



A New Flow-Through Balance for Retropropulsion Testing

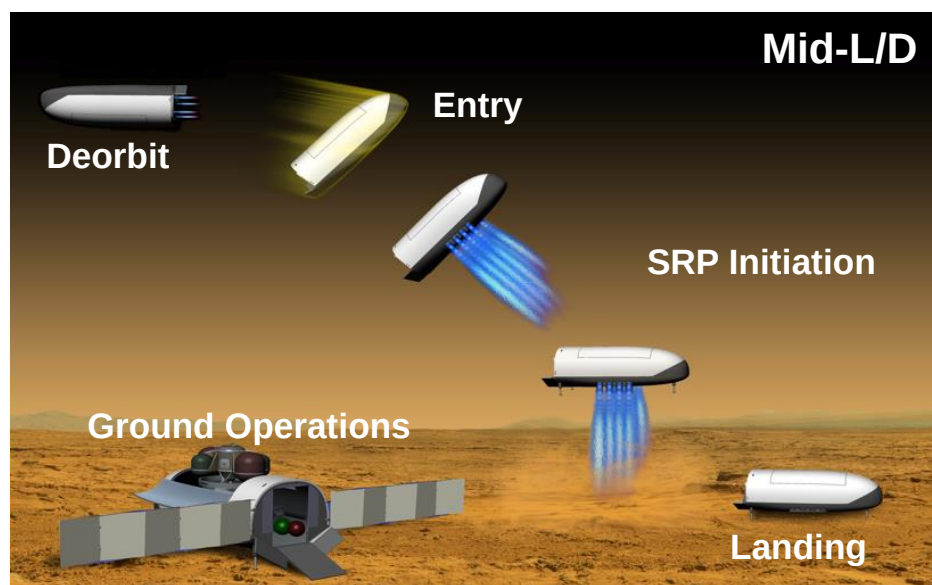
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National Aeronautics and Space Administration

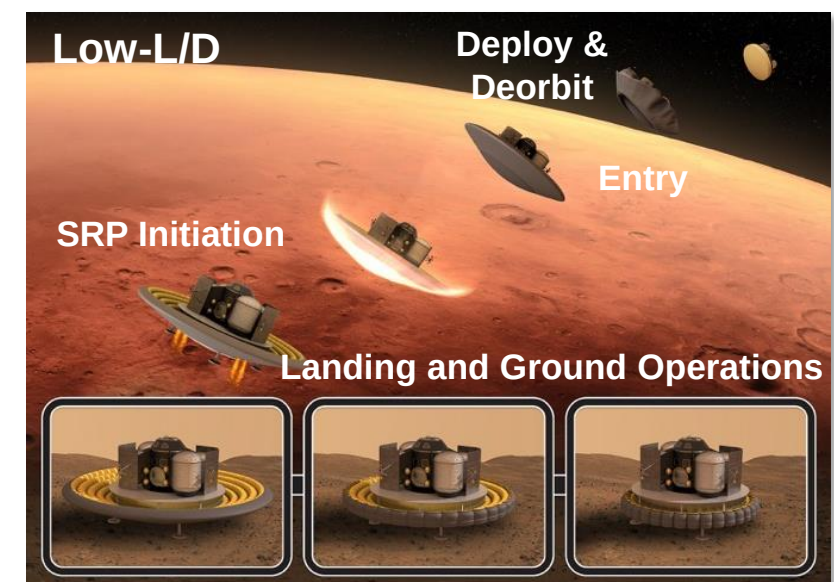
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Retropropulsion for Mars Human Lander

- Propulsive descent & landing is enabling for human Mars landers (extending heritage parachutes is not viable to land the required masses).
- Current vehicle concepts require retropropulsion starting at supersonic conditions – Supersonic Retropropulsion (SRP).
- Principal technology challenge is in aerodynamics interference characterization and reduction of uncertainties.
- Legacy ground test data (1960s) and modern NASA investment form the current basis of experience, but no direct force and moment measurements exist.

