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Exploration Extravehicular Mobility Unit 11 Foot Vacuum Chamber upgrades Test Results

Robert Marsch and Michael Lewandowski
Amentum, Houston, TX, 77058
Sean Miller
NASA, Houston, TX

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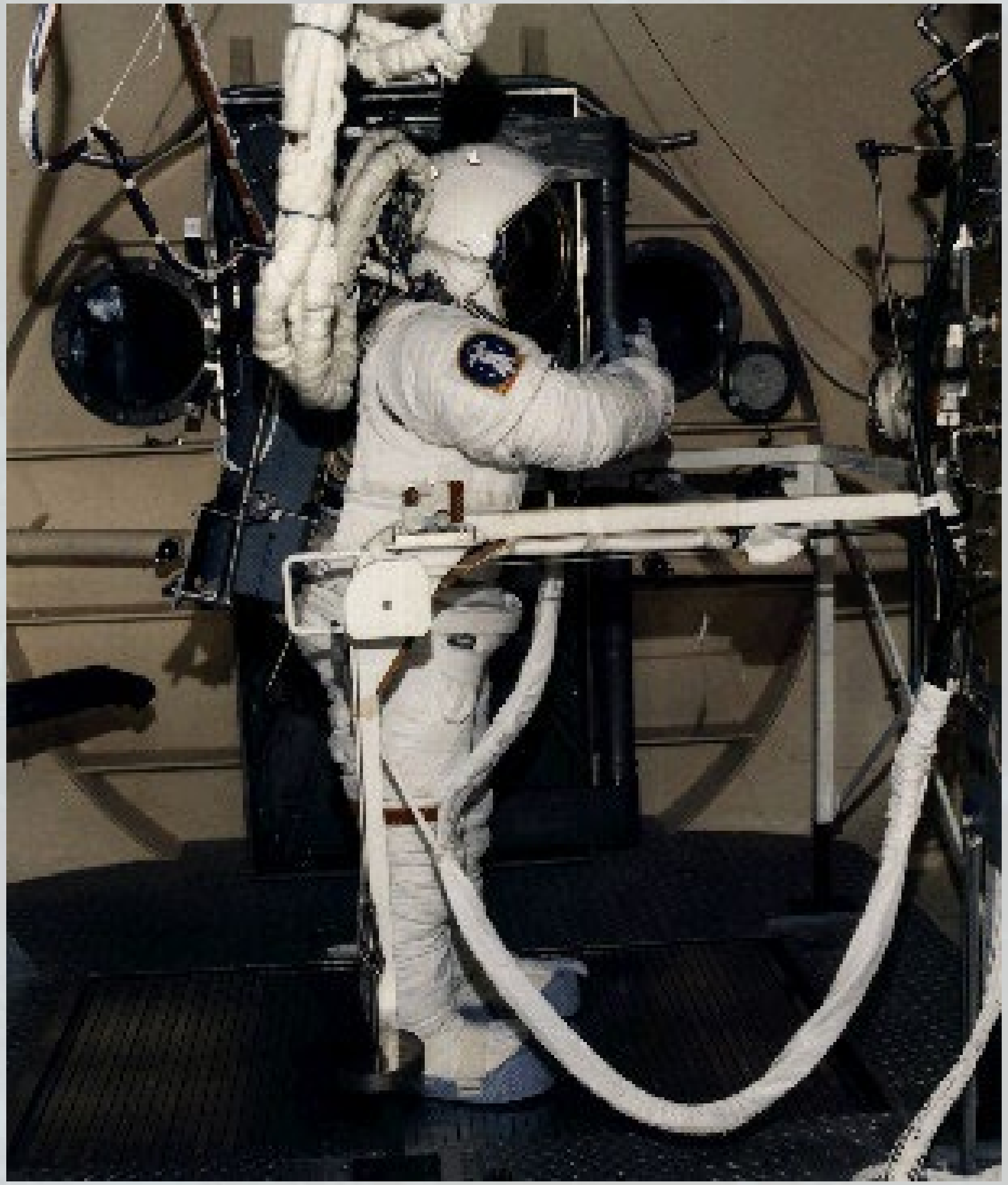
Introduction

- Development of spacesuits has evolved significantly since early space flight
  - Materials advancements
  - Technology advancements
  - Mission Requirements
- Next generation suits, such as those being developed by our xEVAS partners, must be able to evolve and withstand harsh environments of manned missions
- NASA is leveraging their Apollo-Era manned vacuum chambers which are being upgraded for the rigorous testing demands of modern missions.
- The NASA 11 Foot Vacuum Chamber, used in Human-in-the-loop (HITL) testing for ISS EMU, is being upgraded for these modern testing requirements
- Prior to manned testing all facility checkouts will be done at the unmanned stage



Testing Objectives – Overview

- In order to support a full HITL spacesuit test run, the 11ft Chamber must be able to support:
  - a single crewed spacesuit starting with suit donning at atmospheric pressure,
  - suit consumables (water (H_2O), oxygen, battery) recharge,
  - pre-breathe,
  - depressurization to vacuum with the suit connected to its servicing umbilical,
  - simulated EVA with the umbilical's disconnected,
  - chamber repress with umbilical reconnected,
  - vehicle cooling and vehicle power,
  - suit doffing.

Testing Objectives – Extravehicular Activity Test Days

- EVA Test days purpose was to stress the chamber vacuum system to characterize performance across a range of loads representing EVAs with a nominal metabolic profile, maximum-specification transient metabolic profile, single-purge valve operations, and dual purge valve operations
- This sequence of test profiles represented an increasingly challenging gas and water vapor loading for the chamber's vacuum pumps
- IVA cases were tested with each EVA test day which tested
  - the capability of suit cooling via the umbilical,
  - IVA vacuum access for CO_2 removal swing-beds,
  - vehicle power,
  - and procedural validity for running an IVA-EVA-IVA series of procedures as a HITL test would

Testing Objectives – Ambient Test Days

- Due to the unmanned nature of the SxEMU test, several objectives required engineers to operate the suit and test hardware in the chamber in an ambient environment. The main focus was:
  - Consumables Recharge
  - Serial Telemetry Output
  - Ultra High Frequency (UHF) communication with control room
  - UHF telemetry streaming
  - Hardline communications
  - Execution of a critical lift and installation of the SxEMU into upgraded facility donning stand interfaces
  - Integration of Data Acquisition (DAQ) system with the EC4 facility
  - Wi-Fi streaming of telemetry and video

Testing Objectives – Ambient Test Days

- Test level of fidelity column represents the level of fidelity with respect to the manned xEVAS vendor HITL test.
- High – Test replicated a manned test
- Medium – Test realistically demonstrated interface but may not have been perfect
- Low – interface was verified, but not in a way that mirrors a manned test
- Only one low, and that is due to the xEMU not being O2 rated

Objective	Fidelity
Verify Primary/Secondary Recharge to 3000 PSIA	Low
Verify Thermal Loop Cooling via ESCU	High
Verify Feedwater Recharge	Medium
Verify IVA Wastewater Drain/Sampling	High
Verify IVA Vacuum Access for Swing Beds	High
Verify 28 V Umbilical Power	High
Verify Serial Telemetry Output via ESCU	Medium
Verify Chamber Pressure and Quality with Gas and Water Loading	High
Demonstrate EVA Power with Primary and Secondary Power Simulators	Medium
Demonstrate UHF Telemetry Streaming	Medium
Demonstrate Wi-Fi Telemetry and Video Streaming	High
Demonstrate Hardline Communications with Control Room	Medium
Demonstrate Suit Provider DAQ Integration with EC4	Medium
Simulation Manned Chamber Depress/Repress Operations	High
Demonstrate Umbilical Cooling at Vacuum	High
Demonstrate Critical Lift/Installation to Facility Interfaces	Medium
Execute Fit Check of xEMU in Donning Stand	Medium
Execute Fit Check of xEMU in Chamber Weight Relief	Medium
Capture Additional SxEMU Performance Data	High

Test Day Overview

- **Test Day 1: Powered Functional**
  - Test Day Goals:
    - Verify the functionality of all systems, integration and procedural flow minus vacuum chamber pump down
    - Power on the SxEMU
    - Verify Display Control Unit (DCU) simulator (outside the chamber and functional) switch positions
    - Verify SxEMU DCU (attached to the suit and not functional) switch positions
    - Verify ESCU mating and demating and RCA vacuum access line actuator
    - Vehicle cooling capability and SCU to BATT power transitions
  - Test Day Anomalies:
    - None experienced

Test Day Overview

- **Test Day 2: EVA 1**
  - Test Day Goals:
    - 11 Foot vacuum chamber depress with SxEMU
    - Run a full 8hr SxEMU EVA with vacuum chamber at pressure
    - RCA vacuum access actuator switching
    - ESCU mating and demating actuator
    - 11 Foot vacuum chamber repress with SxEMU
  - Test Day Anomalies:
    - RCA vacuum access line leaking.
    - ESCU unsuccessfully mated to the DCU at the end of testing
    - Vacuum appeared to be struggling more than a nominal depress of the chamber based on previous runs. An inspection was carried out to determine if a leak was present. It was discovered that one of the chamber penetrations was improperly sealed which allowed ambient air leakage into the chamber at a significant rate.

