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

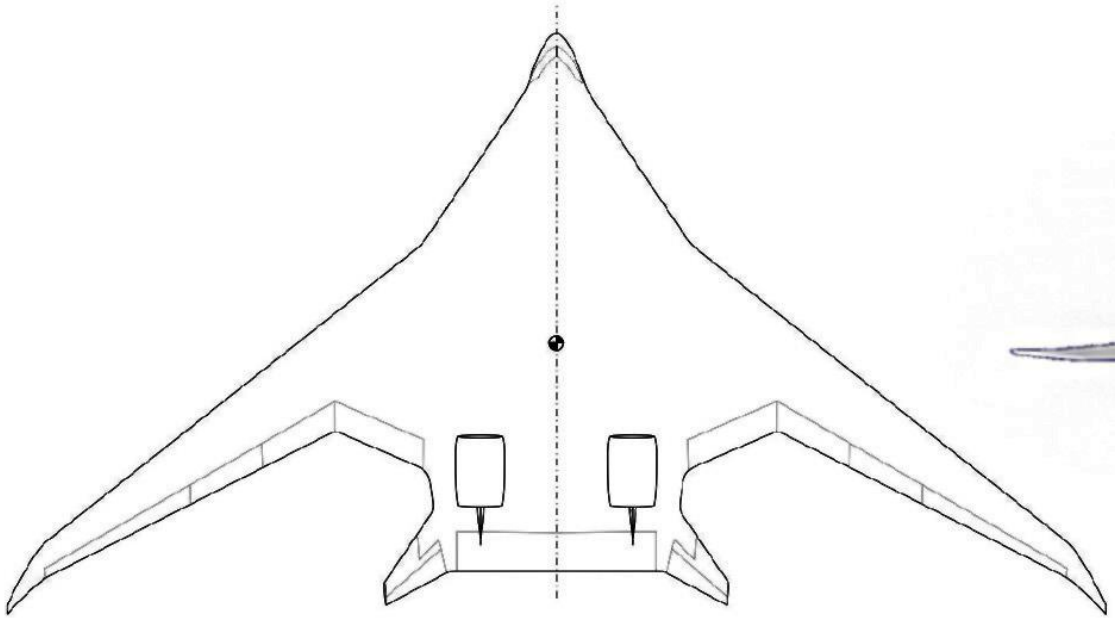
Jeffrey D. Flamm
NASA Langley Research Center

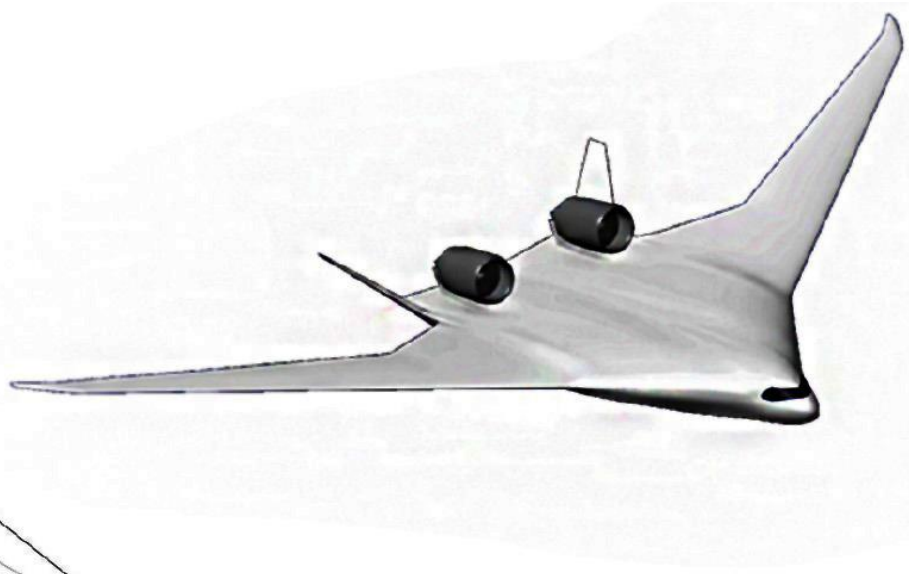
AIAA SciTech 2016, Jan 4-8 2016, San Diego, CA

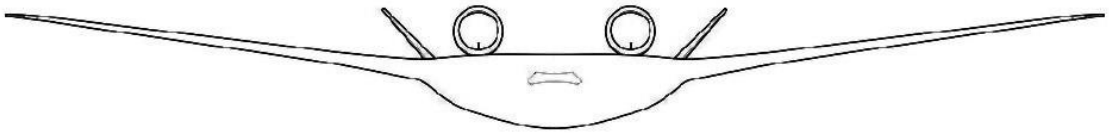
Outline

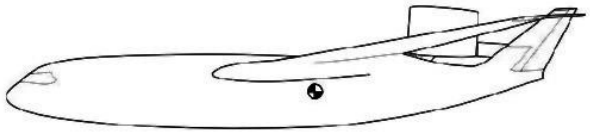
- HWB and Flow-through balance (FTB)
- Control volume approach for FTB
- Momentum tare calculations
- CFD simulations with STAR-CCM+
- Comparisons with FTB calibrations
- Simulations for HWB with TPS in 40x80
- Recommendations for future FTB testing

