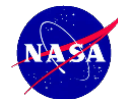


Ventilation Heat Exchanger/Flow Meter for xPLSS

ICES-2023-035

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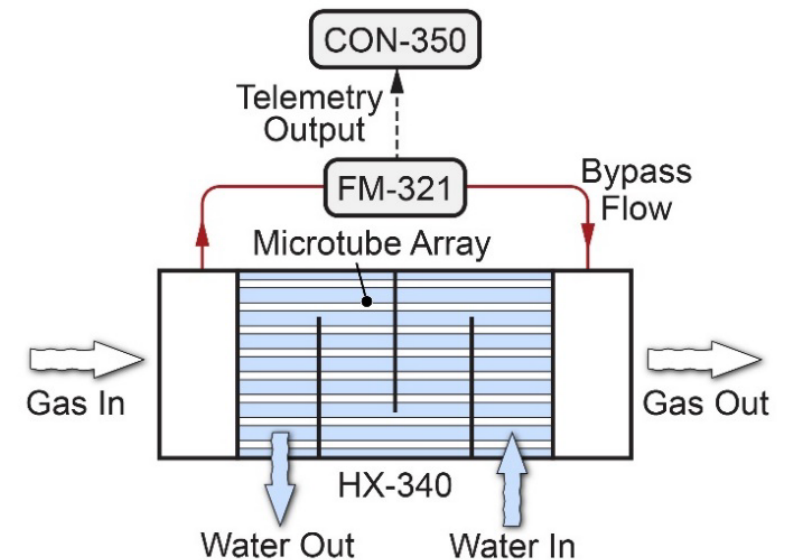
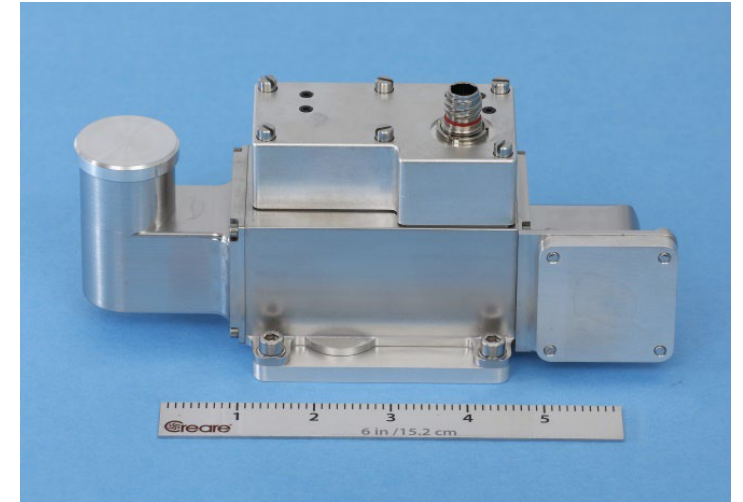
Introduction and Overview

Multifunctional component

- Ventilation loop heat exchanger (HX-340)
- Ventilation loop flow meter (FM-321)
- Attached but separable components

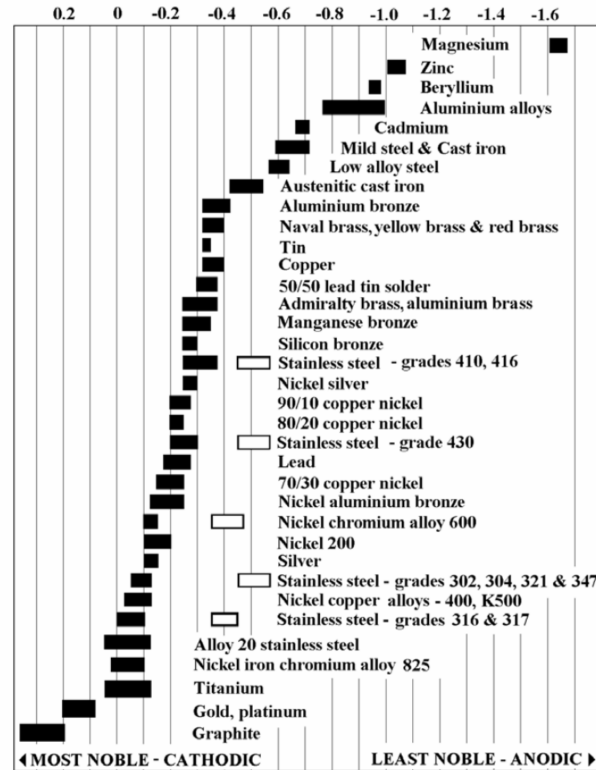
Program Complete

- Four HX-340 delivered to NASA
- Five FM-321 calibrated and delivered to NASA
- Meet requirements for heat transfer and flow measurement
 - Extensive validation testing of all units on benchtop
- Validated in preliminary xPLSS testing

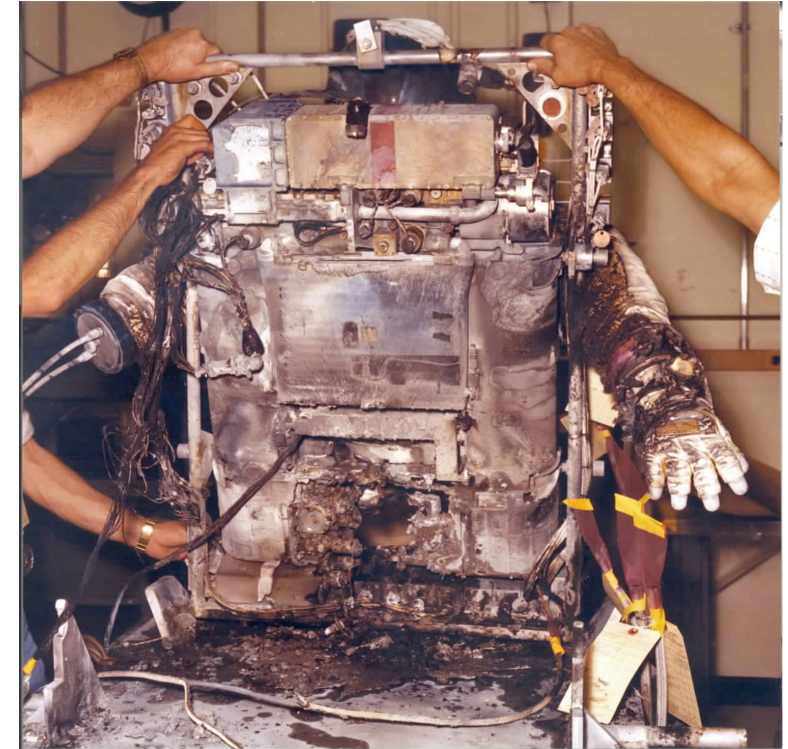


Overall Requirements

- Oxygen safety
- Materials compatibility
- Ventilation gas cooling
- Low pressure loss
- Form factor and mechanical interface
- Electronics interface
- Measurement accuracy
- High-reliability electronics
- Software/firmware