Test Day Overview

- **Test Day 3: Recharge**
  - Test Day Goals:
    - Recharge consumables
    - Fix all anomalies and update procedures as necessary
      - Vacuum chamber leaking was due to an improper sized B-nut. This was replaced and a flare saver added
      - ESCU was unable to mate with high-pressure O_2 poppets. Procedure change to depress lines prior to mating
      - RCA Vacuum access line fittings were replaced with barbed fittings
  - Test Day Anomalies:
    - None

Test Day Overview

- **Test Day 4: EVA 2**
  - Test Day Goals:
    - IVA testing at 400 BTU/hr with active vehicle cooling
    - 11 Foot vacuum chamber depress with SxEMU
    - Run a full 8hr maximum transient metabolic rate profile SxEMU EVA with vacuum chamber at pressure. Modified CO2 injection to account for the lack of water injection.
    - RCA vacuum access actuator switching
    - ESCU mating and demating actuator
    - Feedwater Supply Assembly (FSA) depletion and check valve cracking testing
    - 11 Foot vacuum chamber repress with SxEMU
  - Test Day Anomalies:
    - SWME (HX-440) back pressure valve (BPV) linear potentiometer went out of sync during valve position changes in the closing direction. No constraint to testing.
    - Human Metabolic Simulator (HMS) controlled evaporator mixer (CEM) temperature probes, which measure the temperature of the humidity injection which was not used, read off-scale high. No constraint to testing.

Test Day Overview

- **Test Day 5: Recharge 2**
  - Test Day Goals:
    - Recharge consumables
    - Bypass RCA solenoid valves to pump directly to the IVA vacuum pumps
  - Test Day Anomalies:
    - None
- **Test Day 6: EVA 3 and Recharge 3**
  - Test Day Goals:
    - IVA testing at 400 and 600 BTU/hr with active vehicle cooling
    - IVA Heat injection testing at 205W
    - 11 Foot vacuum chamber depress with SxEMU
    - Load the vacuum chamber to the maximum extent that the suit could reasonably do under conventional operations. Max CO_2, Heat injection and both purge valves opened.
    - RCA vacuum access actuator switching
    - ESCU mating and demating actuator
    - FSA depletion and check valve cracking testing
    - 11 Foot vacuum chamber repress with SxEMU
  - Test Day Anomalies:
    - None

Test Day Overview

- **Test Day 7: IVA Vacuum Access Leak Detection**
  - Test Day Goals:
    - Identify RCA vacuum access line leakage. Source determined to be possible O-ring crushed in the VAC_1003 to VAC_1004 connection
  - Test Day Anomalies:
    - None
- **Test Day 8 and 9: Communications, WI-FI, and Radio**
  - Test Day Goals:
    - Verify communications, signal interfaces, and connectivity through EMU radio and the in-suit microphones
  - Test Day Anomalies:
    - EV-701 communication through EMU radio unsuccessful
    - Suit hardline testing no audio detected
    - The required Linux laptop and software to access streamed telemetry and video from the suit over Wi-Fi was not present

Test Day Overview

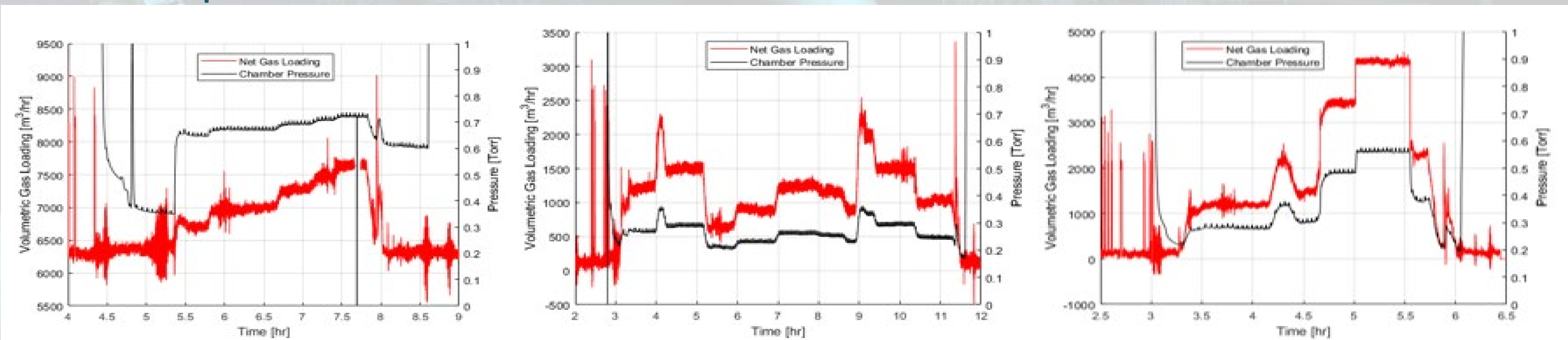
- **Test Day 10: IVA Vacuum Access Testing and Water Drain and Fill**
  - Test Day Goals:
    - Verify communications, signal interfaces, and connectivity through EMU radio and the in-suit microphones. Focused on hardline communications
    - Fill and drain SxEMU water bladders using facility water drain port, recharge and degas
  - Test Day Anomalies:
    - Facility side hardline audio connection to the chamber intercom system and that the SxEMU test article was the issue.
- **Test Day 11: IVA Vacuum Access Testing Re-Test**
  - Test Day Goals:
    - Load various profiles on the IVA vacuum pumps using various Ballast Modes on the vacuum pumps
  - Test Day Anomalies:
    - None

