PROPELLANT MANAGEMENT OF WATER-BASED MICROTHRUSTER FOR SUBORBITAL 0G TESTING

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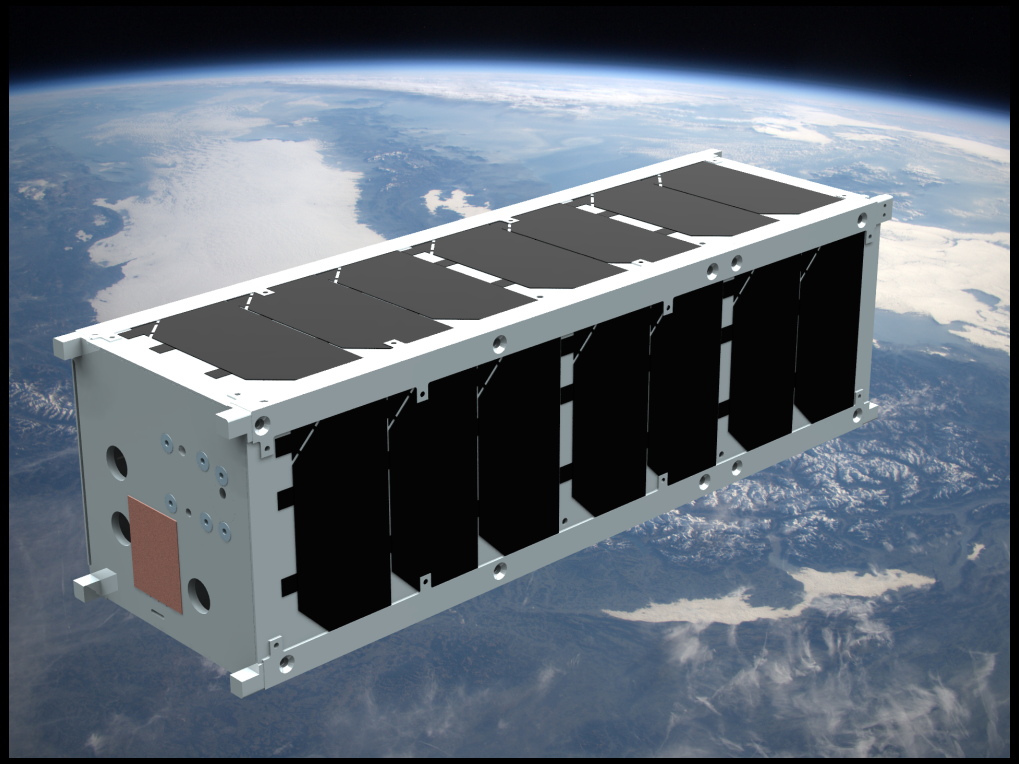
Micropropulsion for SmallSats

Chemical

- Bipropellant
- Monopropellant
- Cold Gas



Electrical

- Electrothermal
- Electrostatic
- Electromagnetic

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Chemical

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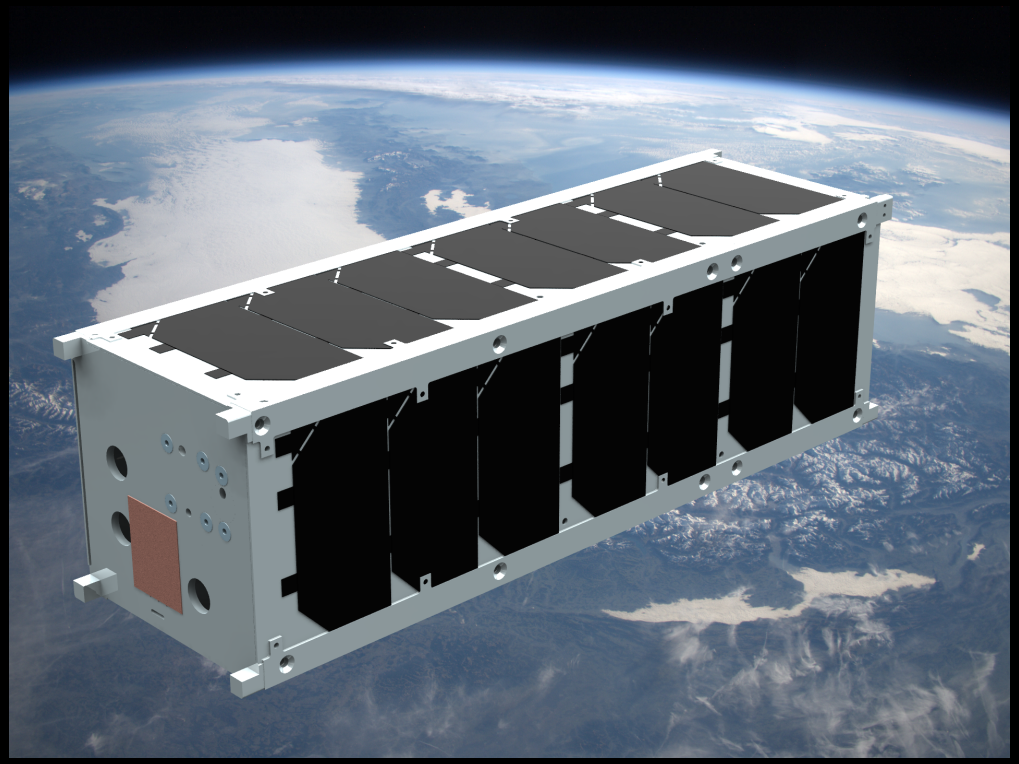
- **Cold Gas**



Electrical

- **Electrothermal**
- Electrostatic
- Electromagnetic

Film-Evaporation MEMs Tunab

Thrust *100-300 μN*

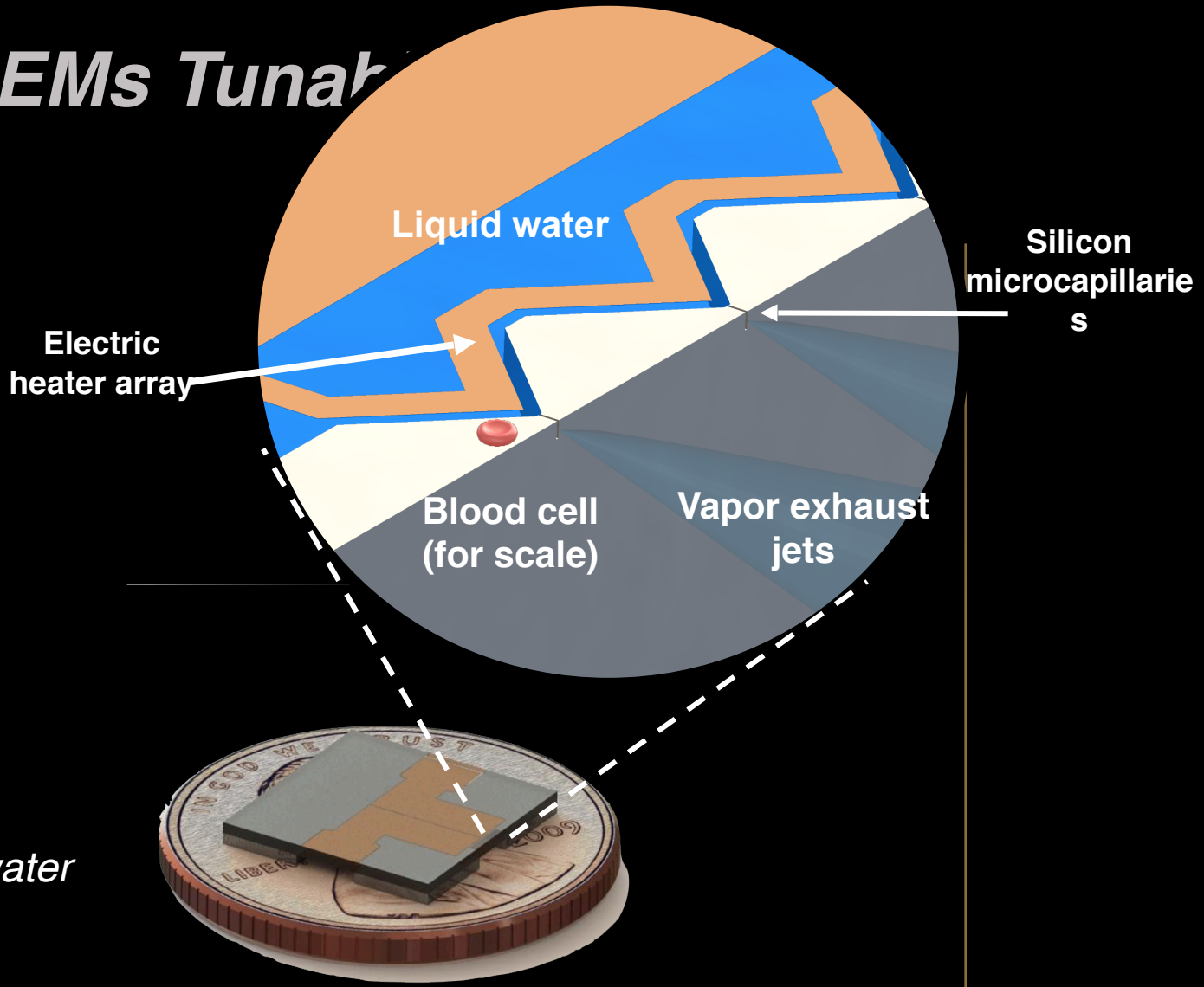
I_{sp} *90 s*

Thrust/Power *300 μN/W*

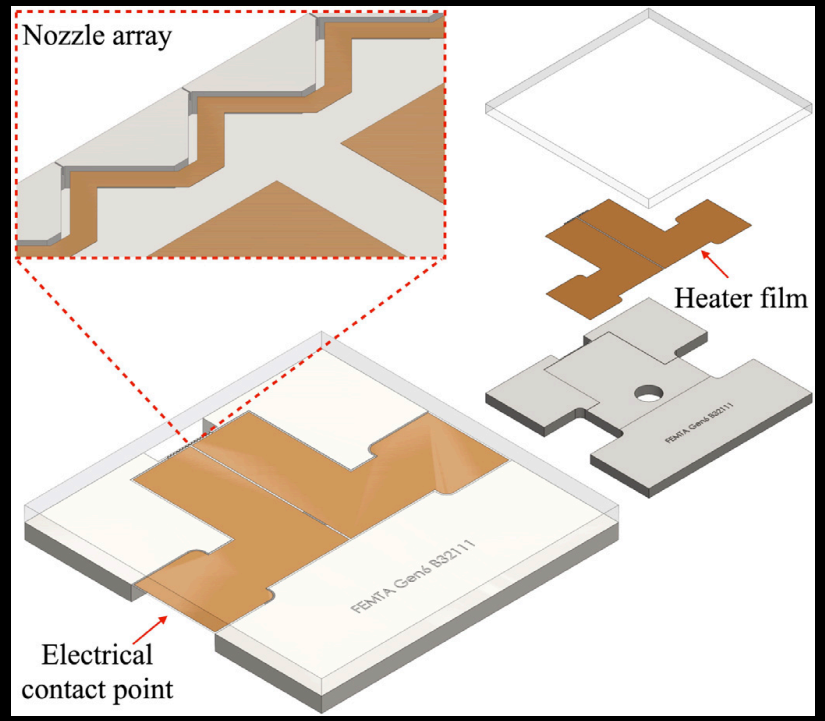
Chip size *1cm x 1cm x 1mm*

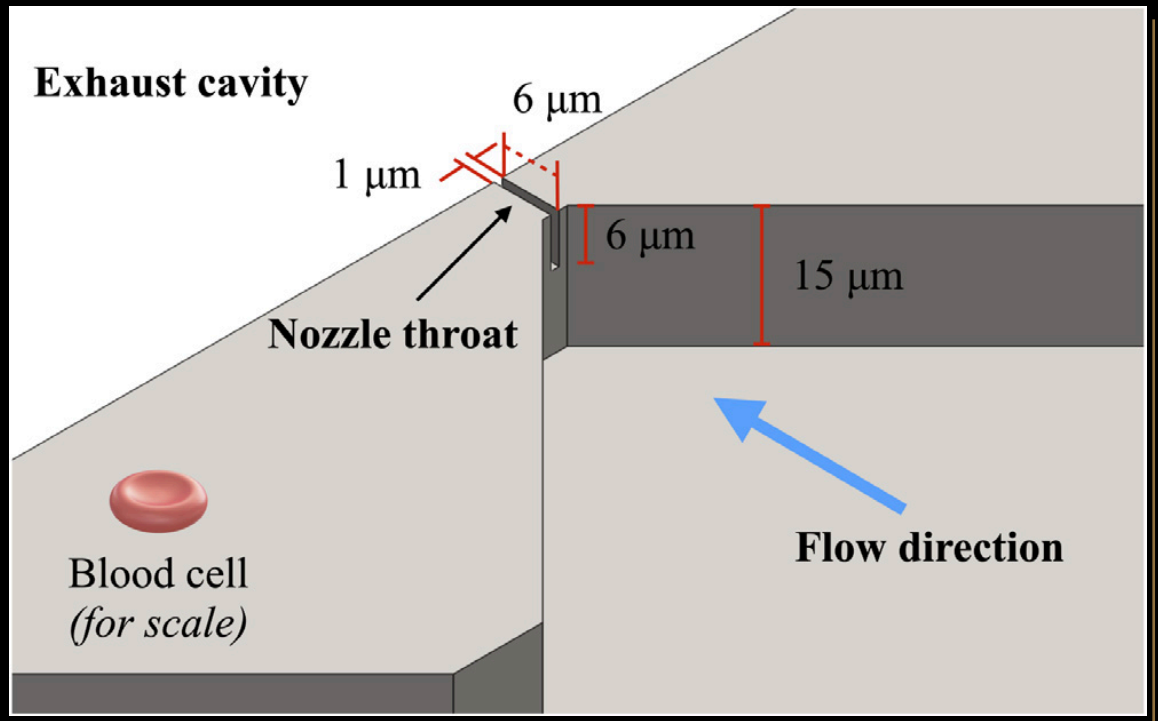
Nozzle width *1 μm*

Propellant *Ultra-pure deionized water*



FEMTA Microthruster – Fabrication & Isometric view





FEMTA Microthruster-Operational Theory

Capillary Flow

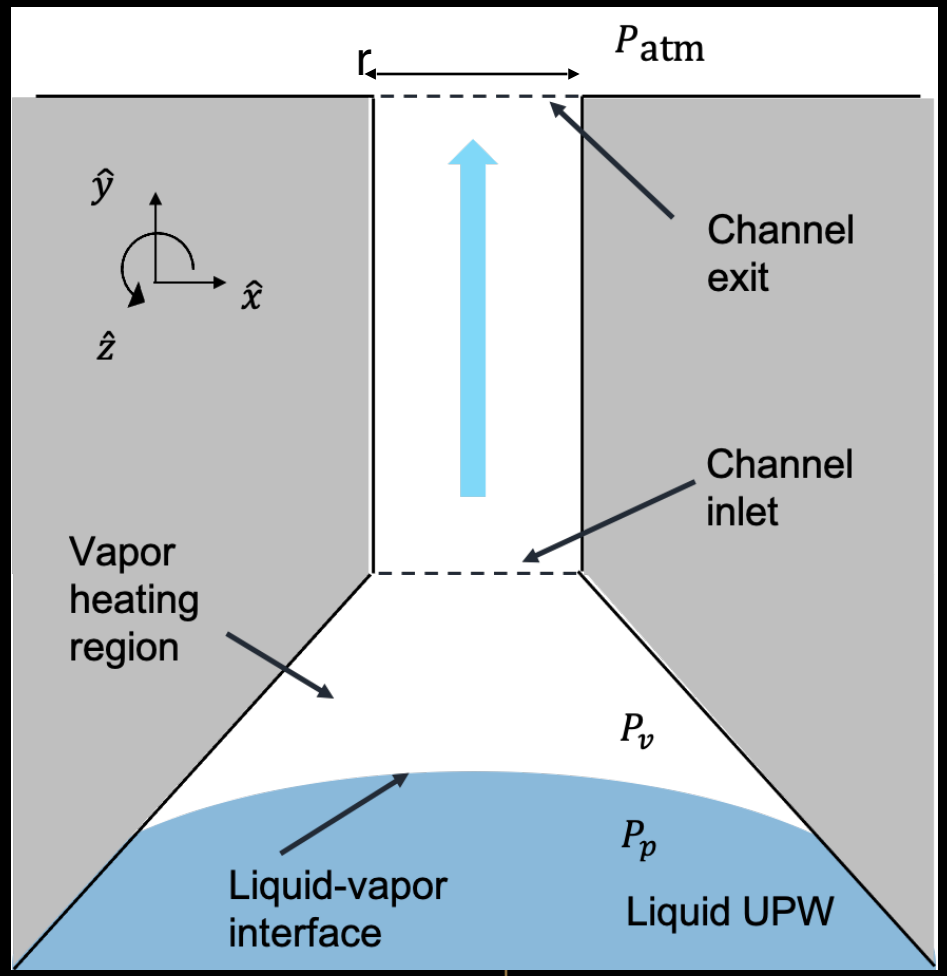
- Small Channel width and high surface tension prevent evacuation of propellant

$$B = \frac{\rho g L^2}{\sigma} \quad (1)$$

$$P_p \leq P_L + P_v \quad (2)$$

$$P_L \approx \sigma \frac{1}{r} \quad (3)$$

$P \equiv$ pressure
$\rho \equiv$ density
$g \equiv$ gravity accel.
$L \equiv$ char. length
$r \equiv$ width of nozzle
$\sigma \equiv$ surface tension
$\mathrm{B} \equiv$ Bond number