Galvanic Series



April 1980, EMU Fire During Development Testing

Heat Exchanger Requirements and Performance

- Wide range of operating conditions

30 to 160 kPa

O₂ inlet temp 16°C to 32°C

Mass flow rate 0.19 to 6.5 g/s (O₂)

- Heat transfer requirements

Gas outlet temperature limits

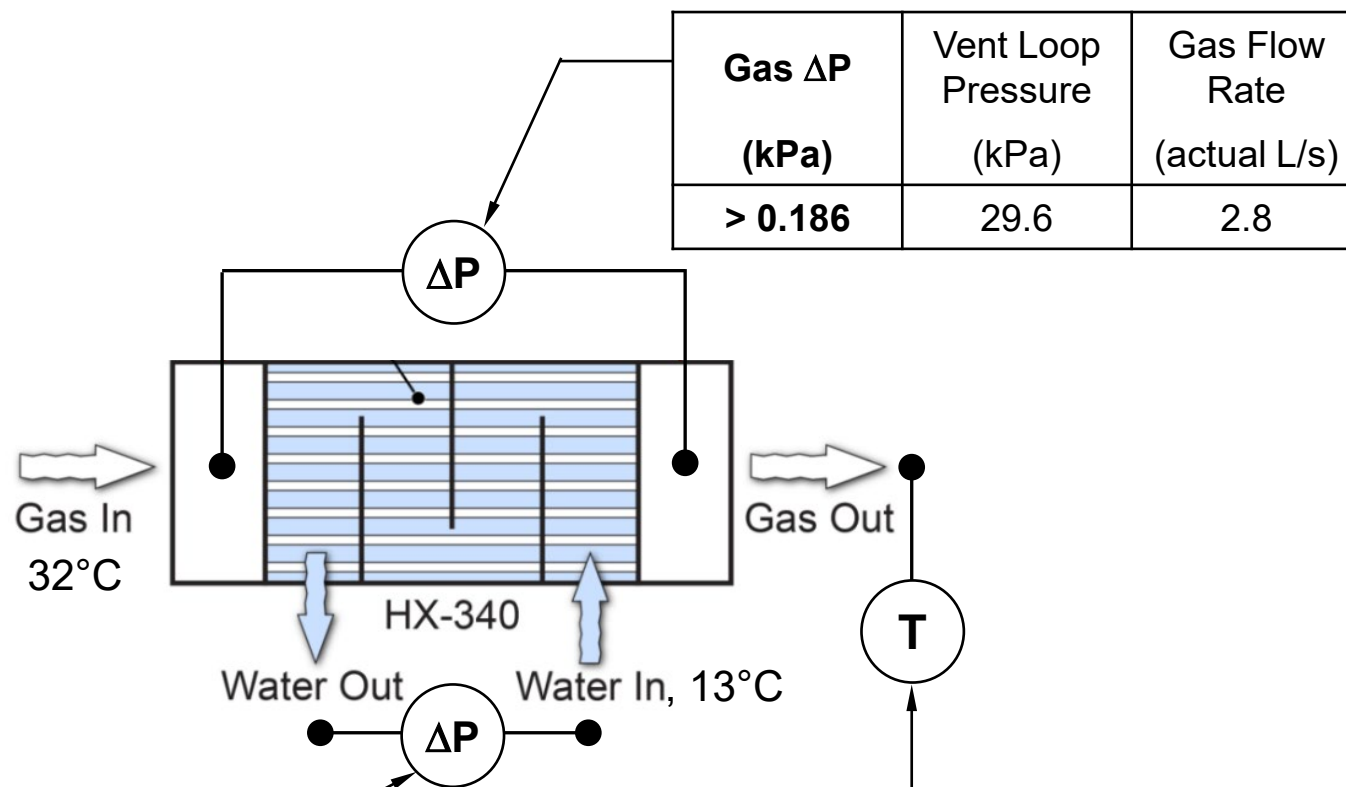
Most challenging at high pressure

Achieved with 2.8°C to 4.5°C margin

- Pressure drop requirements

Gas and water side

Achieved with 8% to 25% margin



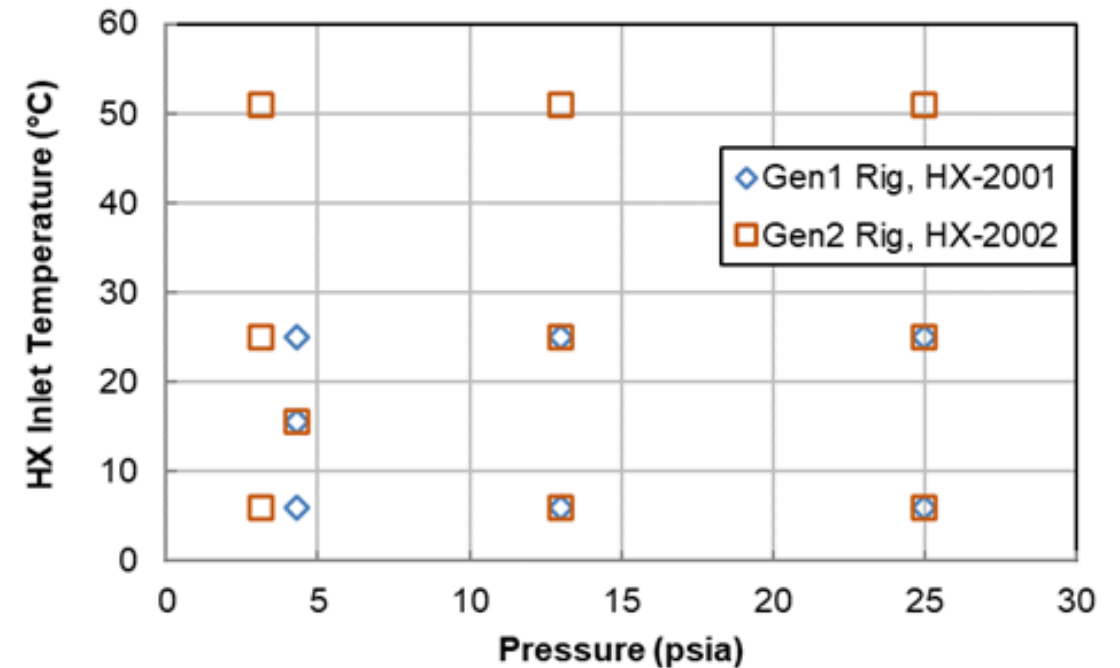
Gas ΔP (kPa)	Vent Loop Pressure (kPa)	Gas Flow Rate (actual L/s)
> 0.186	29.6	2.8

