lbs	+/- 330 in-lbs
Rolling Moment	670,000 in-lbs	+/- 803 in-lbs	+/- 422 in-lbs	+/- 1575 in-lbs
Yawing Moment	110,000 in-lbs	+/- 90.3 in-lbs	+/- 200 in-lbs	+/- 400 in-lbs

For more info:
AIAA 2010-4542
AIAA 2012-3318
AIAA 2014-0275

SMSS Modifications

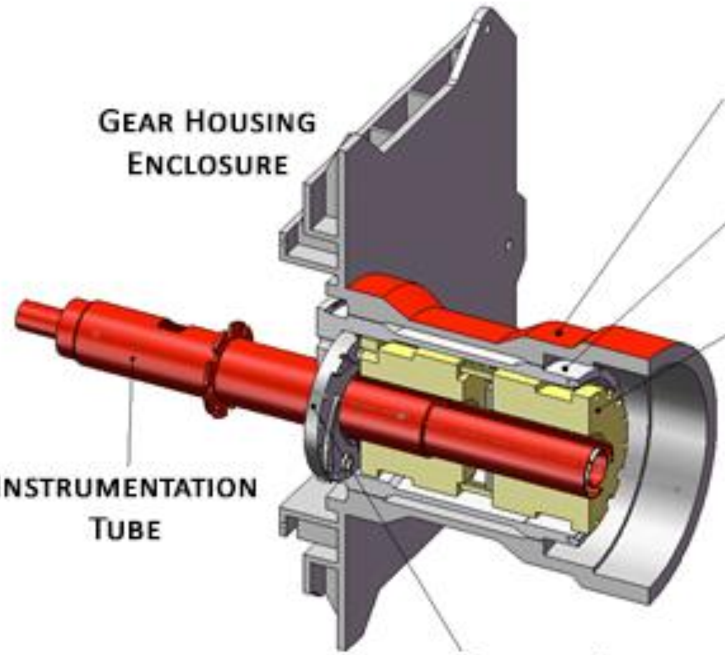




- Addition of supply tube mounting adapter and pins in MIP
- De-coupled FCS from instrumentation tube

➡ **Resulted in more repeatable load path**

Instrumentation Tube Replacement

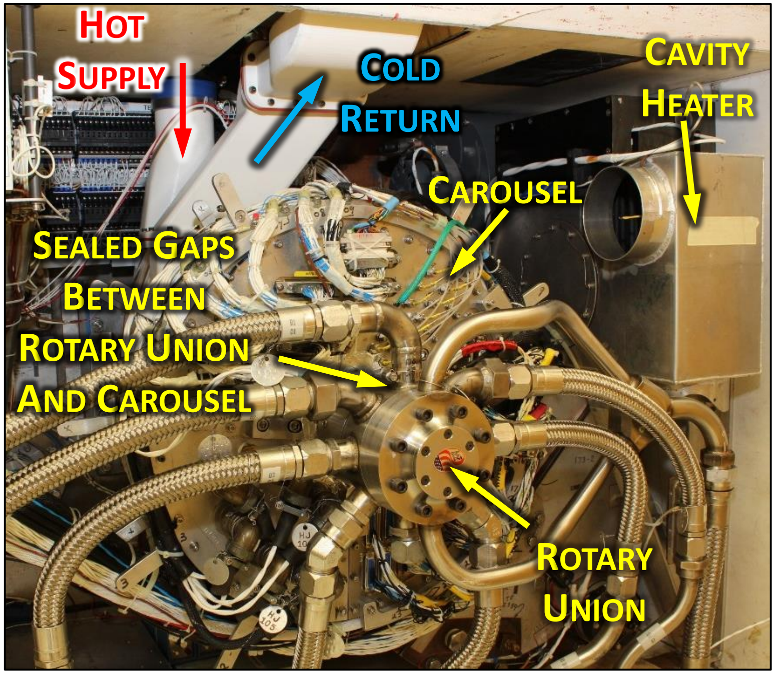


- Original 3-inch diameter instrumentation tube replaced with 3.5-inch diameter tube
- Increased cold-return annulus area by 300%, permitting greater mass flow through the tube for BCRS heat

