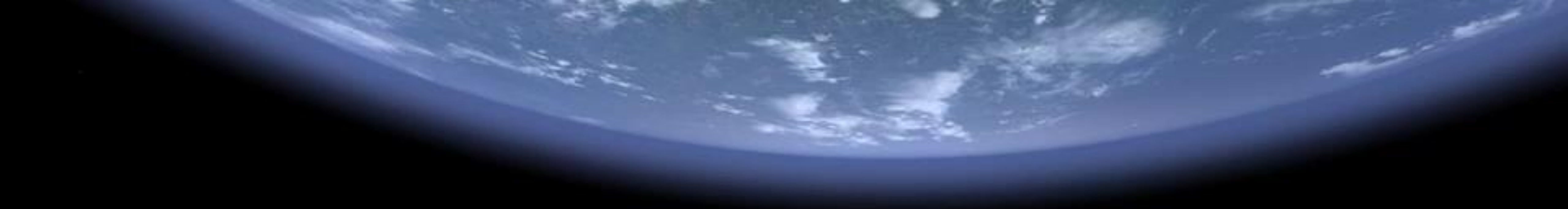

REDWIRE

Micro-Gravity Sediment Trap

Thermal-Fluids Analysis Workshop 2023

Patrick Wayne, Ph.D. **21-25 August 2023**

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Background and Motivation

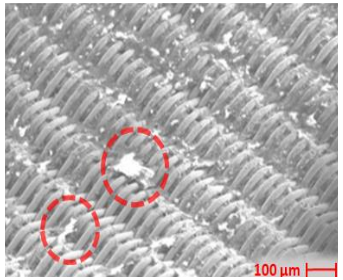
Why Microgravity Sediment Trap (MGST)?

- **Spacecraft pumped fluid loops (PFLs)**
  - Used for heat (thermal and environmental subsystems) and mass transfer
  - Prone to debris generation and resultant damage
    - **AFRL team found 17 spacecraft PFL failures in open-source literature**
      - 16% failure rate (https://apps.dtic.mil/sti/trecms/pdf/AD1195523.pdf)
        - ~ Half of these are due to debris in the system
      - ALL PFL components are susceptible to debris
- **Seeking a solution to capture debris before it causes damage**
- **What's wrong with current (SOTA) sieve-type filters?**
  - Particulates can (and do) clog PFL components
  - They incur significant pressure drop

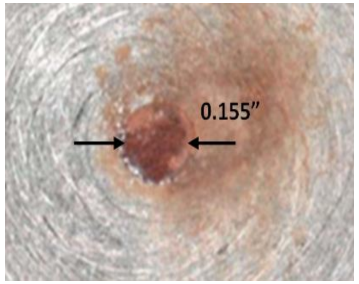
A novel type of filtration device is needed now

Fouling on a quick Disconnect[1]

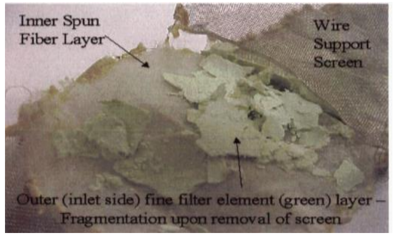
EMU clog in 2013 nearly drowns astronaut[2]



Agglomerations found in EMU 3013 gas trap sieve filter[3]



Clogged gas traps[3]



ISS IATCS filter clogged with nickel phosphate[4]

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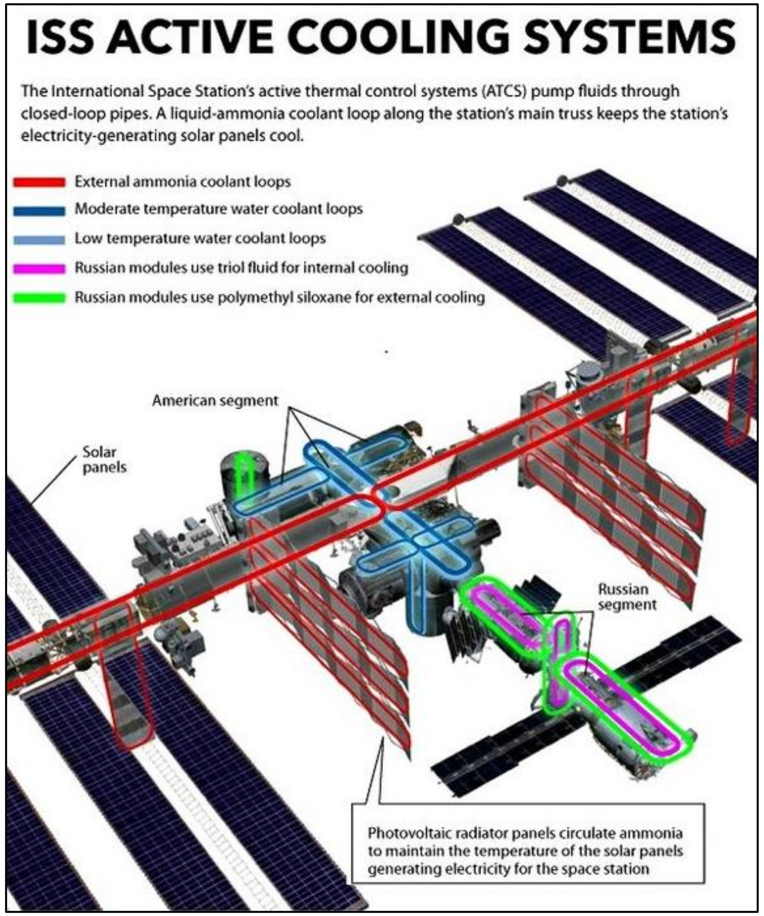
Goal And Requirements For MGST

