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

Scott L. Goodliff (presenter)
Sundareswara Balakrishna
David Butler
C. Mark Cagle
David Chan
Gregory S. Jones
William E. Milholen II
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 Temperature:** -250°F to 120°F (116 K to 322 K)
- **Total Pressure:** 15 psia to 120 psia (1 atm to 8.2 atm)
- **Test Gas:** Air, Nitrogen, Mix
- **Reynolds Number:** 146x10⁶ per foot (max)
- **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)
  - active flow control
  - engine simulation
  - propulsion airframe integration

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

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

<table>
<thead>
<tr>
<th>SMSS/BCRS Version</th>
<th>Flow Area (in²)</th>
<th>Mach Number @ 420 scfm</th>
<th>Mach Number @ 700 scfm</th>
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<tr>
<td>Pre-Upgrade to FCS (2003)</td>
<td>7.00</td>
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<td>0.189</td>
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<tr>
<td>Post-Upgrade with FCS (2010-2012)</td>
<td>1.55</td>
<td>0.625</td>
<td>0.920</td>
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<tr>
<td>With New Instrumentation Tube (2013)</td>
<td>4.66</td>
<td>0.220</td>
<td>0.313</td>
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</table>
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
Force Measurement Improvements to the NTF Sidewall Model Support System

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?