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Operational Theory

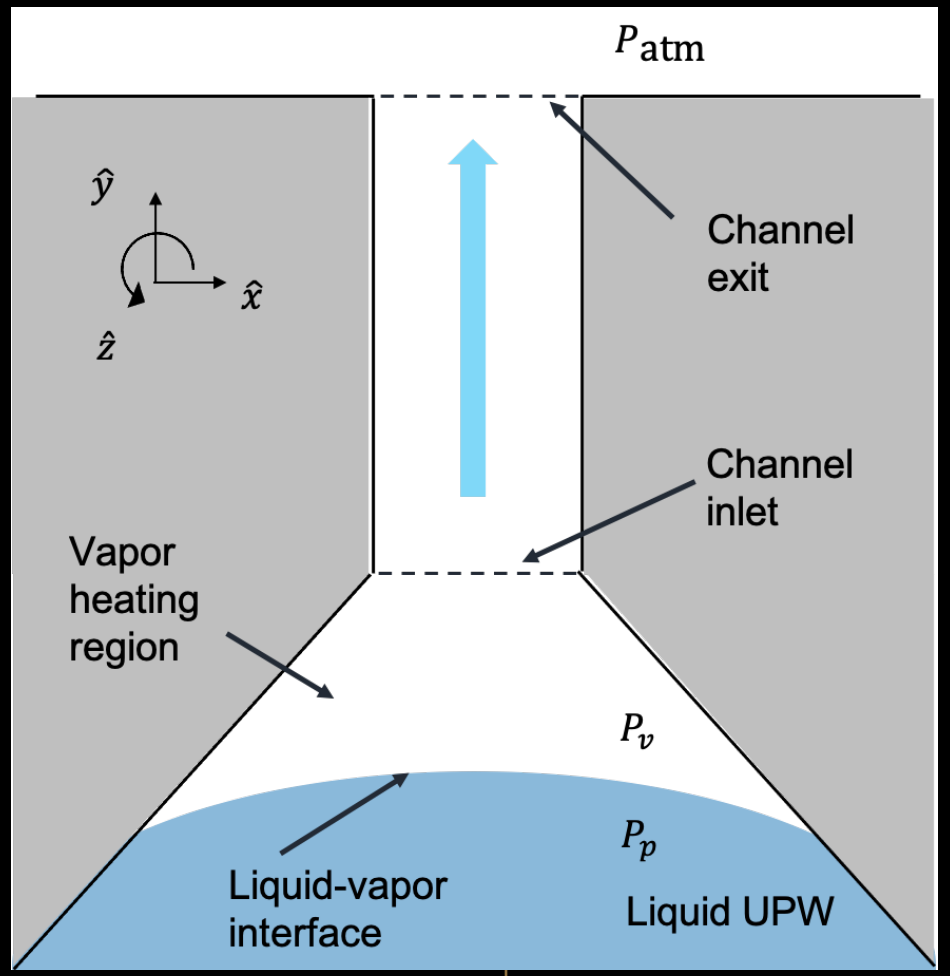
Capillary Flow

- Heating the water increases vapor pressure
- Equilibrium is broken, thrust begins

$$P_v = -P_{\text{ref}} \left[\exp\left(\frac{\Delta H_{\text{vap}}}{R} \left(\frac{1}{T_i} - \frac{1}{T_{\text{ref}}} \right) \right) \right] \quad (4)$$

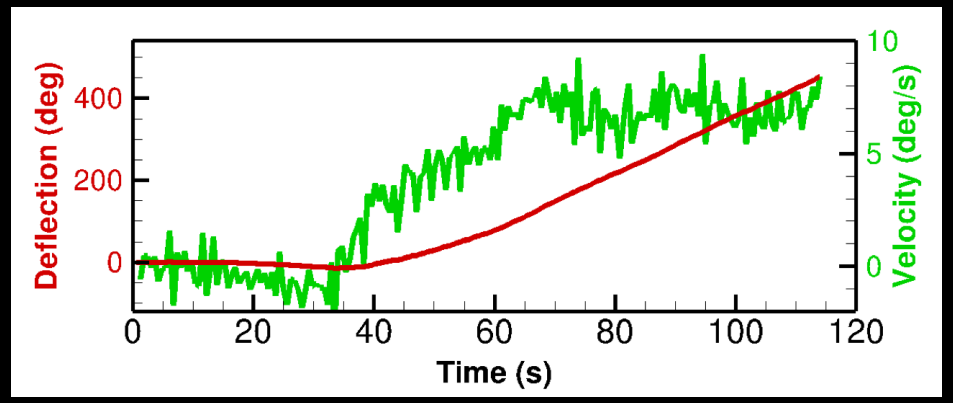
$$F = \dot{m} u_e + P_e A_e \quad (5)$$

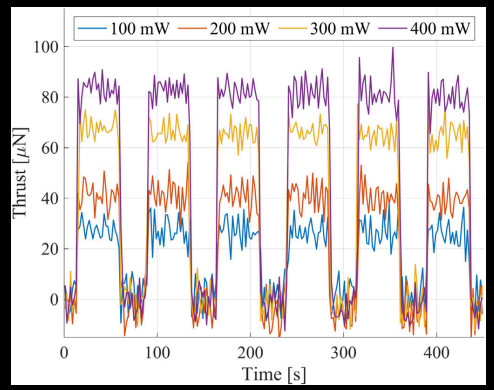
$e \equiv$ exit condition
ref $\equiv$ reference condition
$i \equiv$ interface condition
T $\equiv$ temperature
$u \equiv$ magnitude of velocity
$R \equiv$ spec. gas const.
$\dot{m} \equiv$ mass flow rate
A $\equiv$ Area
$\Delta H_{\text{vap}} \equiv$ Heat of vaporization
$F \equiv$ thrust

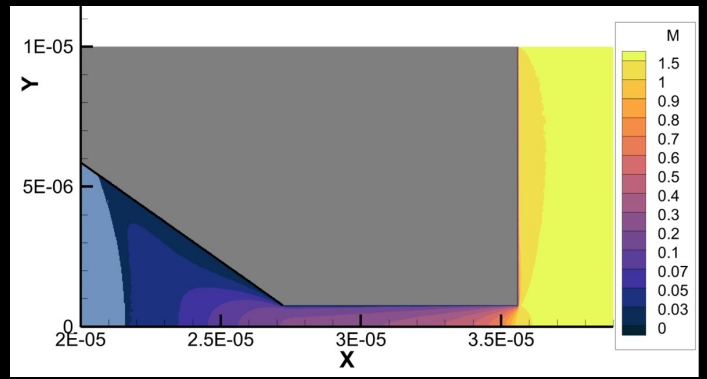


FEMTA Microthruster-Previous Work

- Control Demonstration[1]
- Failure mode analysis[2]
- DSMC modeling[3,4]
- New fabrication design[5]







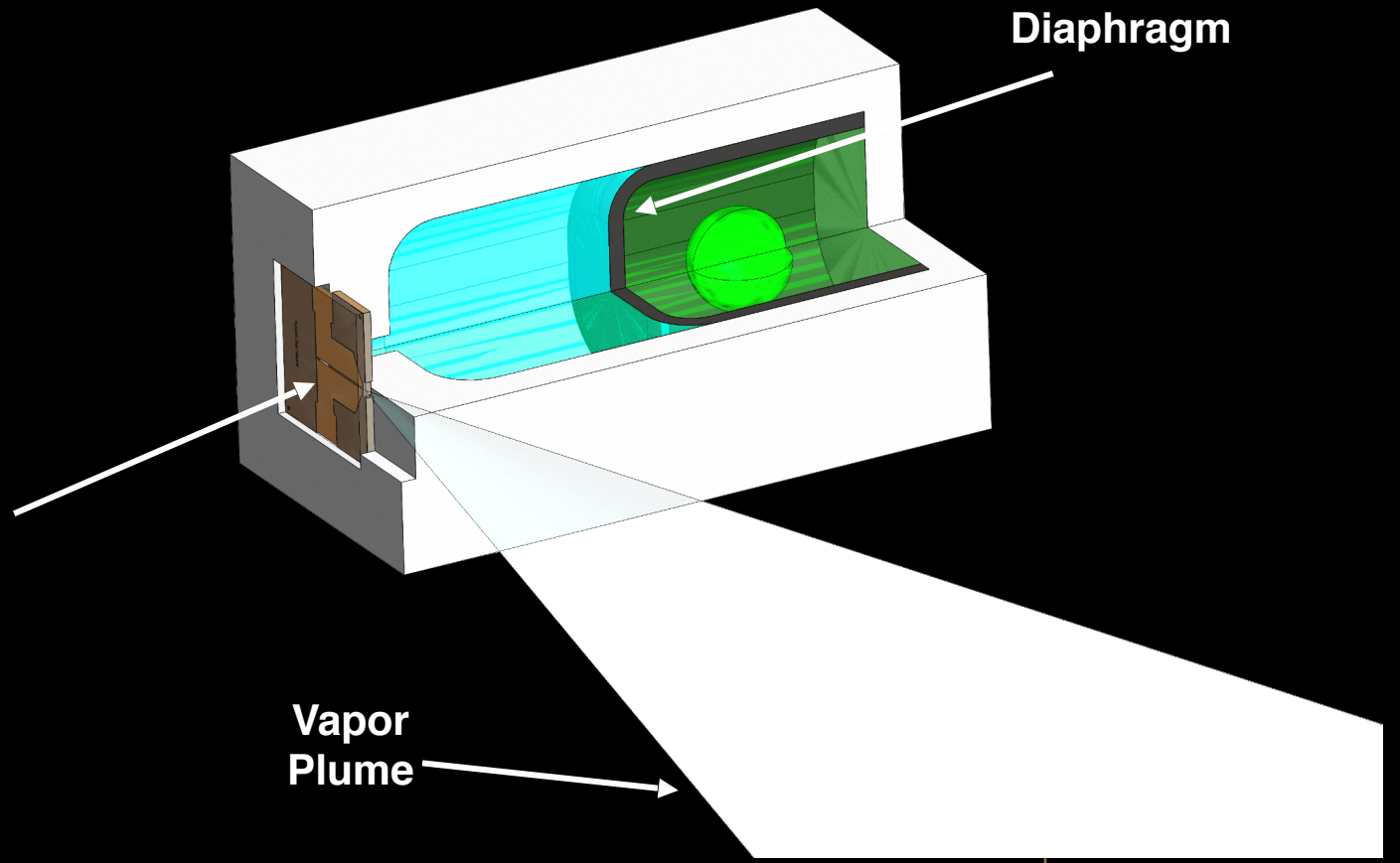
Propellant Management System- Vapor Pressure Driven Pump