GOAL

Create a passive filtration device to remove contamination and debris from pumped fluid loops (PFLs) in microgravity

Requirements
Low pressure drop (< 1.0 psid)
Targeting microscale particles (< 200 µm in diameter)
Designed to last to spacecraft EOL
No moving parts
Operational for a wide range of flowrates
Scalable according to PFL specifications



ISS ACTIVE COOLING SYSTEMS

The International Space Station's active thermal control systems (ATCS) pump fluids through closed-loop pipes. A liquid-ammonia coolant loop along the station's main truss keeps the station's electricity-generating solar panels cool.

Photovoltaic radiator panels circulate ammonia to maintain the temperature of the solar panels generating electricity for the space station

High level schematic of ISS active cooling system.[5]

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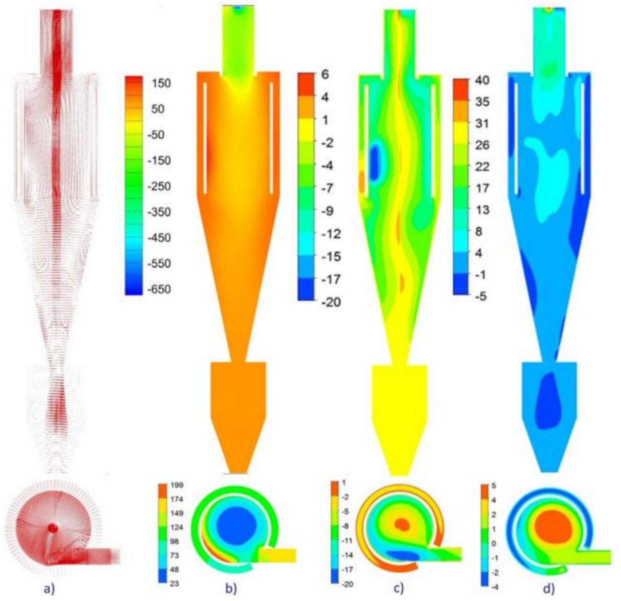
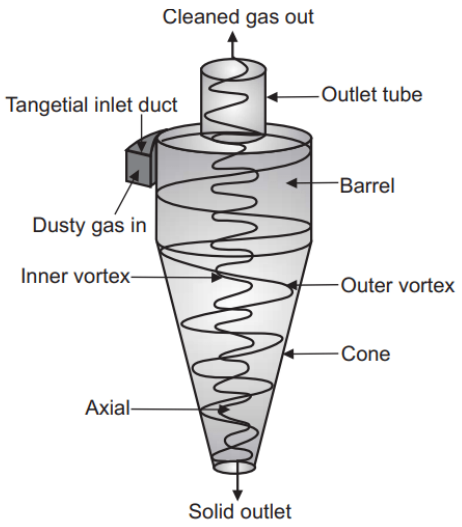
MGST Design Based on Cyclone Separators

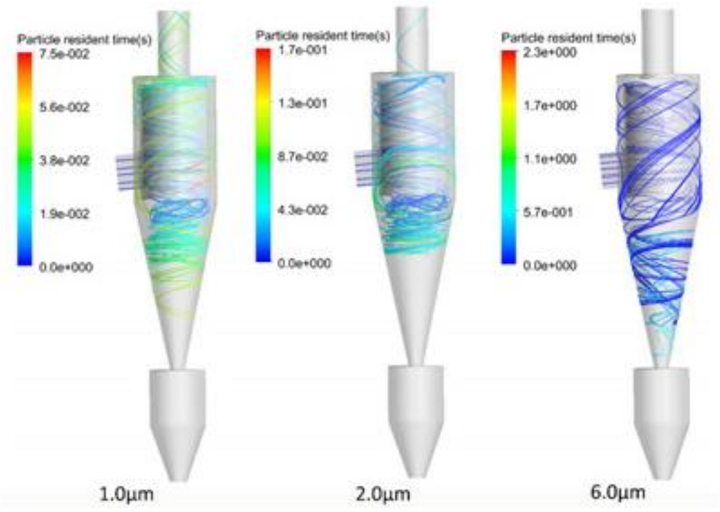


Velocity vector and contour plots for a cyclone separator. a) velocity vector, b) pressure distribution, c) tangential velocity, and d) axial velocity.[6]



Cyclone separator diagram obtained from https://pharmacygyan.com/principle-and-construction-of-cyclone-separator/

- Can we take advantage of centrifugal forces to remove particles from the flow?