Detailed Testing/Anomalies – EVA Vacuum Loading

- 3 EVAS, largest vacuum loading on EVA 2 and 3. Total loading seen below

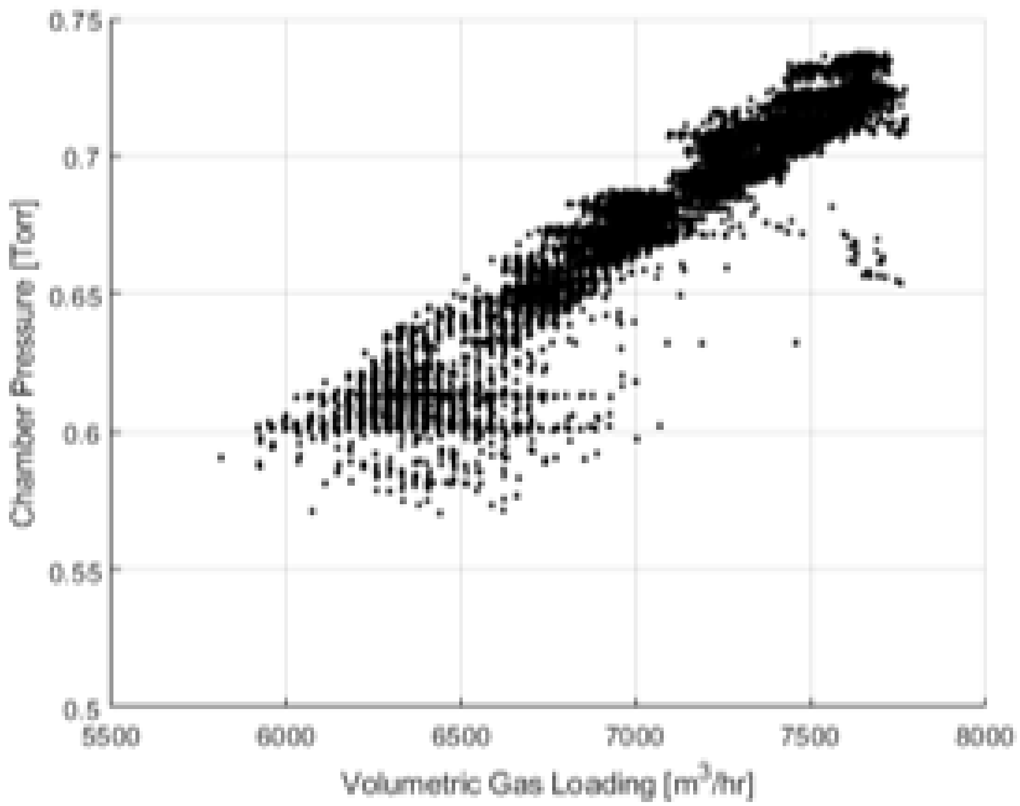
Metabolic Rate [BTU/hr]	CO_2 Loading [g/min]	CO_2 Loading [m^3/min]	Water Vapor Loading [g/min]	Water Vapor Loading [m^3/min]	O_2 Loading [g/min]	O_2 Loading [m^3/min]	Net Loading [m^3/min]	Net Loading [m^3/hr]
1200	1.820	1.512	8.023	16.297	0.415	0.475	18.284	1097.050
3000	4.550	3.781	17.973	36.507	1.052	1.202	41.489	2489.366
1200 w/ purge	1.820	1.512	8.023	16.297	13.267	15.159	32.969	1978.114
3000 w/ purge	4.550	3.781	17.973	36.507	13.904	15.886	56.174	3370.430

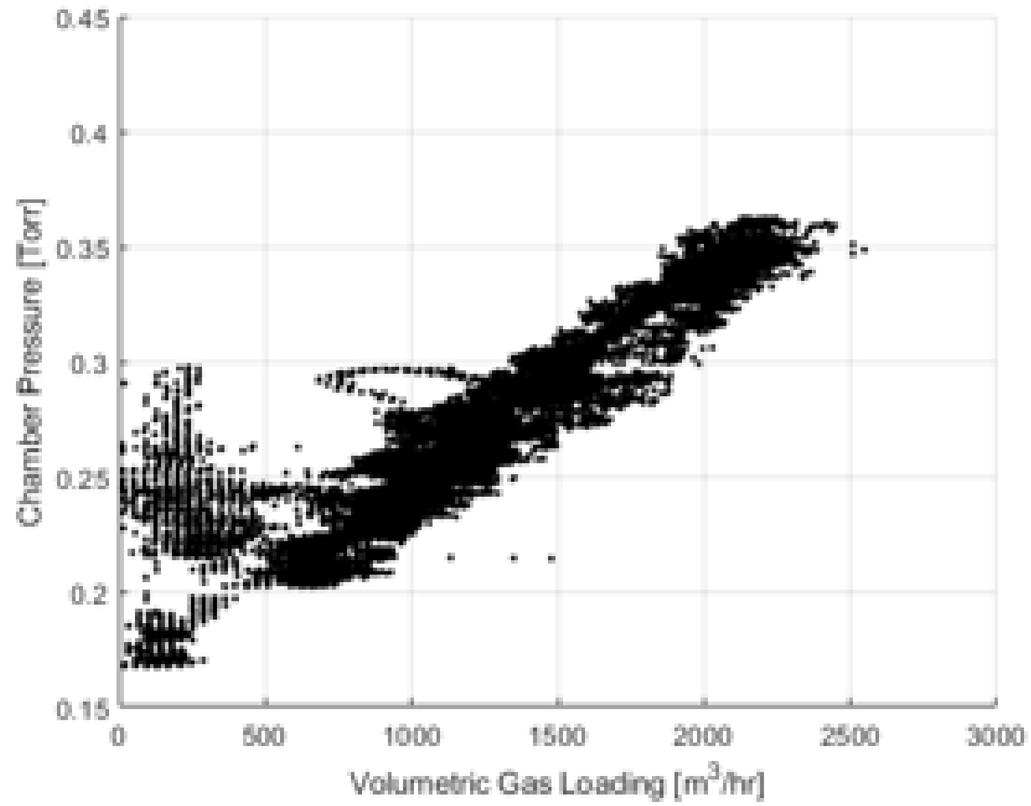
- Volumetric gas loading for EVAs 1, 2 and 3. Shows that with high loading the chamber pressure remains around .7 Torr

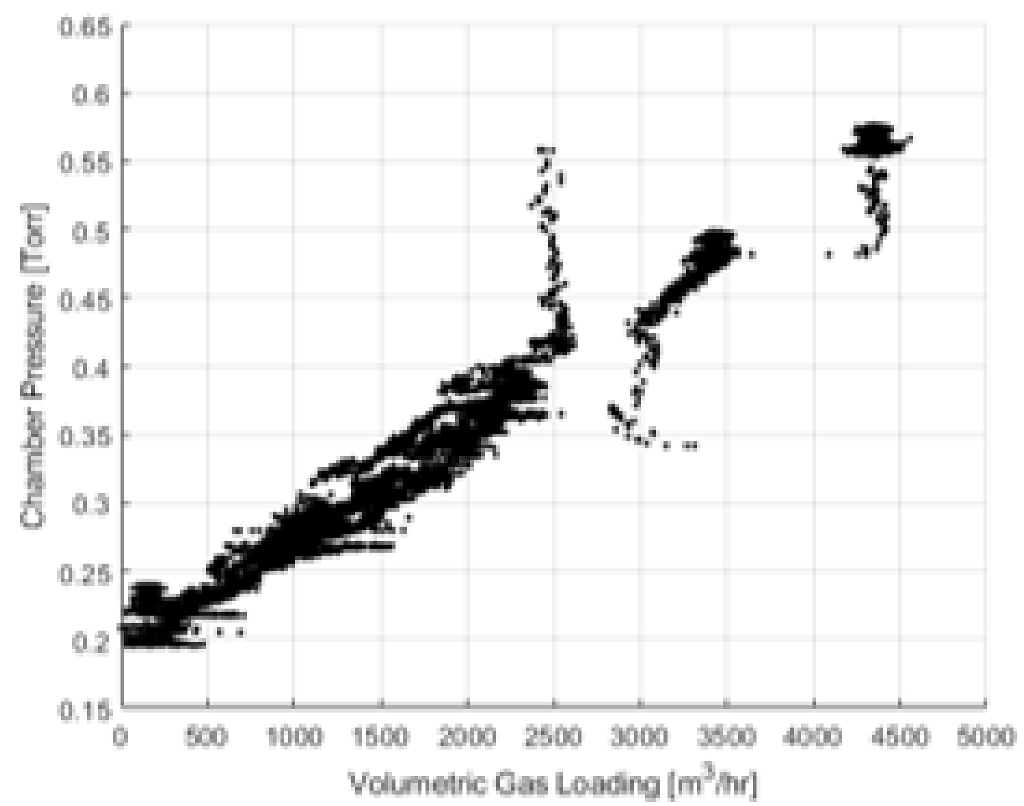


Detailed Testing/Anomalies – EVA Vacuum Loading

- Chamber Pressure as a function of volumetric gas loading shows that the gas loading to chamber pressure is linear