Liquid water

Water vapor

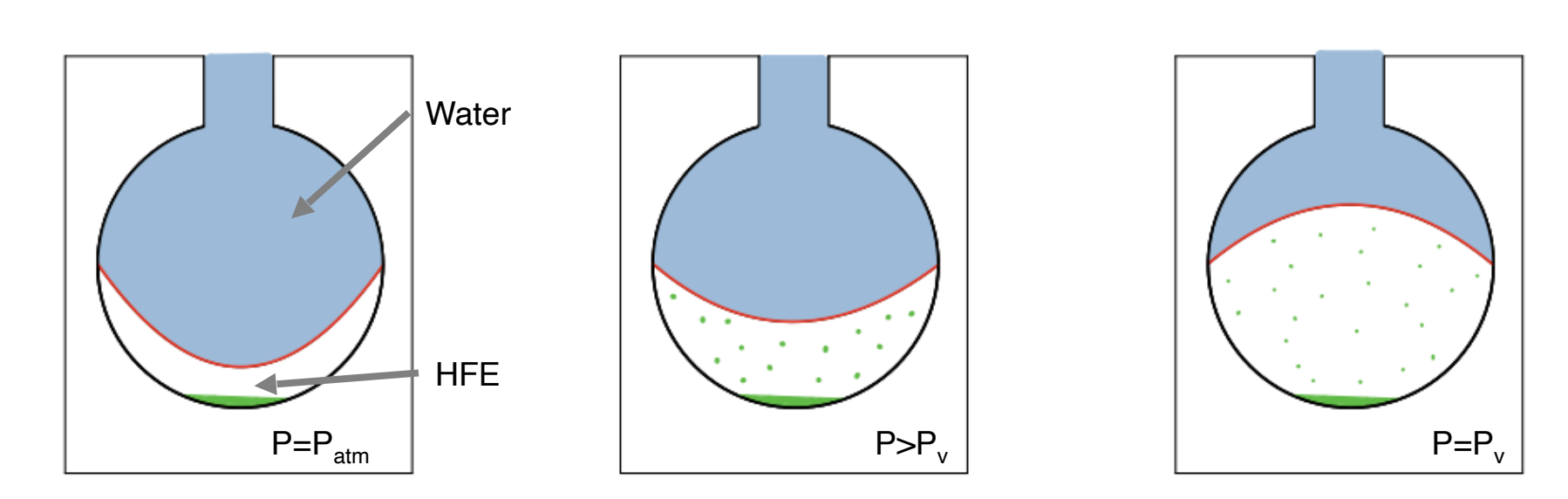
Pressurant Liquid

Pressurant vapor

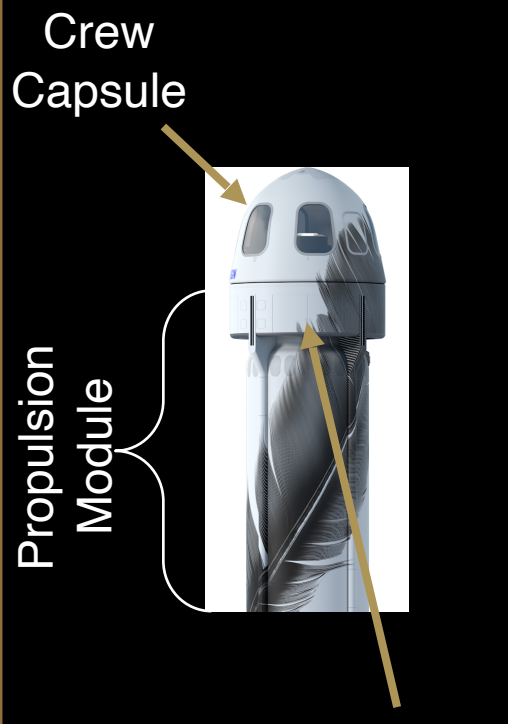


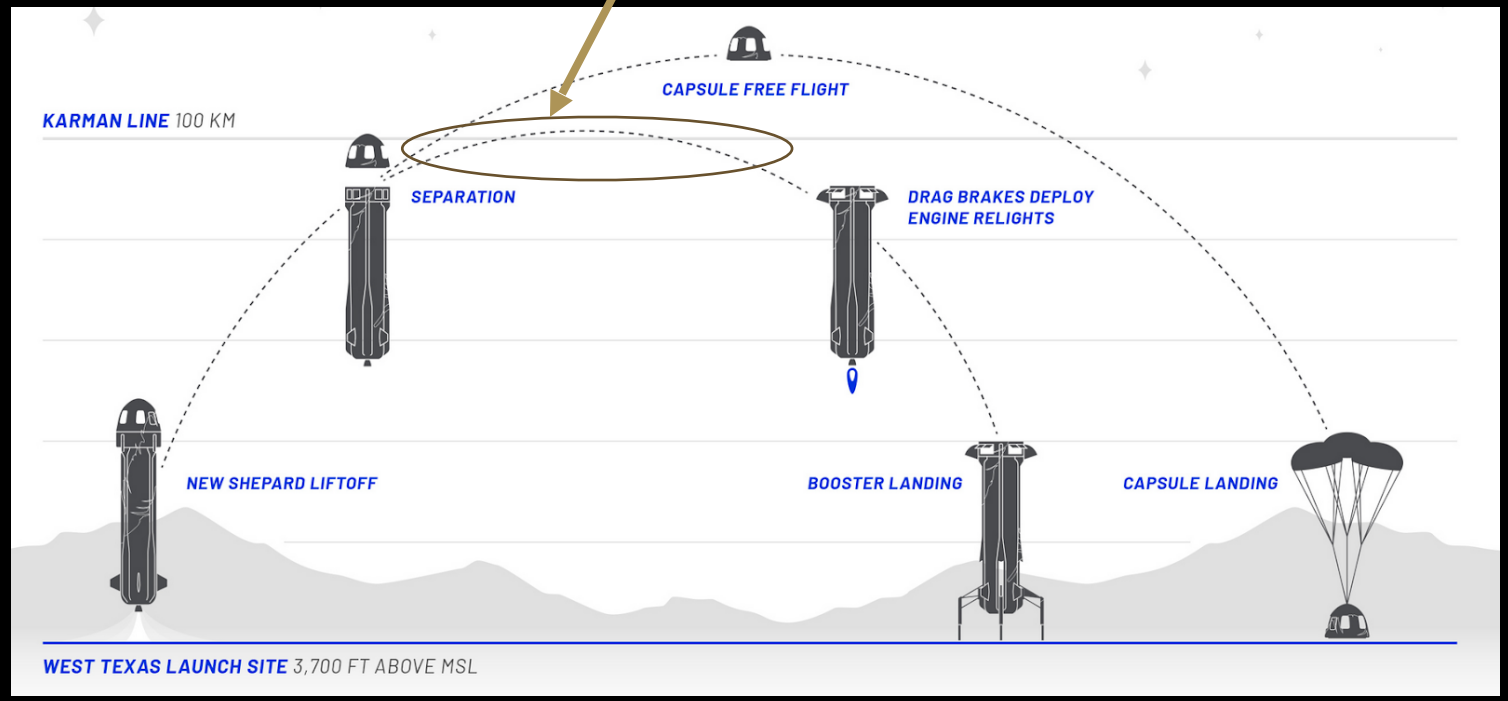
Propellant Management System

Vapor Pressure Driven Pump

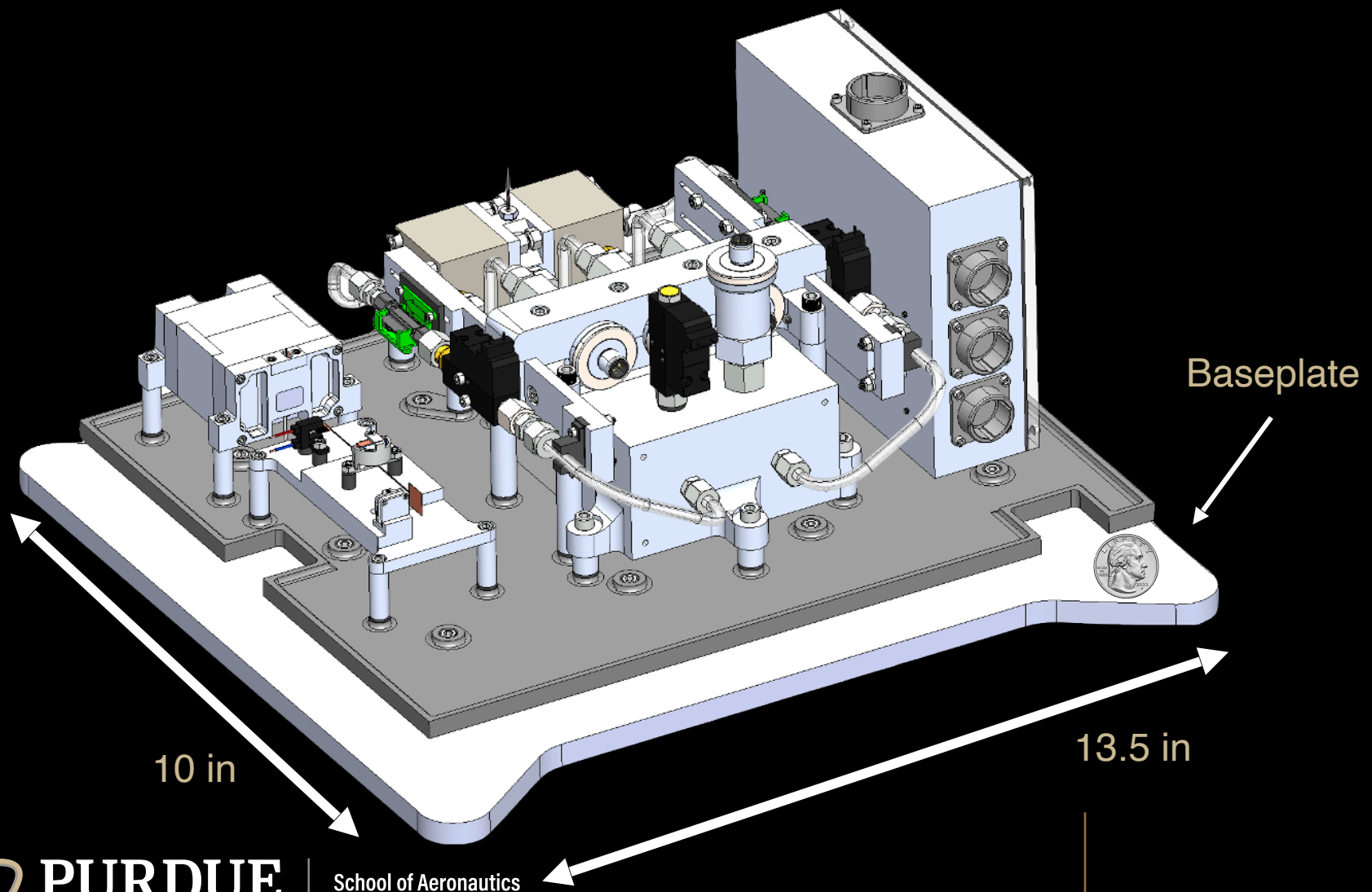


Suborbital Launch Payload





Propellant Management Experiment Design



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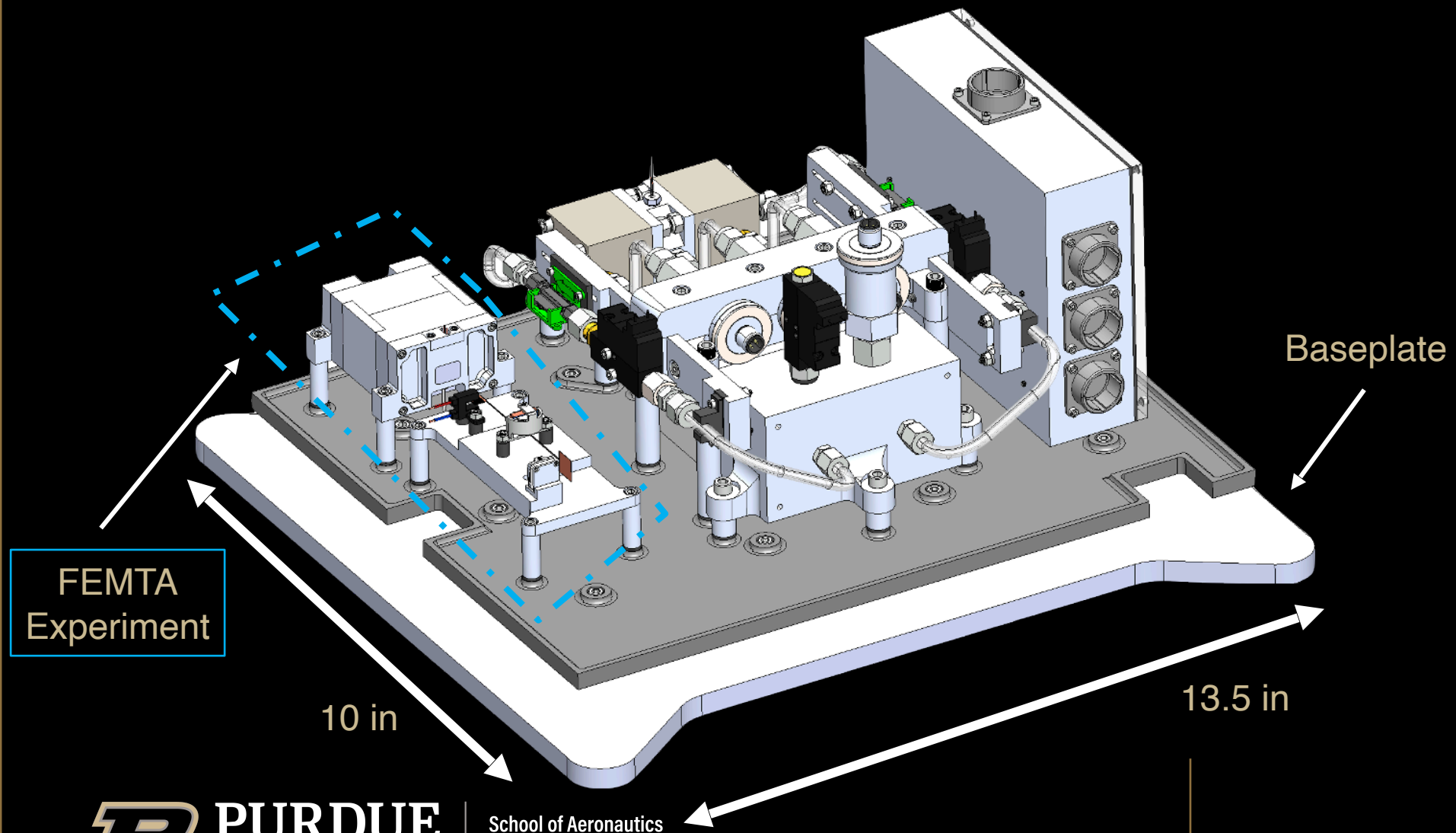

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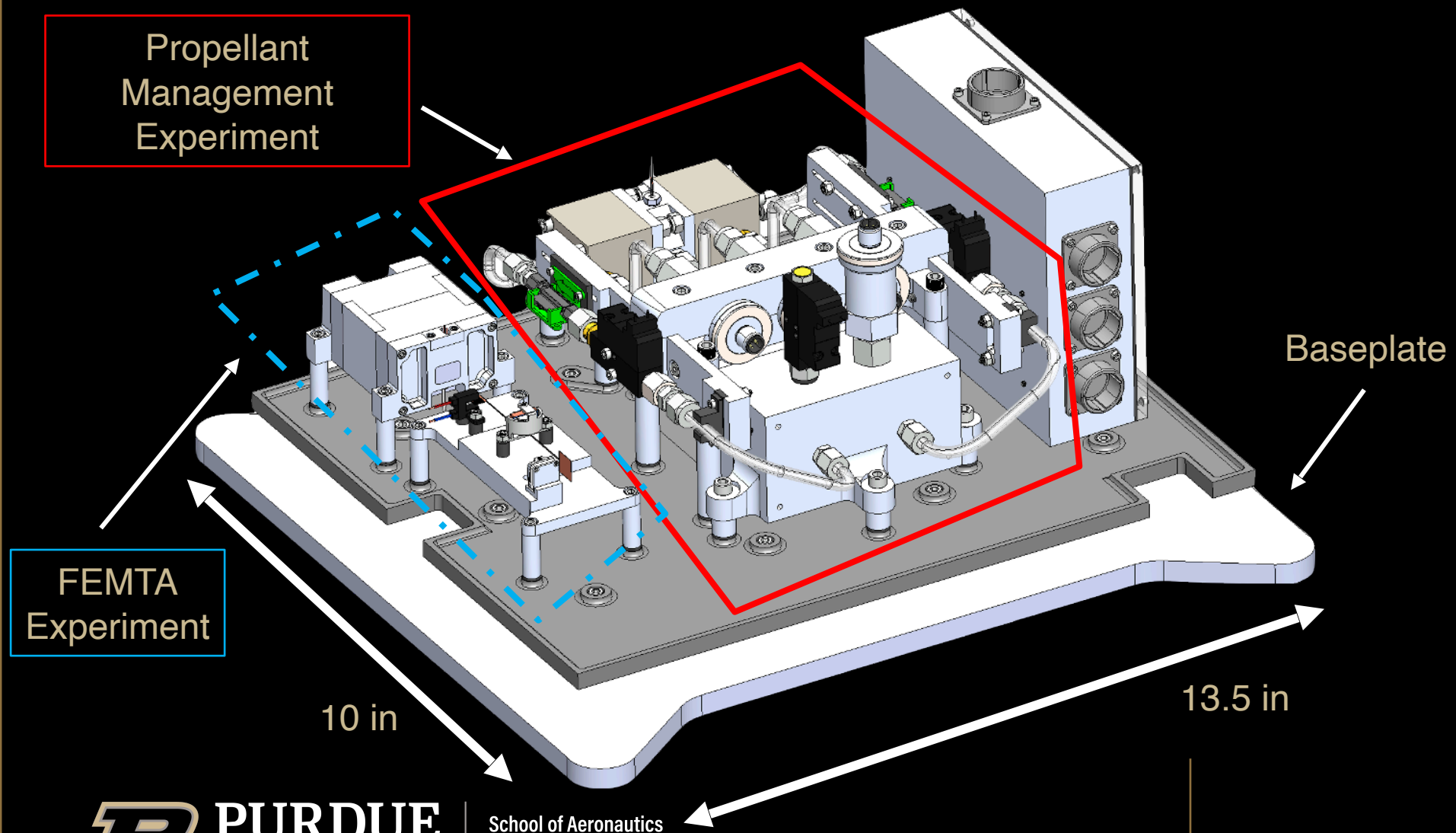

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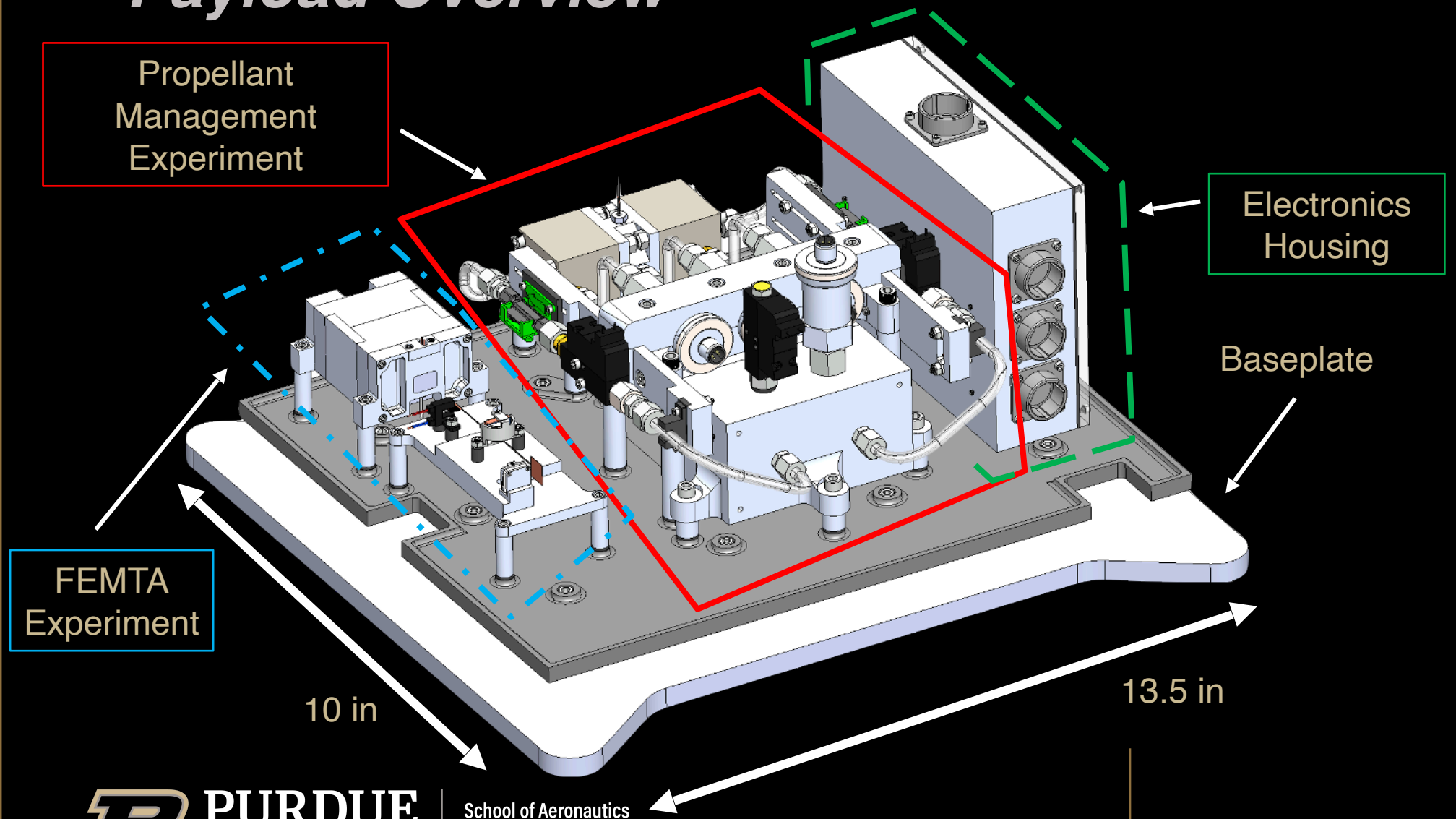
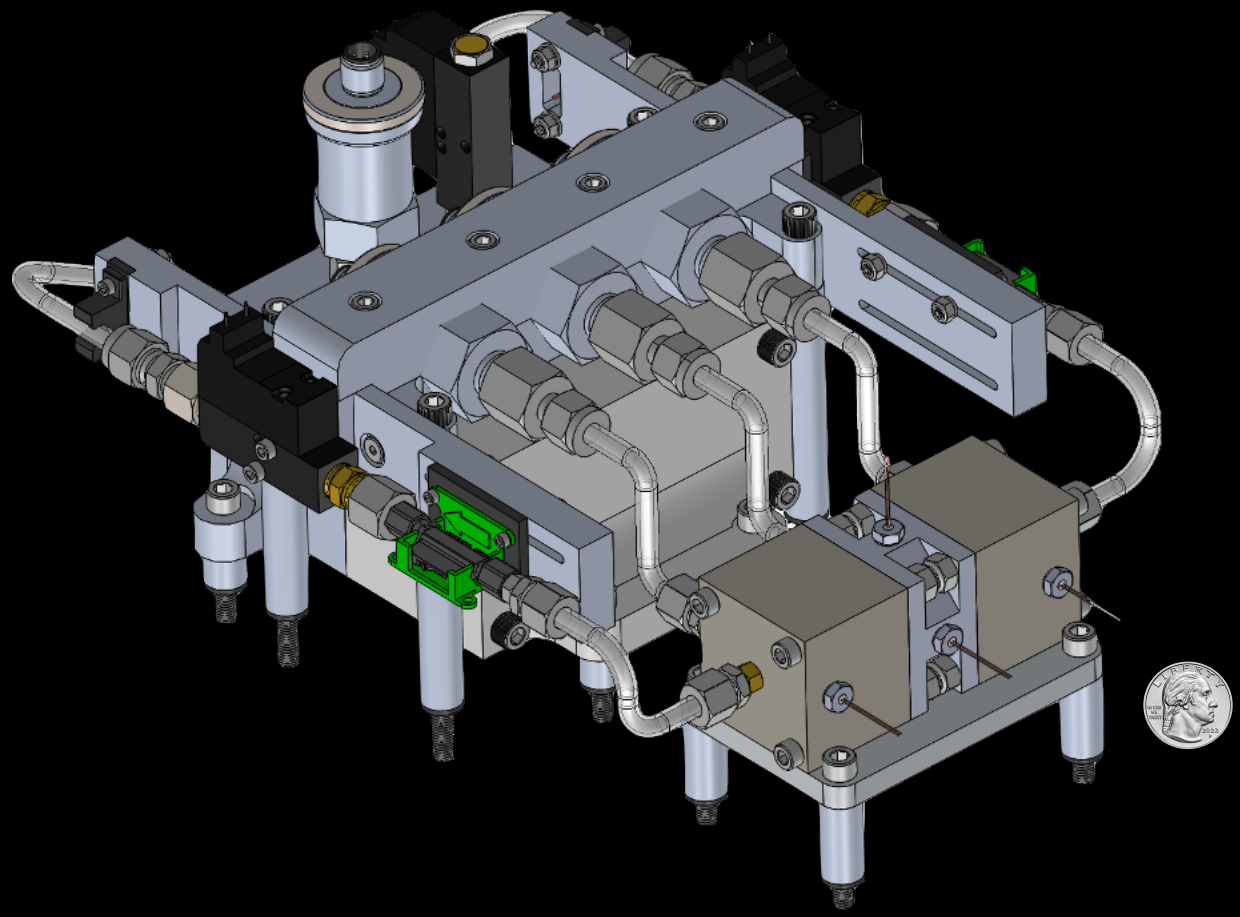
Payload Overview



