Spacesuit Portable Life Support System Breadboared (PLSS 1.0) Development and Test Results

Authors: Carly Watts & Matt Vogel

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Executive Summary

A multi-year effort has been carried out at the Johnson Space Center to develop an advanced EVA PLSS design intended to further the current state of the art by increasing operational flexibility, reducing consumables, and increasing robustness. This multi-year effort has culminated in the construction and operation of PLSS 1.0, a test rig that simulates full functionality of the advanced PLSS design. PLSS 1.0 integrates commercial off-the-shelf hardware with prototype technology development components, including the primary and secondary oxygen regulators, ventilation loop fan, Rapid Cycle Amine (RCA) swingbed, and Spacesuit Water Membrane Evaporator (SWME).

PLSS 1.0 was tested from June 17th through September 30th, 2011. Testing accumulated 233 hours over 45 days, while executing 119 test points. An additional 164 hours of operational time were accrued during the test series, bringing the total operational time for PLSS 1.0 testing to 397 hours. Specific PLSS 1.0 test objectives assessed during this testing include:

- Confirming prototype components perform in a system level test as they have performed during component level testing
- Identifying unexpected system-level interactions
- Operating PLSS 1.0 in nominal steady-state EVA modes to baseline subsystem performance with respect to metabolic rate, ventilation loop pressure and flow rate, and environmental conditions
- Simulating nominal transient EVA operational scenarios
- Simulating contingency EVA operational scenarios
- Further evaluating prototype technology development components

Successful testing of the PLSS 1.0 provided a large database of test results that characterize system level and component performance. With the exception of several minor anomalies, the PLSS 1.0 test rig performed as expected. Documented anomalies and observations include:

- Ventilation loop fan controller issues at high fan speeds (near 70,000 rpm, whereas the fan speed during nominal operations would be closer to 35,000 rpm)
- RCA performance at boundary conditions, including carbon dioxide and water vapor saturation events, as well as reduced vacuum quality
- SWME valve anomalies (4 documented cases where the SWME failed to respond to a control signal or physically jammed, preventing SWME control)
- Reduction of SWME hollow fiber hydrophobicity and significant reduction of the SWME degassing capability after significant accumulated test time.

1.0 Introduction

A space suit life support system, or portable life support system (PLSS), is the collection of components designed to meet all of the crew member's life support needs during an extravehicular activity (EVA). The primary functions of the life support system include providing habitable pressurization, breathing gas (oxygen), carbon dioxide (CO_2) and water (H_2O) removal, trace contaminant removal, ventilation flow, and cooling (both to the crew member and space suit electronics).

Currently, the Shuttle/International Space Station (ISS) Extravehicular Mobility Unit (EMU) PLSS represents the state of the art in space suit life support systems. The EMU PLSS was developed in the late 1970s and early 1980s to enable EVA for the Space Shuttle Program. Though the EMU PLSS has functioned largely as intended over the past three decades, there have been a number of hardware issues that have impacted the EVA program. Some failures have necessitated partial system redesigns and others have had real-time mission impacts, such as reducing active EVA time. Now, with the EMU PLSS fleet nearing the end of its lifetime certification, it is time to consider what comes next for space suit life support systems. In the past thirty years, advancements in technology have occurred that demonstrated significant improvements over the current flight system.

For the past several years, engineers, designers, and analysts have been working to advance the technical readiness level (TRL) of an advanced space suit PLSS design that, if proven successful, could supersede the EMU PLSS. These development efforts culminated in the first system-level test of the advanced PLSS design, which included several technology development components. The test stand, known as PLSS 1.0 or the PLSS Breadboard, was constructed using a combination of prototype technology development components and commercial-off-the-shelf (COTS) hardware. PLSS 1.0 testing started in June 2011 in building 220 at the Johnson Space Center (JSC) and continued until the end of September 2011.