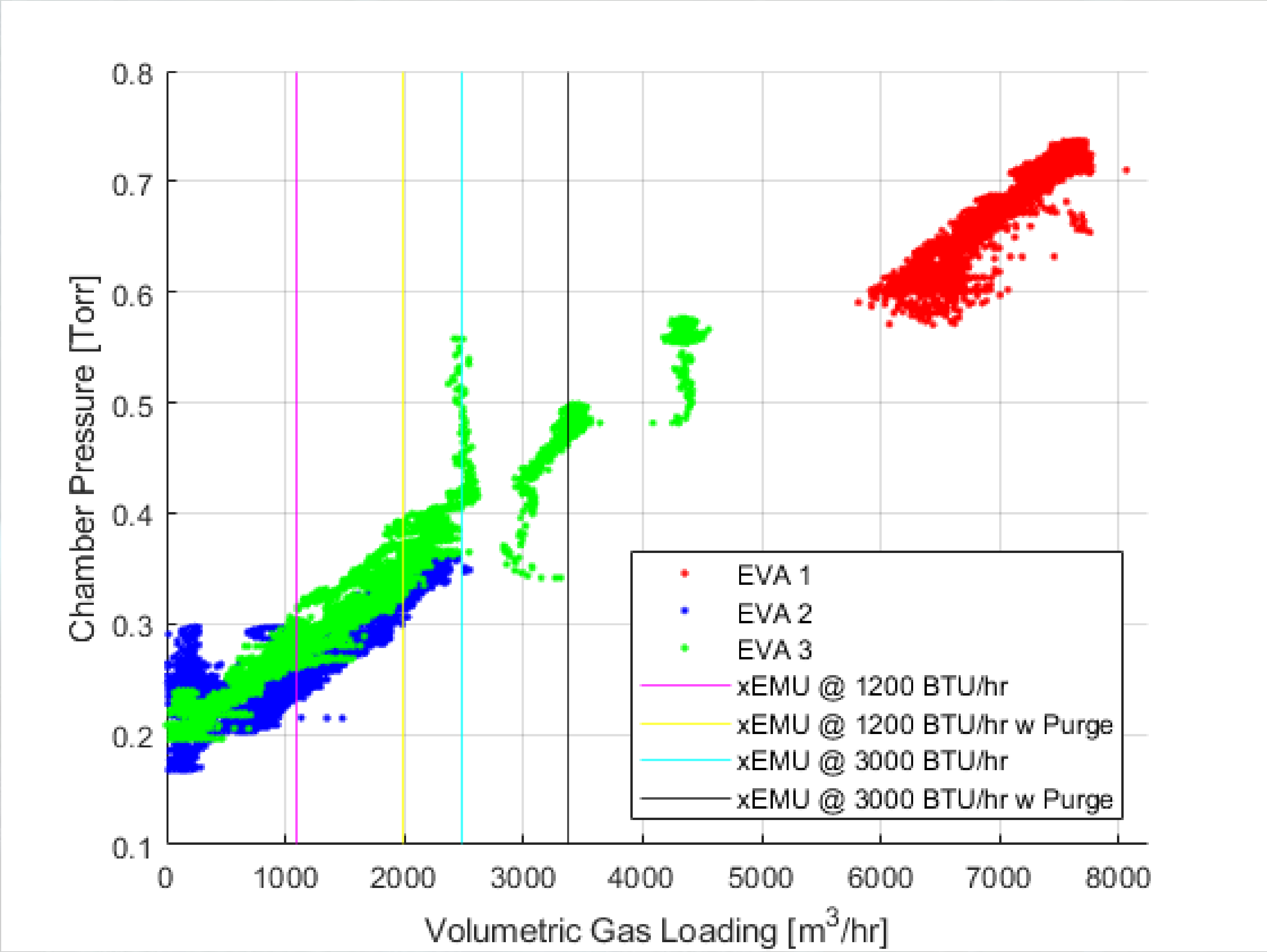






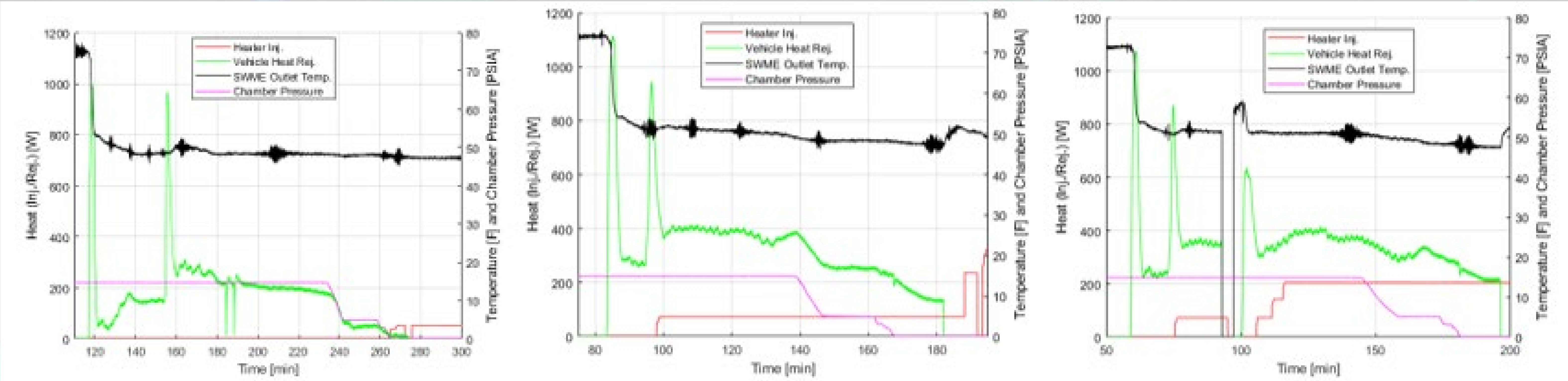
Detailed Testing/Anomalies – EVA Vacuum Loading

- Comparison of the xEMU loading with test all tested loads. For maximum RCA and SWME desorbing the vacuum pressure should be as low as possible, ideally less than 1 torr.
- For the xEMU, vacuum pressure was sufficient, new providers should be aware of their predicted hardware performance under the now-known 11-ft vacuum environment



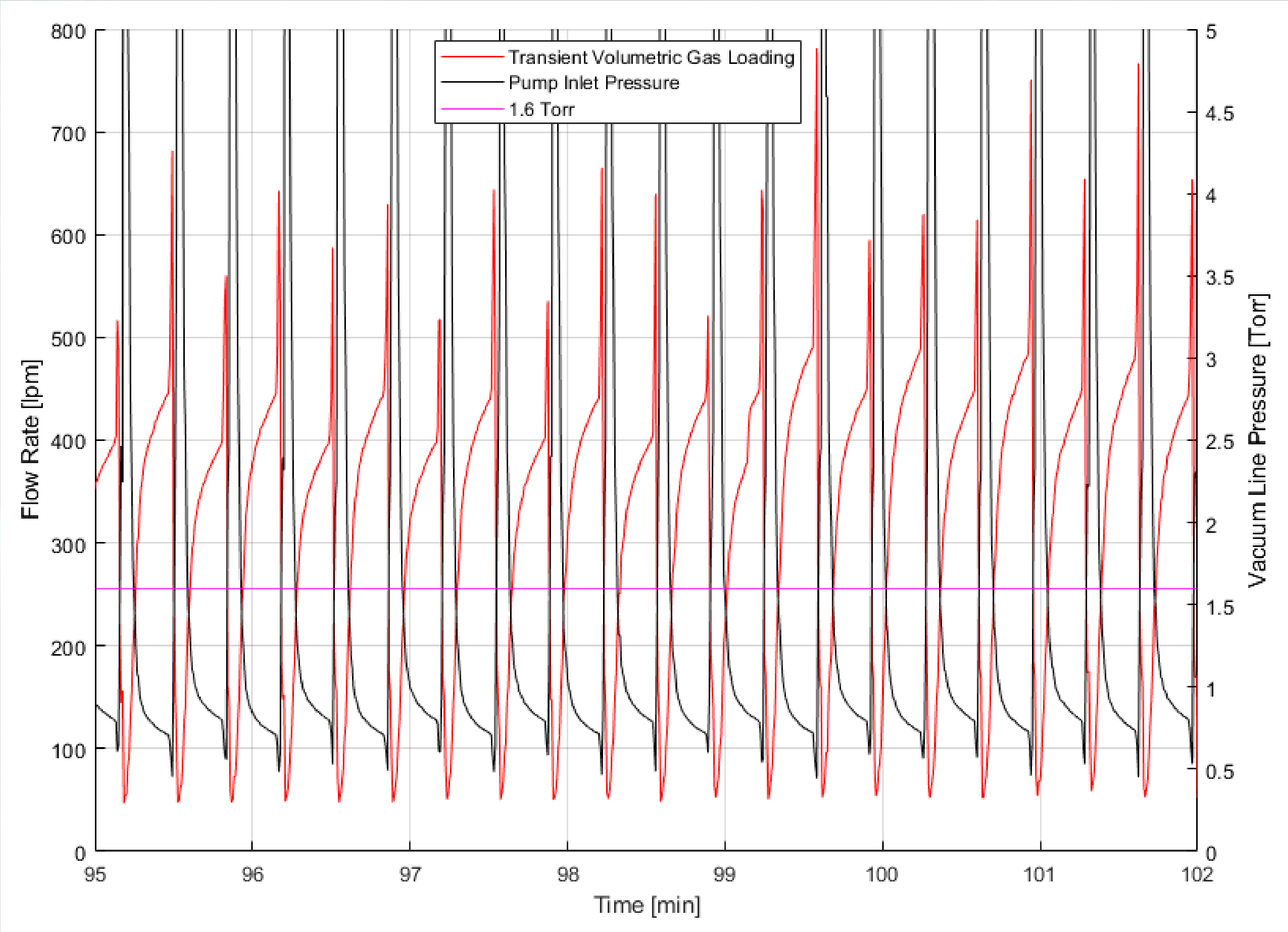
Detailed Testing/Anomalies – IVA Cooling