Particle trajectories with particle residence time as the scalar field function for multiple diameters (from left to right are 1.0 μm, 2.0 μm , and 6.0 μm).[6]

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MGST

- Initial Simulations were very promising
  - Water @ 22°C

- Reynolds Stress Transport model (RSM)
  - Elliptic blending variant
  - ~1M cells in fluid volume

- Lagrangian Multiphase model (LMP) for particles
  - Alumina (ρ = 3950 kg/m^3)
  - 3 particle diameters: 3.5 μm, 60 μm, and 150 μm

- Several iterations of this design were evaluated

- Particle mass trapping efficiency is between 50% (3.5 μm) and 100% (150 μm)

$$\rho_f = 995\frac{kg}{m^3}$$

$$\rho_p = 3950\frac{kg}{m^3}$$

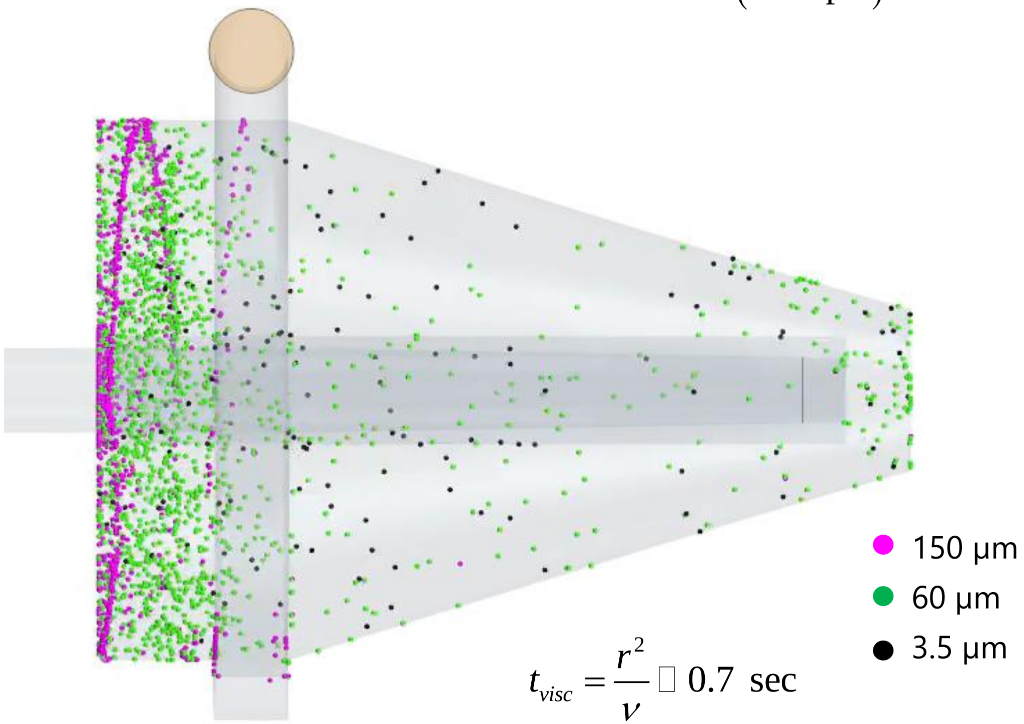
$$\dot{Q} = 1800 \text{ ml / min}$$

$$u_{inlet} = 0.94\ m/s$$

$$\nu = 8.9\times10^{-4}\ m^2/s$$