HWB Configuration

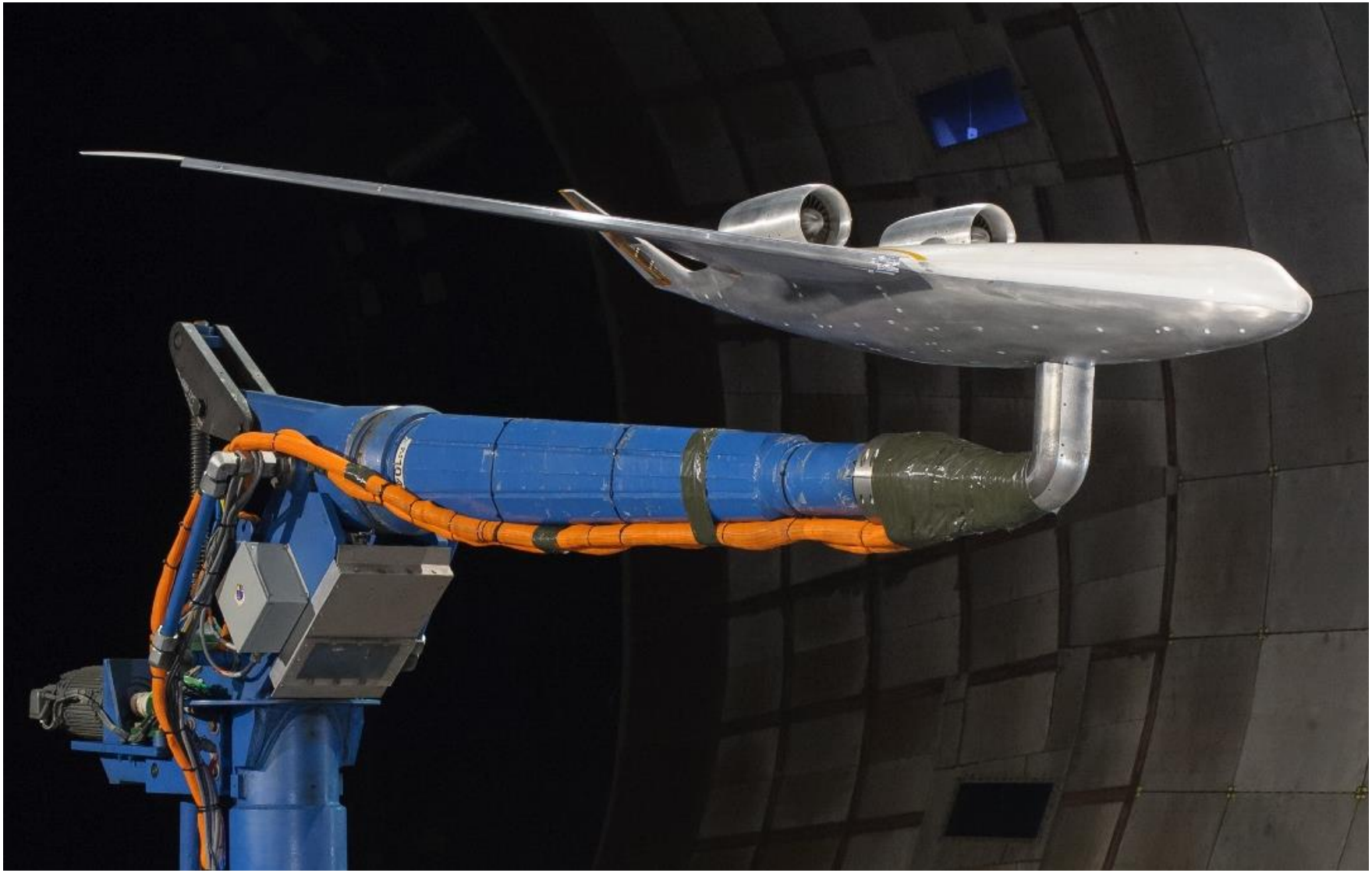






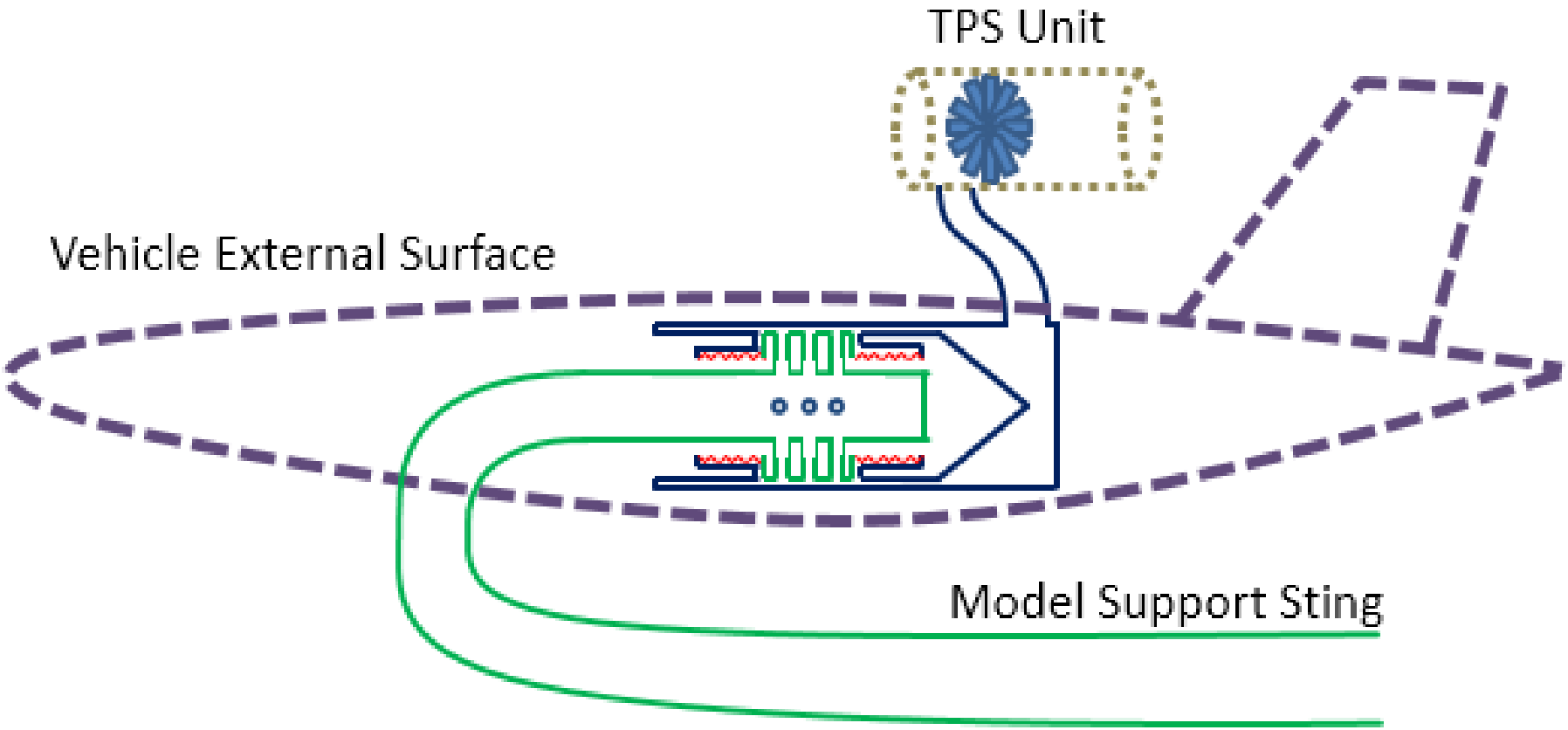


HWB 40x80 Installation with TPS units



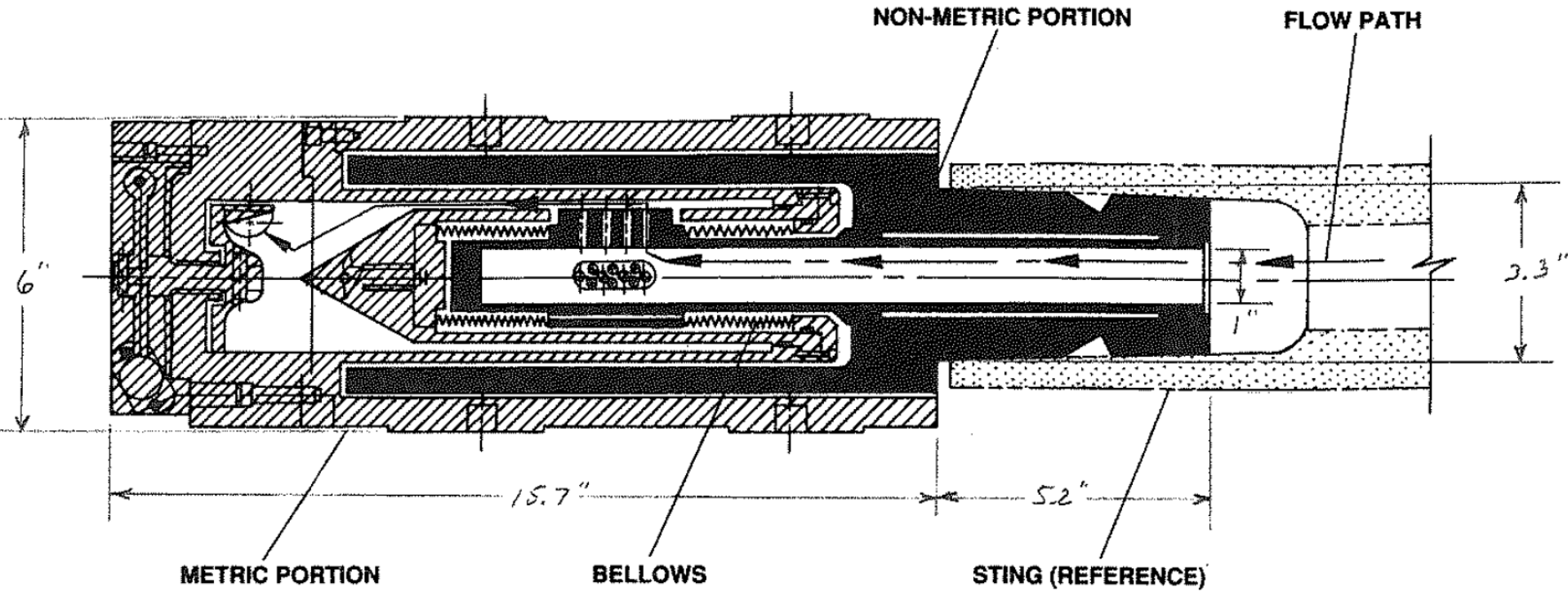
Control Volume

- Control volume



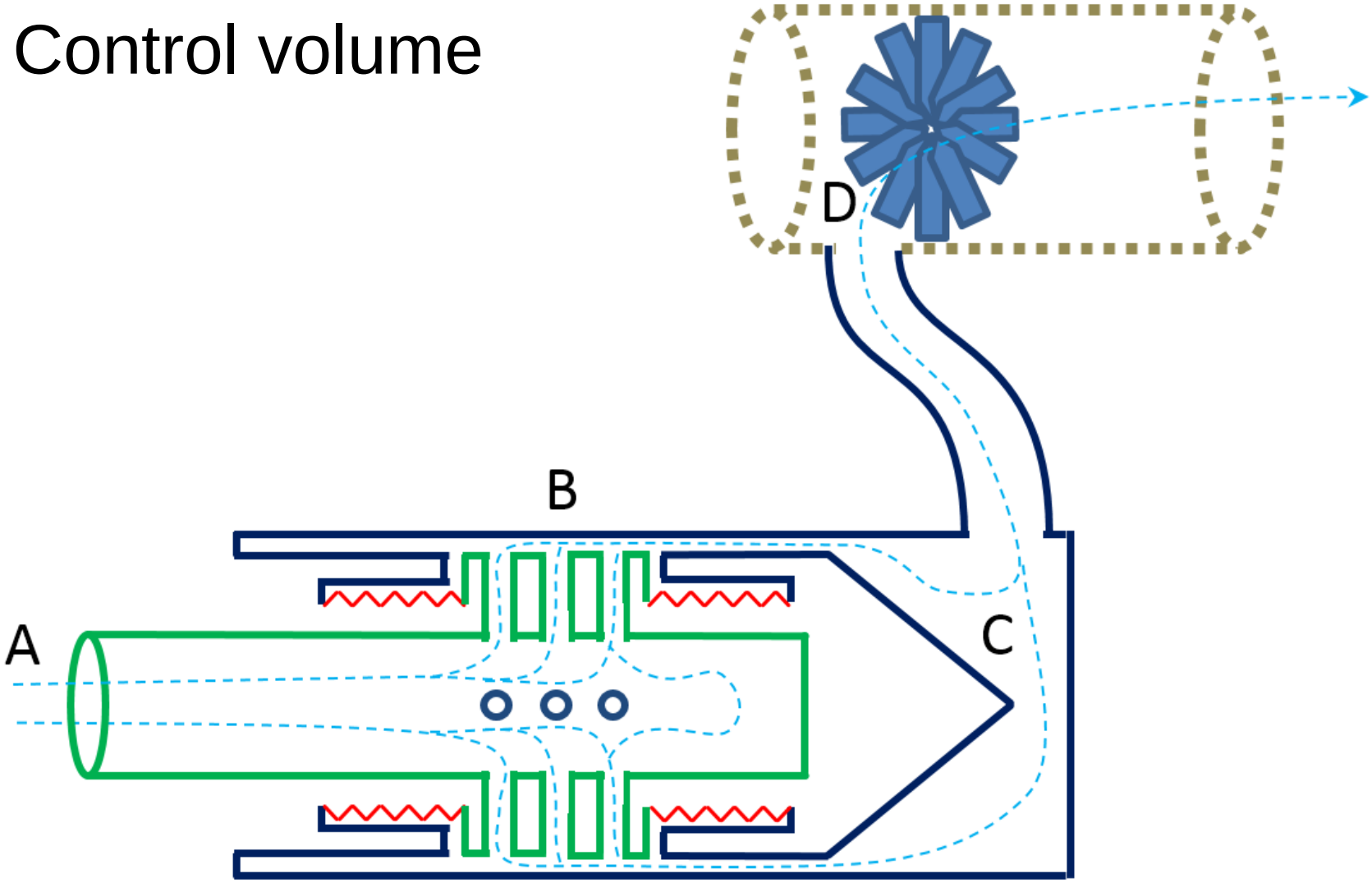
Flow-through Balances

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



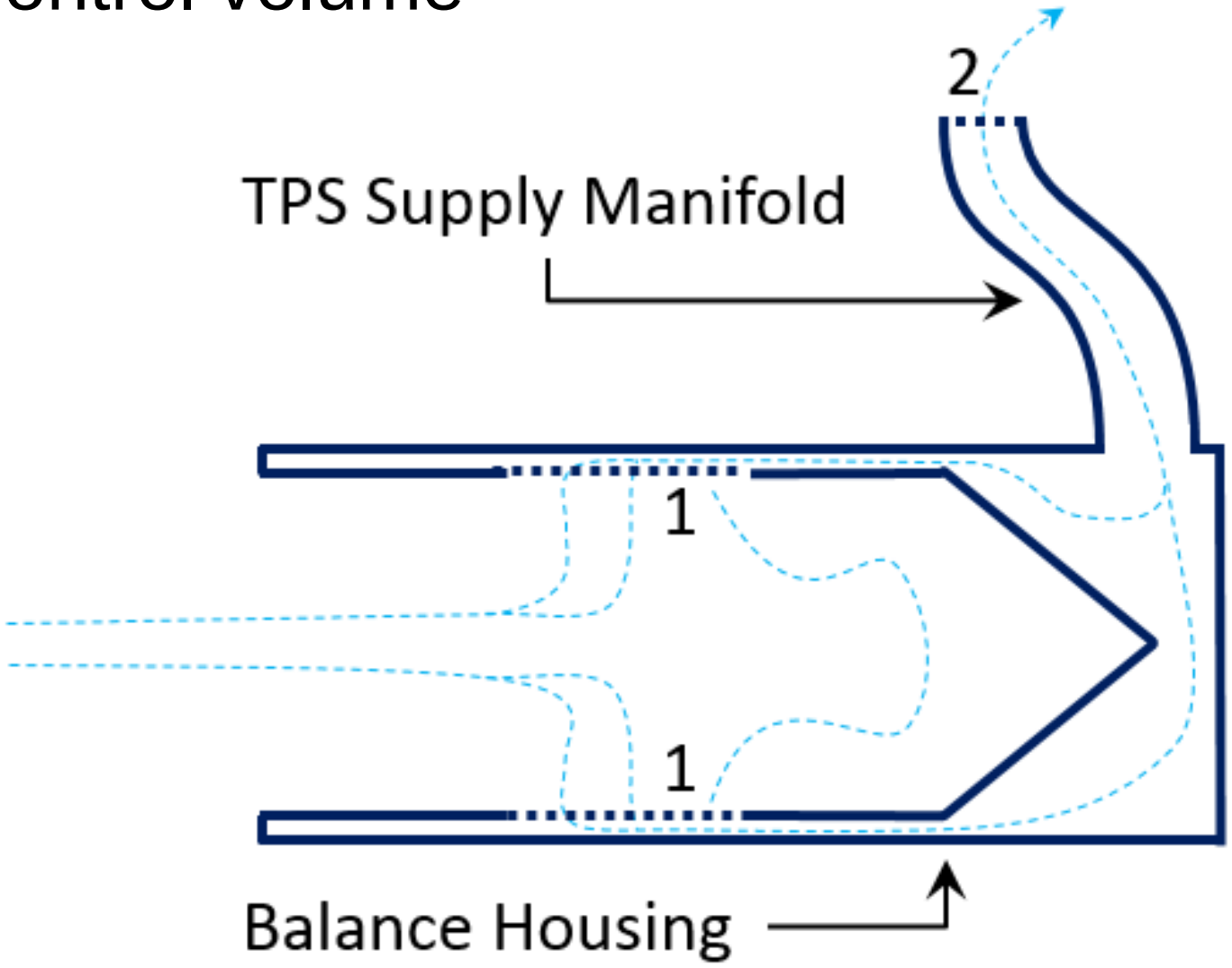
Control Volume

- 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