- IVA cooling was tested by injecting controlled heat via the test systems cold plate heaters.
- The vehicle chiller cart was set to 45°F (7.22°C) and not adjusted throughout all IVA test days. The outlet temperature was monitored to have the outlet temperature of 50°F +/- 1.5°F



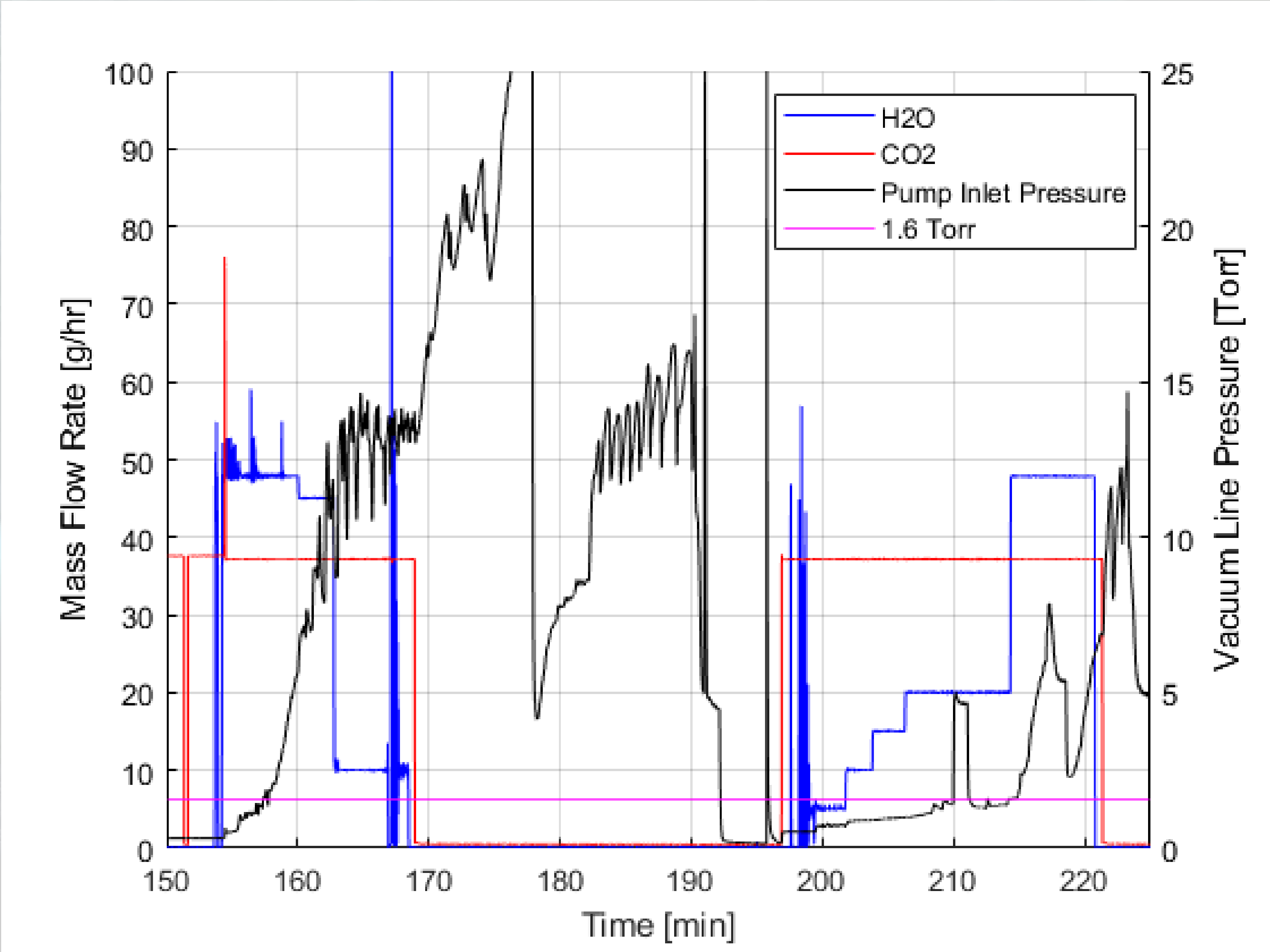
Detailed Testing/Anomalies – IVA Vacuum Access

- Vacuum access testing was composed of 2 days testing, the first with the RCA attached directly to the IVA vacuum access system and the second when the pressure transducers were updated and retested.
- Figure shows the RCA loading of the IVA vacuum access through the SxEMU and the RCA hit a max of 15s half cycle time.



Detailed Testing/Anomalies – IVA Vacuum Access

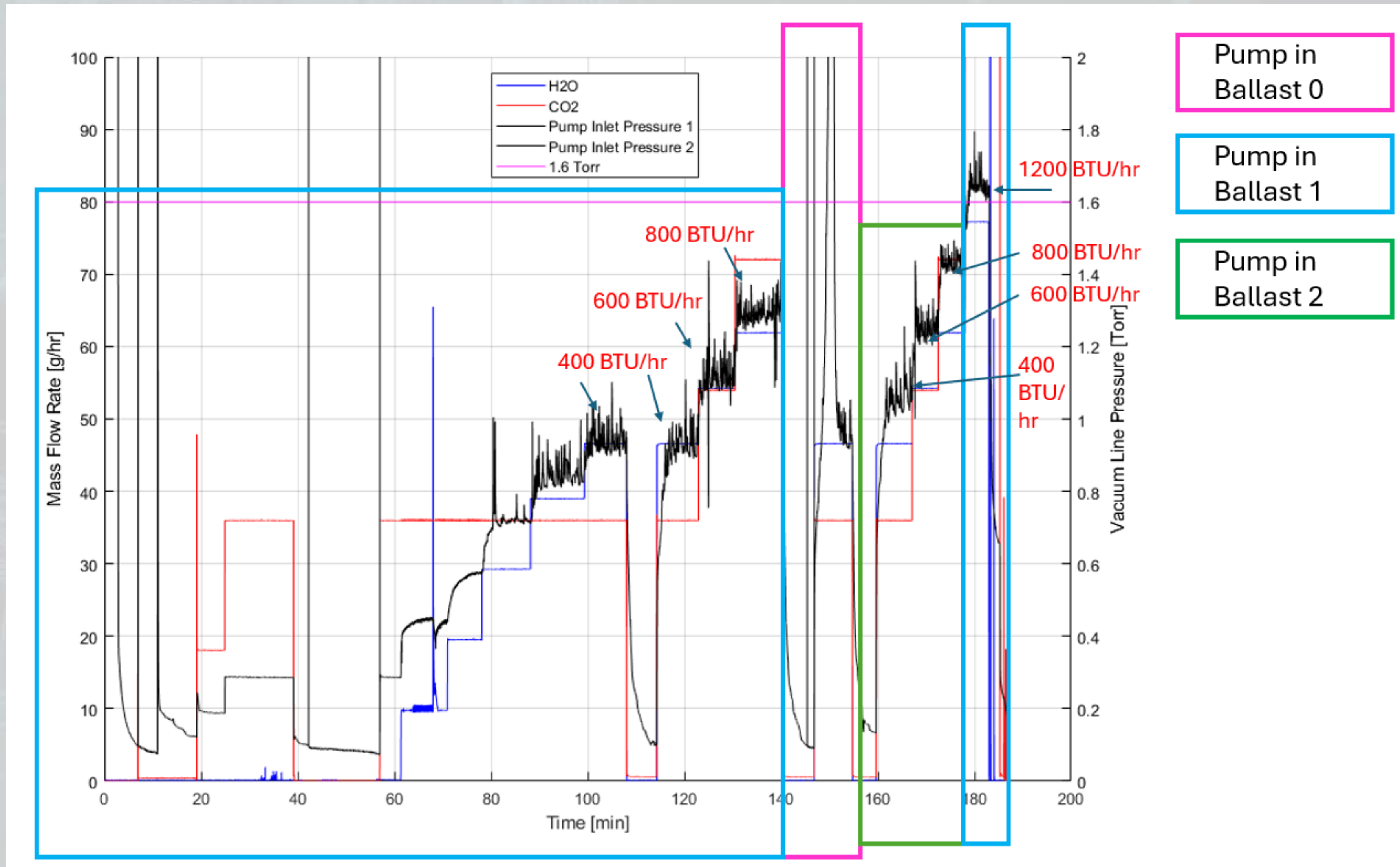
- The second configuration on test day 1 was to inject HMS directly into the IVA vacuum pumps.
- An equivalent met rate of 400BTU/hr