Water ΔP (kPa)	Water Pressure (kPa)	Water Flow Rate (g/s)
> 5.5	101	25.2

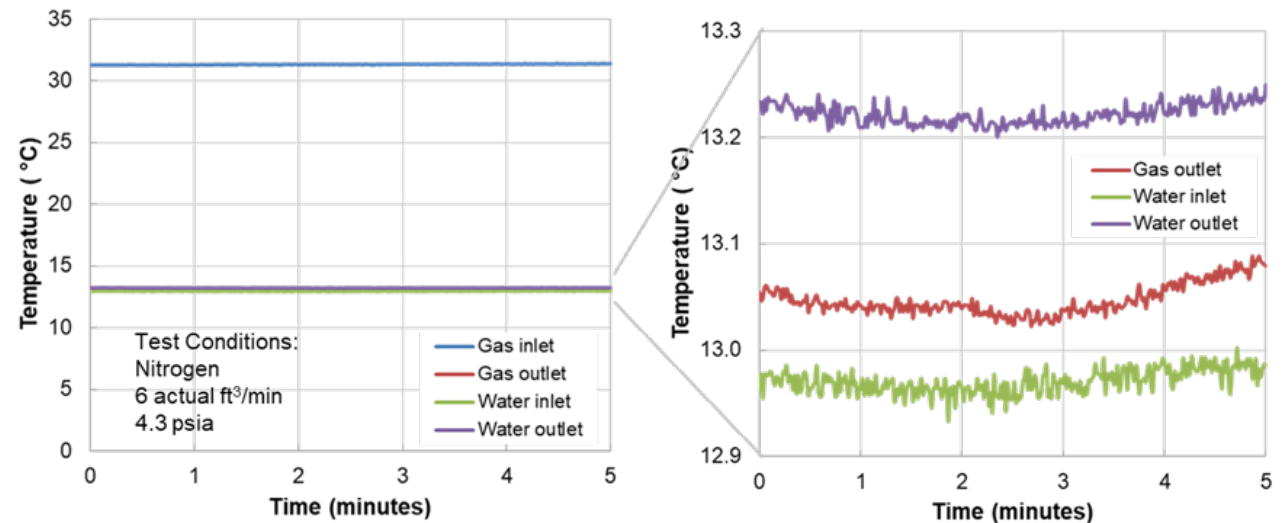
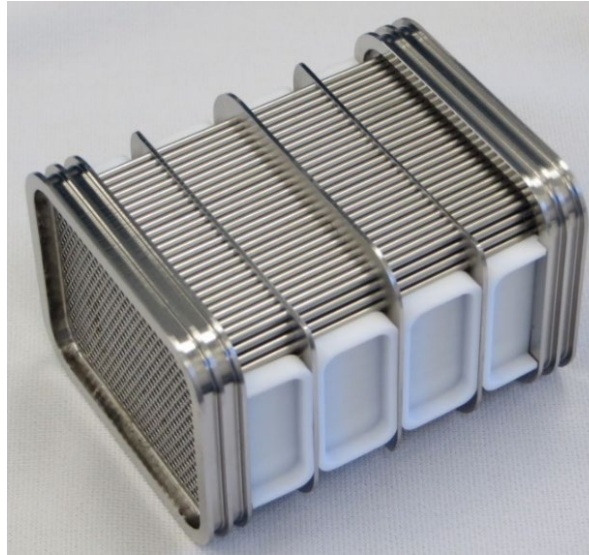
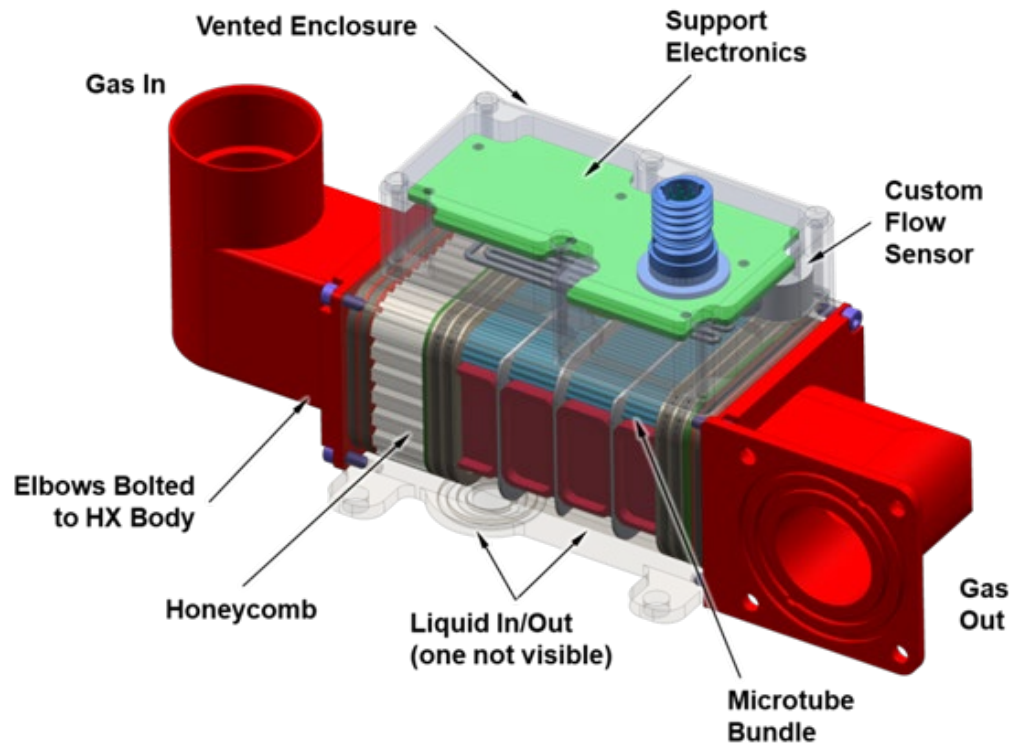
Outlet Gas Temp (°C)	Vent Loop Pressure (kPa)	Gas Flow Rate (actual L/s)
< 15.8	29.6	2.1
< 17.4	29.6	2.8
< 20.2	156	2.8