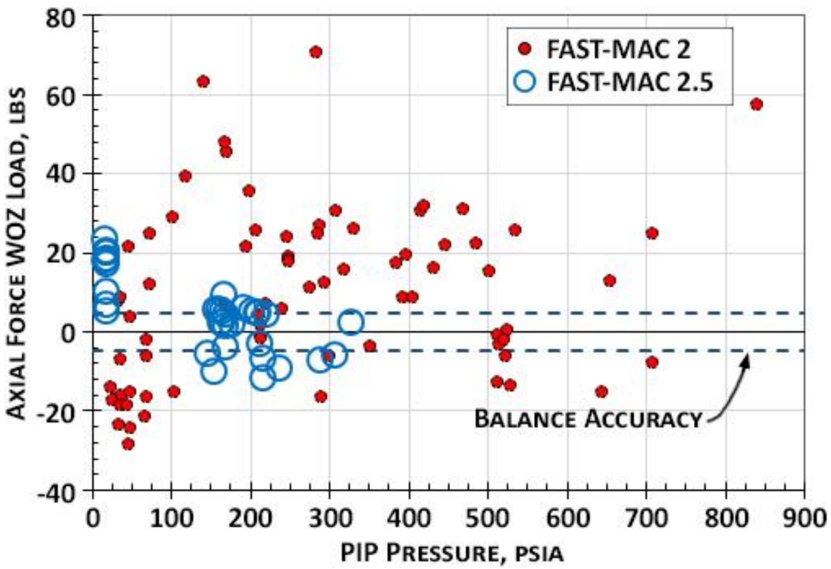
SMSS/BCRS Version	Flow Area (in^2)	Mach Number @ 420 scfm	Mach Number @ 700 scfm
Pre-Upgrade to FCS (2003)	7.00	0.144	0.189
Post-Upgrade with FCS (2010-2012)	1.55	0.625	0.920
With New Instrumentation Tube (2013)	4.66	0.220	0.313

BCRS Modifications

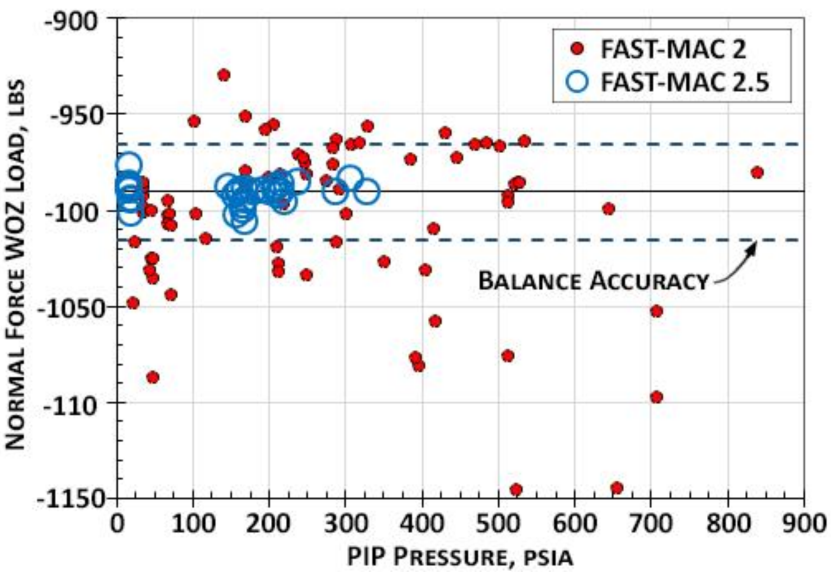
- New instrumentation tube allowed for 60 scfm of BCRS heat, not enough to offset enthalpy losses and maintain balance thermal stability
  - original blower motor insufficient, limited blower speed
  - new motor enabled blower to reach its full capability of 700 scfm
- Re-design of BCRS ductwork required to interface with new instrumentation tube
  - removal of old interface created gaps between carousel and rotary union, had to be sealed
- Wiring upgrades provided 3x more power to 10 kW BCRS heater
- Modifications to BCRS control and usage
  - blower speed variation depending upon test condition
  - new temperature sensor on balance used as feedback for BCRS heater