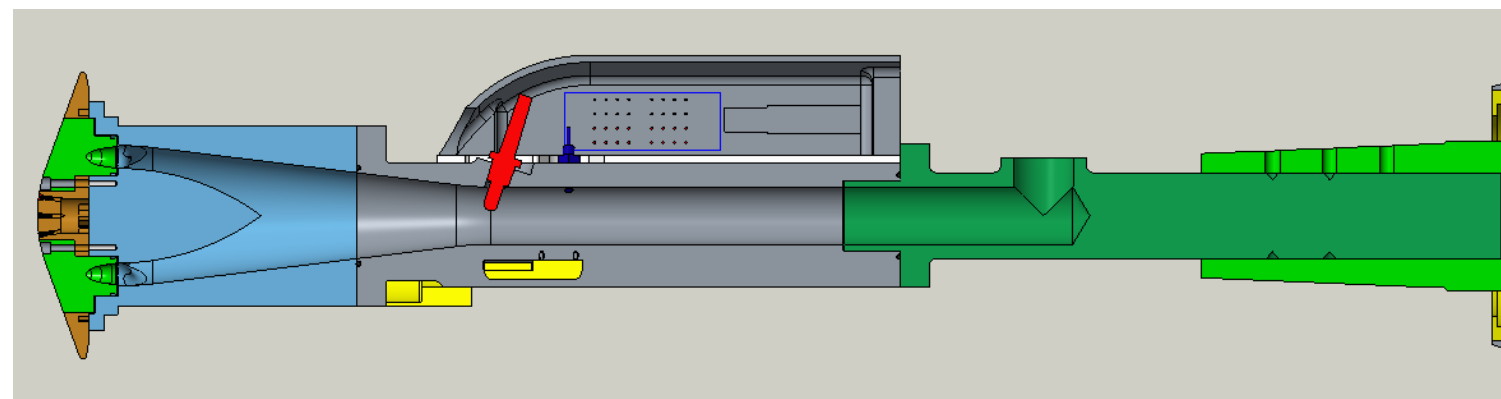
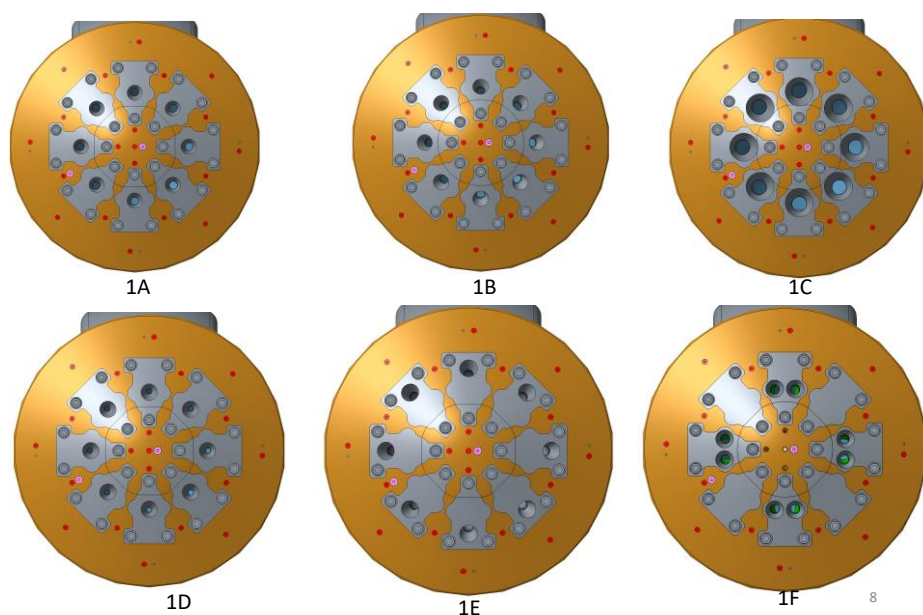


SRP landing concepts.