Flow Meter Requirements

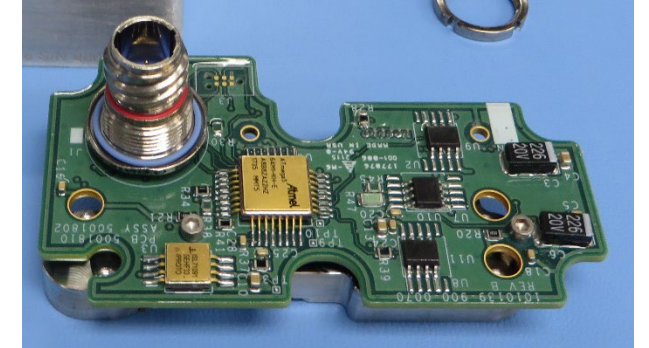
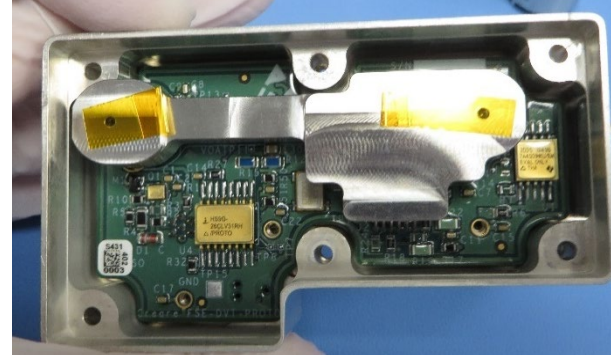
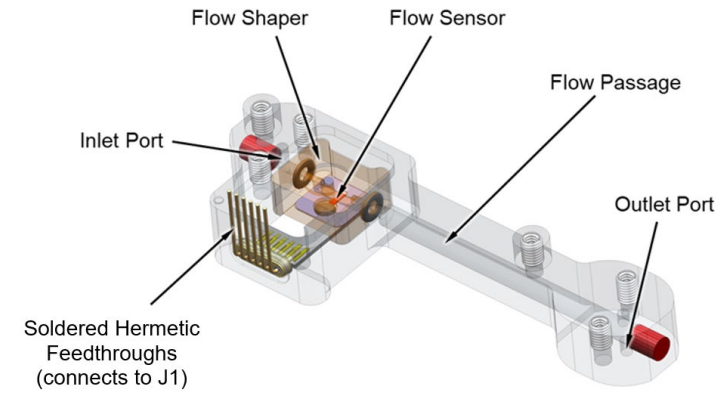
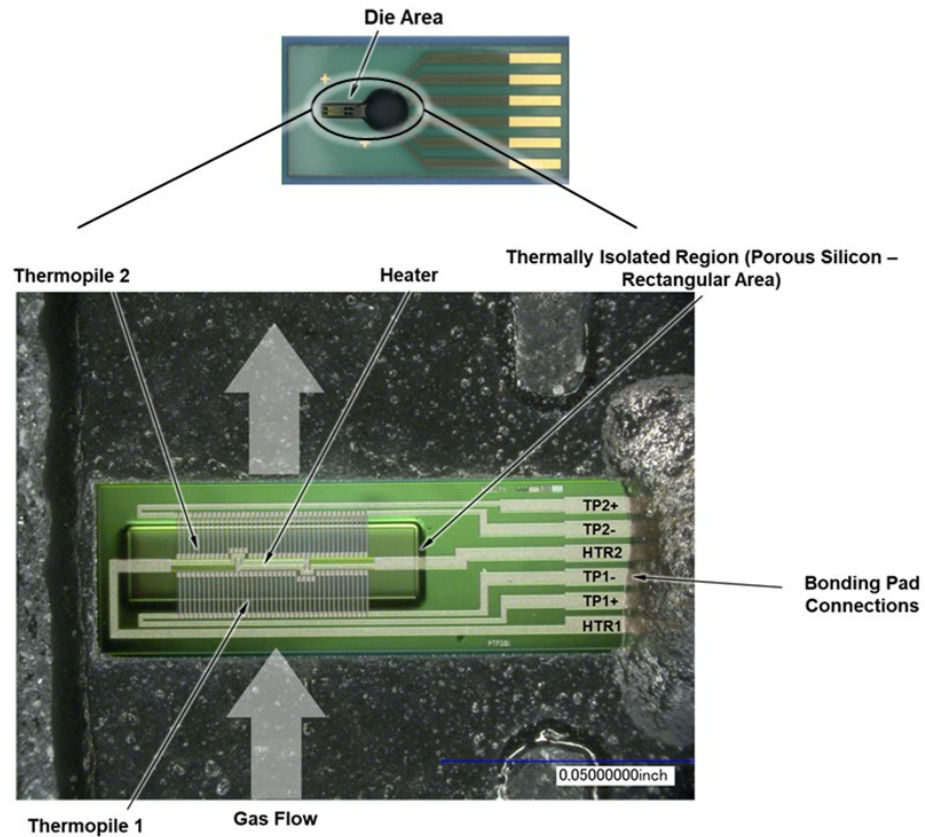
- Purpose of flow meter is to measure the mass flow rate of ventilation gas
- Measurement accuracy requirement
 - Mass flow rate of ventilation gas
 - Measure to within 3% of full scale
 - Min uncertainty @ 29.6 kPa (4.3 psia)
- Wide range of operating conditions
 - 21.4 to 172 kPa (3.1 to 25 psia)
 - 1.7°C to 51.7°C (35°F to 125°F)
 - 0.47 to 3.3 actual L/s (1.0 to 7.0 actual ft³/min)
 - Full range: 0.12 to 7.97 g/s (66x)



