Estimating Flow-Through Balance Momentum Tares with CFD

John E. Melton
NASA Ames Research Center

Kevin D. James
NASA Ames Research Center

Kurtis R. Long
NASA Ames Research Center

Jeffrey D. Flamm
NASA Langley Research Center
Outline

• HWB and Flow-through balance (FTB)
• Control volume approach for FTB
• Momentum tare calculations
• CFD simulations with STAR-CCM+
• Comparisons with FTB calibrations
• Simulations for HWB with TPS in 40x80
• Recommendations for future FTB testing
HWB 40x80 Installation with TPS units
• Control volume
Flow-through Balances

- Flow-through balance internal details
  - Designed and patented by ARC, 1988
Control Volume

- Control volume
• Control volume
Momentum Tare Calculations

- Momentum tare calculation approach
  - Assume steady flow, inertial frame
  - Momentum change computed by flux across inlets and exits
  - Equivalent to restraining forces on CV

\[
\Delta \text{Mom} = \oint_{CV} \mathbf{V} \cdot (\mathbf{V} \cdot dA) = \sum F_{CV} = F_{\text{bellows}} + F_{\text{pressure}} + F_{\text{shear}} = F_{\text{bellows}} - \oint_{CV} (p - p_\infty) dA + \oint_{CV} dF_{\text{shear}}
\]

\[
\oint_{\text{inlet}} \mathbf{V} \cdot (\mathbf{V} \cdot dA) + \oint_{\text{exit}} \mathbf{V} \cdot (\mathbf{V} \cdot dA) = -\oint_{\text{walls}} (p - p_\infty) dA - \oint_{\text{inlet}} (p - p_\infty) dA - \oint_{\text{exit}} (p - p_\infty) dA + \oint_{\text{walls}} dF_{\text{shear}}
\]

\[
T_{\text{inlet}} + T_{\text{exit}} = \oint_{\text{inlet}} \mathbf{V} \cdot (\mathbf{V} \cdot dA) + \oint_{\text{inlet}} (p - p_\infty) dA + \oint_{\text{exit}} \mathbf{V} \cdot (\mathbf{V} \cdot dA) + \oint_{\text{exit}} (p - p_\infty) dA = -\oint_{\text{walls}} (p - p_\infty) dA + \oint_{\text{walls}} dF_{\text{shear}}
\]
Momentum Tare Calculations

• Momentum tare calculation approach
  – Tare can be calculated using integration over geometrically simple inlet and exit faces
  – Thrust formulation provides a check on wall pressure and shear integrations

\[
T_{inlet} + T_{exit} = \int_{inlet} V (V \cdot dA) + \int_{inlet} (p - p_\infty) dA + \int_{exit} V (V \cdot dA) + \int_{exit} (p - p_\infty) dA = -\int_{walls} (p - p_\infty) dA + \int_{walls} dF_{shear}
\]
Roberts Balance Calibration (1988)

- Momentum tare calculation approach
- Good match between mass flow and supply pressure
CFD Simulations with STAR-CCM+

- CFD simulations with STAR-CCM+
Comparisons with Calibration in 9x7

- Single TPS unit calibration in 9x7 test section
• Single TPS unit calibration in 9x7 test section
Comparisons with Calibration in 9x7

- Single TPS unit calibration in 9x7 test section

<table>
<thead>
<tr>
<th>Exp. Supply Mass Flow (lbm/s)</th>
<th>Exp. Plenum Total Pressure (psi abs)</th>
<th>Exp. Plenum Total Temperature (F)</th>
<th>Exp. Venturi ΔP (psi)</th>
<th>Balance Axial Force (lbsf)</th>
<th>Balance Normal Force (lbsf)</th>
<th>CFD Supply Pressure (psi abs)</th>
<th>CFD Mass Flow (lbm/s)</th>
<th>CFD Plenum Total Pressure (psi abs)</th>
<th>CFD Plenum Total Temperature (F)</th>
<th>CFD Venturi ΔP (psi)</th>
<th>CFD Axial Tare (lbsf)</th>
<th>CFD Normal Tare (lbsf)</th>
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<td>24.5</td>
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Simulations for HWB with TPS

- Simulations for HWB with TPS in 40x80
Simulations for HWB with TPS

- Simulations for HWB with TPS in 40x80
Simulations for HWB with TPS

- Simulated two TPS exhaust directions

<table>
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<tr>
<th>CFD Mass Flow (lbm/s)</th>
<th>CFD Plenum Total Pressure (psi_abs)</th>
<th>Balance Axial Force (lbsf)</th>
<th>Balance Normal Force (lbsf)</th>
<th>CFD: Hz Exit Axial Tare (lbsf)</th>
<th>CFD: Hz Exit Normal Tare (lbsf)</th>
<th>CFD: Vertical Exit Axial Tare (lbsf)</th>
<th>CFD: Vertical Exit Normal Tare (lbsf)</th>
<th>CFD: Hz Exit Axial Thrust (lbsf)</th>
<th>CFD: Hz Exit Normal Thrust (lbsf)</th>
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<td>350</td>
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Recommendations for Future Testing

• Recommendations for future FTB testing
  – Buildup of manifold in concert with tares
  – Additional interior flowpath sensors
  – Accurate inlet and exhaust face measurements
  – Support and insight using CFD

• Acknowledgments
  – ARMD ERA Program
  – NAS Supercomputing Facility