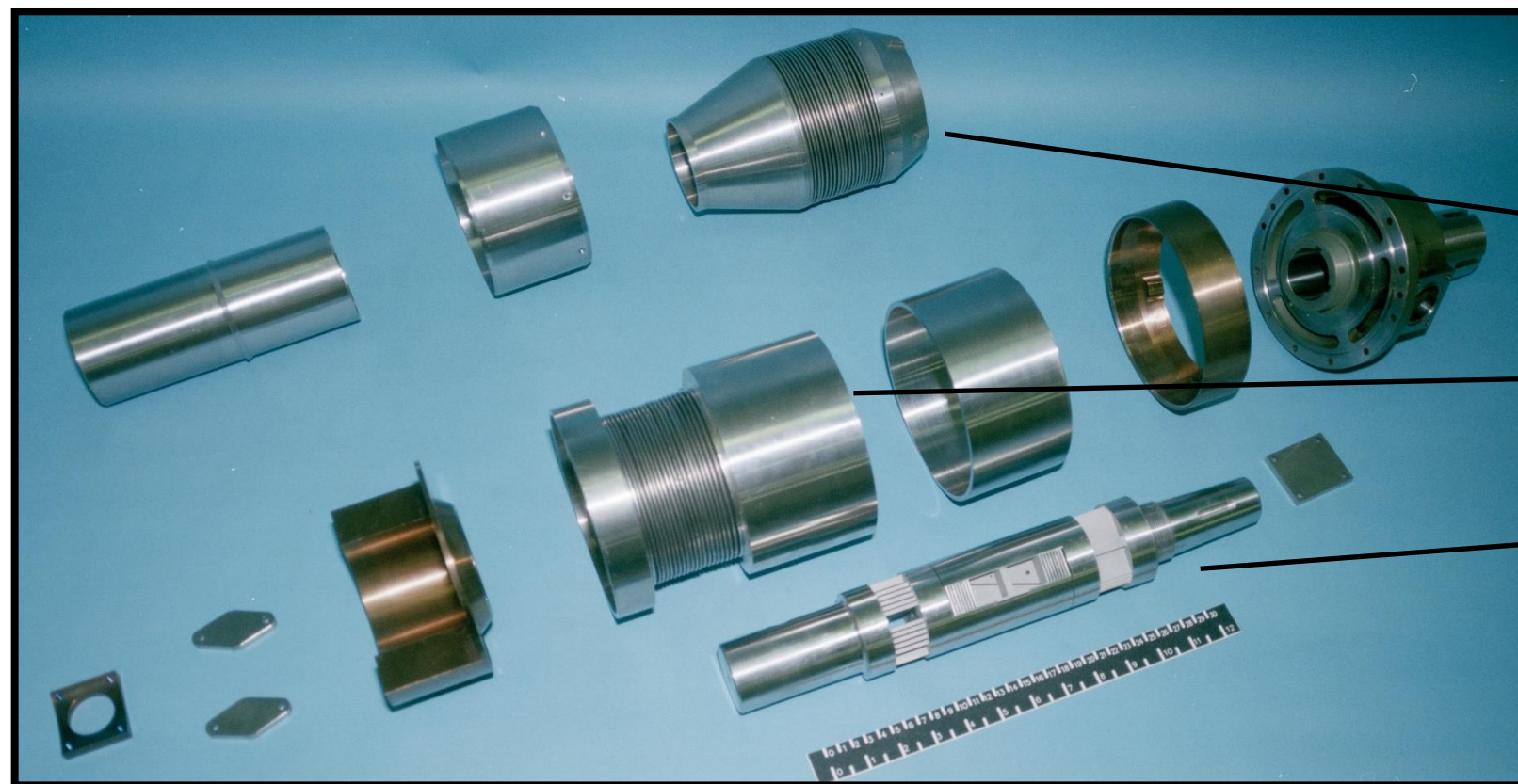
Force Measurement for Mars Human Lander

- **Supersonic wind tunnel test campaign is on-going to generate ground test data for SRP with subscale models and inert gas simulant.**
- **Next test planned to use Pressure-Sensitive Paint (PSP) for force info:**
 - No existing flow-through balances met test requirements.
 - Cannot simultaneously use PSP and off-body flow visualization techniques.
- **Direct force measurement capability:**
 - Will provide critical data for CFD validation, directly measuring aerodynamic loads on the model, separate from thrust.
 - Allows for simultaneous off-body, quantitative flow visualization.



SRP wind tunnel model (AIAA 2020-2230).

- **Existing six-component flow through balances require bellows to contain the flow.**
 - Complex to manufacture and maintain.
 - Can lead to hysteresis.