$$\Delta\mathbf{Mom} = \iint_{CV} \mathbf{V}\,(\mathbf{V}\bullet d\mathbf{A}) = \sum \mathbf{F}_{CV} = \mathbf{F}_{bellows} + \mathbf{F}_{pressure} + \mathbf{F}_{shear} = \mathbf{F}_{bellows} - \iint_{CV} (p - p_\infty) d\mathbf{A} + \iint_{CV} d\mathbf{F}_{shear}$$

$$\iint_{inlet} \mathbf{V}\,(\mathbf{V}\bullet d\mathbf{A}) + \iint_{exit} \mathbf{V}\,(\mathbf{V}\bullet d\mathbf{A}) = -\iint_{walls} (p - p_\infty) d\mathbf{A} - \iint_{inlet} (p - p_\infty) d\mathbf{A} - \iint_{exit} (p - p_\infty) d\mathbf{A} + \iint_{walls} d\mathbf{F}_{shear}$$

$$\mathbf{T}_{inlet} + \mathbf{T}_{exit} = \iint_{inlet} \mathbf{V}\,(\mathbf{V}\bullet d\mathbf{A}) + \iint_{inlet} (p - p_\infty) d\mathbf{A} + \iint_{exit} \mathbf{V}\,(\mathbf{V}\bullet d\mathbf{A}) + \iint_{exit} (p - p_\infty) d\mathbf{A} = -\iint_{walls} (p - p_\infty) d\mathbf{A} + \iint_{walls} d\mathbf{F}_{shear}$$