Test Results – WOZ Comparisons



- WOZs during latest FAST-MAC test showed significant improvement in variation in all balance components
- Correlation between WOZ load and PIP pressure/temperature was higher



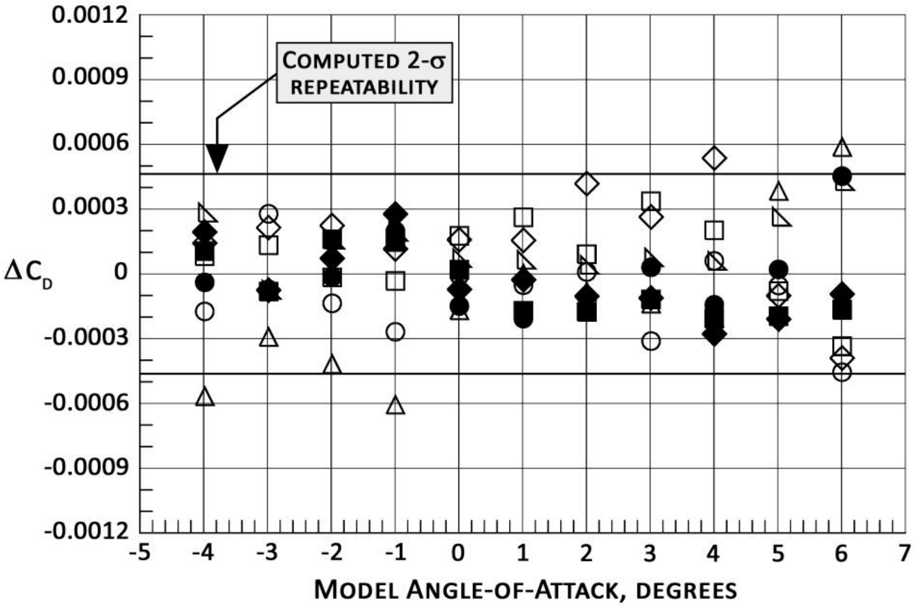
Good evidence that hysteresis and non repeatable pre-loads had been successfully reduced

Test Results – FCS In/Out Comparisons

- Latest FAST-MAC test compared effect of removing the FCS
- First phase of test with FCS in
  Second phase of test with FCS out
  - removing FCS required full disassembly and removal of model and support hardware from SMSS
  - supply piping, hubcap, PIP removed
  - model re-assembled, exact same outer mold line
  - two different balance calibrations used

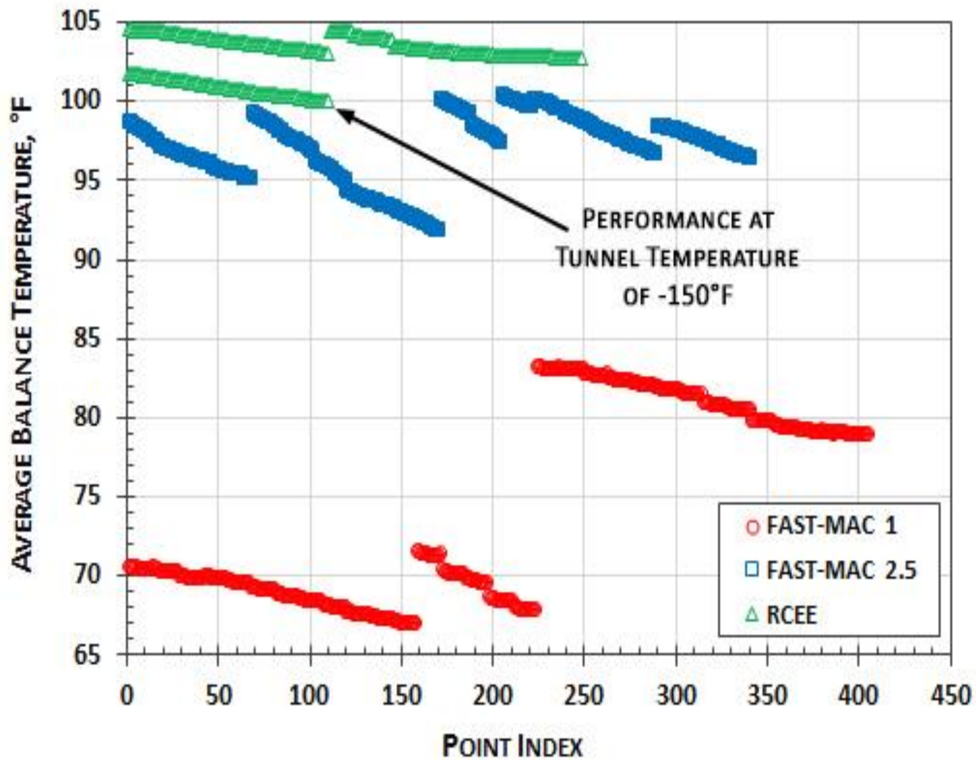
Drag measurements agree (no bias effects), system calibration removed effect of FCS bridging