Heat Exchanger Design and Performance

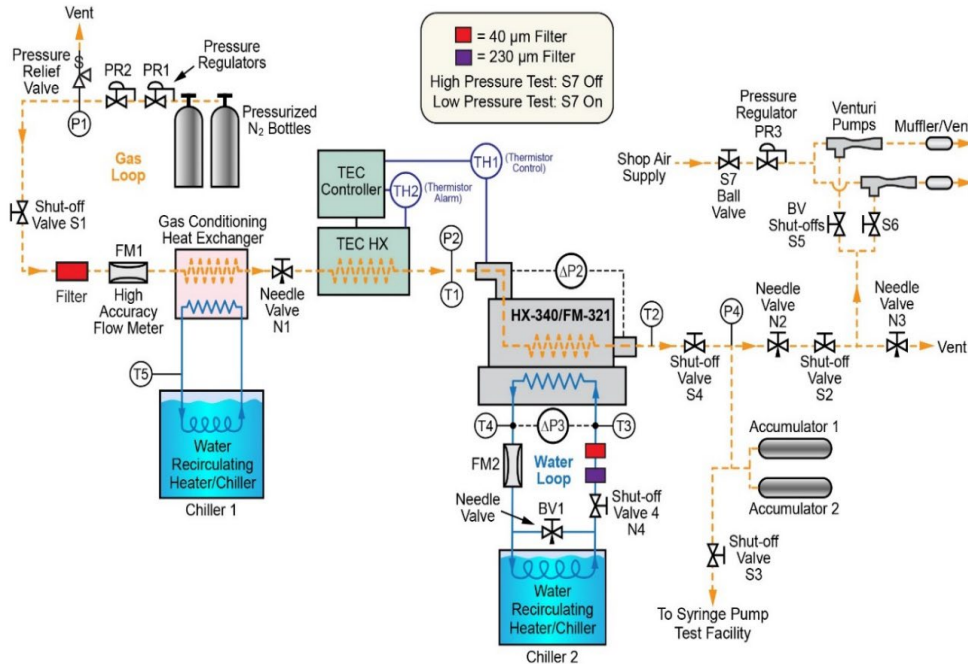


Flow Meter Design



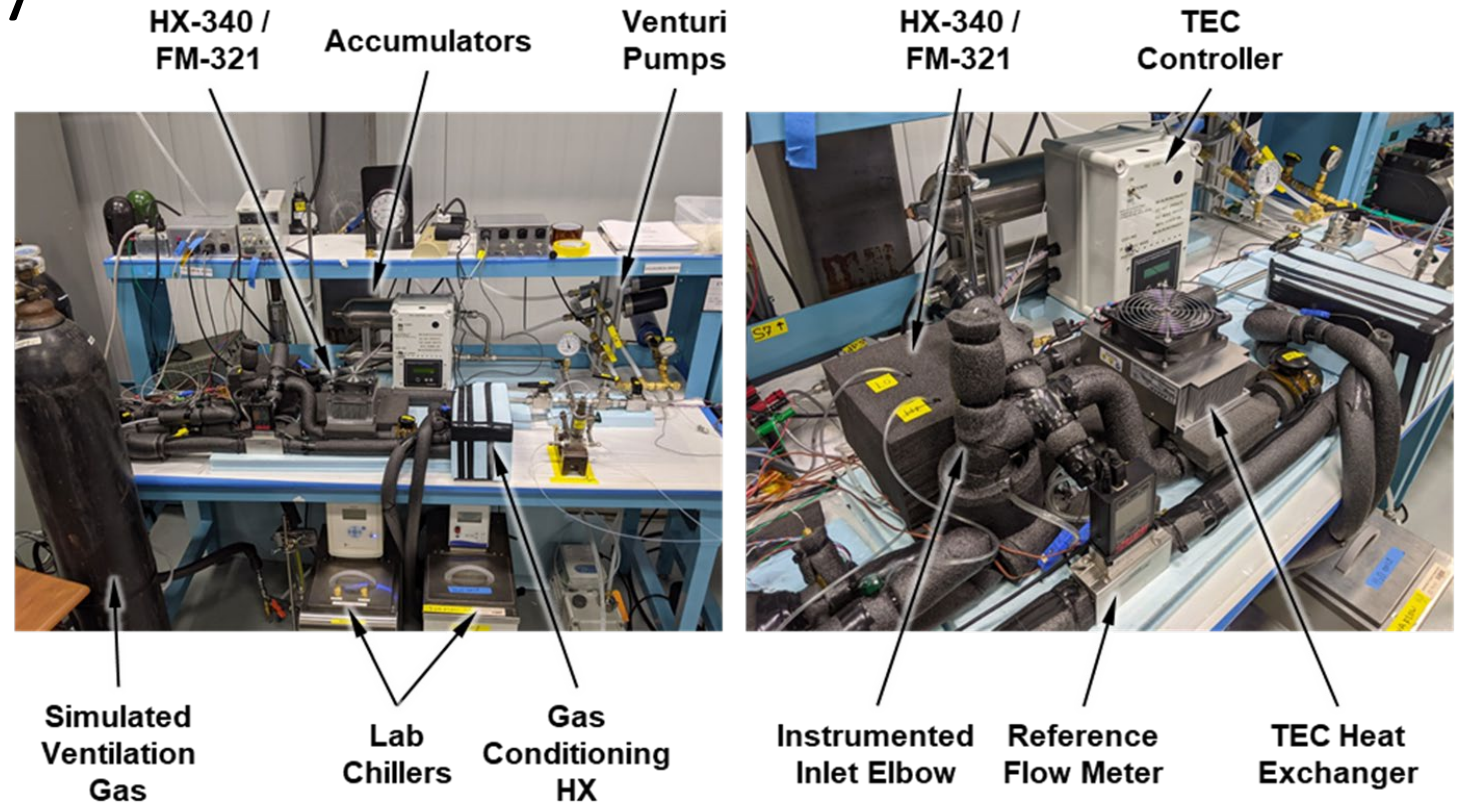
- Thermal flow sensor
- Electronics
- Housing for gas bypass across sensor
- Firmware