Propellant Management Experiment Design



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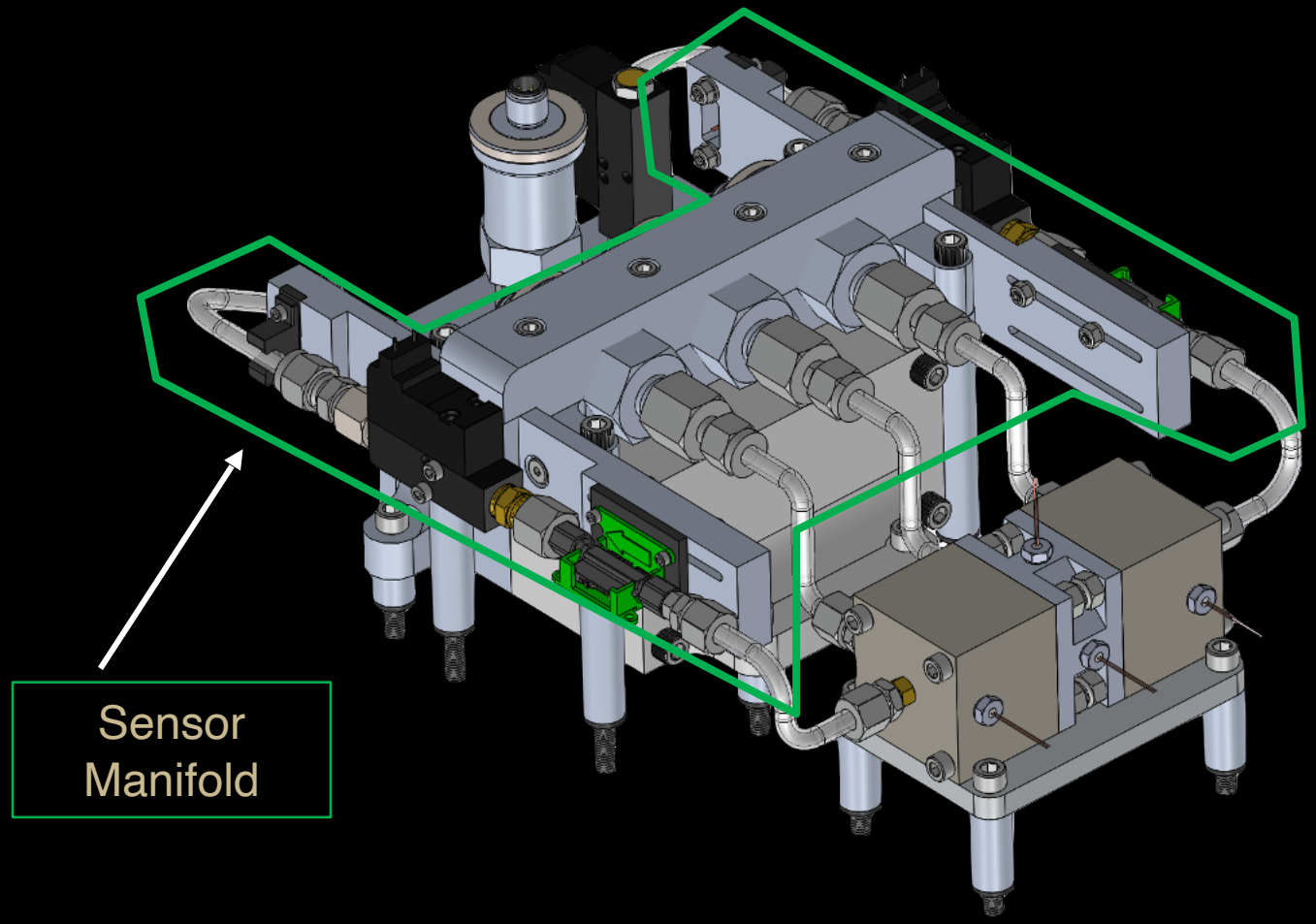
Propellant Management Experiment Design



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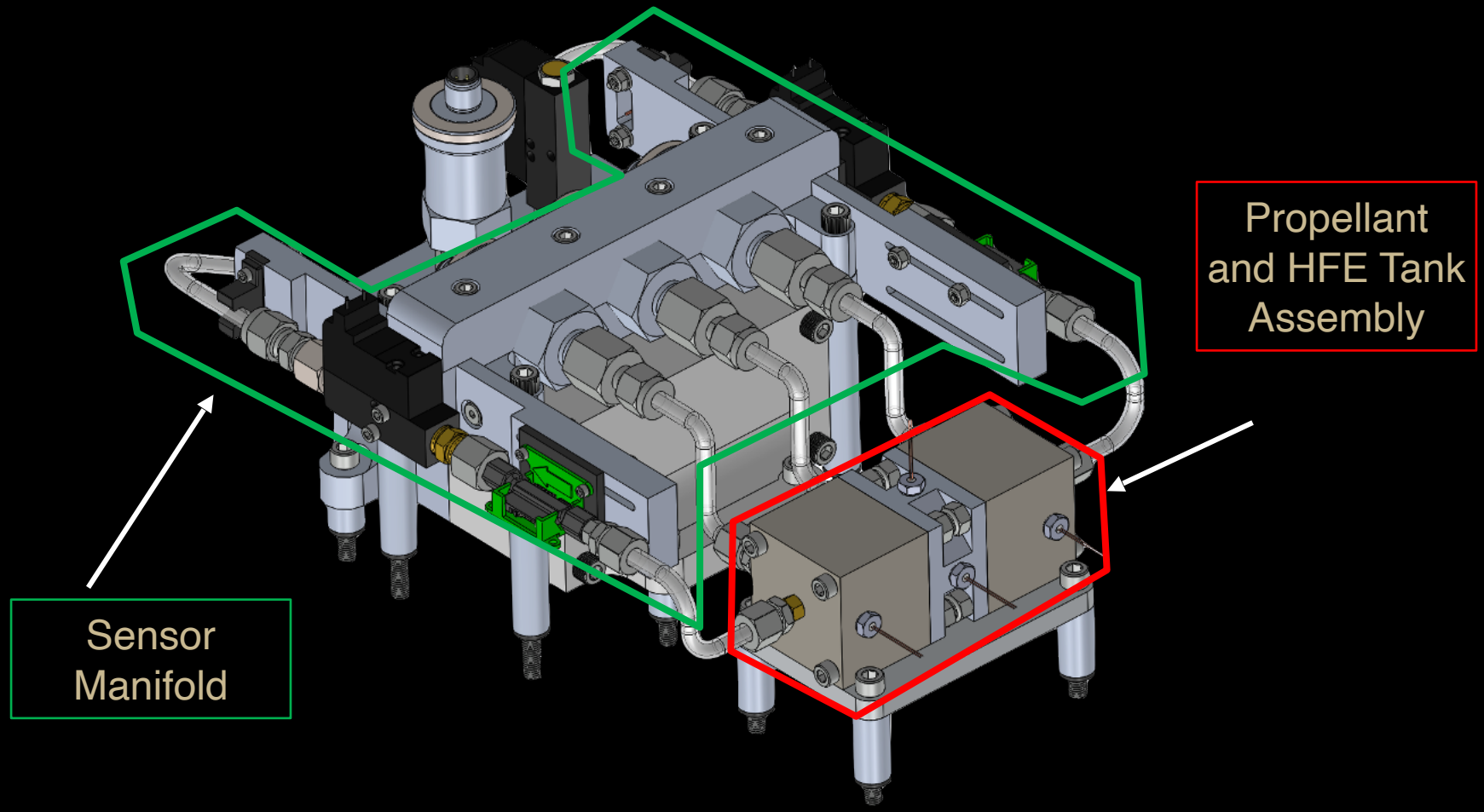

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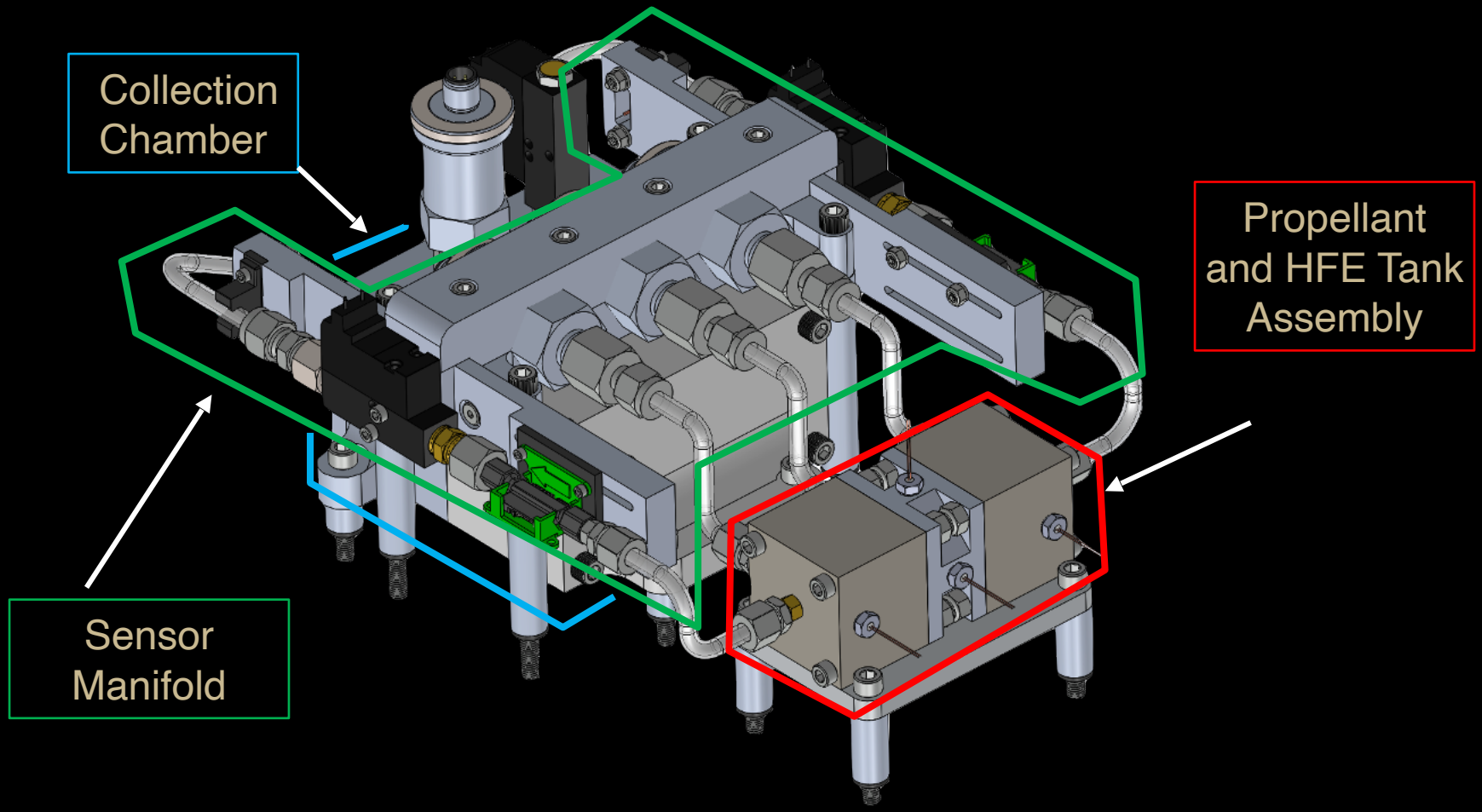
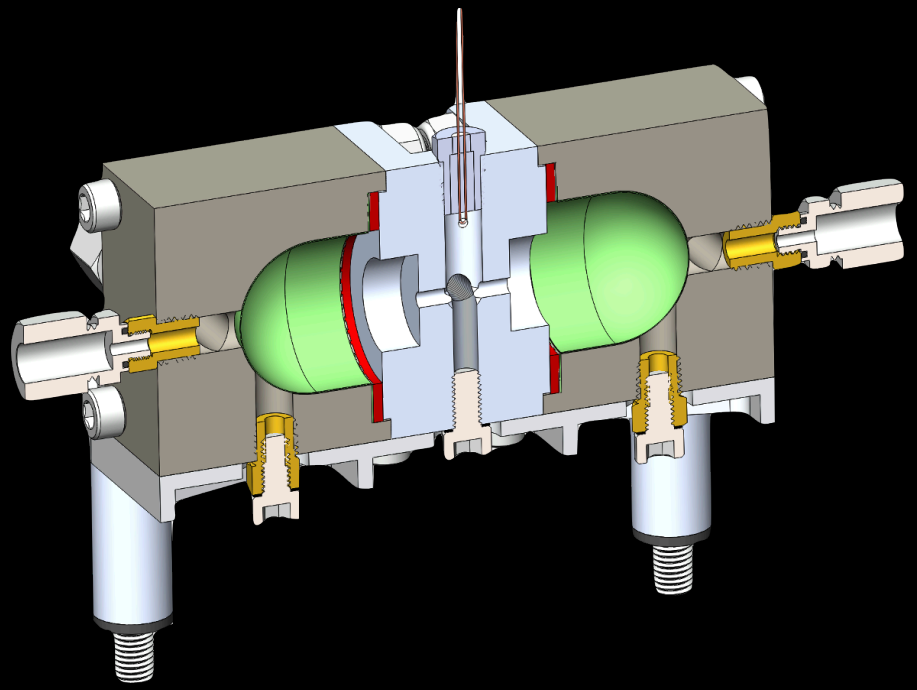
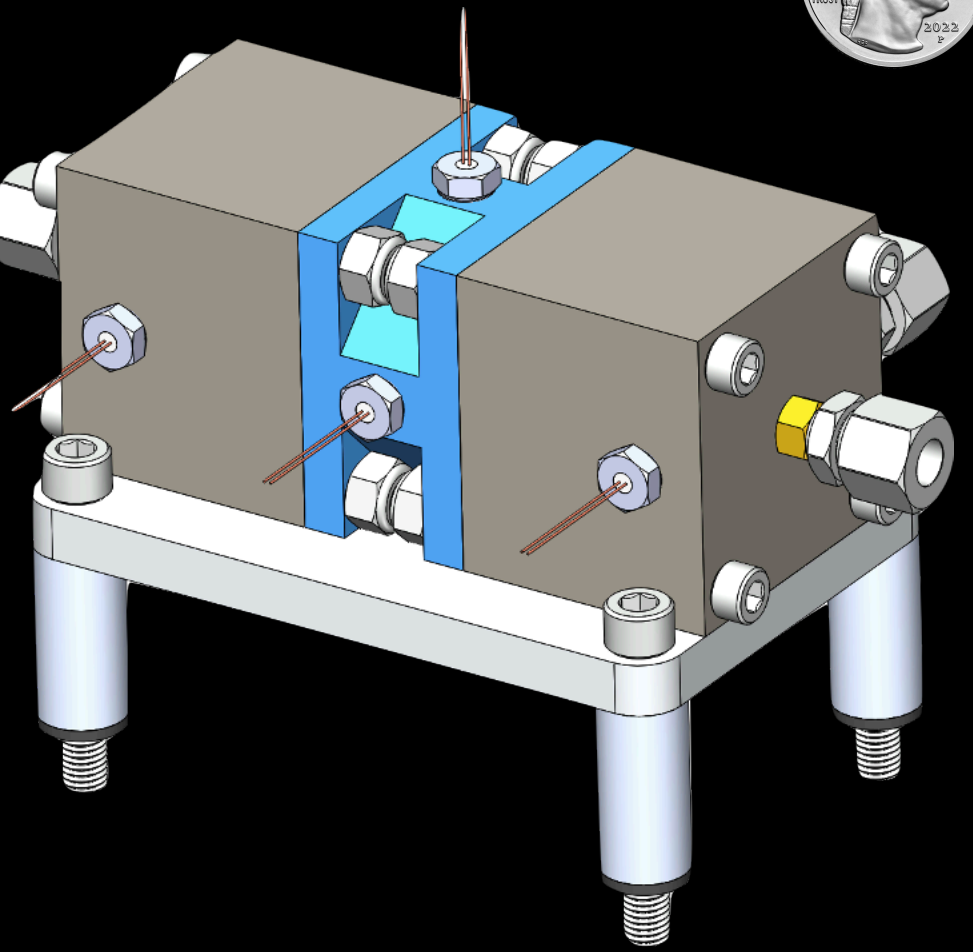