$$\text{Re}_{\max} \square 15{,}000$$

$$dP \square 5000 \text{ Pa } (0.72 \text{ psi})$$



$$t_{visc} = \frac{r^2}{\nu} \square 0.7 \text{ sec}$$

Total physical time elapsed ~ 1 sec

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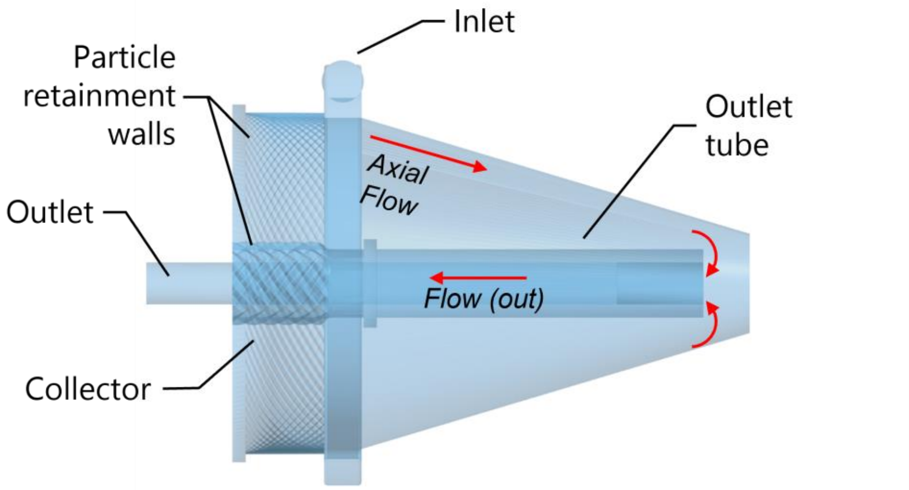
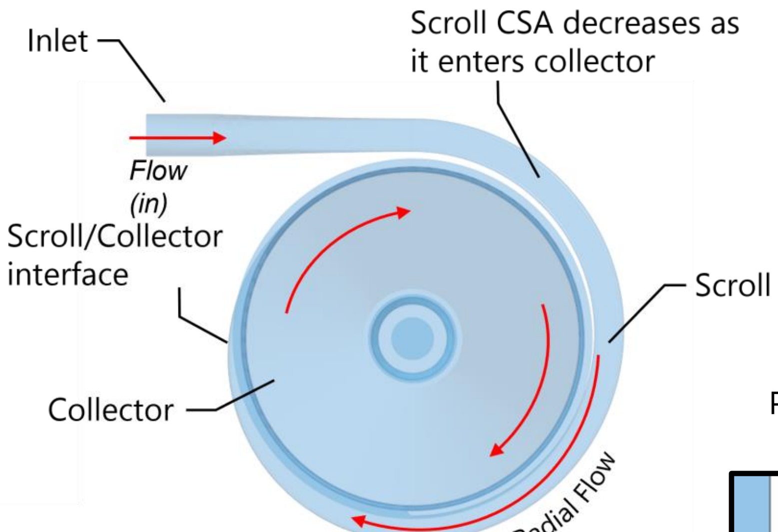
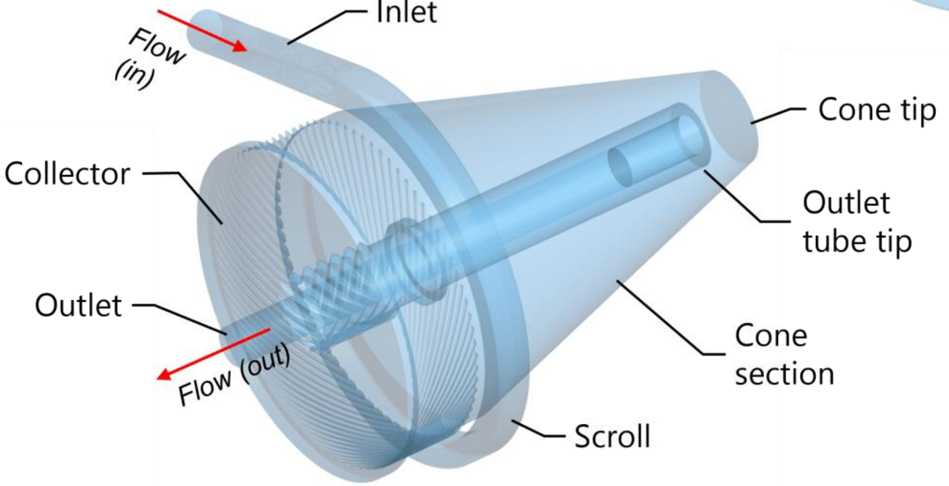
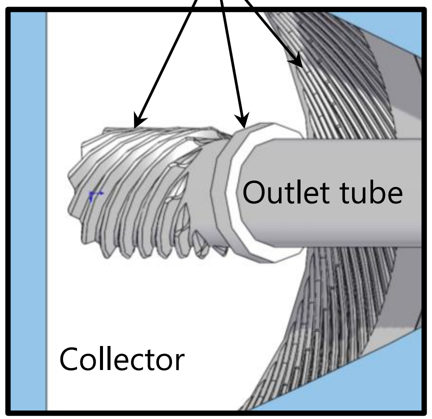
MGST Fluid Volume









Section view of collector showing particle retainment wall geometry

- Unlike terrestrial separators, particles are collected in the barrel (collector) of MGST
- Particle retainment walls promote rotational flow and prevent migration

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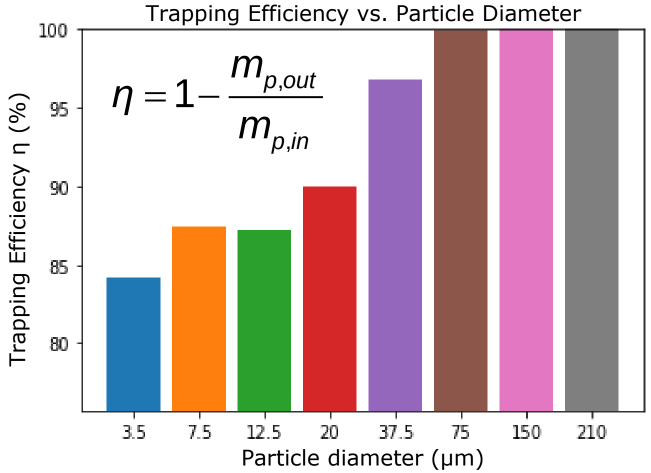
MGST Latest Simulation Results

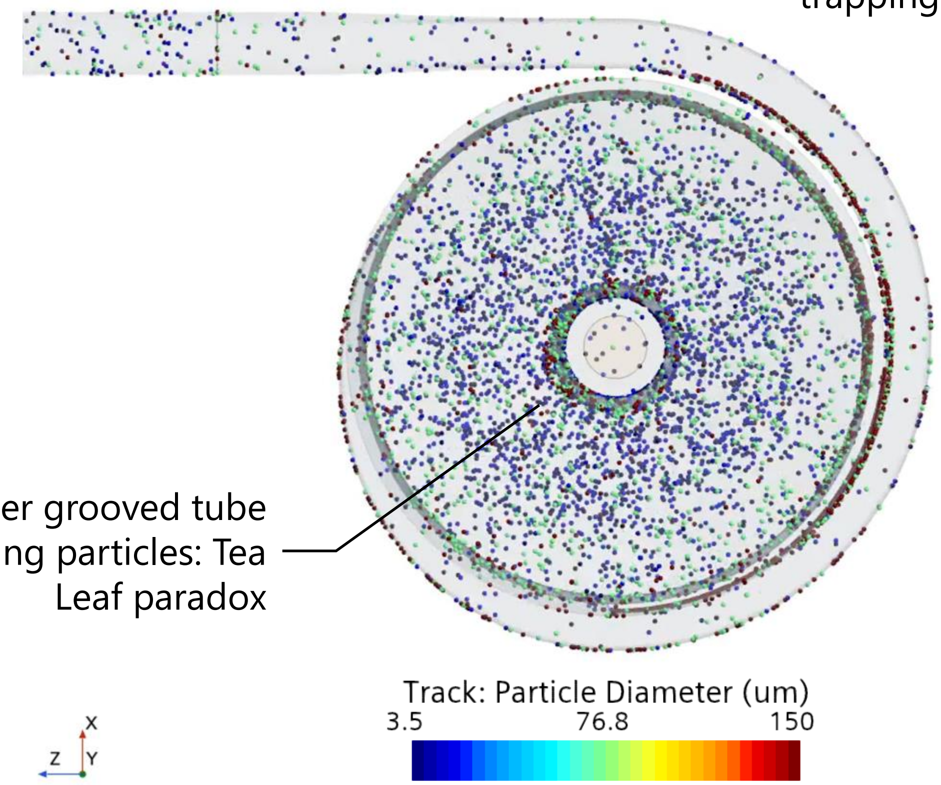
Alumina:

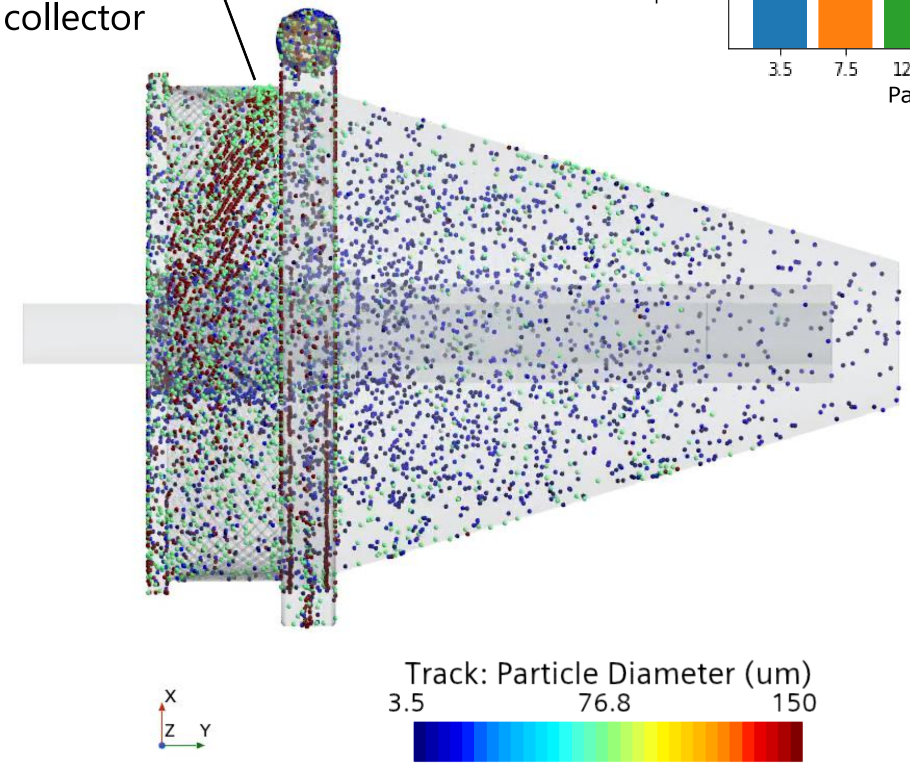
$\rho_p = 3950\ kg / m^3$



Significant amount of trapping occurring in the collector

Inner grooved tube collecting particles: Tea Leaf paradox





$\dot{Q} = 1800\ \mathrm{ml/min}$

$u_{inlet} = 0.94\ m / s$

$\nu = 8.9 \times 10^{-4}\ m^2 / s$

$\mathrm{Re}_{\max} \approx 15{,}000$

$dP \approx 4200\ \mathrm{Pa}\ (0.61\ \mathrm{psi})$

Total physical time elapsed ~ 0.9 sec

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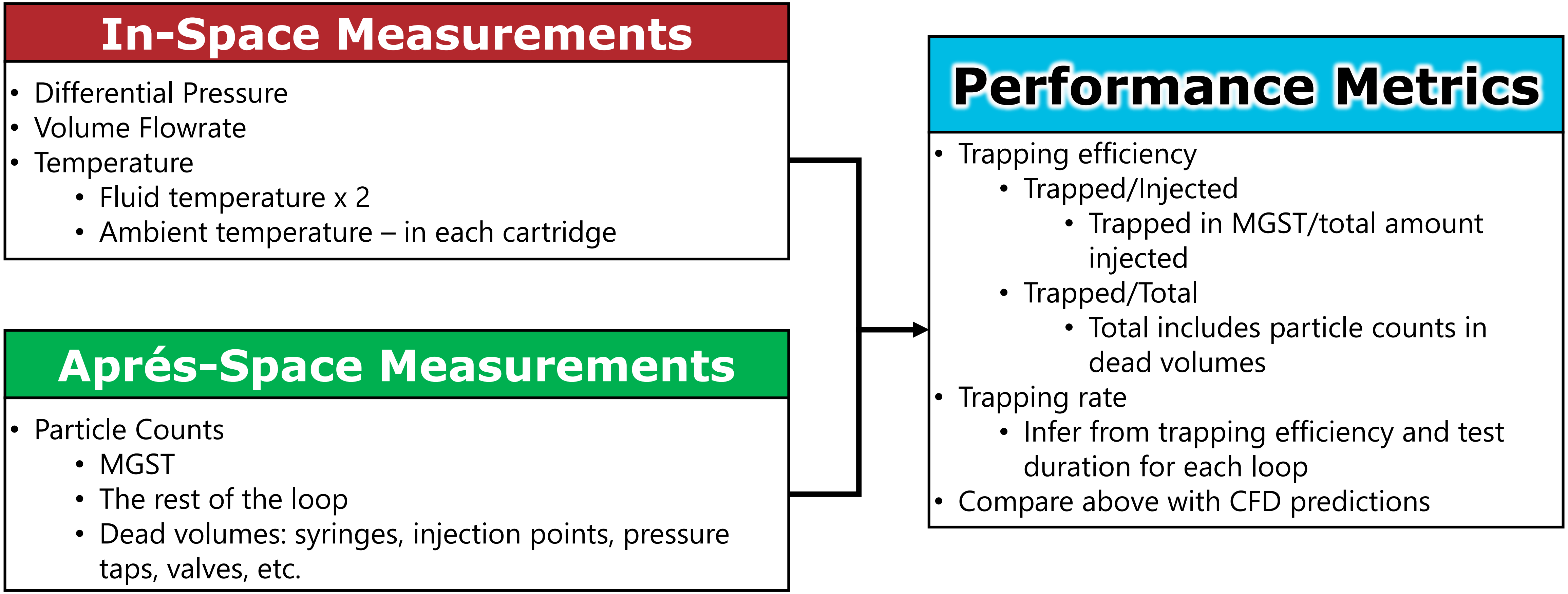
MGST Flight Unit Goals



In-Space Measurements

- Differential Pressure
- Volume Flowrate
- Temperature