Detailed Testing/Anomalies – IVA Vacuum Access

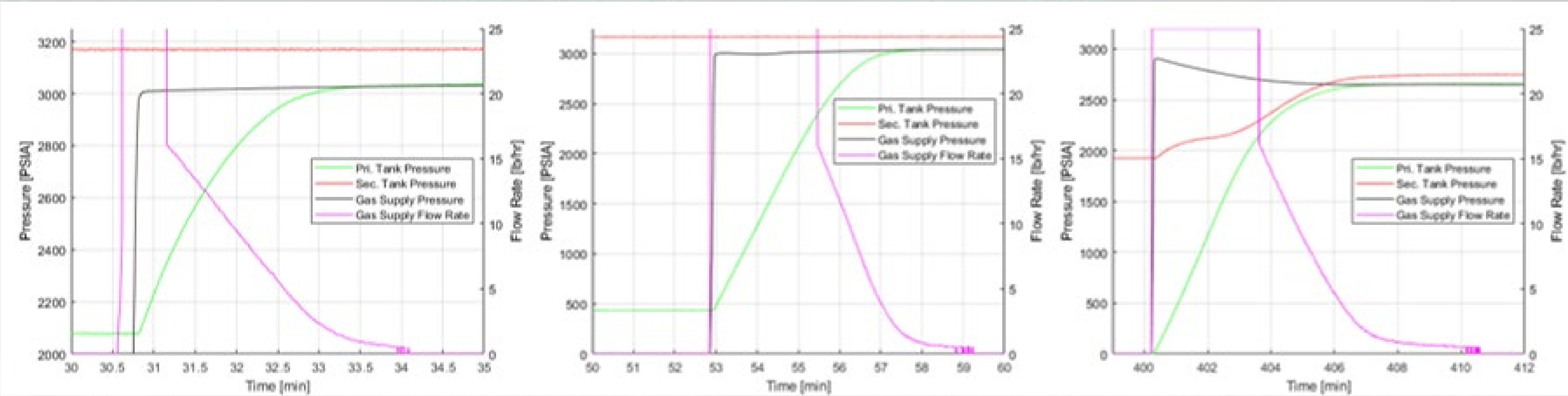
- The second test day was carried out after a faulty pressure sensor was swapped out.
- HMS was installed close as possible to the IVA vacuum line
- Table below shows the different ballast modes and the figure shows the various pressures at those modes

Case #	CO_2 [g/min]	H_2O [g/hr]	Notes	Average Pressure [Torr]
1	0	0	Baseline Isolated Ballast 1	0.08
2	0	0	Baseline Connected Ballast 1	0.12
3	0.276	0.000	~1/2 CO_2 Loading, 400 BTU/hr	0.187
4	0.552	0.000	Full CO_2 Loading, 400 BTU/hr	0.288
5	0.552	11.600	~1/5 H_2O Loading, 400 BTU/hr	0.45
6	0.552	23.200	~2/5 H_2O Loading, 400 BTU/hr	0.575
7	0.552	34.800	~3/5 H_2O Loading, 400 BTU/hr	0.72
8	0.552	46.400	~4/5 H_2O Loading, 400 BTU/hr	0.85
9	0.552	55.455	Full 400 BTU/hr Loading, Ballast 1	0.94
10	0.828	64.549	Full 600 BTU/hr Loading, Ballast 1	1.125
11	1.104	73.644	Full 800 BTU/hr Loading, Ballast 1	1.3
12	0	0	Ballast 0 Baseline Connected	0.094
13	0.552	55.455	Ballast 0 400 BTU/hr	FAIL, reached 5 torr at 400 BTU/hr loading
14	0.828	64.549	Ballast 0 600 BTU/hr	
15	1.104	73.644	Ballast 0 800 BTU/hr	
16	0	0	Ballast 2 Baseline Connected	0.135
17	0.552	55.455	Ballast 2 400 BTU/hr	1.05
18	0.828	64.549	Ballast 2 600 BTU/hr	1.25
19	1.104	73.644	Ballast 2 800 BTU/hr	1.43
20	1.656	91.833	Ballast 1 1200 BTU/hr	1.65



Detailed Testing/Anomalies – Primary Oxygen Vessel (POV) and Secondary Vessel (SOV) Recharge

- 3 total recharge days with recharge day 3 being a POV full discharge.
- All days were successful in charging the POV. Initially read offscale high and then showed 16lbm/hr recharge
- Recharge day 1, 2, and 3



Detailed Testing/Anomalies – FSA Fill and Drain

- FSA recharge performed on days 3, 5 and 6
  - Day 6 was a fill and drain test day
- Testing showed that xEMU can successfully be filled and drained with the updated 11ft chamber water system

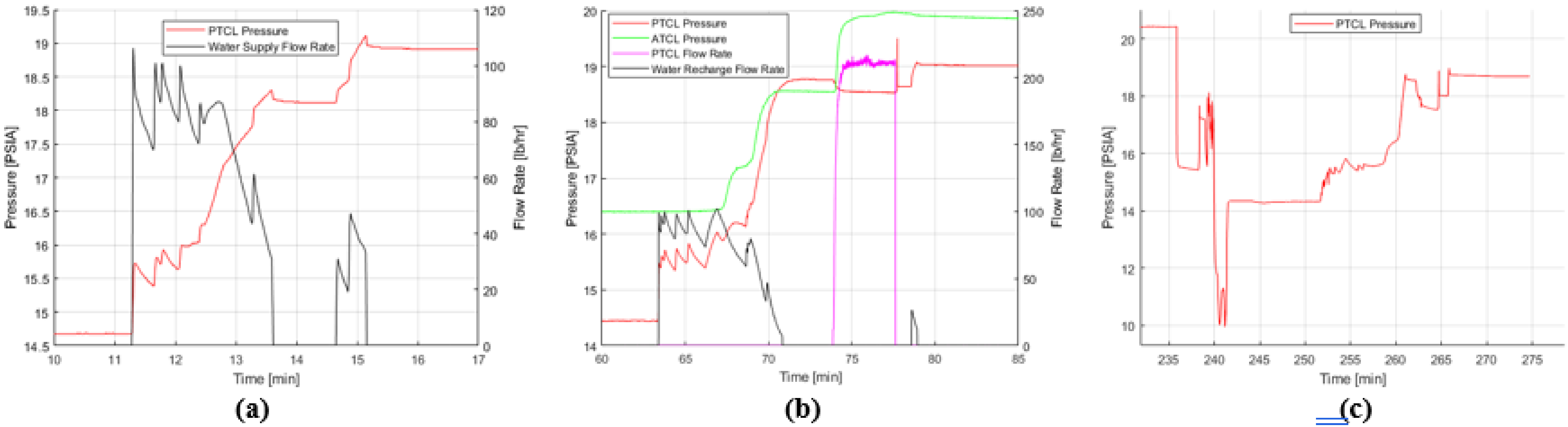


Figure 11: (a) Day 2 Water Recharge, (b) Day 4 Water Recharge, (c) SxEMU PTCL Drain