Propellant and HFE Tanks





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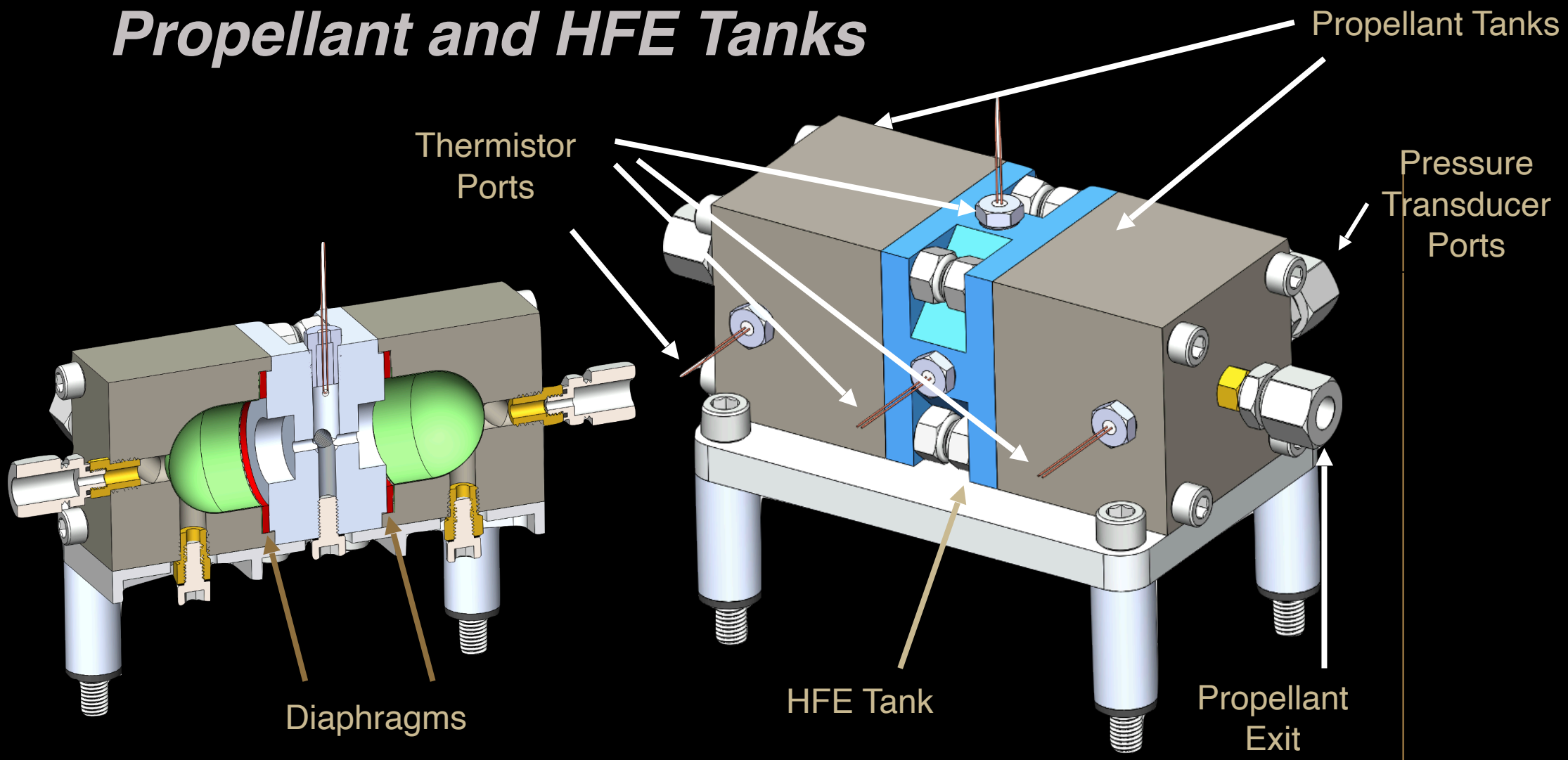
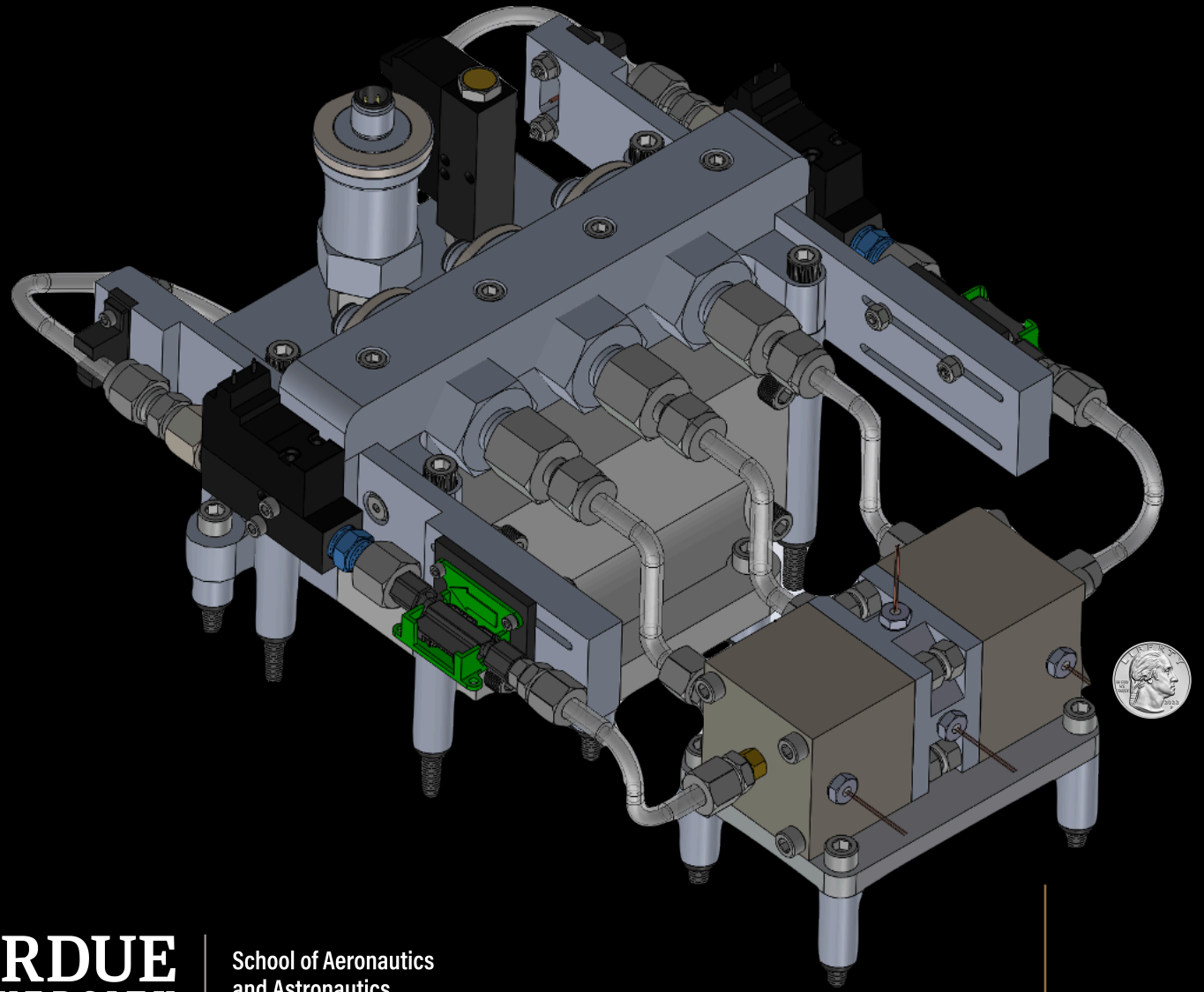


Sensors and Valves



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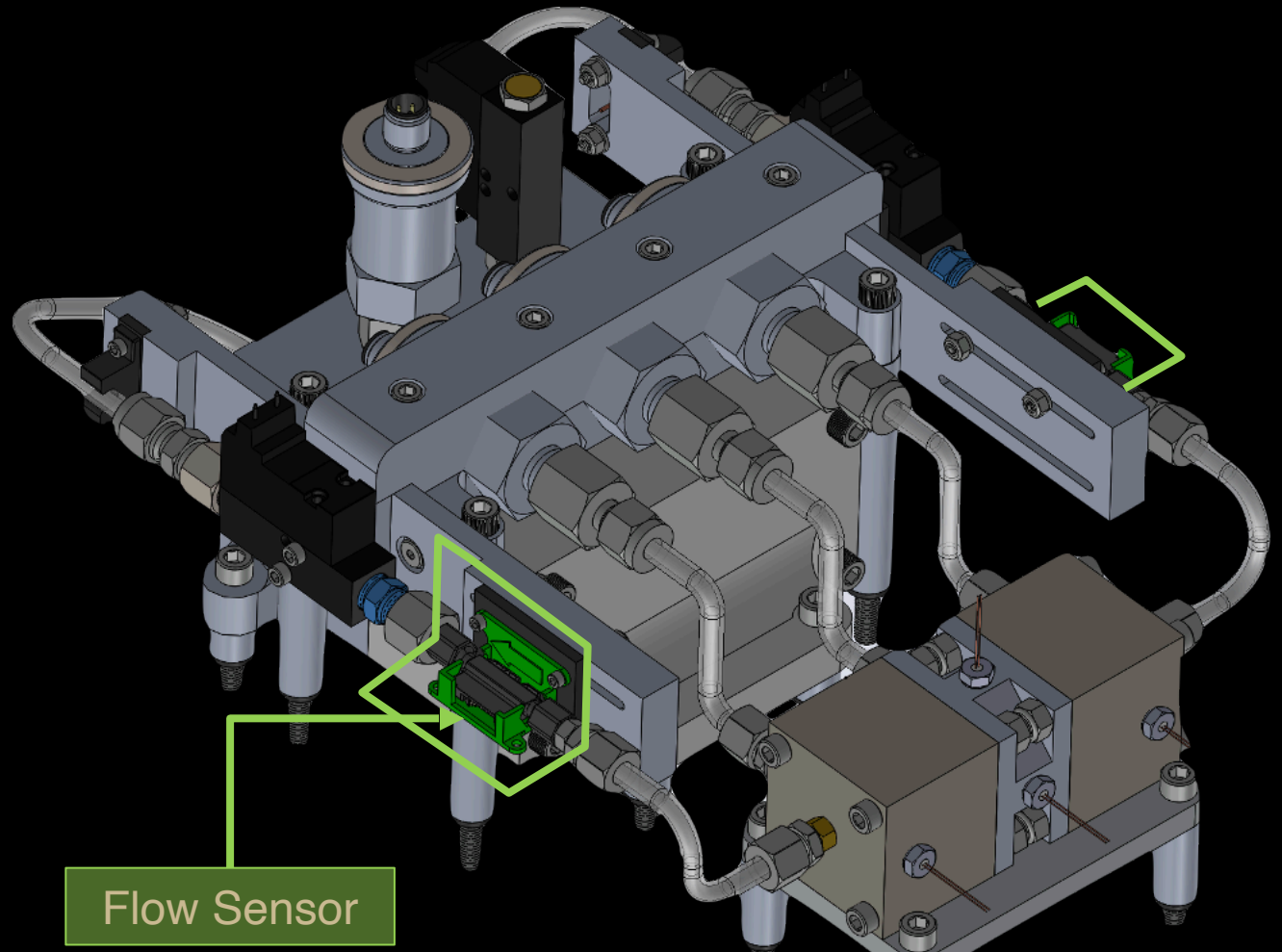

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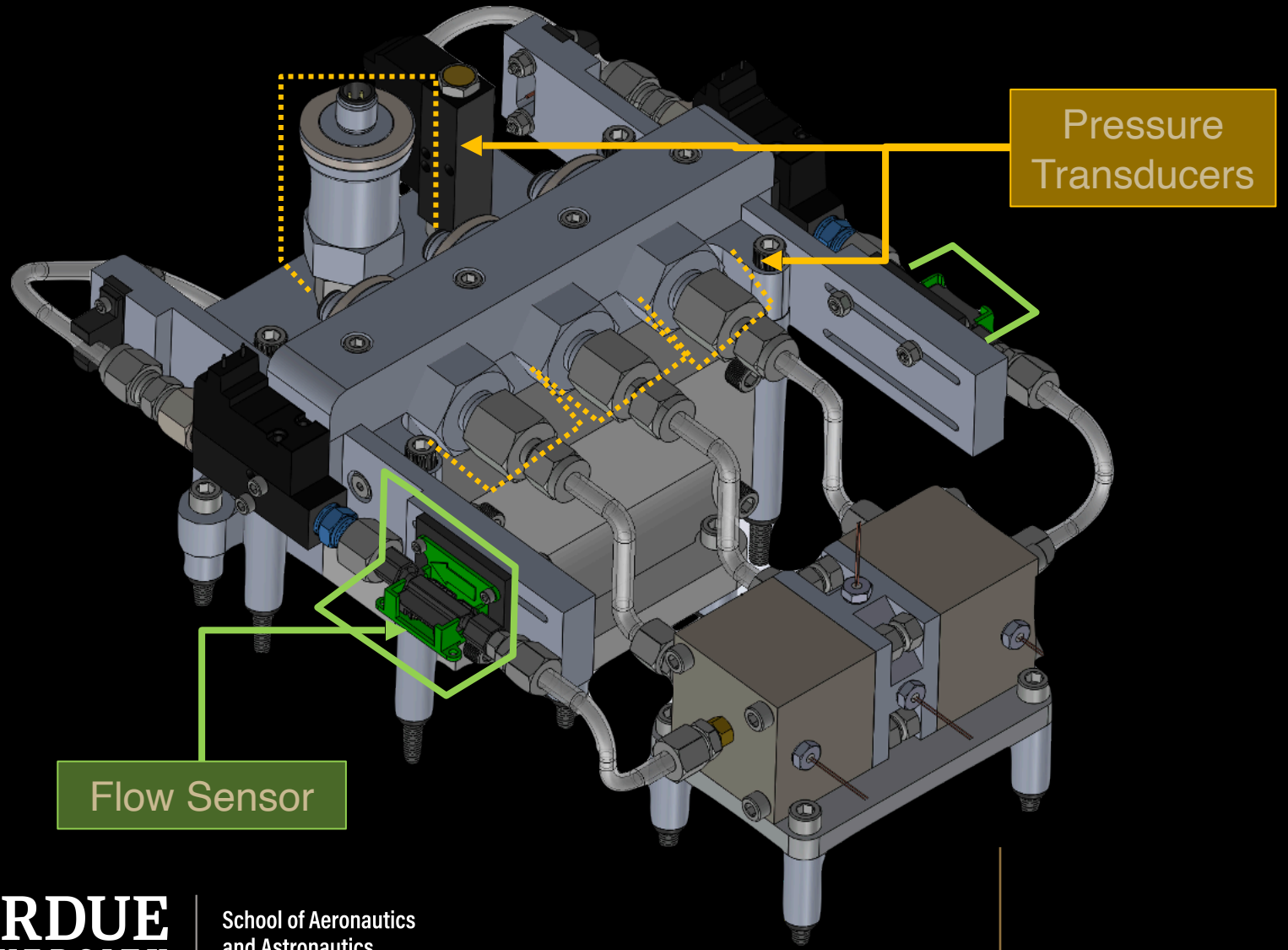