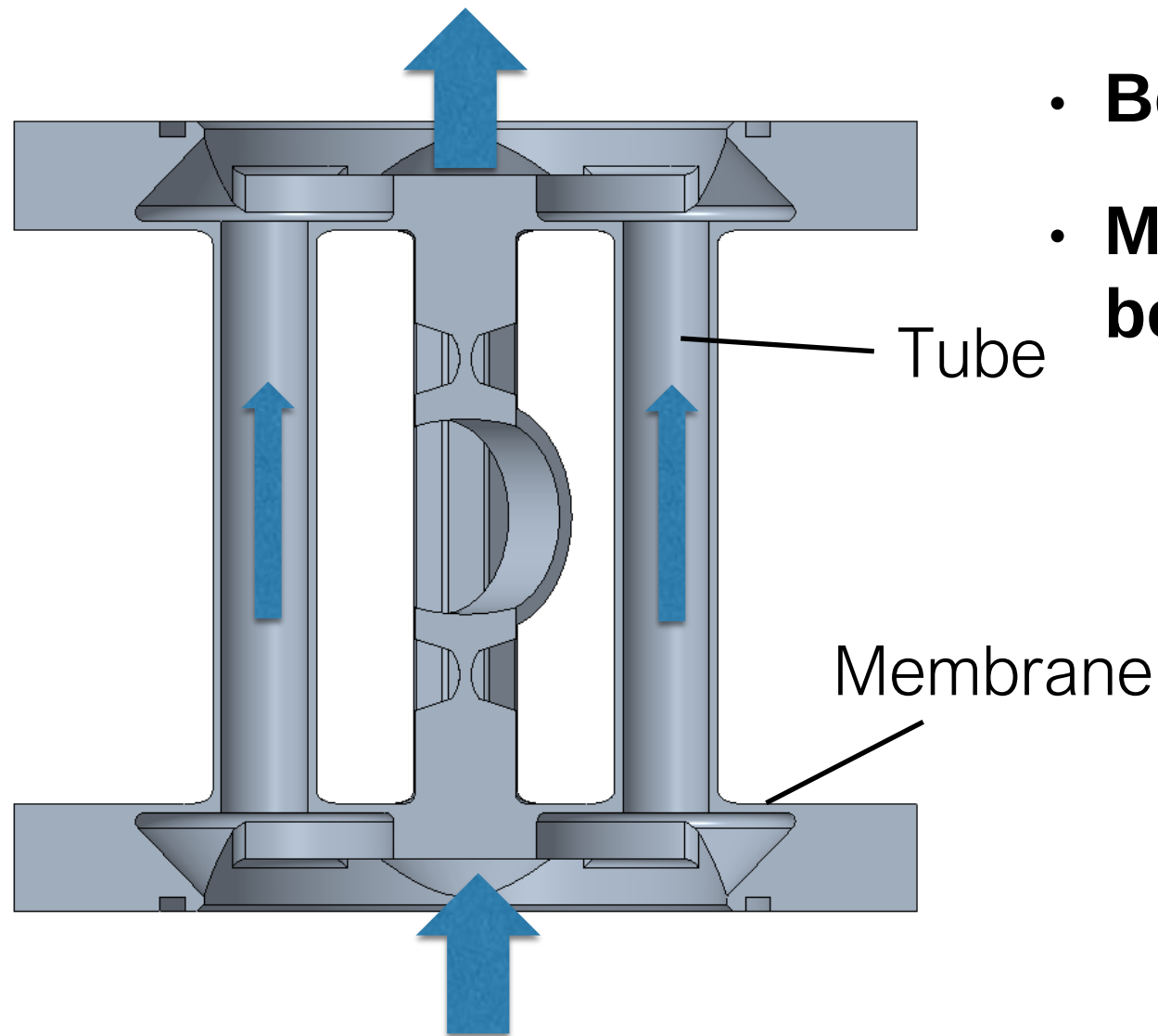
Inner bellows

Outer bellows

Force transducer

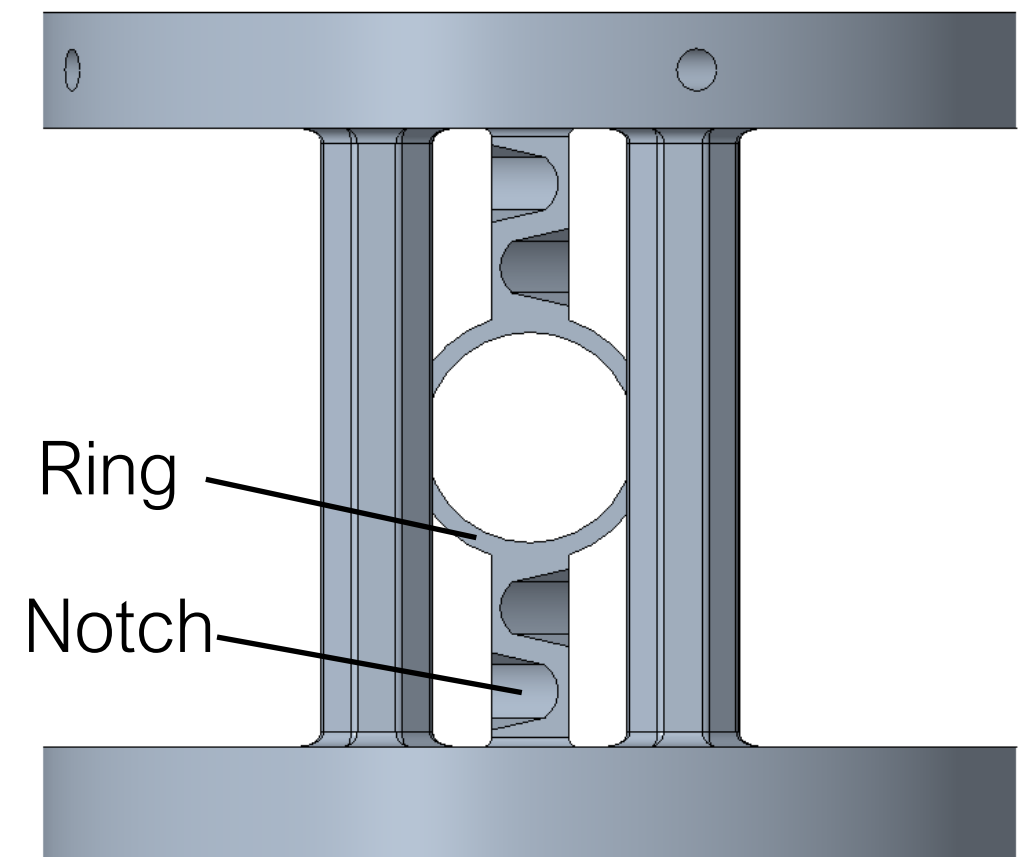
Disassembled view of heritage NASA flow through design.