2.0 Advanced PLSS Design

2.1 Advanced PLSS Schematic, Rev. C

The PLSS 1.0 test stand was created to simulate the functionality of the advanced PLSS design documented in the Advanced PLSS Schematic, Rev. C (see Figure 1). The concept incorporates significant technological advancements into a system that is intended to be more robust, use less consumables, and provide more mission flexibility than previous space suit PLSS designs. Prior to the completion of PLSS 1.0 testing, this design was theoretical and untested; though it should be noted that substantial analytical performance modeling had been conducted. The Advanced PLSS design is primarily composed of three subsystems: an Oxygen Subsystem, Ventilation Subsystem, and Thermal Subsystem.

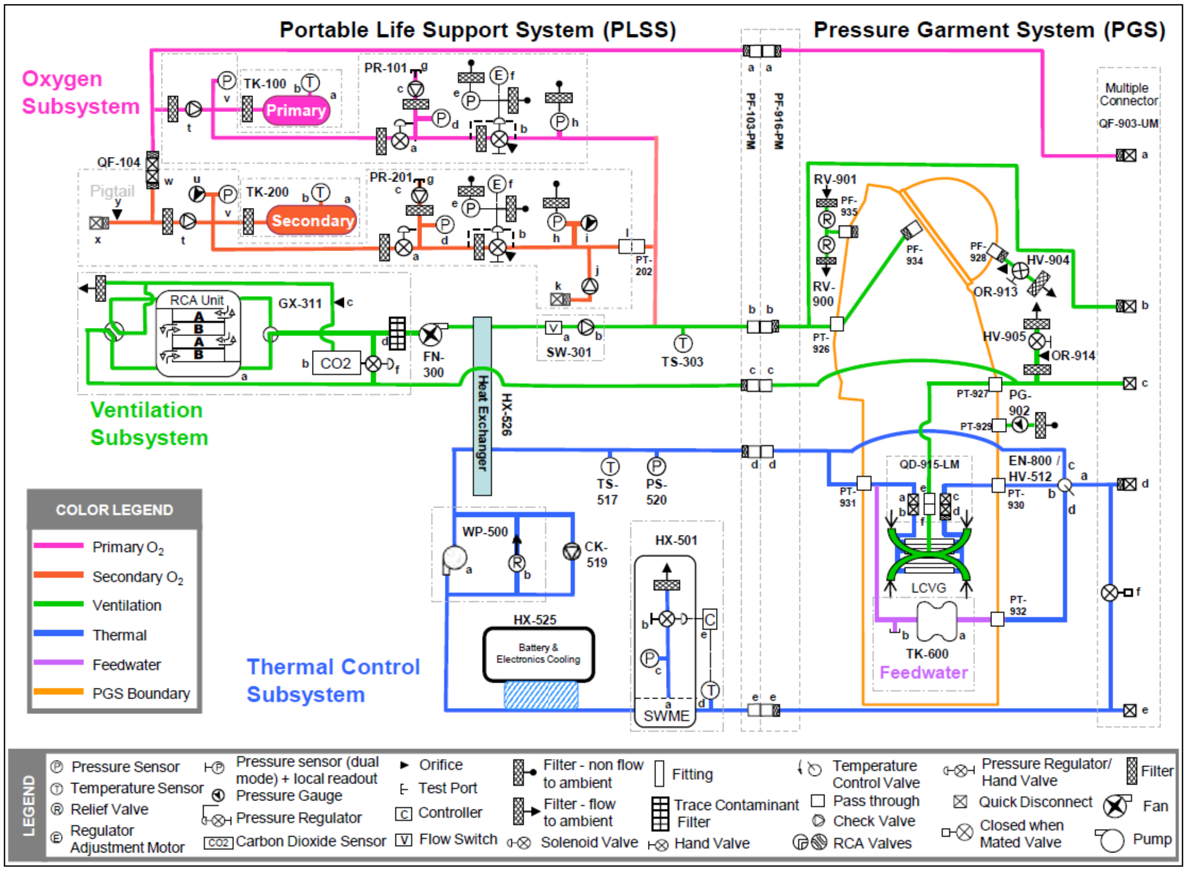


Figure 1. Advanced PLSS Schematic, Rev. C

The oxygen subsystem consists of the primary and secondary oxygen systems; both systems provide oxygen gas for space suit pressurization and metabolic consumption. Both systems consist of gas bottles (tanks) that store high pressure oxygen and regulators that control the delivery of oxygen to the ventilation loop. During nominal operations, only the primary oxygen system provides gas to the pressurized space suit. In the event of a failure that compromises the primary system, the secondary system can act as a fully redundant capability to sustain the EVA crewmember until he or she can make it back inside the vehicle.