	Test	Run	Mach	ReC (million)	Blowing	Config
○	222	82	0.850	15.0	Off	FCS In
□	222	84	0.850	15.0	Off	FCS In
◇	222	85	0.850	14.9	Off	FCS In
△	222	135	0.850	14.9	Off	FCS In
◺	222	150	0.850	15.0	Off	FCS In
●	222	275	0.850	14.7	Off	FCS Out
■	222	279	0.850	14.7	Off	FCS Out
◆	222	280	0.850	14.6	Off	FCS Out



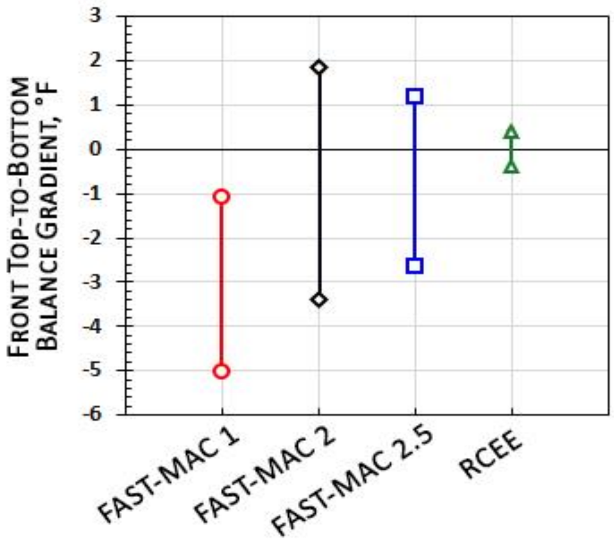
Test Results – Balance Thermal Stability

- Balance temperature stability poor during first FAST-MAC test
  - temperature allowed to drop below 70°F
  - recovery back to 100°F not possible
- Temperature control better during third FAST-MAC test (FAST-MAC 2.5)
  - 100°F temperature achievable, but not maintainable
  - fairly rapid recovery with brief wind-off periods
- Stability achieved during RCEE test
  - balance stable even at -150°F