  - Fluid temperature x 2
  - Ambient temperature – in each cartridge

Aprés-Space Measurements

- Particle Counts
  - MGST
  - The rest of the loop
  - Dead volumes: syringes, injection points, pressure taps, valves, etc.

Performance Metrics

- Trapping efficiency
  - Trapped/Injected
    - Trapped in MGST/total amount injected
  - Trapped/Total
    - Total includes particle counts in dead volumes
- Trapping rate
  - Infer from trapping efficiency and test duration for each loop
- Compare above with CFD predictions

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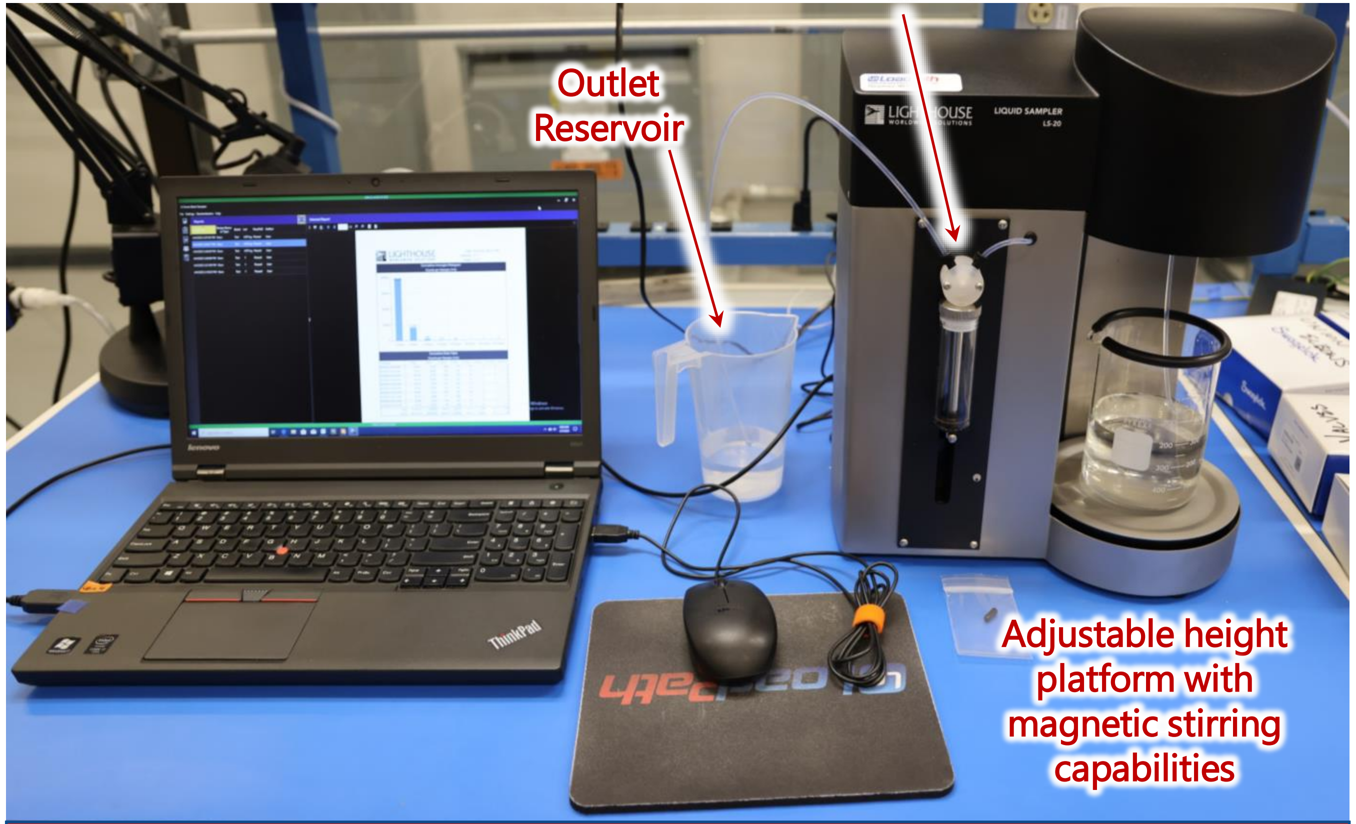
MGST – Particle Counter