Once the oxygen subsystem supplies the gas, it is fed into the ventilation subsystem where a fan (FN-300 in Figure 1) circulates the gas through the space suit free volume and then back through the PLSS. In the space suit, the oxygen serves as breathing gas to the crew member and washes out any localized build-up of CO_2 from exhalation. As it flows through the suit, the oxygen gas mixes with CO_2, water vapor, and other trace contaminants before it returns to the PLSS, where the majority of these impurities are removed.

The thermal subsystem is a water loop that operates largely independently of the other two subsystems. A water pump (WP-500 in Figure 1) circulates the fluid through the thermal loop, providing cooling to the crew member via the liquid cooling and ventilation garment (LCVG) and to the PLSS electronics via a coldplate. A heat exchanger, HX-526, is the only interface between the thermal and ventilation subsystems and serves the purpose of cooling the fan exhaust gas before entering the crew helmet volume. The heat exchanger uses the cold water of the thermal subsystem to cool the gas in the ventilation loop before it returns to the crew member.

2.2 Technology Development Components

Critical components in the PLSS 1.0 test rig were technology development components that have been designed and tested independently over the past 3-5 years and are highlighted below. Each of the following components has features that support the overall PLSS design objectives of increasing operational flexibility, reducing consumables, and increasing robustness.

2.2.1 Primary Oxygen Regulators

The primary oxygen regulator (POR) is represented as item PR-101 in Figure 1 and is presented in Figure 2. Part of the primary oxygen subsystem, this unit is a high pressure regulator that allows for various regulation set-points across the suit operating pressure range for the purposes of reducing prebreathe time, treating decompression sickness (DCS), and adjusting suit flexibility real-time during EVA. The test article functioning as the POR is the Primary Variable Regulator (PVR), a two-stage electromechanical regulator designed and fabricated by Cobham (formerly Carleton Technologies). The upper stage of the device regulates the high pressure supply gas at 250-3750 psia down to 250-200 psia. At the outlet of the lower stage, the pressure is variable between 0-8.4 psig with reference pressures ranging from 0-14.7 psia. The PVR has approximately 4000 possible set-points across the 0-8.4 psig suit operating pressure range, which is significantly greater than the two set-points of the EMU PLSS Primary Pressure Control Module, EMU Item 113, and engenders the expected increase of margin and flexibility for various modes of operation. Though the regulator set-point is controlled electronically, by design it will maintain the set-point without power thus making it a fail-safe device and enabling low power usage during nominal operations.