FM/HX Test Facility



Gas Side

- Once-through N₂
- High-accuracy calibration flow meter
- ΔP measurement across HX
- Gas conditioning
- Partial vacuum maintained by ejectors



Liquid Side

- Circulating water loop
- Temperature controlled by lab chiller
- Flow rate and ΔP measurements

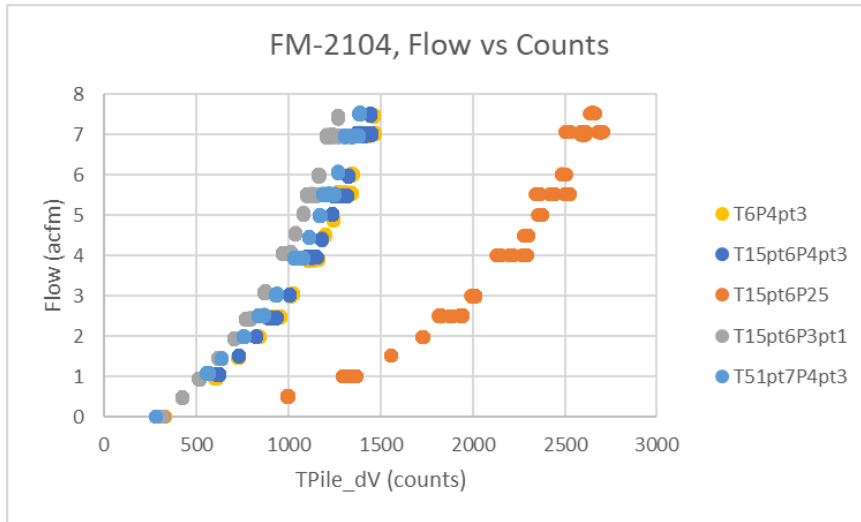
Calibration Test Conditions

	AA	AB	AC	AD	AE	Tolerance
Pressure, P2 (psia)	4.3	4.3	4.3	25	3.1	± 0.1
Gas Inlet Temp, T1 (°C)	15.6	51.7	6	15.6	15.6	± 0.2
Flow rates, FM1 (ACFM)	0 to 7.5	0 to 7.5	0 to 7.5	0 to 7.5	0 to 7.5	± 0.1
Flow rates, FM1 (std L/min)	0 to 64	0 to 57	0 to 66	0 to 373	0 to 46	-
Flow rates (lb _m /hr)	0 to 9.7	0 to 8.6	0 to 10.1	0 to 56.5	0 to 7.0	-
Input Voltage (V)	4.9, 5.05, 5.2	4.9, 5.05, 5.2	4.9, 5.05, 5.2	5.05	4.9, 5.05, 5.2	± 0.01

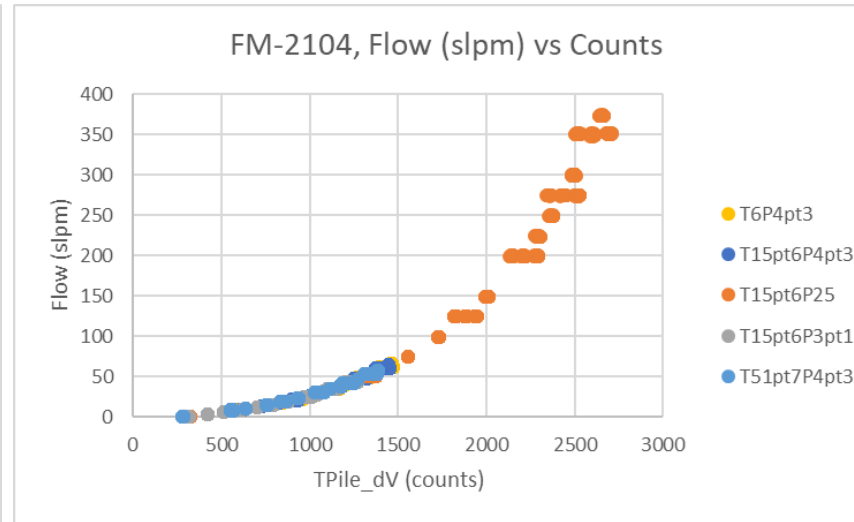
Actual volumetric flow rate specifications are the same for all test pressures

The mass flow rates in std L/min or lb_m/hr vary at each point because the gas density increases with pressure