New Balance Design



Section view depicting flow path through transducer.

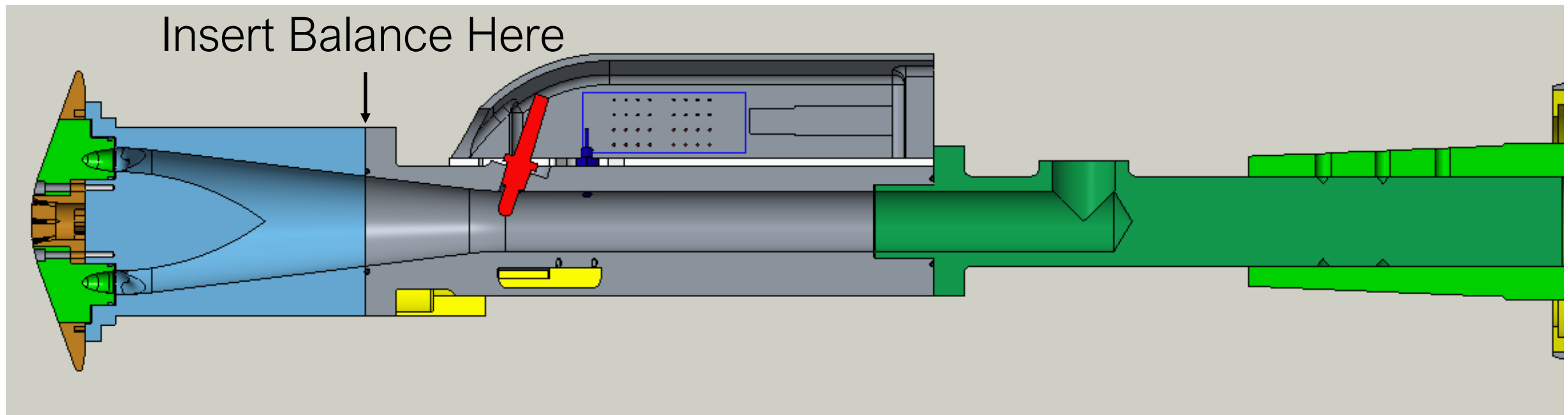
- Bellows replaced with structural tubes.
- Membranes provide compliance like bellows.