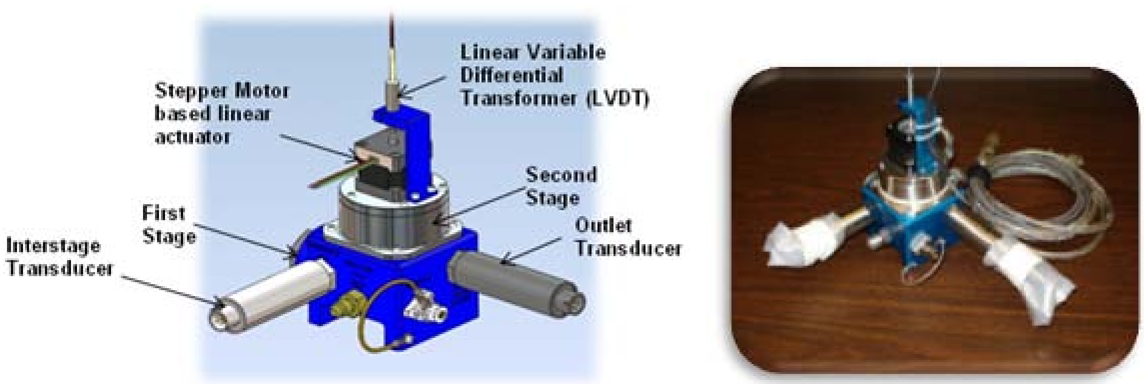


Figure 2. Primary Variable Regulator

2.2.2 Secondary Oxygen Regulator

The secondary oxygen regulator (SOR), represented as item PR-201 in Figure 1, was also developed and fabricated by Cobham (see Figure 3). Similar to the primary regulator, this device is a 2-stage electromechanical regulator that regulates high pressure oxygen (250-3750 psia) down to its output pressure set-points ranging from 0 to 8.4 psig. The stepper motor based linear actuator covers the 0-8.4 psig set-point range in about 4000 steps, thus effectively yielding a variable set-point regulator. The SOR is intended to operate at a set-point slightly lower than the POR in off-nominal situations when a failure has resulted in an ineffective primary oxygen system.

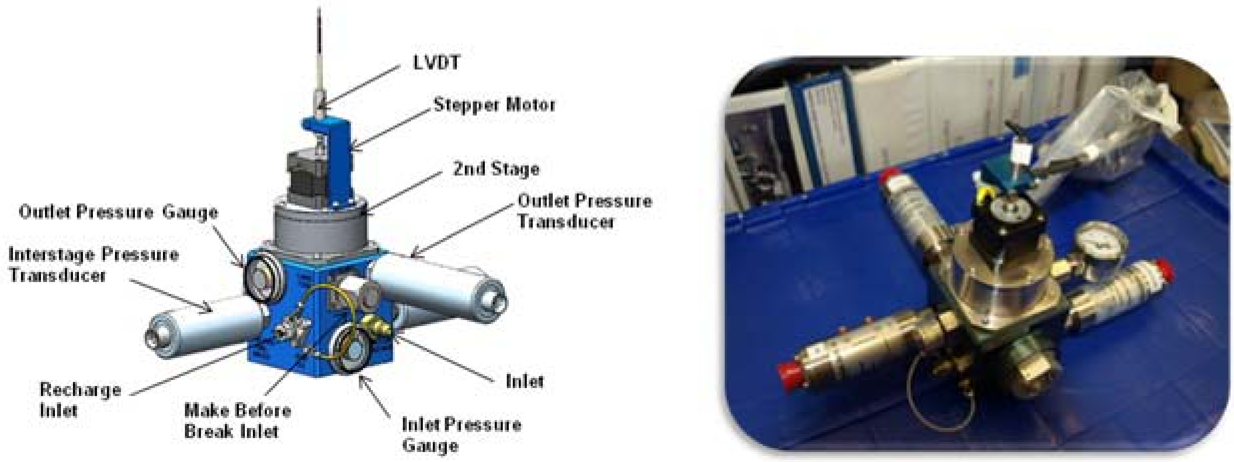


Figure 3. Secondary Oxygen Regulator

2.2.3 Ventilation Loop Fan

The ventilation loop fan, item FN-300 in Figure 1 and also shown below in Figure 4, was designed and fabricated by Hamilton Sundstrand. At nominal EVA operating conditions with oxygen gas at approximately 4 psia, the fan will operate between 35,000-45,000 rpm, providing a flow rate in the ventilation loop of 4.5-6 ACFM. The fan is also designed to operate with minimal decrease in efficiency at off-nominal conditions in order to support contingency operations. For example, the fan is capable of operating up to 70,000 rpm providing a flow rate up to 8 ACFM at low suit pressures.