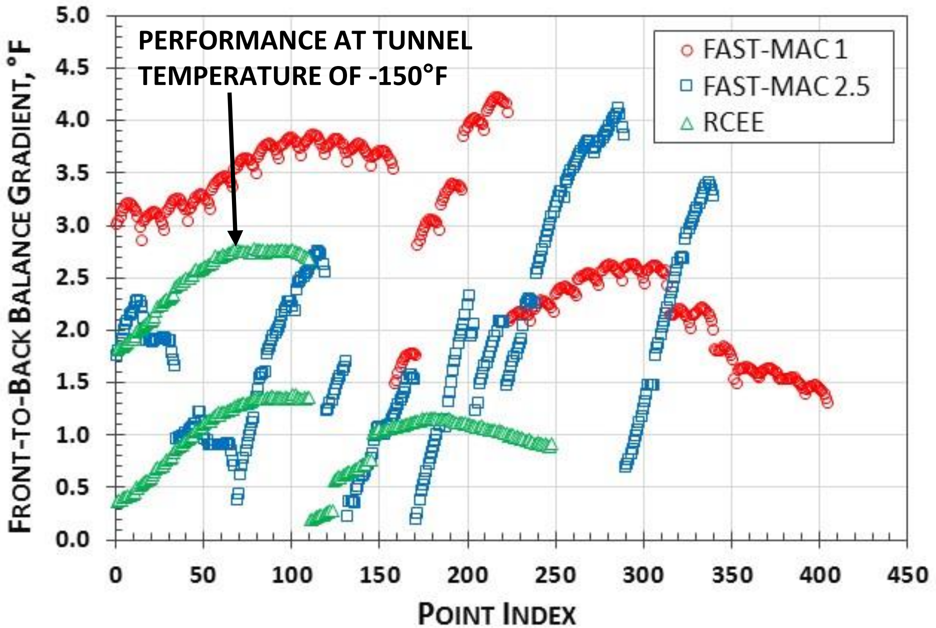


Transonic test conditions at -50°F and -150°F

Test Results – Balance Thermal Gradients



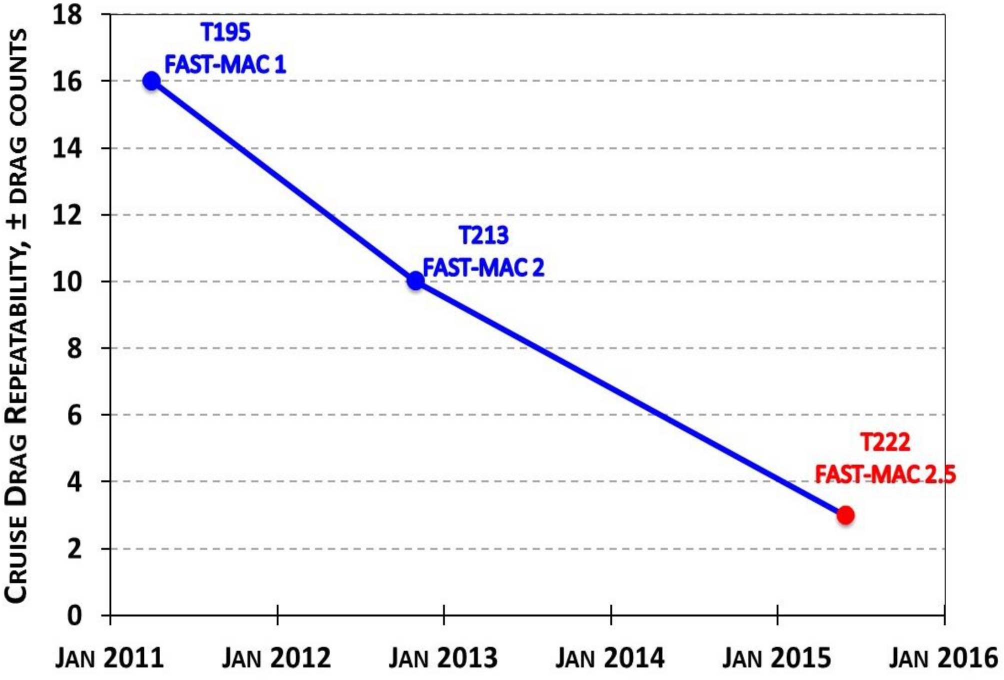
- Range of front (metric end) top-to-bottom balance temperature gradients significantly reduced
  - maximum gradient for RCEE less than 0.5°F
  - increased mass flow of BCRS able to offset the ingestion of cold gas



- Front-to-back thermal gradients also reduced
  - rate of gradient change reduced
  - allowed for more wind-on testing time and less wind-off recovery time

Test Results – Drag Repeatability

- Drag repeatability is a good cumulative metric for quantifying improvement
- Overall drag repeatability was poor for first FAST-MAC test
    - included blowing and non-blowing runs, air and cryogenic runs
- Repeatability was about 5 times better for latest FAST-MAC test
- Based on results from RCEE test, further improvement is expected



Concluding Remarks

- Integration of flow control system required many improvements to the SMSS
  - early tests had poor data quality due to temperature instabilities and non-repeatable mechanical assemblies

- Balance temperatures stable at cryogenic conditions with minimal gradients
- Mechanical bridging effects now repeatable and compensated for in system calibration
- SMSS originally designed for low-speed high-lift applications

➡ **Now capable of providing high-quality data for powered transonic tests at cryogenic temperatures as low as -150°F**

Questions?