Isotropic view showing posts and central ring.

- Ring, common transducer geometry, used for AF.
- Notches isolate ring and accentuate NF, PM, SF and YM.

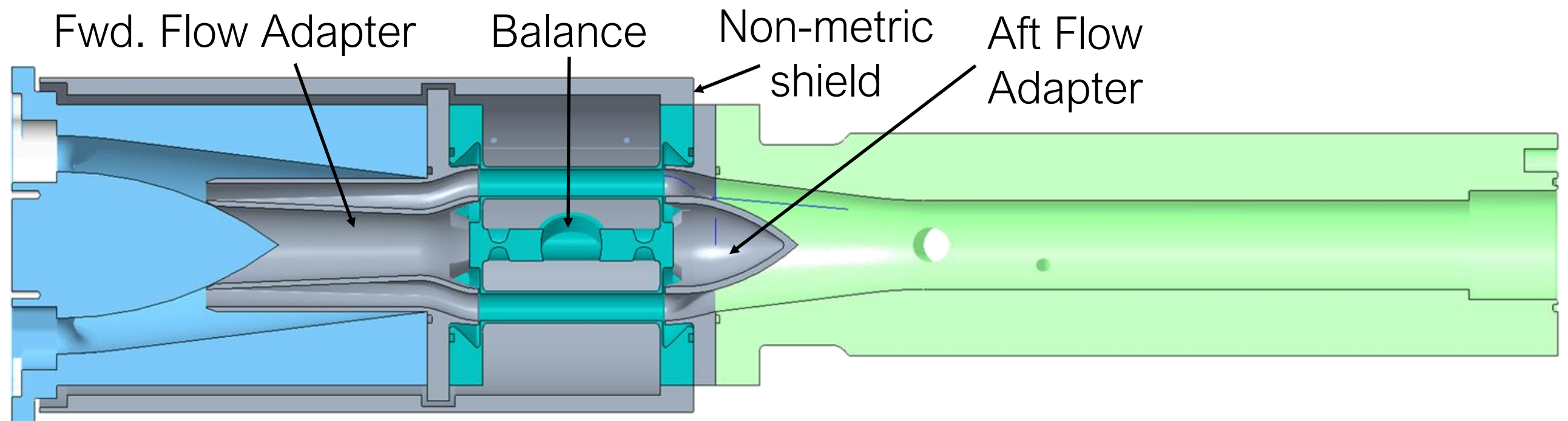
Original Model System



Representation of Mars lander model.

- **Model system was not designed to accommodate a balance and model was already built – no modifications to existing hardware.**
- **Model emphasized a clean flow of high pressure gas through the model and out the nozzles with minimal pressure losses.**
- **Balance design must allow sufficient mass flow and minimize pressure losses.**

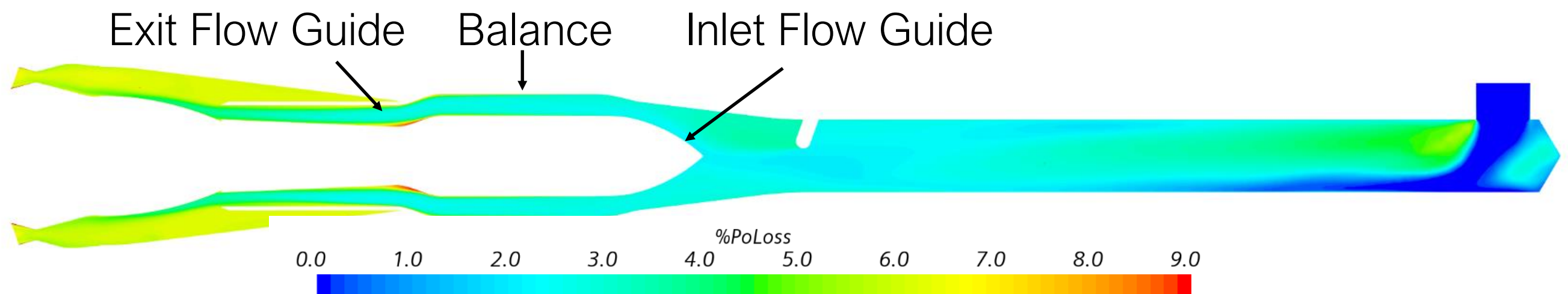
Model System with Balance



Model design with balance, flow adapters, and non-metric shield.