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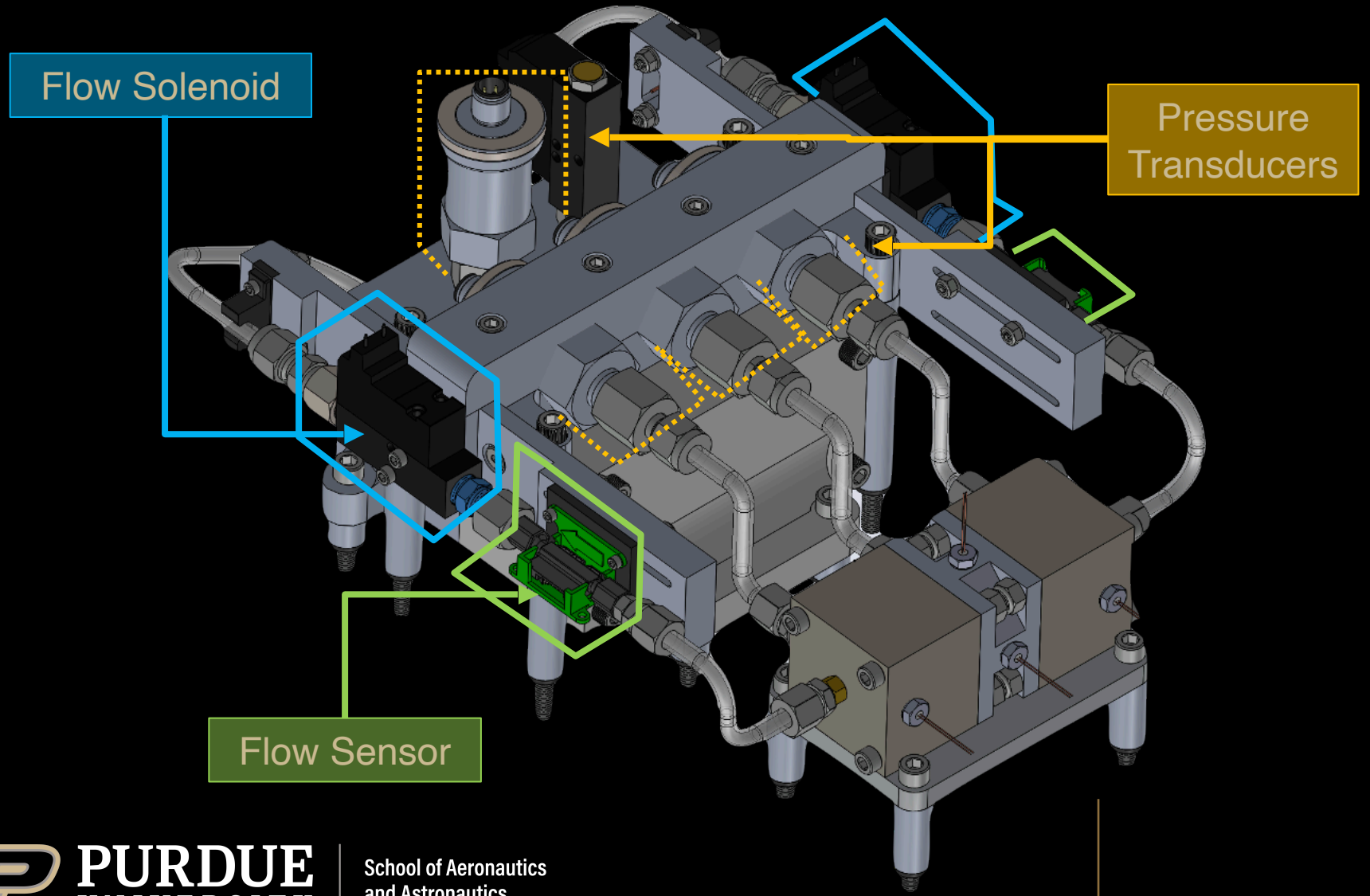
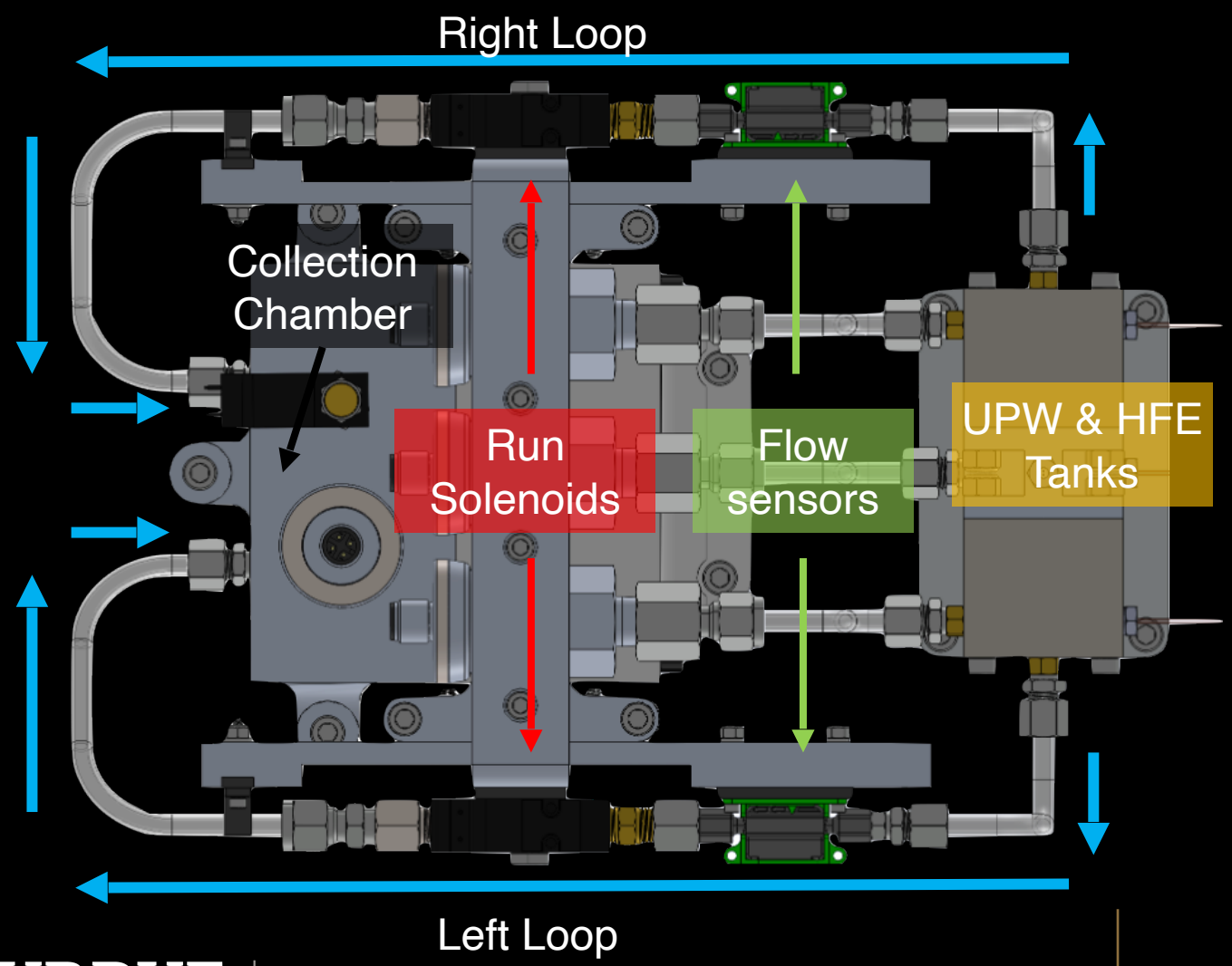
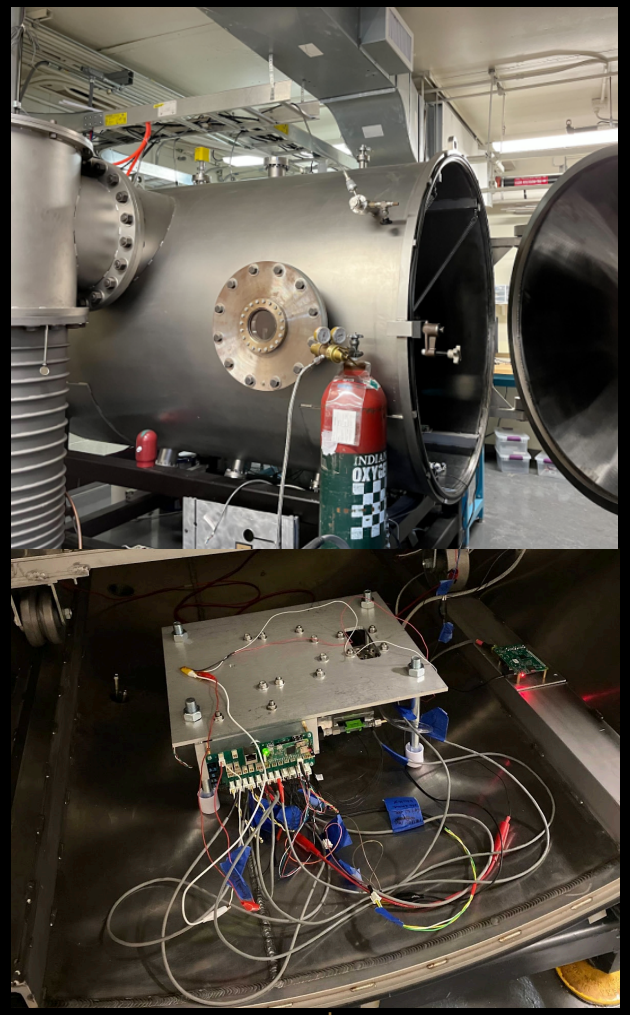


Flow Diagram

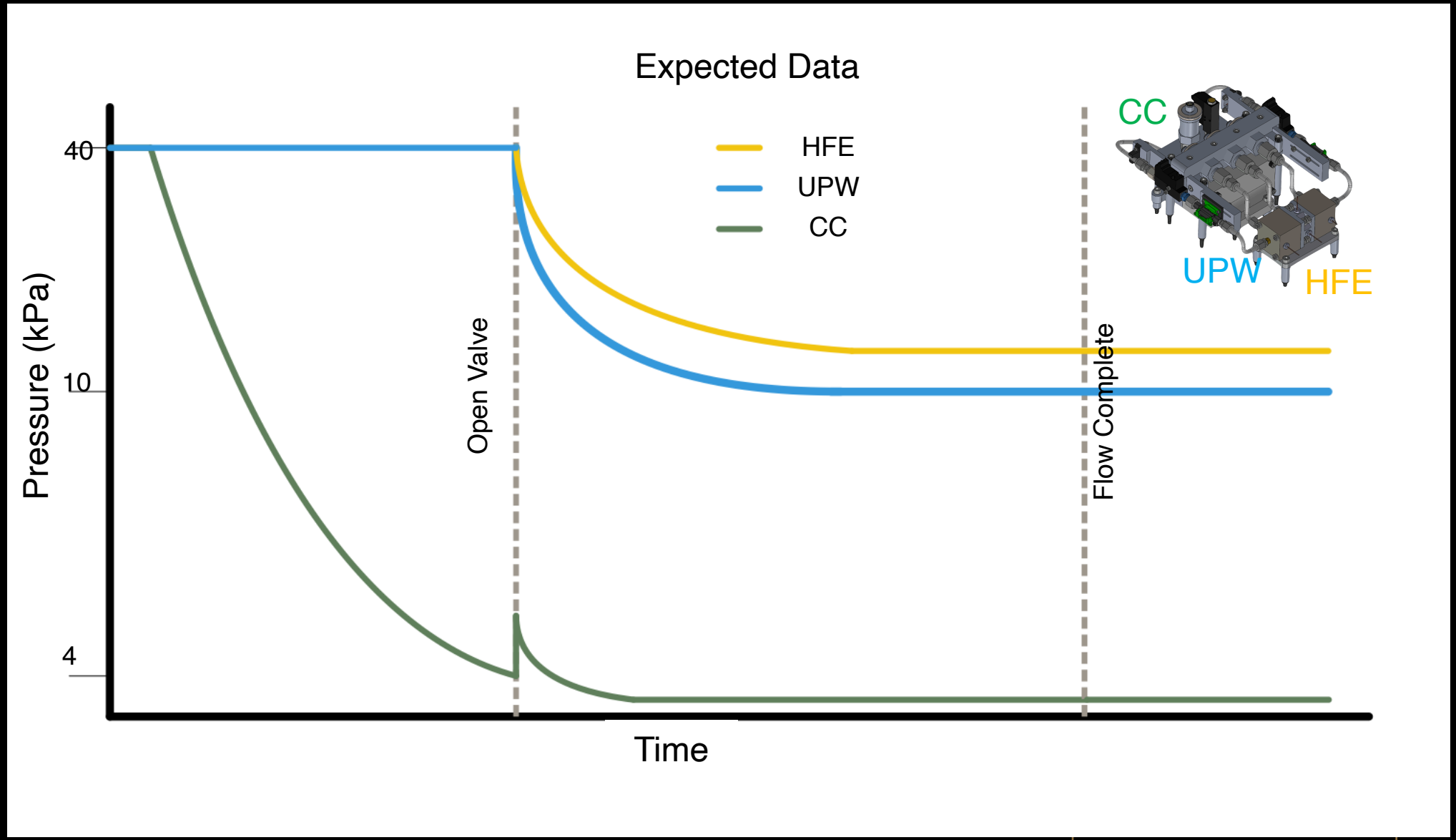


Flow Test Procedure

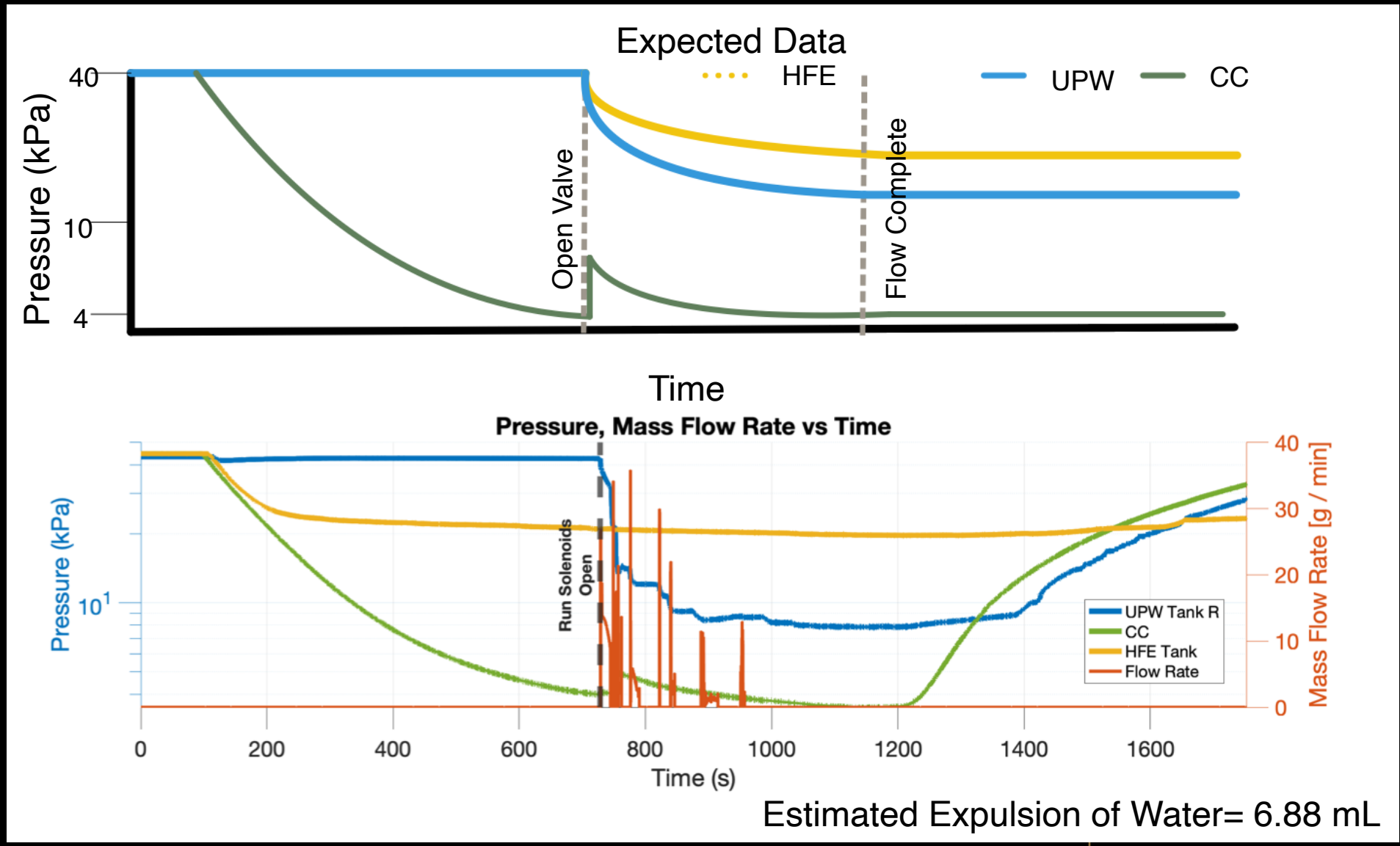
- ↓ Degass and load propellant
- ↓ Initialize flight computer
- ↓ Close run solenoid & open vent valve
- ↓ Begin data collection
- ↓ Begin chamber depressurization
- ↓ Close vent valve & open run solenoids at P < 4kPa

