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 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:** 146x10^6 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

<table>
<thead>
<tr>
<th>Test Title</th>
<th>Test Completion Date</th>
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</thead>
<tbody>
<tr>
<td>Flow Control Acceptance</td>
<td>December 2010</td>
</tr>
<tr>
<td>FAST-MAC 1</td>
<td>April 2011</td>
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<tr>
<td>FAST-MAC 2</td>
<td>December 2012</td>
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<tr>
<td>FAST-MAC 2.5</td>
<td>June 2015</td>
</tr>
<tr>
<td>RCEE</td>
<td>September 2015</td>
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</table>
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
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
Force Measurement Improvements to the NTF Sidewall Model Support System

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

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>MAX LOAD</th>
<th>2009 BALANCE ALONE</th>
<th>T213 SYSTEM CALIBRATION</th>
<th>T222 SYSTEM CALIBRATION</th>
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<tbody>
<tr>
<td>NORMAL FORCE</td>
<td>12,000 LBS</td>
<td>+/- 6.00 LBS</td>
<td>+/- 16.3 LBS</td>
<td>+/- 24.8 LBS</td>
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<tr>
<td>AXIAL FORCE</td>
<td>1,800 LBS</td>
<td>+/- 2.52 LBS</td>
<td>+/- 7.78 LBS</td>
<td>+/- 4.64 LBS</td>
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<tr>
<td>PITCHING MOMENT</td>
<td>90,000 IN-LBS</td>
<td>+/- 144 IN-LBS</td>
<td>+/- 64.8 IN-LBS</td>
<td>+/- 330 IN-LBS</td>
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<td>ROLLING MOMENT</td>
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<td>+/- 803 IN-LBS</td>
<td>+/- 422 IN-LBS</td>
<td>+/- 1575 IN-LBS</td>
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<tr>
<td>YAWING MOMENT</td>
<td>110,000 IN-LBS</td>
<td>+/- 90.3 IN-LBS</td>
<td>+/- 200 IN-LBS</td>
<td>+/- 400 IN-LBS</td>
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</table>
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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<tbody>
<tr>
<td>Pre-Upgrade to FCS (2003)</td>
<td>7.00</td>
<td>0.144</td>
<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
Force Measurement Improvements to the NTF Sidewall Model Support System

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

<table>
<thead>
<tr>
<th>Test</th>
<th>Run</th>
<th>Mach</th>
<th>ReC (million)</th>
<th>Blowing</th>
<th>Config</th>
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<tr>
<td>222</td>
<td>82</td>
<td>0.850</td>
<td>15.0</td>
<td>Off</td>
<td>FCS In</td>
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<td>222</td>
<td>150</td>
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<td>Off</td>
<td>FCS Out</td>
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<tr>
<td>222</td>
<td>280</td>
<td>0.850</td>
<td>14.6</td>
<td>Off</td>
<td>FCS Out</td>
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</table>
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
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.
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?