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

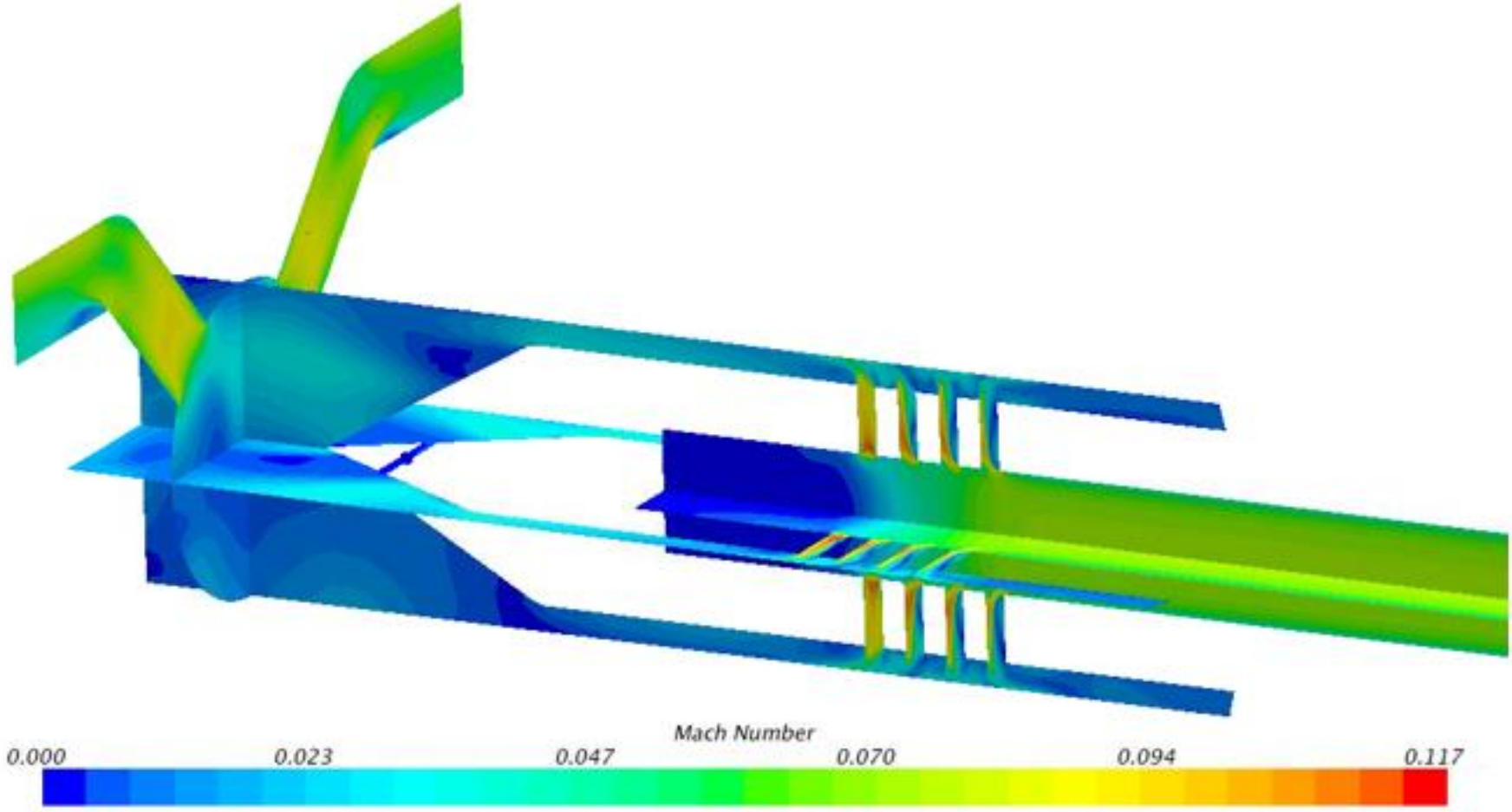
$$\mathbf{T}_{inlet} + \mathbf{T}_{exit} = \iint_{inlet} \mathbf{V}\,(\mathbf{V}\bullet d\mathbf{A}) + \iint_{inlet} (p - p_\infty) d\mathbf{A} + \iint_{exit} \mathbf{V}\,(\mathbf{V}\bullet d\mathbf{A}) + \iint_{exit} (p - p_\infty) d\mathbf{A} = -\iint_{walls} (p - p_\infty) d\mathbf{A} + \iint_{walls} d\mathbf{F}_{shear}$$

Roberts Balance Calibration (1988)

- Momentum tare calculation approach
- Good match between mass flow and supply pressure