- Using a Lighthouse Worldwide Solutions LS-20 batch sampling particle counter
  - Automatic report generation with statistical information on all samples
  - Includes dilution protocols up to 99:1
  - Only drawback – the magnetic stirring function is ***NOT*** constant

- Particle re-entrainment process is currently under evaluation
  - Best/most efficient method to re-entrain particles post-flight



The LS-20 provides automated PDF reports of particle counts with statistical information

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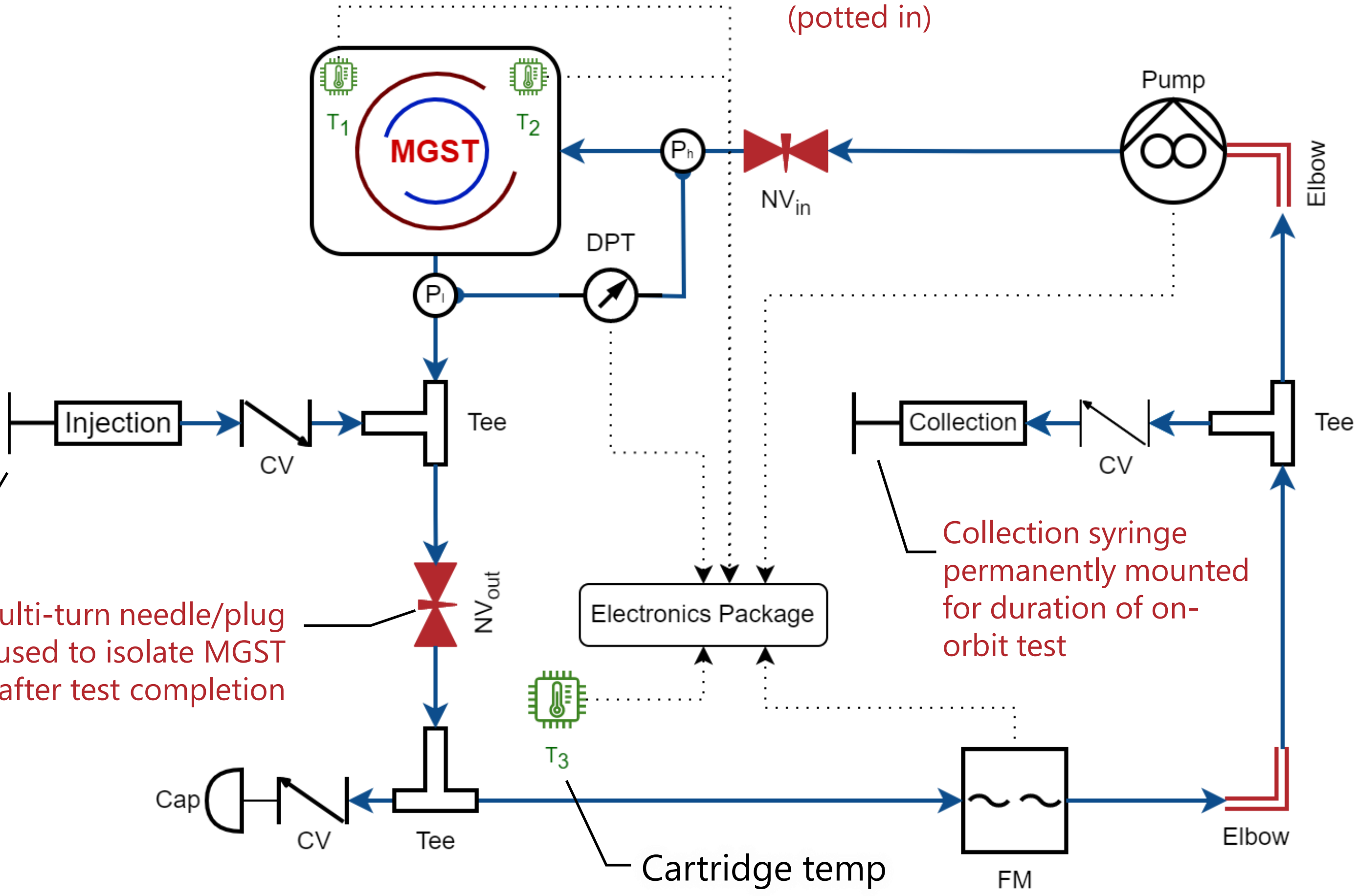
MGST PFL Schematic

- Blue arrows indicate flow direction
- Check valves on syringes prevent backflow
  - Collection syringe remains in place for the entire test
    - Provides clean sample and compliance
- Pump, ultrasonic FM, DPT, and TCs connect to electronics package
- Total liquid volume per loop ~150 ml