Detailed Testing/Anomalies – Battery Simulators and Vehicle Power

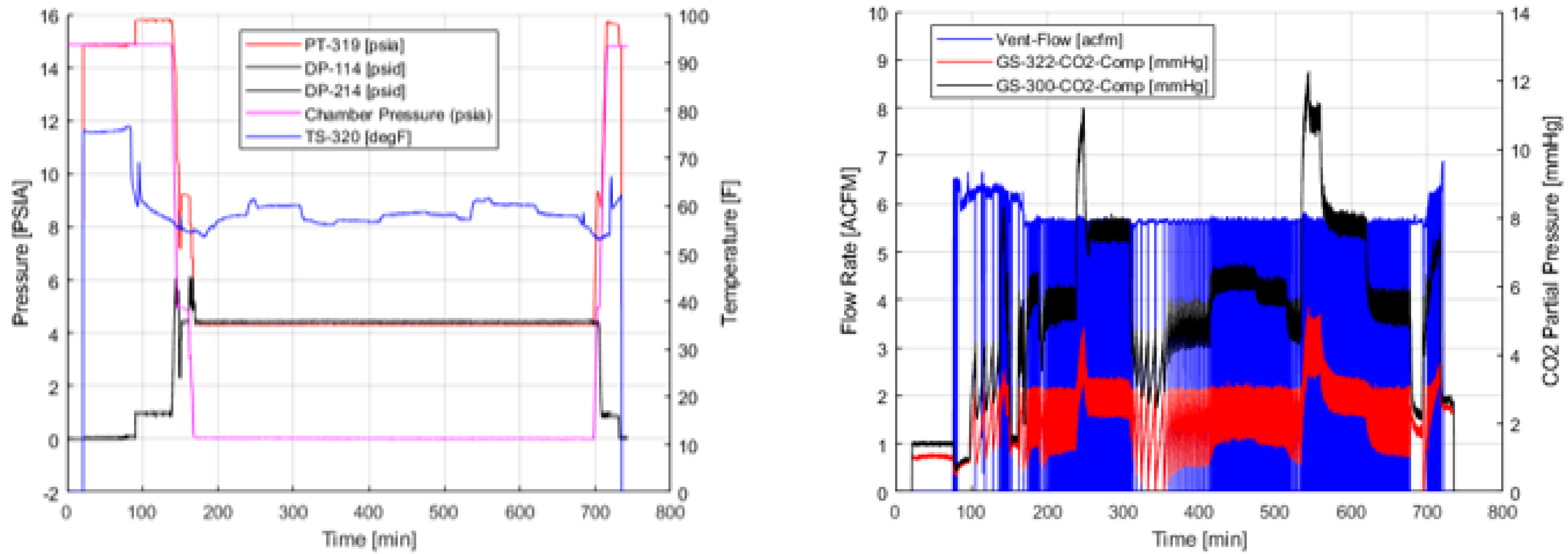
- Two power supplies, simulated vehicle power and battery simulators, both of which showed good performance.
- There was an accidental disable of vehicle power by a technician while the SxEMU was operating off of vehicle power, however once power was restored, the SxEMU recovered from the power loss exactly as intended and gave the expected faults and warning messages
- after power was restored to the SxEMU, the suit recovered from the power loss as expected. Other than these two unintentional power resets, the battery simulators and vehicle power supply operated nominally with no other anomalous behavior

Detailed Testing/Anomalies – Suit Telemetry and Communications

- Ambient test days were used to verify suit communication and telemetry. Engineers removed the SxEMU helmet and verified radio communications to the control room
- While the SxEMU software was not configured for communication over the ESCU hardline, engineers were able to inject audio signals into the ESCU and verify connectivity to the control room. These tests verified the infrastructure for safety-critical communications between a suited test subject and the test team.
- WiFi connectivity was confirmed between a test engineer's laptop and the SxEMU's informatics box via command terminal. Suit telemetry was successfully transmitted via the serial connection in the ESCU umbilical and via the suit radio.

Detailed Testing/Anomalies – SxEMU Performance

- Overall the SxEMU performed well during the test series with minimal anomalous behavior.
- Figures below are from EVA 2 which is the only 8-hr EVA.
- Shows a GS_322 goes high for higher met rates due to RCA degradation

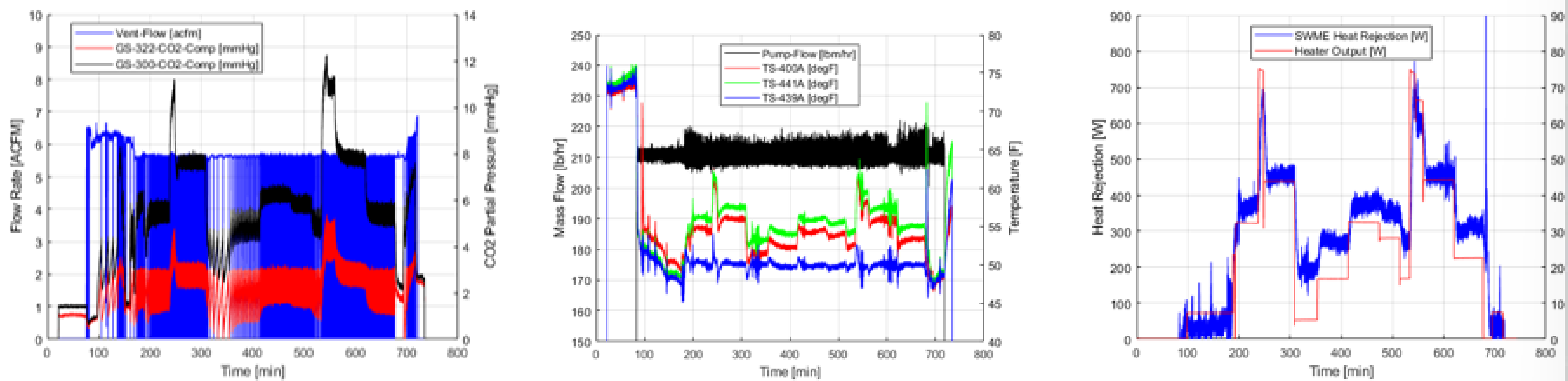


(a) (b)

Figure 12: (a) EVA 2 OVL Pressures and Temperatures, (b) EVA 2 OVL Flow Rate and CO2 Concentrations

Detailed Testing/Anomalies – SxEMU Performance

- The PTCL operated nominally during this test series providing cooling flow to the SxEMU.
- Figure below shows the flow rates, temperature, heat injection, heater output, and pressure during EVA 2