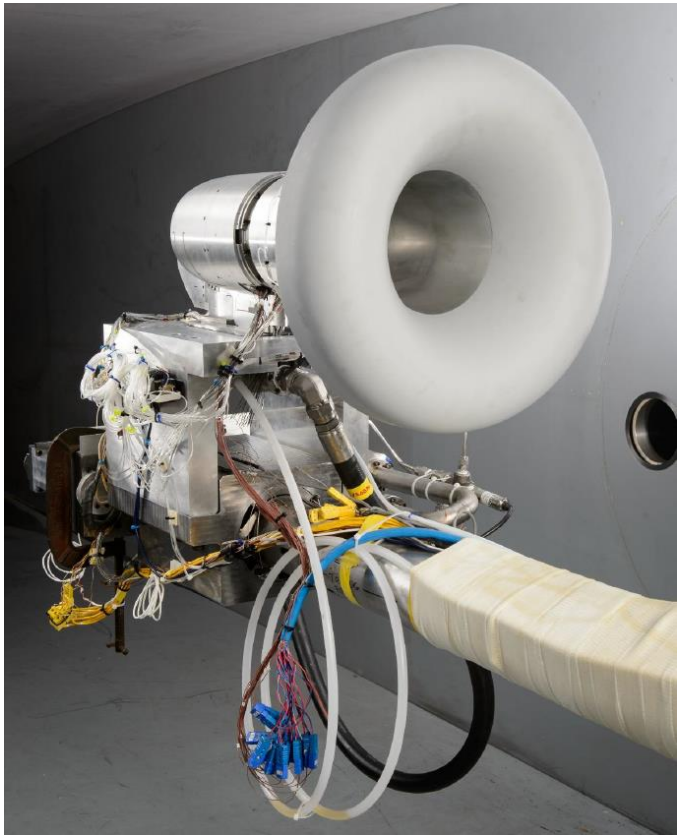
CFD Simulations with STAR-CCM+

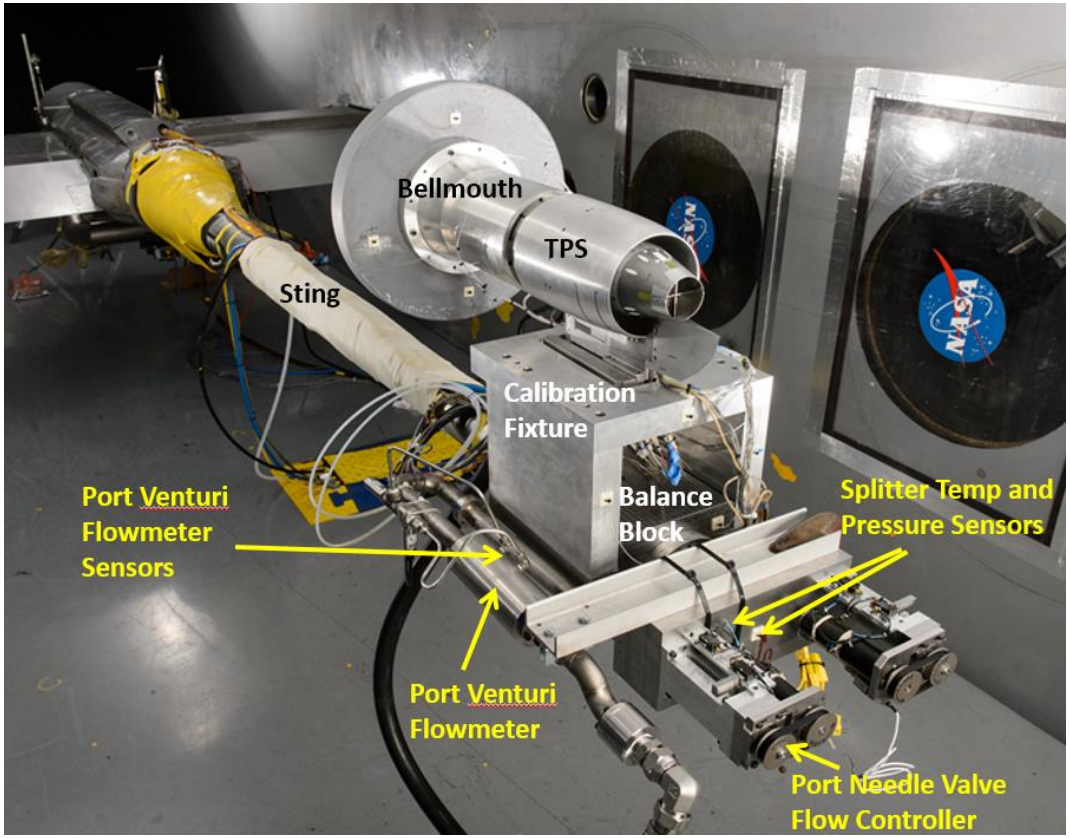
- CFD simulations with STAR-CCM+



Comparisons with Calibration in 9x7

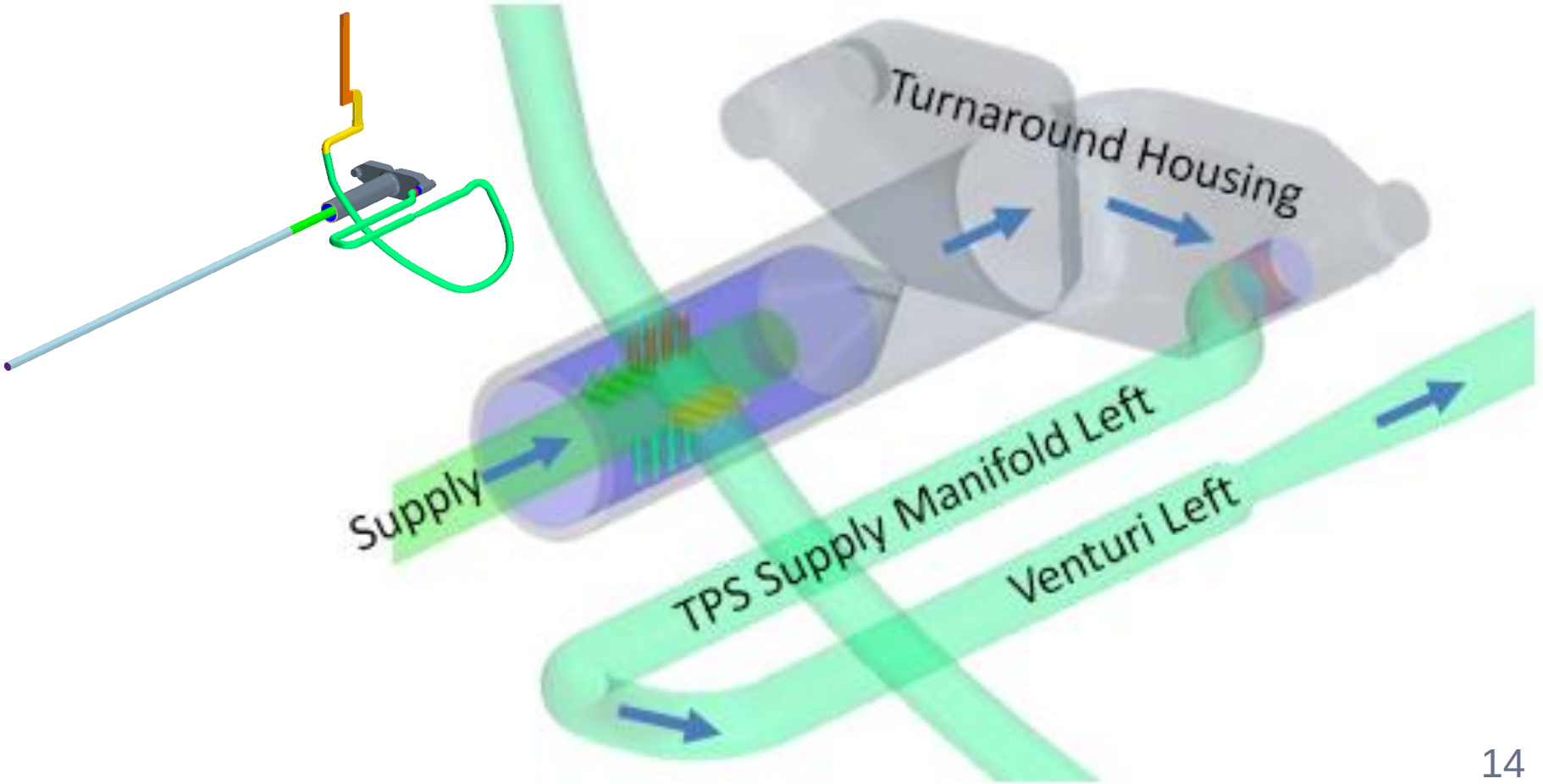
- Single TPS unit calibration in 9x7 test section