- **Model system with addition of balance, flow adapters, and non-metric shield.**
- **The addition of this hardware requires no modification of existing hardware.**
- **Non-metric shield prevents balance from measuring aero forces on parts of the model aft of the heat shield.**

- Iterative CFD analyses to determine flow guide geometry that minimized pressure loss through the balance.
- Flow transitioned from aft plenum into the balance using the inlet flow guide and then diffused out gradually into the forward plenum using an exit flow guide.
- CFD results suggest pressure loss through the balance should be close to zero.



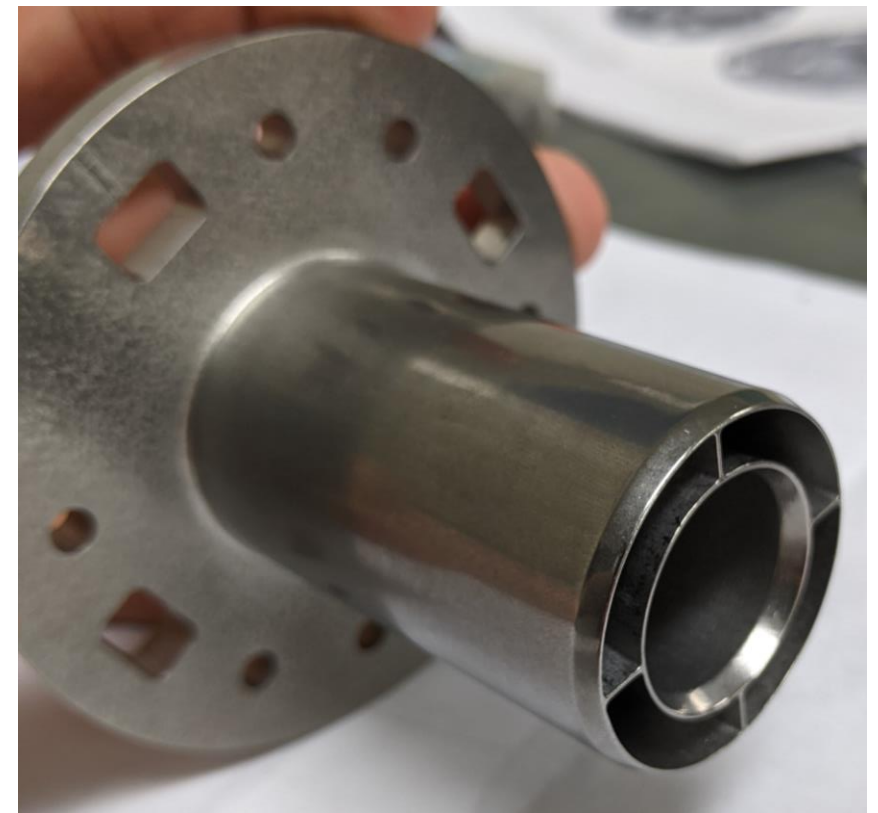
CFD prediction of pressure loss through balance.



Balance in non-metric shield.



Inlet flow guide.



Exit flow guide.

- **Balance and non-metric shield conventionally manufactured.**
- **Flow guides additively manufactured then surface finished.**

Balance Calibration



- **Calibration consisted of:**
 - Force calibration
 - Force calibration under pressure (up to 300 psi)
 - Force calibration at temperature (up to 200°F)
- **Balance output and accuracies (expressed as a % of full-scale load) reflecting force and pressure loadings:**

	Normal	Axial	Pitch	Roll	Yaw	Side
Output ($\mu\text{V}/\text{V}$)	1168	203	573	53	553	1010
Accuracy (% of F.S. load)	0.2	1.1	0.3	0.7	1.0	0.2



Balance in calibration stand.

- **Demonstrated a new six-component flow through balance design which can directly measure supersonic retropropulsion performance of powered descent vehicles.**
 - Bellows are replaced with structural tubes and membranes.
 - Flow guides are used to transition flow into and out of the balance.
 - Fluid flow is directed through the flexures of the balance versus around.
- **Higher axial force output can be achieved in future designs and fabrication refinements, which should help improve accuracy.**
- **The internal air flow path can be further optimized by considering the balance earlier in the model design process.**