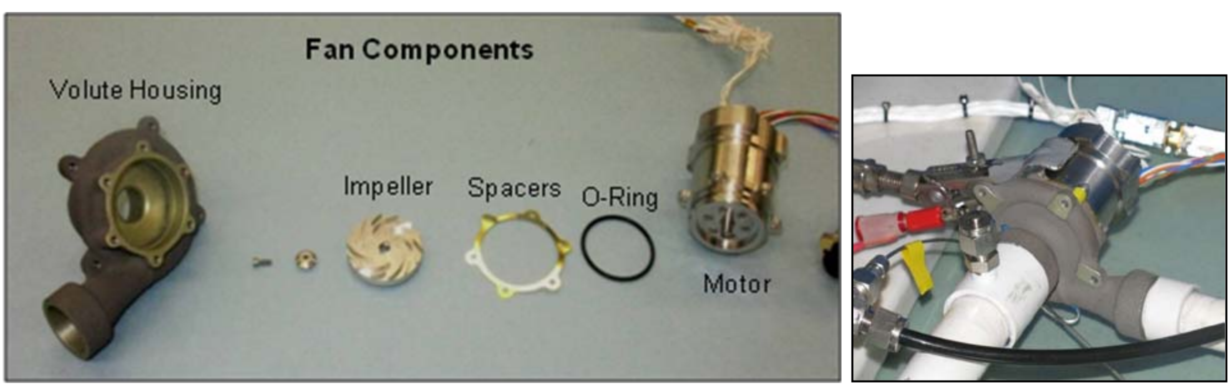


Figure 4. Ventilation Loop Fan

2.2.4 Rapid Cycle Amine (RCA) Swingbed

Shown as item GX-311 in Figure 1 and presented in Figure 5, the RCA swingbed represents a potentially significant technological advancement over the state of the art EMU PLSS CO_2 removal systems. In the EMU PLSS, CO_2 is removed from the suit environment using one of two systems: lithium hydroxide (LiOH) canisters or metal oxide (Metox) canisters. Both technologies require water to catalyze the reaction to absorb water in the conversion of LiOH to $LiCO_3$ or AgO to $AgCO_2$. If the moisture balance is not correct, the canisters may not be properly conditioned rendering them incapable of removing CO_2 and EVA duration may be decreased. For the ISS application, LiOH canisters are less advantageous because they are a single-use item that cannot be recycled after CO_2 saturation. Metox canisters can be regenerated on orbit with a 14 hour regeneration cycle that heats the canister to 400°F for ten hours followed by a 4 hour cool-down period. Two independent regenerators and quantity 10 Metox canisters are maintained on ISS in order to provide the regeneration ability with fault tolerance.

One of the key benefits over the current EMU PLSS systems is the RCA swingbed is regenerable real-time during an EVA, thus eliminating consumables and post-EVA recharging. In addition, it is designed to operate for 100 EVAs. The RCA swingbed is a dual bed system; each bed is filled with beads coated with a solid amine sorbent known as SA9T. While one bed is exposed to the space suit environment via the ventilation loop, the CO_2 in the loop forms a chemical bond with the SA9T in a process called adsorption. Meanwhile, the other bed is exposed to vacuum via a vent-to-vacuum port. As the CO_2 laden sorbent is exposed to vacuum, the interstitial gas is removed from the bed driving the equilibrium between solid-vapor phases toward vapor releasing the adsorbed material. The valve that interfaces with the canister changes the flow paths through the unit to cycle the beds between exposure to the suit environment and exposure to space (vacuum), thereby providing real-time regeneration of the CO_2 removal capability. This unit eliminates the need for ancillary hardware or logistics and can be used to support over 100 consecutive 8-hour EVAs. Similarly to Metox, the desorption process is endothermic although far less energy is required for desorption from SA9T. However, this is accomplished passively by an inter-leaved bed design which facilitates the conduction of exothermic heat released during adsorption into the desorbing beds thereby self-regulating the energy exchange required for the adsorption/desorption processes. Furthermore, the SA9T amine also bonds with water (H_2O) vapor, adsorbing and desorbing H_2O simultaneously with CO_2. This eliminates the need for a water separator, as is currently required in the EMU PLSS.

Figure 5. Rapid Cycle Amine (RCA) Swingbed

2.2.5 Spacesuit Water Membrane Evaporator

The spacesuit water membrane evaporator (SWME), shown as HX-501 in Figure 1 and presented in Figure 6, is an evaporative cooling unit that removes heat from the water in the thermal loop, thereby providing cooling to the Power, Avionics, and Software (PAS) System and to the crew member. The current SWME is a second generation hollow fiber SWME designed and fabricated in-house by the NASA-JSC/Jacobs Engineering-ESCG SWME team. The SWME performance specification calls out a maximum heat rejection of 810 watts (2754 BTU/hr) at nominal operating conditions (200 lbm/hr flow rate and 10°C at SWME outlet). This unit can operate in microgravity, lunar, and Martian environments. In addition, the SWME is operable across a broad range of thermal loop water pressures and meets performance requirements while operating with low quality water (potable water with particulate matter). The SWME also functions as a degasser, removing gas bubbles from the water loop and thereby eliminating the need for a gas trap and water separator as are required in the ISS EMU. Finally, unlike the current EMU PLSS sublimator, the SWME does not require a separate feedwater supply system.