Comparisons with Calibration in 9x7

- Single TPS unit calibration in 9x7 test section



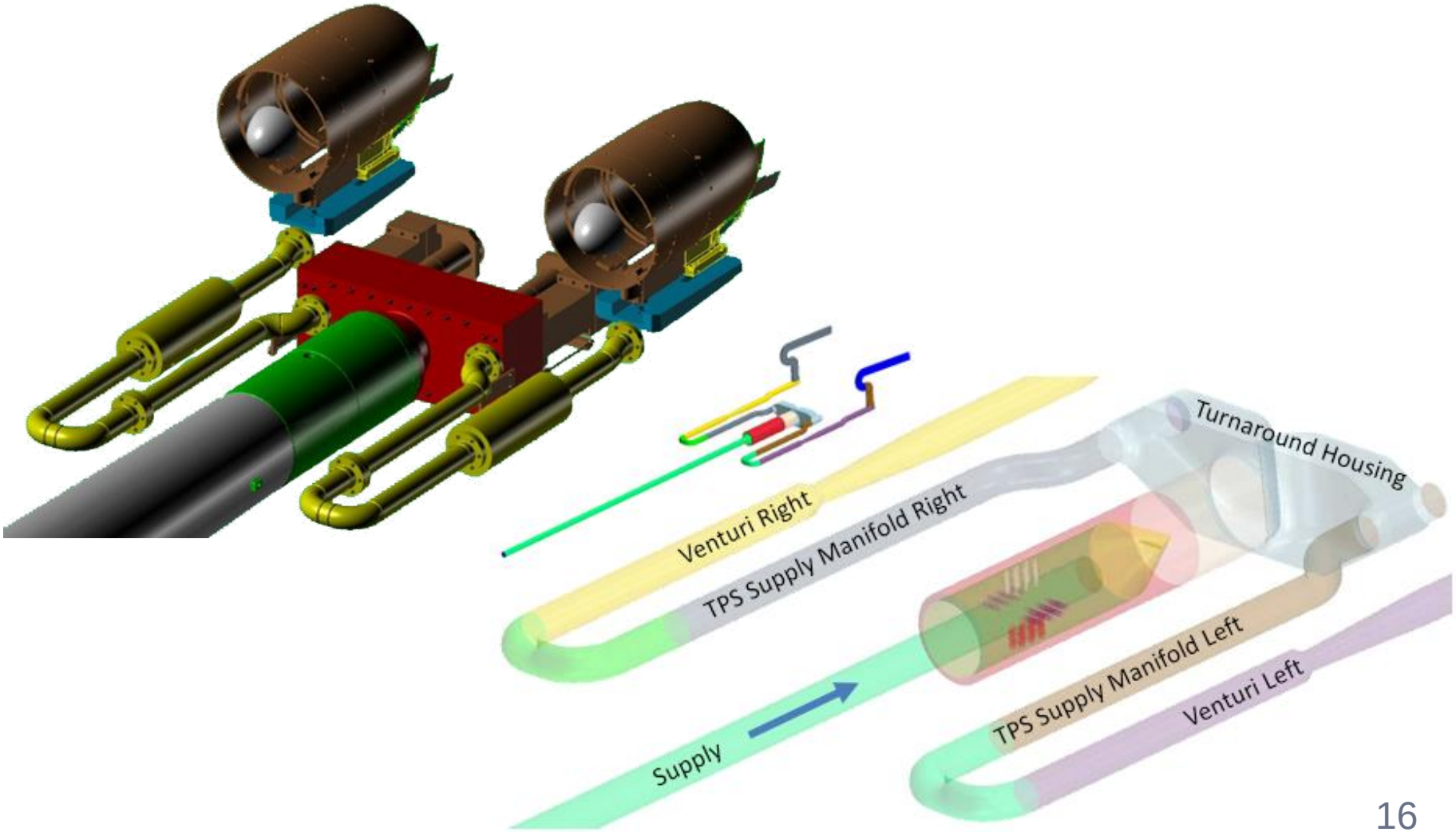
Comparisons with Calibration in 9x7

- Single TPS unit calibration in 9x7 test section

Exp. Supply Mass Flow (lbm/s)	Exp. Plenum Total Pressure (psi abs)	Exp. Plenum Total Temperature (F)	Exp. Venturi ΔP (psi)	Balance Axial Force (lbsf)	Balance Normal Force (lbsf)	CFD Supply Pressure (psi abs)	CFD Mass Flow (lbm/s)	CFD Plenum Total Pressure (psi abs)	CFD Plenum Total Temperature (F)	CFD Venturi ΔP (psi)	CFD Axial Tare (lbsf)	CFD Normal Tare (lbsf)
0.489	87.188	80.1	4.51	39.1	0.56	88.7	0.493	85.6	82	5.9	-0.4	50.8
1.509	279.14	89.7	14.6	134.2	2.48	283.7	1.55	274.4	90	18.3	-1.1	187.3
2.018	375.312	119.7	19.8	170.3	1.23	382.7	2.02	370.5	120	24.5	-1.7	256.9