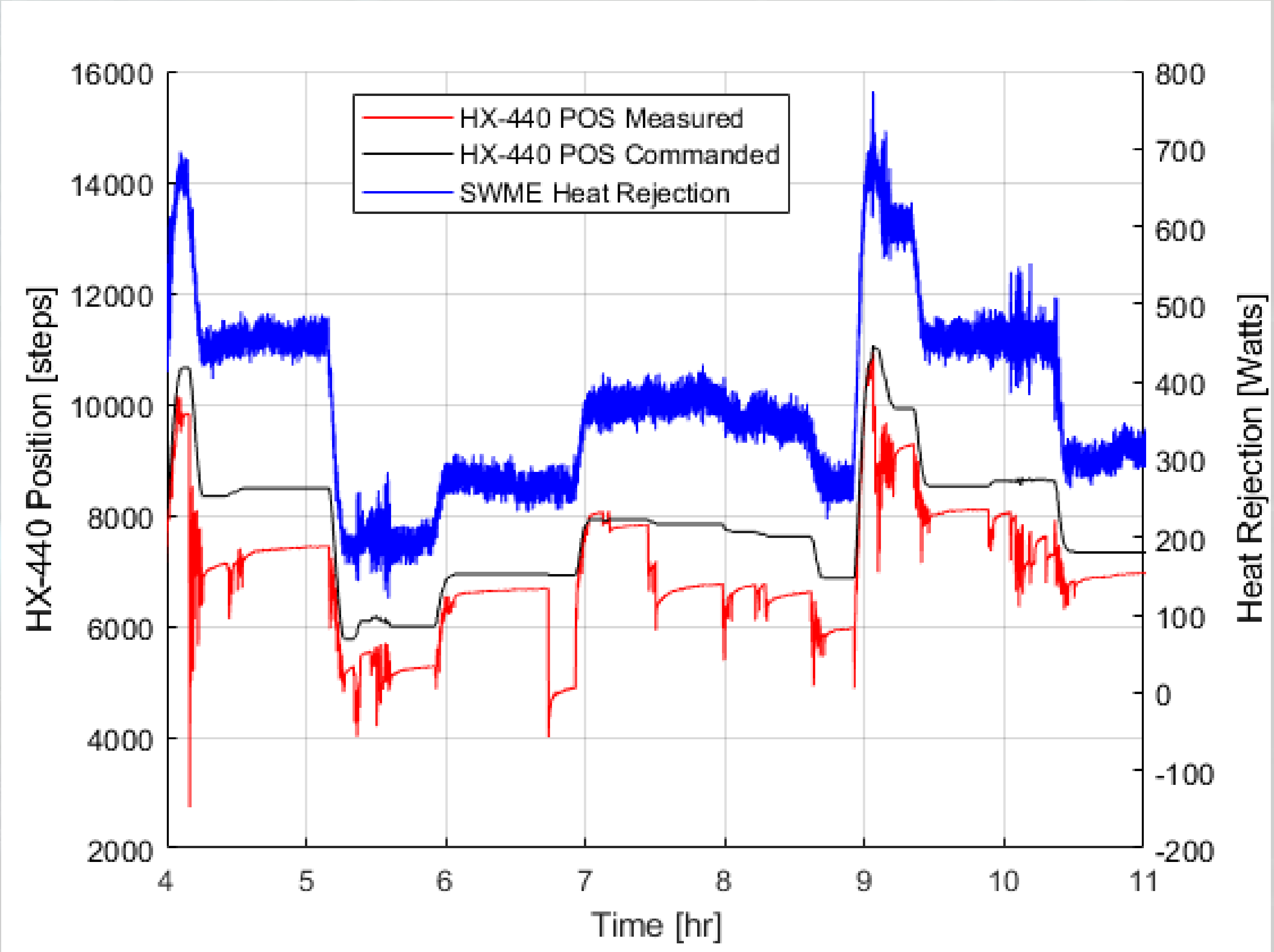


(a) (b) (c)

Figure 13: (a) EVA 2 PTCL Flow Rate and Temperatures, (b) EVA 2 PTCL Heat Balance, (c) EVA 2 PTCL Pressures

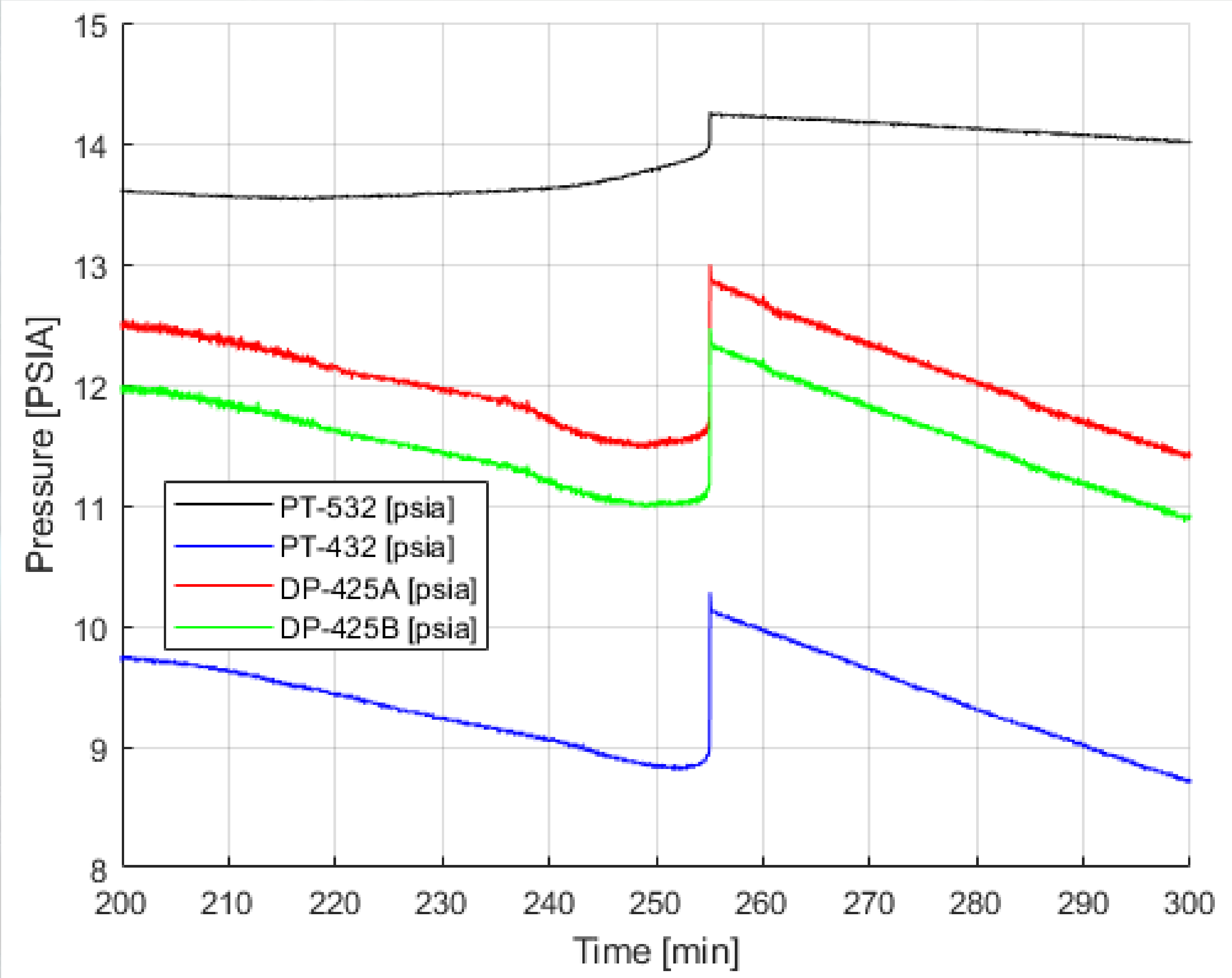
Detailed Testing/Anomalies – Anomalies

- SWME BPV anomalous behavior was observed. The measured position and the commanded position became misaligned when adjusting to the CLOSED position.



Detailed Testing/Anomalies – Anomalies

- During the simulated EVAs there was also anomalous behavior on both water loop pressure sensors
- An unexpected spike in pressure on all water loop pressure sensors
- additionally the water loop absolute pressure did not follow the suit absolute pressure as expected during depress.
- Figures are from EVA 2
- the prevailing hypotheses are FSA shifting, or entrained gas or bubble interactions in both water loops



Conclusions

- The SxEMU 11-ft Chamber Test was successful, verifying that the chamber is capable of testing an advanced spacesuit in preparation for a planned manned test in 2026.
- A key finding of the test was that the IVA vacuum pumps must be operated in Ballast Mode 1 or Ballast Mode 2, preferably Mode 1 as it gives the best performance
- Supporting interfaces for high-pressure gas and water fill and drain operations were successfully tested, with only minor anomalies in the flow meters of each system

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