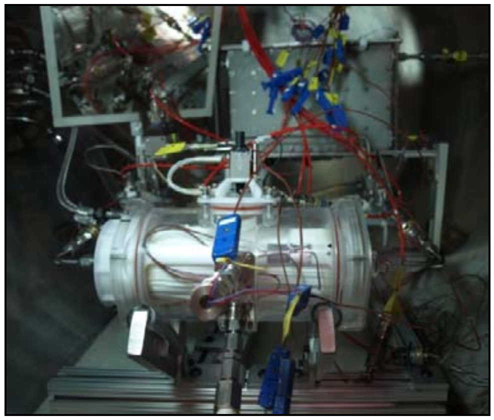


Figure 6. Spacesuit Water Membrane Evaporator (SWME)

3.0 PLSS 1.0 (PLSS Breadboard) Test Rig

The PLSS 1.0 test rig was designed and fabricated over the course of FY11 in NASA-JSC building 220 (Figure 7). This effort represents the first system-level experimental evaluation of an advanced PLSS design in nearly three decades. The five technology development test articles – primary and secondary oxygen regulators, ventilation loop fan, RCA, and SWME - were integrated with commercial off-the-shelf (COTS) hardware to simulate full functionality of the advanced PLSS design. The full test setup, including data acquisition (DAQ) rack and vacuum chamber R can be seen in Figure 8. Although the advanced PLSS design calls for 100% oxygen as the primary gas constituent, PLSS 1.0 testing was conducted with nitrogen due to safety considerations and the current TRL of the developmental hardware.

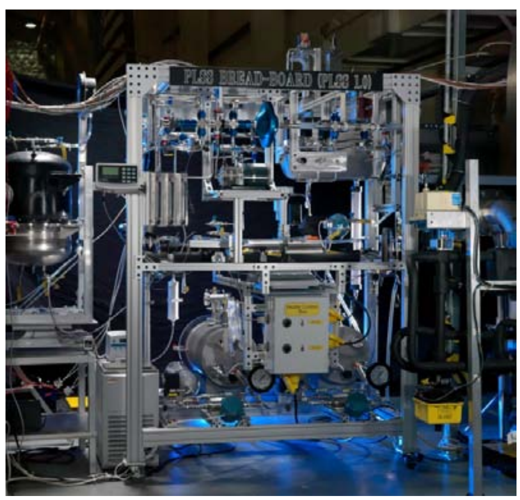


Figure 7. PLSS 1.0 (PLSS Breadboard) Test Rig

The POR, SOR, RCA, and SWME all require vacuum access for nominal EVA operations. The POR and SOR reference ambient pressure to maintain a set-point above ambient. During pre-EVA and EVA operations, ambient pressure can range from 0-14.7 psia. For this test, the POR and SOR were plumbed into small cylindrical vacuum chambers that could be operated over the required pressure range. The RCA vent-to-vacuum line was plumbed into a port on Chamber R, and the SWME was placed inside Chamber R (Figure 8).

Human metabolic products were simulated in this test rig by adding CO_2 and water vapor to the nitrogen in the ventilation loop. The thermal loop fluid was a water composition prepared by the Crew and Thermal Systems

Division (CTSD) Water Lab meant to represent the water obtainable from the ISS Water Processing Assembly. Line heaters on the thermal loop simulated thermal loads of the crew member and PAS system. COTS valves were used to simulate the functionality of the suit and helmet purge valves, as well as metabolic gas consumption. The full test system schematic is illustrated in Appendix A. PLSS 1.0 Test Schematic.