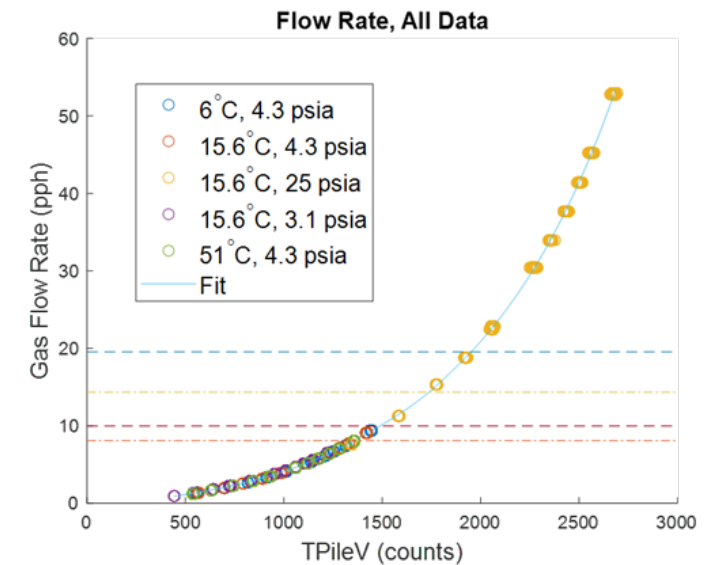
Flow Meter Calibration



Calibration Data, Actual Volumetric Flow



Calibration Data, Mass Flow

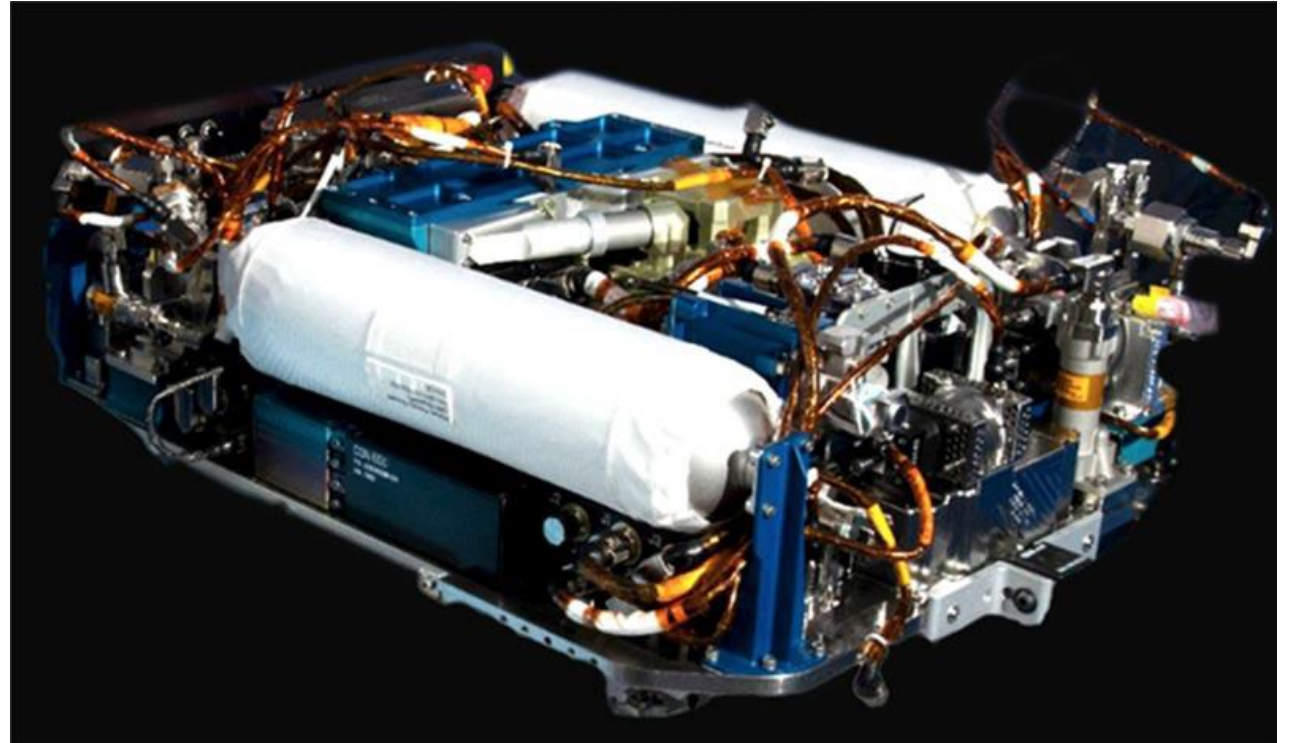


Corrected for Voltage
and Temperature

- All data for FM-2104
- Thermal sensor responds to mass flow (measured in std. L/min or lb_m/hr)
- Voltage output varies slightly with temperature and heater voltage

Validation: PIA Functional Testing of xPLSS

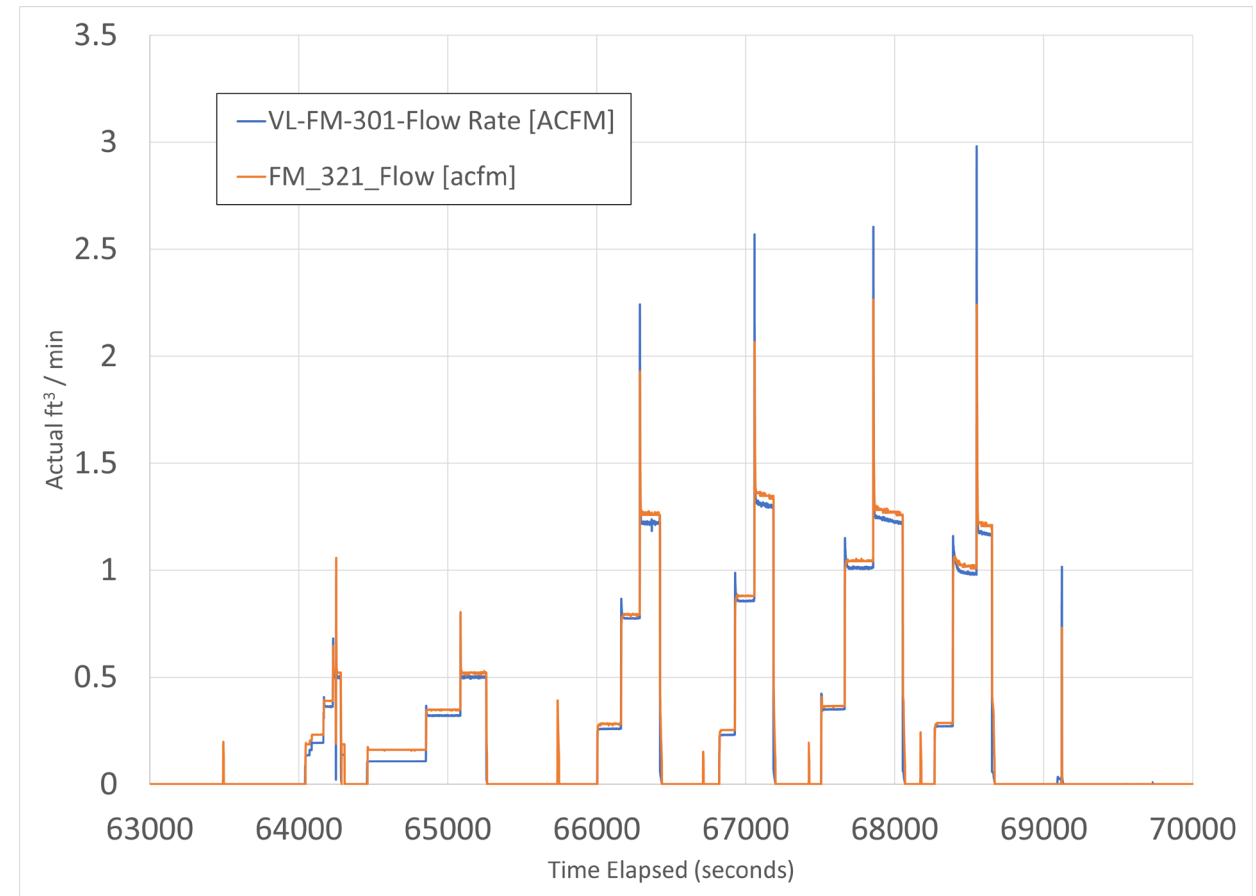
- xPLSS assembly and preliminary testing completed in June 2022 at JSC
- Tests included both lab ambient and vacuum environment functional testing
 - Pressure integrity, leakage tests, individual component, and integrated subsystem assessments
- All O₂ and ventilation loop tests performed with GN2 to minimize risk to system and test personnel