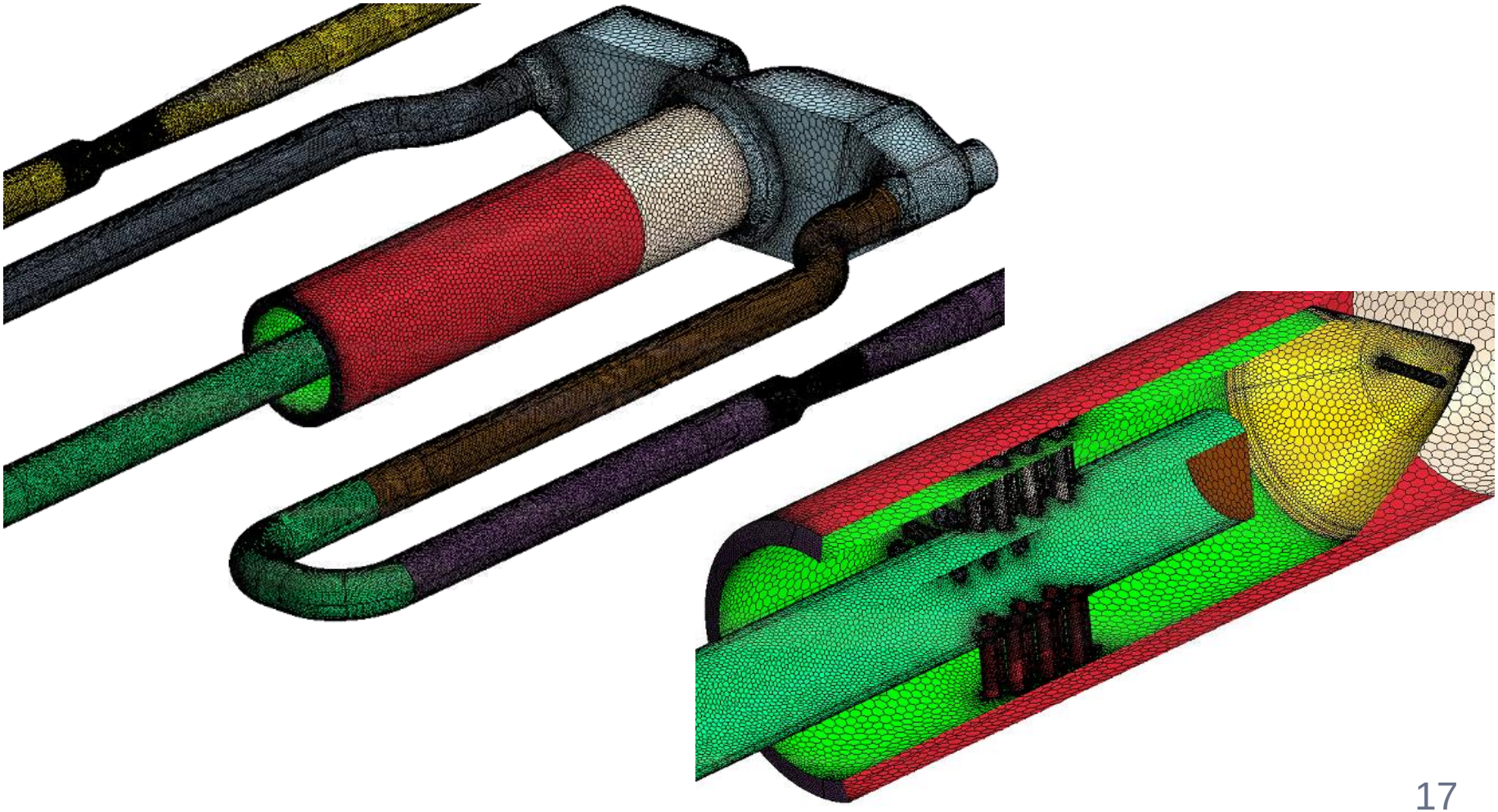
Simulations for HWB with TPS

- Simulations for HWB with TPS in 40x80



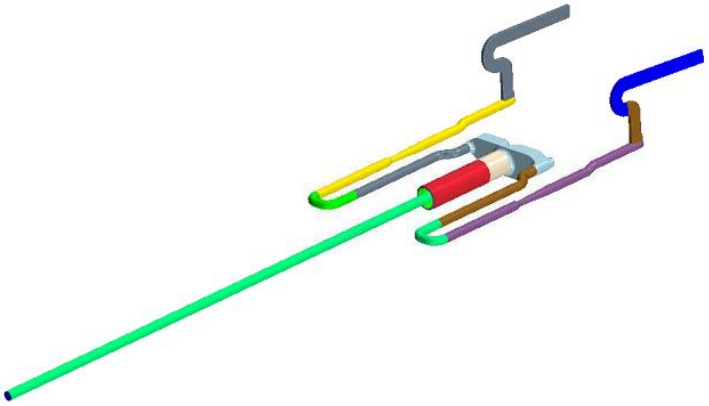
Simulations for HWB with TPS

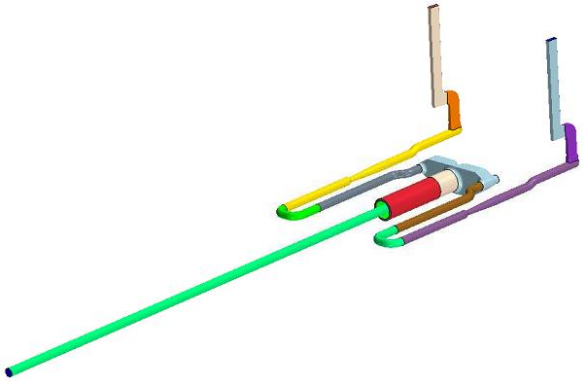
- Simulations for HWB with TPS in 40x80



Simulations for HWB with TPS

- Simulated two TPS exhaust directions



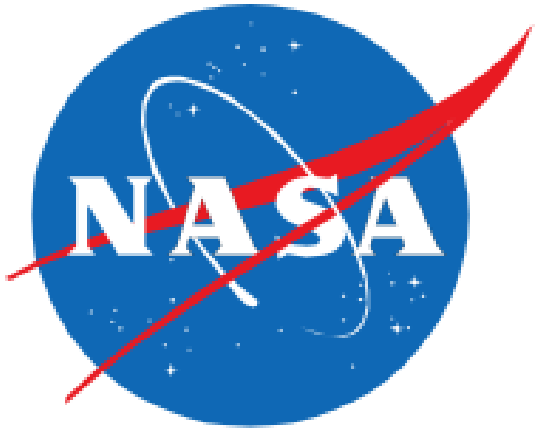


CFD Mass Flow (lbm/s)	CFD Plenum Total Pressure (psi_abs)	Balance Axial Force (lbsf)	Balance Normal Force (lbsf)	CFD: Hz Exit Axial Tare (lbsf)	CFD: Hz Exit Normal Tare (lbsf)	CFD: Vertical Exit Axial Tare (lbsf)	CFD: Vertical Exit Normal Tare (lbsf)	CFD: Hz Exit Axial Thrust (lbsf)	CFD: Hz Exit Normal Thrust (lbsf)
0.42	28.4	-	-	-19.5	-1.2	-1.5	18.2	19.2	1.24
0.9	65	35.4	-4.5	-77	-5.5	-5.3	69	77.1	4.95
3.4	245	221.0	60.6	-366	-21	-23.6	350	366	23.4

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


NASA