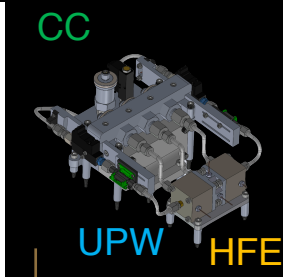


Results: Expected D



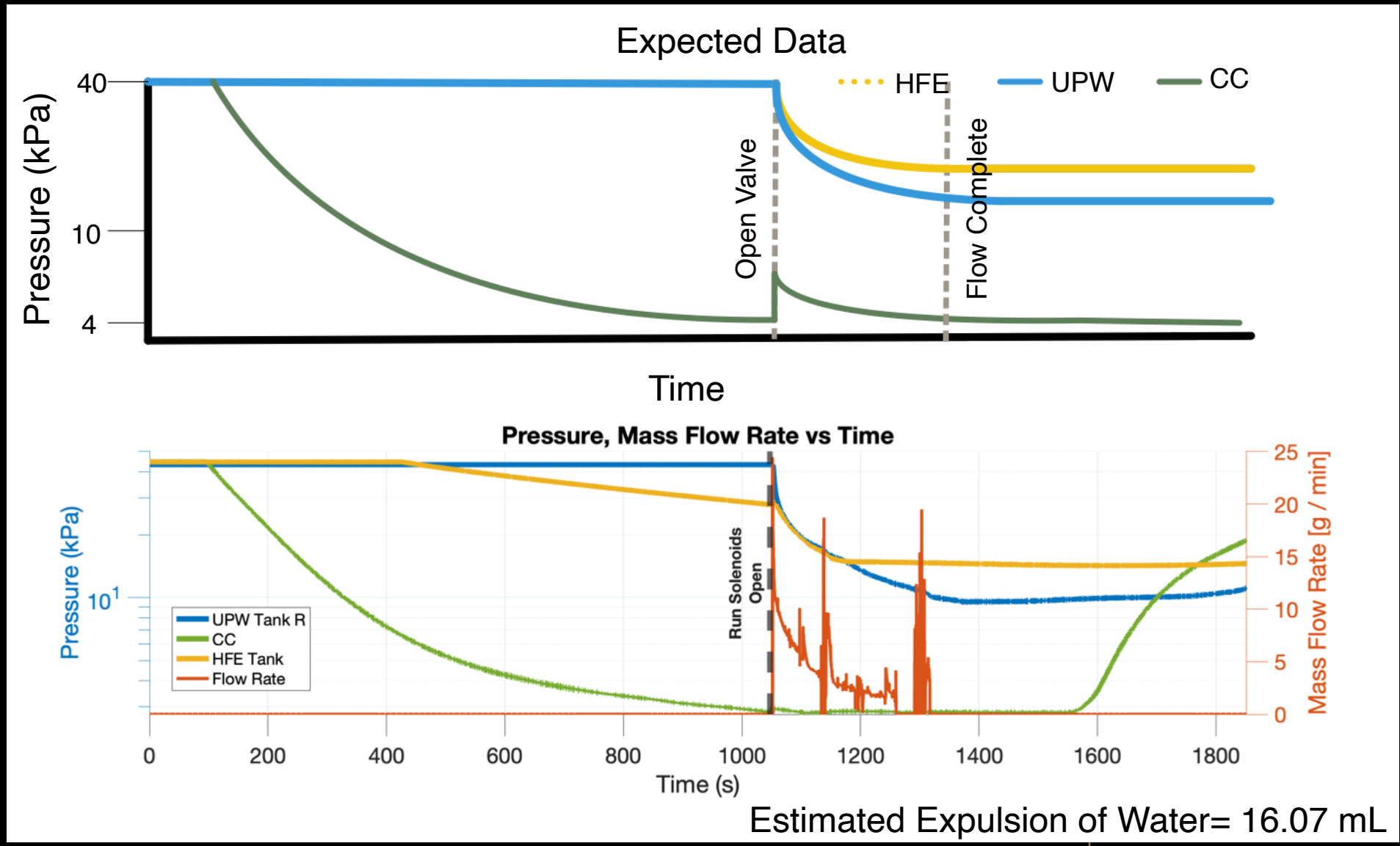
Results: Data Set A

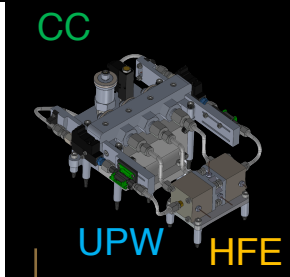




Estimated Expulsion of Water= 6.88 mL

Results: Data Set B





Estimated Expulsion of Water= 16.07 mL

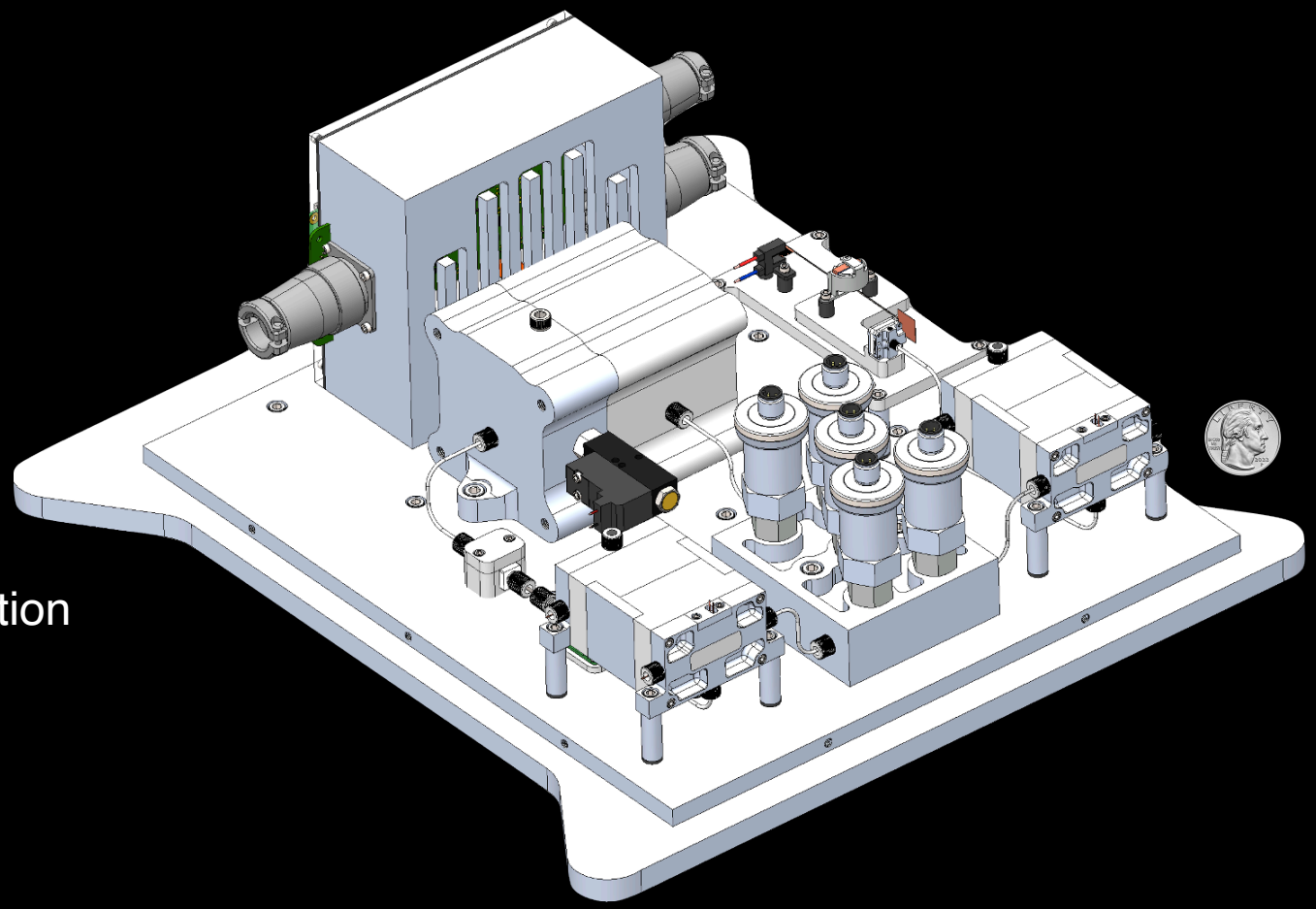
Final Design

Changes

- Single Flow Path
- Valve change
- Microfluidic tubes/fittings

Motivation

- Reduce risk and complication
- Circuit Design
- Flow improvement



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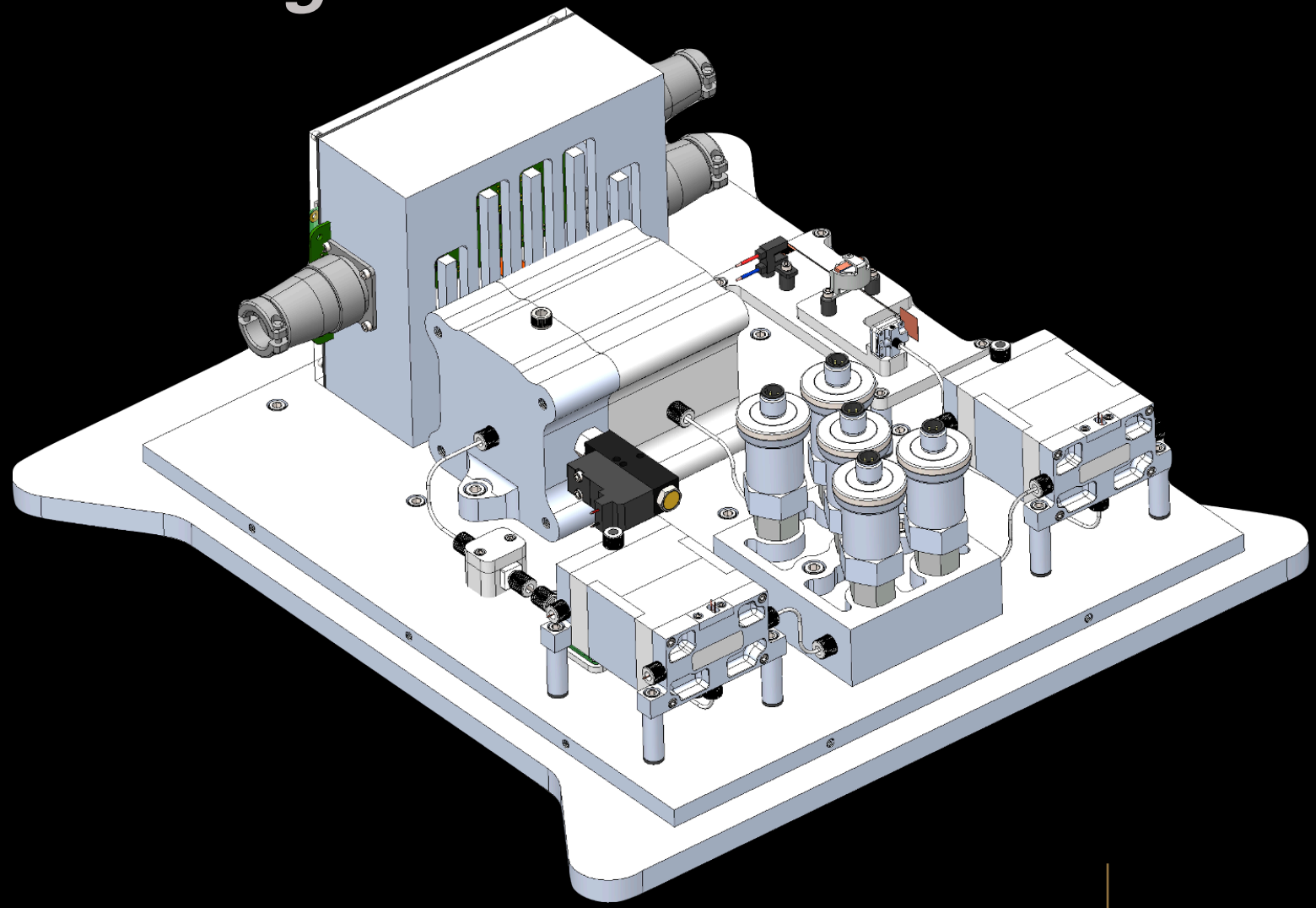
Final Design



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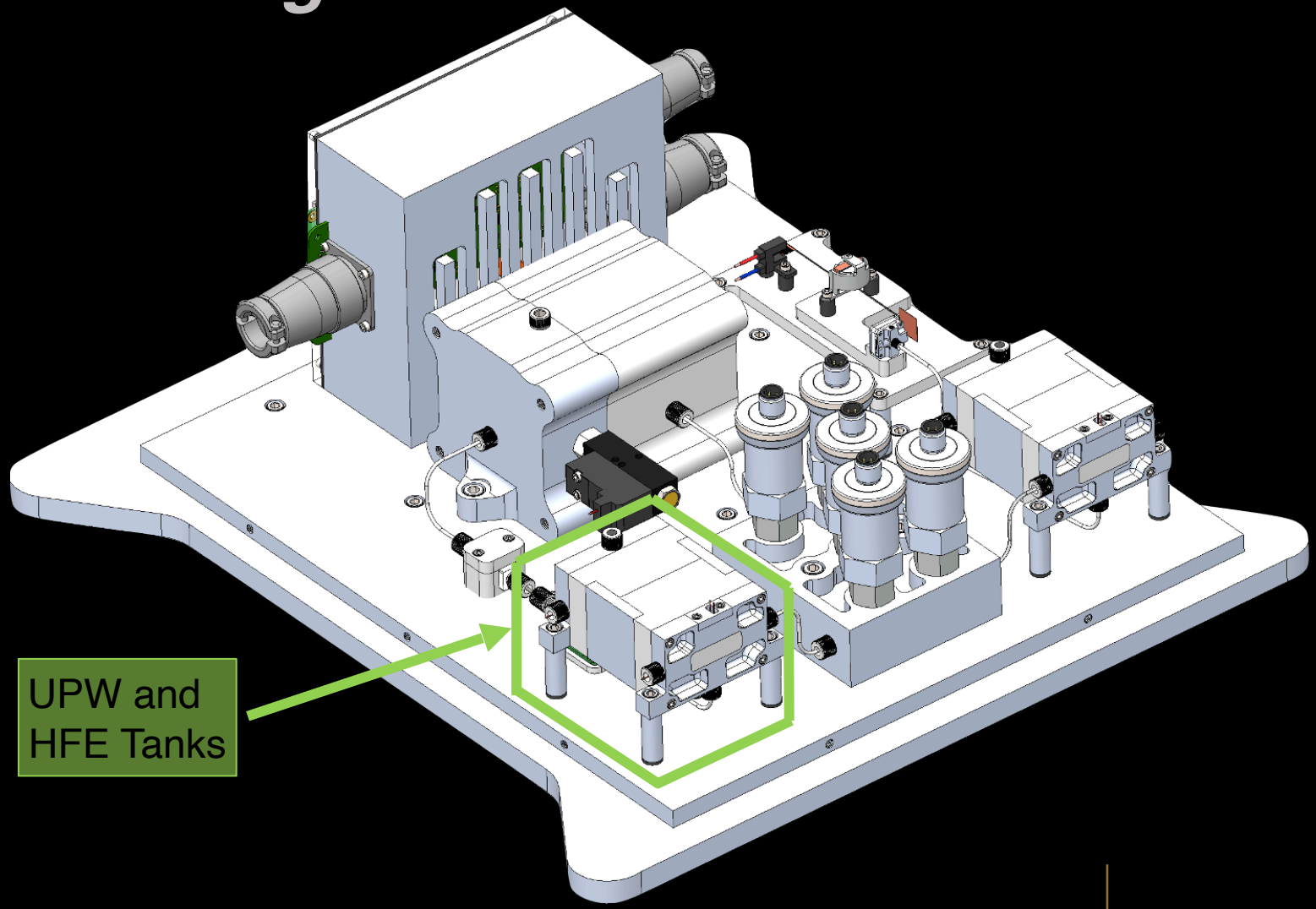