Assembled DVT xPLSS

FM-321 Validation

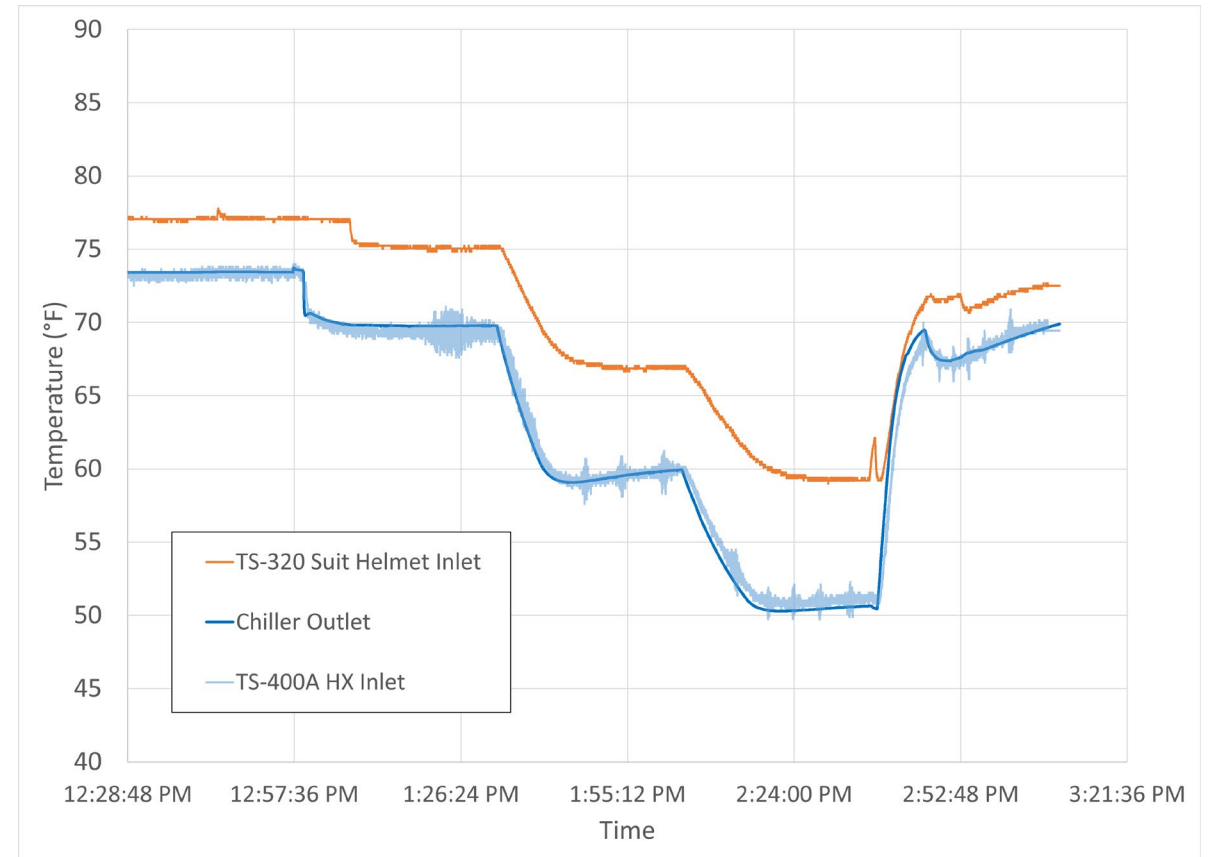
- FM-321 functionality checks completed during fan verification test segment
 - Primary/secondary Fan verification tests completed at 6.0 acfm
- Additional data points for FM-321 verification performed by introducing flow to the ventilation loop via a test entry port
 - Flow provided by the test system gas pressurization panel
- Test system included an independent volumetric flow meter to verify FM-321 outputs
- FM-321 mass flow output converted to a volumetric flow rate using test operating conditions for comparison
- **FM-321 readings showed consistent agreement with test system flow readings, indicating that the FM-321 functioned as expected**



Comparison of FM-321 and Test System Flow Meter (VL-FM-301) Data From xPLSS PIA Testing

HX-340 Validation

- HX-340 functionality checks completed during CO₂ scrubber verification test segment
- Cool water introduced to xPLSS thermal loop via a chiller in the test system
 - Simulated cooling that would be accomplished via the SWME during an EVA
- Temperature of GN2 flow at 7.5 acfm through the ventilation loop monitored via TS-320, which is the suit helmet inlet temperature sensor
 - Secondary test system temperature sensor used to verify TS-320 readings
- **As the supply water temperature was reduced from the lab ambient value of 70°F to 50°F, the ventilation loop gas temperature was reduced from approximately 73°F to 63°F, indicating that the HX-340 functioned as expected**



Comparison of Suit Helmet Inlet (TS-320) and Test System Chiller Outlet Temperature Data From xPLSS PIA Testing

Conclusions

- DVT flow meter/heat exchangers delivered to NASA
- Meet all performance requirements based on extensive bench testing:
 - Cooling ventilation flow
 - Low ΔP for ventilation and cooling water flow
 - Flow measurement accuracy
- Performance validated in PIA testing of xPLSS

Acknowledgments

- NASA Lyndon B. Johnson Space Center
- Space Suit and Crew Survival Systems Branch, Crew and Thermal Systems Division
- NASA SBIR Program