Liquid Temp: Thermocouples in two locations on MGST (potted in)

Post injection – syringe is removed, and CV is capped for safety

Multi-turn needle/plug valve used to isolate MGST after test completion

Collection syringe permanently mounted for duration of on-orbit test

Cartridge temp

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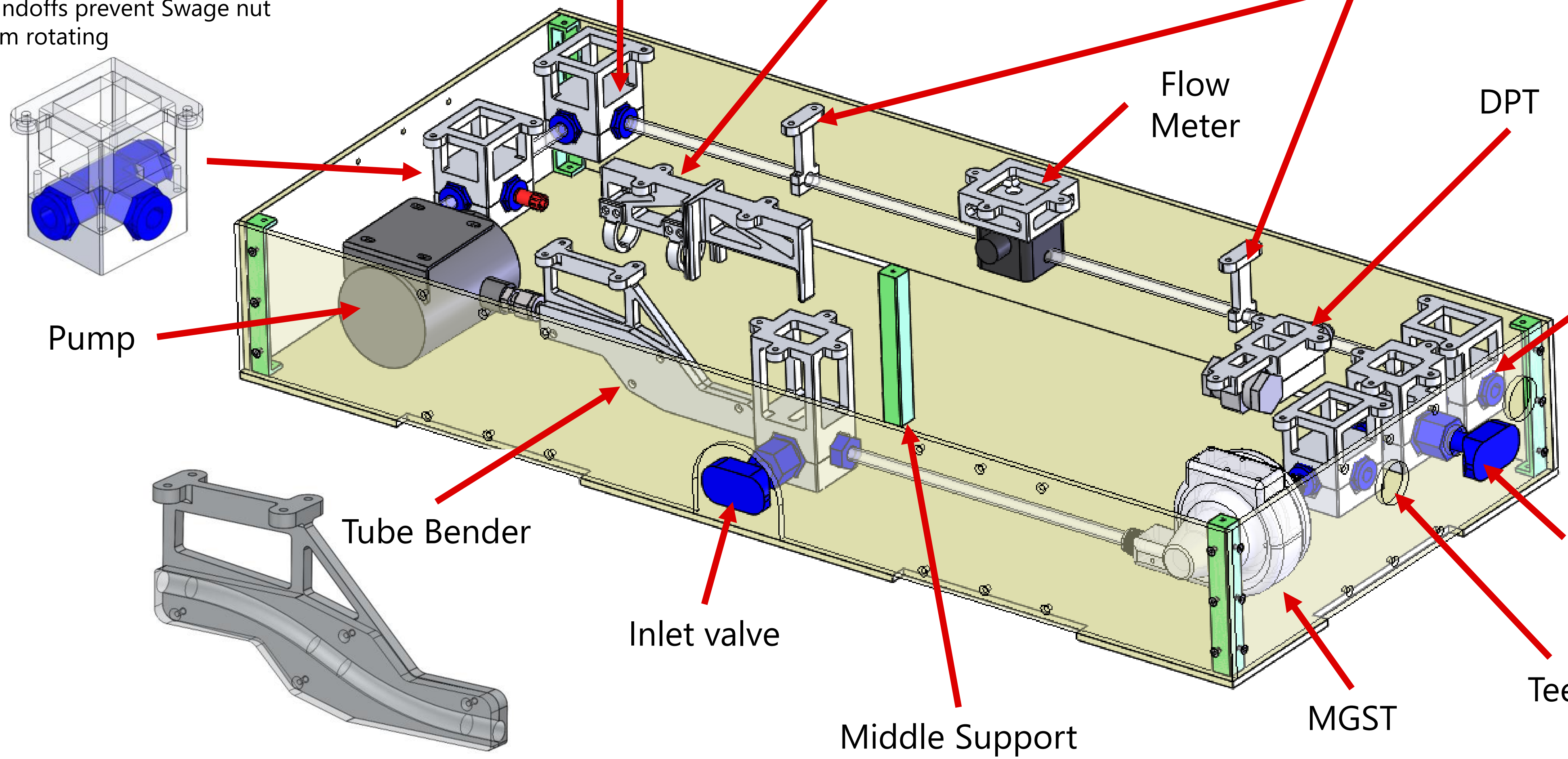
Cartridge Design

All PFL components are made of PFA – with the exception of the pump housing



Tee

- Standoffs prevent Swage nut from rotating

90° Elbow

Collection syringe

- Slotted mounting holes for assembly with lure

Tube Supports

Flow Meter

DPT

Tee (used for fill/degas)

Pump

Tube Bender

Inlet valve

Middle Support

MGST

Tee (injection point)

Outlet valve

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Future Work and Upcoming Plans

- **We are planning to launch cartridges; 3 performance and 1 control**
  - All cartridges will mount into Microgravity Science Glovebox on ISS
  - Each PFL will be self-contained with all components and electronics
    - Particles used: silica, alumina, iron (III) oxide

- **Currently working on the nature of the performance loops**
  - *Different particle concentrations*
  - *Different materials*
  - *Different run times*

- **CDR of flight design scheduled for late September**
  - We are currently working on PFL design, based on PDR recommendations

- **Concurrent CFD simulations using DSRC**
  - Run for much longer periods of physical time
  - Evaluation of current and any future designs

Obtained from: https://www.nasa.gov/centers/marshall/history/msg.html

Launch date is tentatively scheduled for mid-June 2024

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QUESTIONS?

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