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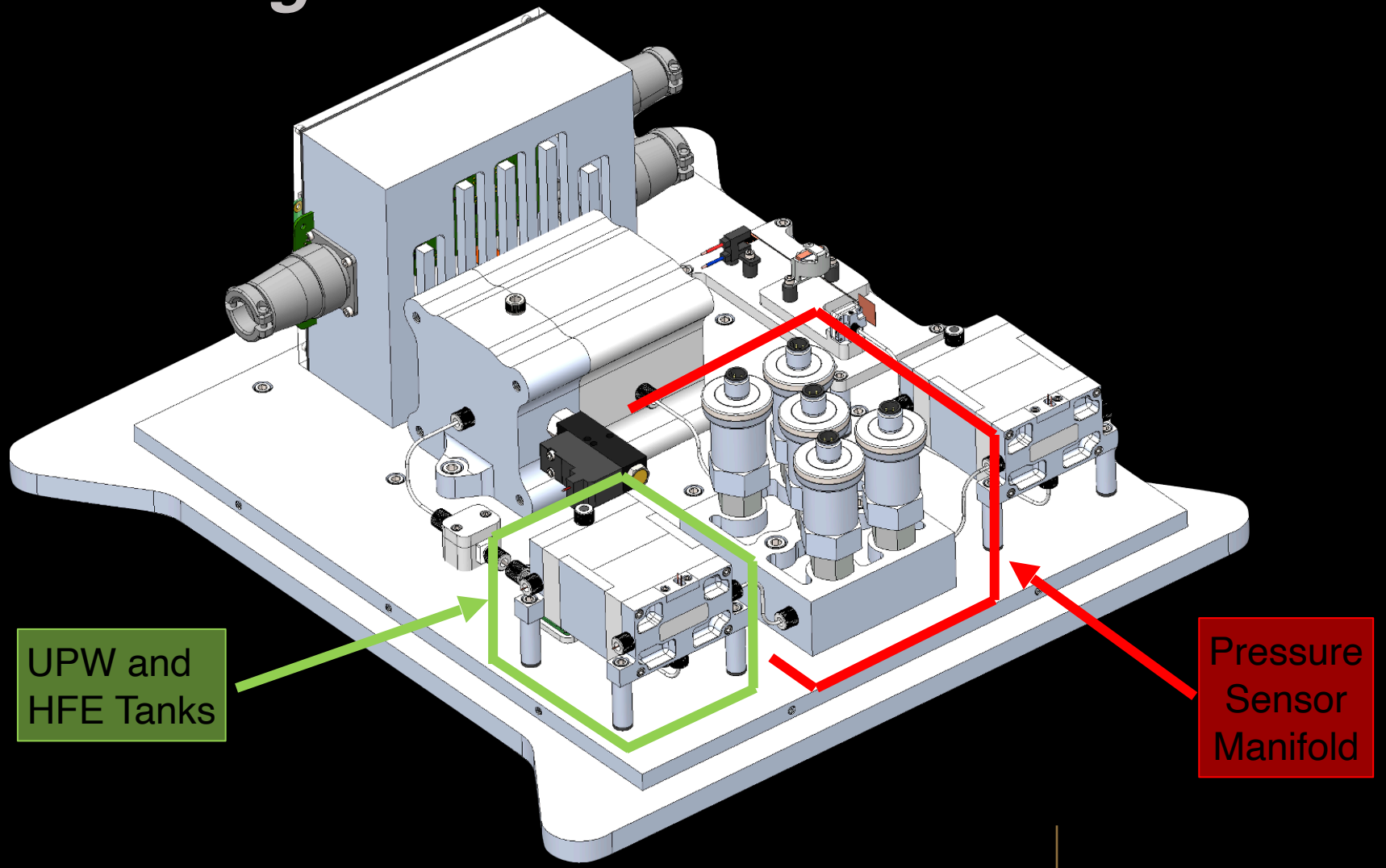

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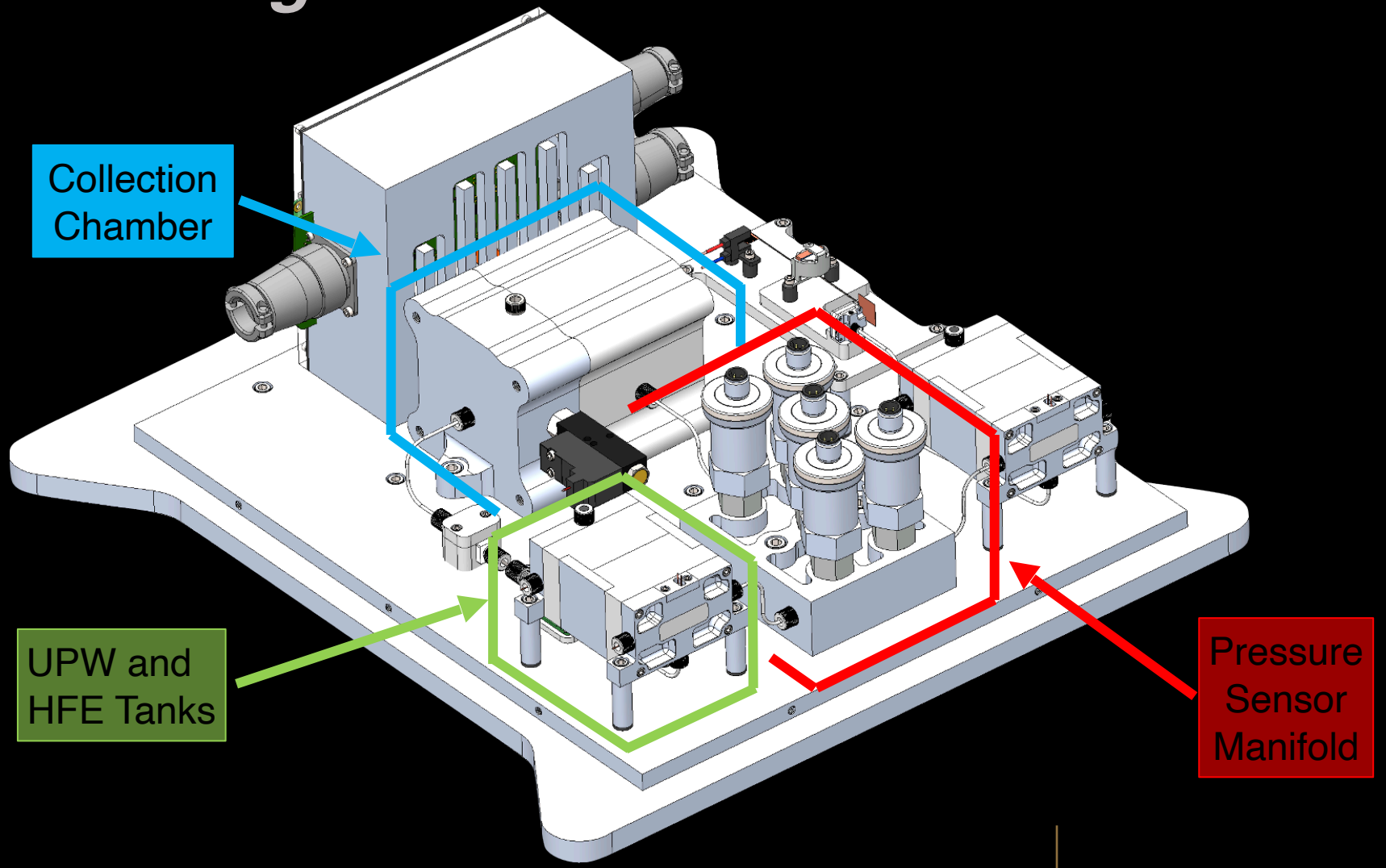

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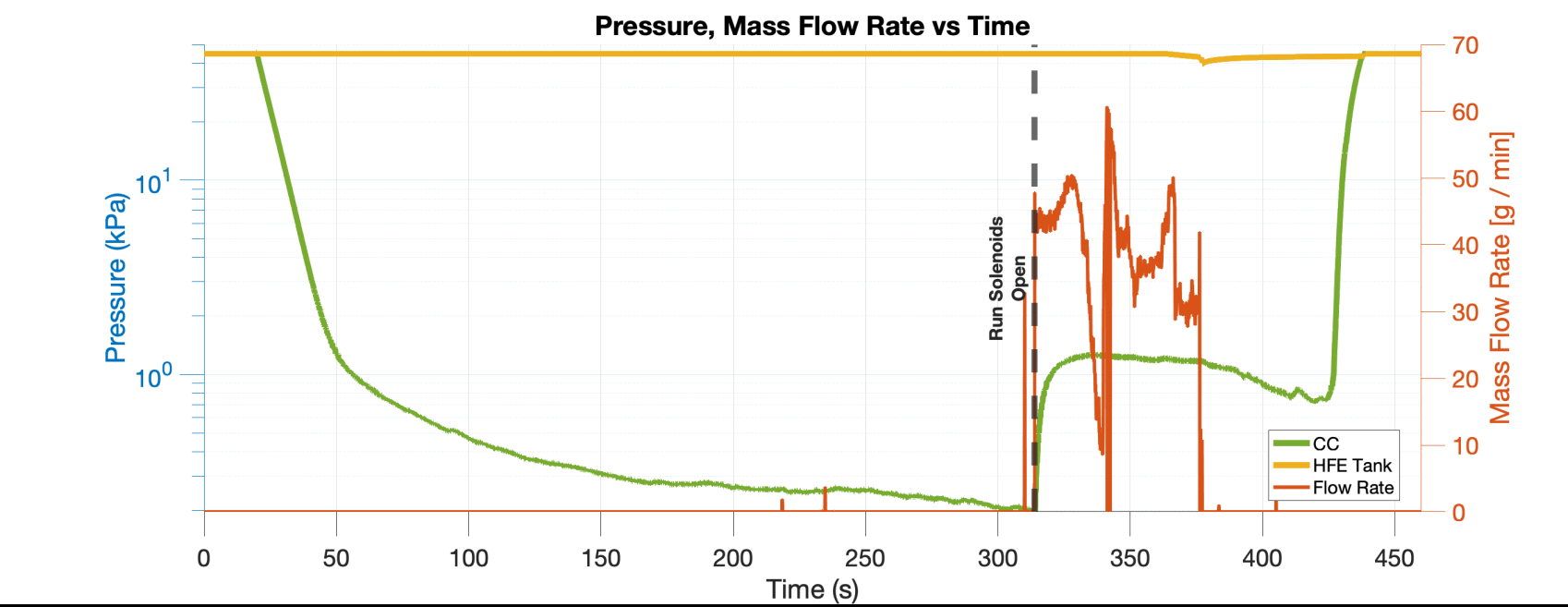
New Design Results



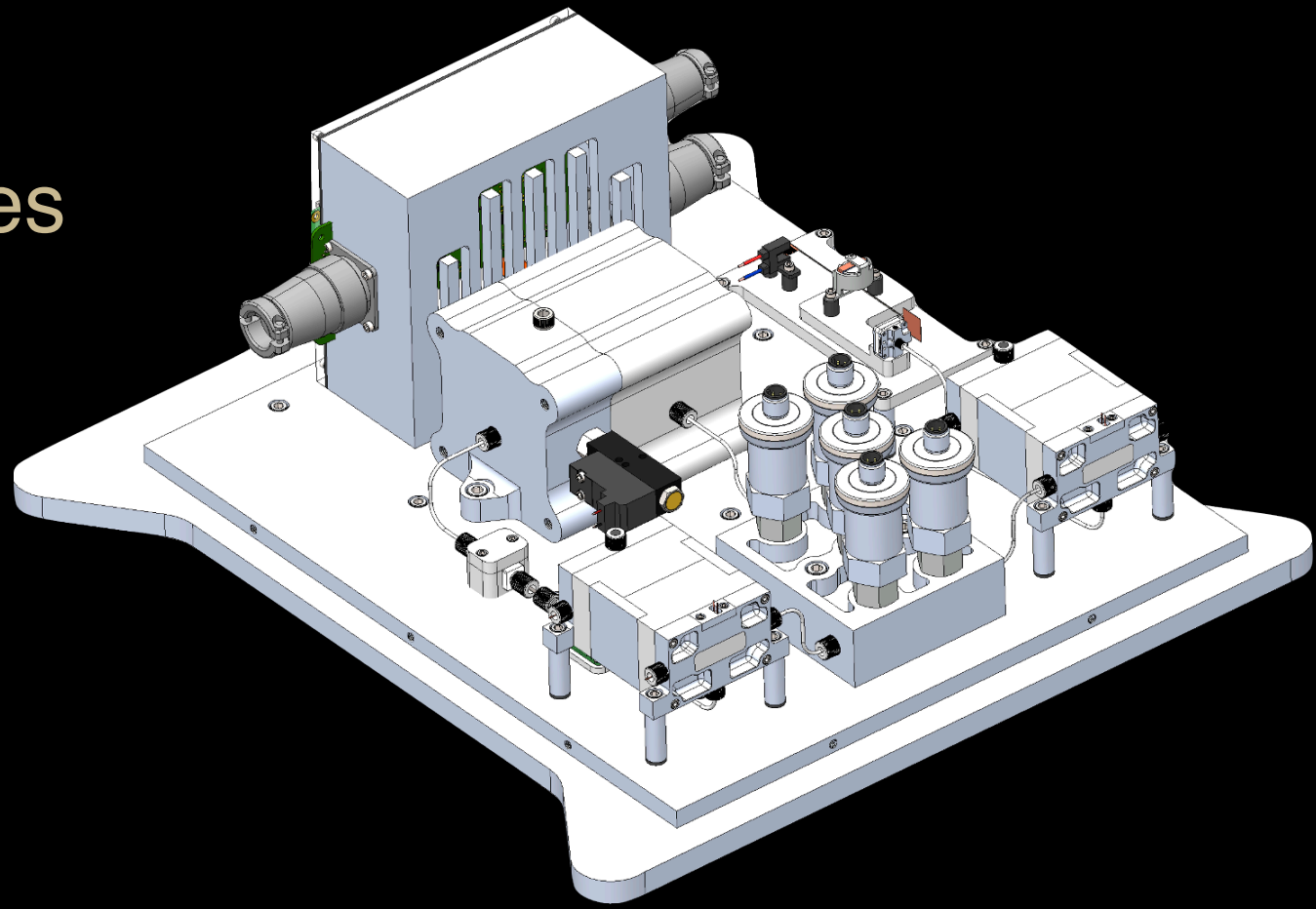
Mass change= 50 g

Estimated expulsion of water= 40.17 mL

Next Updates

Planned Changes

- Novec 7000
- Pressure Sensors
- Software
- Mission Computer



ACKNOWLEDGEMENTS

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Thank you to Blue Origin for working so closely with us this year.

Thank you to the 85 undergraduate students who have spent time helping with this research project in the last 5 years.

In particular the students in 2022 *Kunle Akinleye, Keshav Agarwal, Nikolai Baranov, Gouri Bellad, Kevin Ganbold, Joe Kawiecki, Max Lantz, Carly Mckean, Ankit Mondal, Abhirama Rachabattuni, Evan Rittner, Yashoheet Sethi, Hersh Thapar, Ata Torman, Jacob Valdez, Philip Voronin*

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NASA

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WORKS CITED

Citations

[1] Pugia, S., Linker, M., Fuehne, M., Clay, R., Fowee, K., Cofer, A., & Alexeenko, A. (2017). Quad-Thruster FEMTA Micropropulsion System for CubeSat 1-Axis Control.

[2] Pugia, S. M., Mayper, D., Cofer, A., & Alexeenko, A. (2020). Failure Investigation and Improvement of MEMS Microthruster for SmallSat Attitude Control. In *AIAA Scitech 2020 Forum* (p. 0928).

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Thank You

Questions?

Presentation by
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Results: Outgassing