Figure 8. PLSS 1.0 Test Setup (B220)

The DAQ system for PLSS 1.0 was constructed using National Instruments (NI) LabVIEW software in conjunction with the NI SCXI platform. The LabVIEW Datalogging and Supervisory Control (DCS) Module was used to log all 168 data channels at a rate of 1 Hz. Many of the electronic controls for both technology development and COTS hardware were operated manually and controlled to a predetermined value determined through analysis.

4.0 Testing

The formal test series started on June 16, 2011 and was completed on September 30, 2011. In all, testing accumulated 233 hours over 45 days, while executing 119 test points. An additional 164 hours of operational time were accrued during the test series, bringing the total operational time for PLSS 1.0 testing to 397 hours.

The primary test objectives were to demonstrate basic life support functions, including habitable pressurization, thermal control, and moisture and partial pressure of carbon dioxide ($ppCO_2$) removal across a range of metabolic and thermal test points. Secondary & tertiary objectives aimed to evaluate system performance during off-nominal contingency modes of operation. The complete list of test points can be seen in Appendix B. Test Point Matrix, with supporting documentation regarding variable test conditions located in Appendix C. Transient 8-Hour Metabolic Profile Data through Appendix E. High Humidity Test Conditions. Appendix F. Schedule of Test Points shows the date and time each test point was completed.

5.0 Test Results

5.1 Oxygen and Ventilation Subsystems

Because functionality of the Oxygen and Ventilation Subsystems is largely coupled, performance of the subsystems was jointly considered. For each test point that was completed, the ventilation loop set-points were plotted against the test data. Along with other quantitative measures, these plots were used to ascertain whether or not the objective of the test point was successfully accomplished. One example of a nominal test point (TP), TP #2, is shown in Figure 9.

