Estimating Flow-Through Balance Momentum Tares with CFD

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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
HFB Configuration
Control Volume

- Control volume
Flow-through Balances

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

• 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

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

\[
\iiint_{\text{inlet}} \mathbf{V} \cdot (\mathbf{V} \, d\mathbf{A}) + \iiint_{\text{exit}} \mathbf{V} \cdot (\mathbf{V} \, d\mathbf{A}) = -\iiint_{\text{walls}} (p - p_{\infty})d\mathbf{A} - \iiint_{\text{inlet}} (p - p_{\infty})d\mathbf{A} - \iiint_{\text{exit}} (p - p_{\infty})d\mathbf{A} + \iiint_{\text{walls}} dF_{\text{shear}}
\]

\[
T_{\text{inlet}} + T_{\text{exit}} = \iiint_{\text{inlet}} \mathbf{V} \cdot (\mathbf{V} \, d\mathbf{A}) + \iiint_{\text{inlet}} (p - p_{\infty})d\mathbf{A} + \iiint_{\text{exit}} \mathbf{V} \cdot (\mathbf{V} \, d\mathbf{A}) + \iiint_{\text{exit}} (p - p_{\infty})d\mathbf{A} = -\iiint_{\text{walls}} (p - p_{\infty})d\mathbf{A} + \iiint_{\text{walls}} dF_{\text{shear}}
\]
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

\[ T_{\text{inlet}} + T_{\text{exit}} = \iint_{\text{inlet}} \mathbf{V} (\mathbf{V} \cdot \mathbf{dA}) + \iint_{\text{inlet}} (p - p_{\infty}) \mathbf{dA} + \iint_{\text{exit}} \mathbf{V} (\mathbf{V} \cdot \mathbf{dA}) + \iint_{\text{exit}} (p - p_{\infty}) \mathbf{dA} = -\iint_{\text{walls}} (p - p_{\infty}) \mathbf{dA} + \iint_{\text{walls}} \mathbf{dF}_{\text{shear}} \]
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
Comparisons with Calibration in 9x7

- 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 ∆P (psi)</th>
<th>Balance Axial Force (lbf)</th>
<th>Balance Normal Force (lbf)</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 ∆P (psi)</th>
<th>CFD Axial Tare (lbf)</th>
<th>CFD Normal Tare (lbf)</th>
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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>
<td>366</td>
<td>23.4</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
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