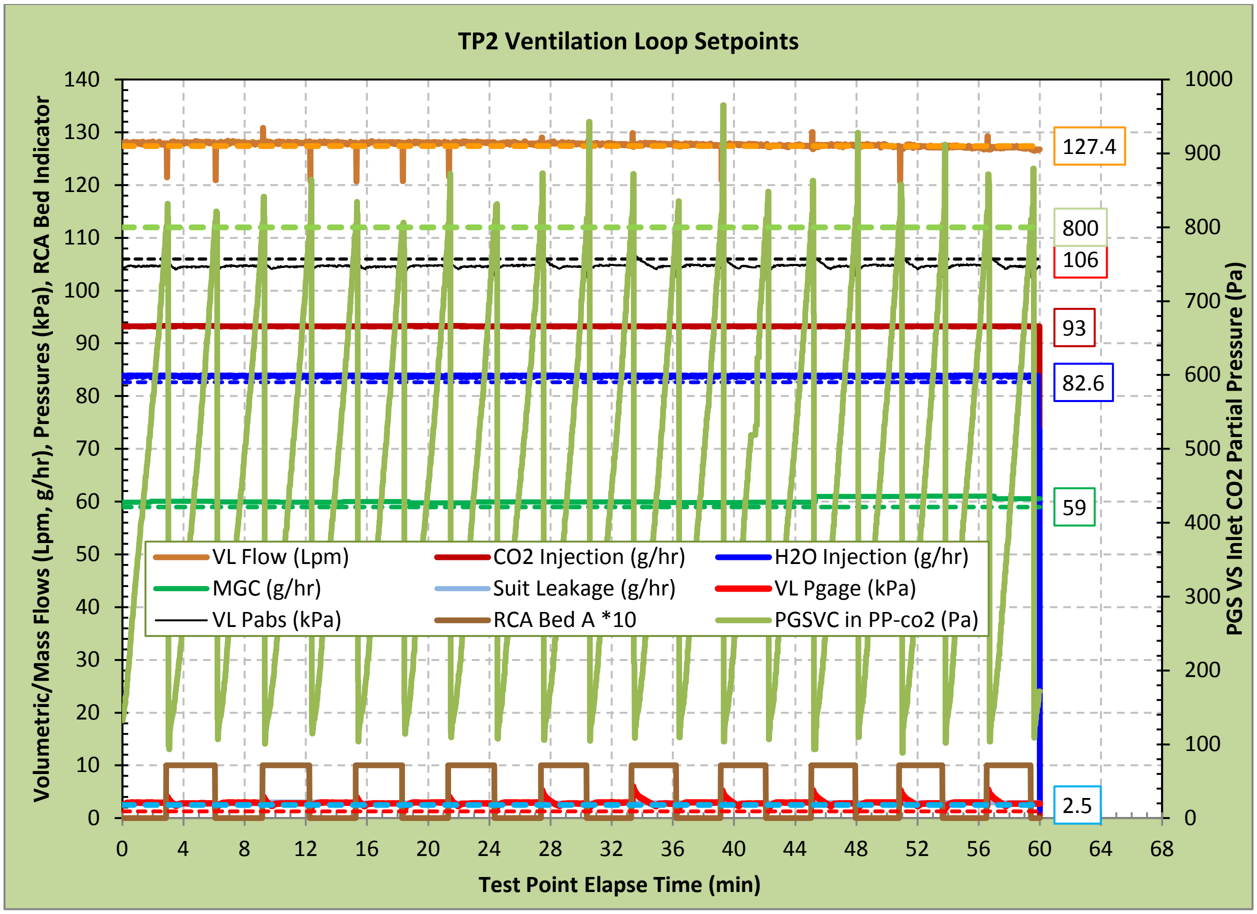


Figure 9. Test Data Plotted Against Ventilation Loop Set-Points for Test Point #2

In Figure 9, the dotted lines indicate the variable set-point values from the test point matrix; the solid lines show test data. For the case of TP#2, initial observations indicate that all ventilation and oxygen subsystem data remained near the desired set-points for the duration of the test point. The human metabolic simulator (HMS), a COTS unit that injects a mixture of CO_2 and water vapor to replicate the crew member's metabolic products, was performing nominally as shown by the close agreement between desired and measured CO_2 and water vapor injection flow rates. The ventilation loop (VL) pressure and flow rate are at or near the expected values, as are the suit leakage and metabolic gas consumption (MGC) rates. Finally, the cyclic RCA performance is consistent with pretest predictions and previous RCA test data.

For TP#2, the RCA was cycling based off the $ppCO_2$ at the inlet to the pressure garment subsystem volume simulator (PGSVS), shown as TK-968 in the test schematic in Appendix A. PLSS 1.0 Test Schematic. When the $ppCO_2$ at this location reached 6 millimeters of mercury (mm Hg), or 800 pascals (Pa), it would trigger the RCA to cycle, exposing a clean amine bed to the ventilation loop and producing a rapid decrease in $ppCO_2$. The sawtooth green line in Figure 9 demonstrates cyclic steady-state behavior as CO_2 successfully achieves breakthrough from each fresh bed following vacuum desorption.

Figure 10 illustrates an example of a testing anomaly that occurred during an attempt to run TP#12. On the morning of 6/23/11, TP#12 was the first test point initiated. During startup, the team inadvertently failed to open the isolation valve on the CO_2 k-bottle. The solid burgundy line near the bottom of the graph shows the quantity of CO_2 injected into the system decrease as residual CO_2 in the line downstream of the k-bottle isolation valve was expended. During this time, from t = 0-20 minutes, the pp CO_2 at the PGSVS (indicated by the solid green line) increased steadily until it triggered the RCA to cycle. After t = 20 minutes, the CO_2 in the loop was not sufficient to trigger another RCA cycle. Though the CO_2 isolation valve was closed, the HMS was still injecting water vapor into the system. Without the RCA cycling, the relative humidity (RH) reached approximately 98% as indicated by RH sensor OHS-350 (solid thin black line). Approximately 44 minutes into the test, the RH leveled out, indicating that liquid water was condensing in the ventilation loop. From t = 20-44 minutes, the dew point at the PGSVS outlet, indicated by sensor OHS-350Td (solid red line near bottom of chart), increased until it reached approximately 23°C. Meanwhile, temperature senor OTS-351 showed the gas temperature in the ventilation loop was constant near 23°C (solid brown line). All evidence suggests that some amount of liquid water condensed in the ventilation loop from t = 44-53.5 minutes. At t=53.5 minutes, the test team realized the anomalous system behavior and took corrective action to regain nominal conditions.

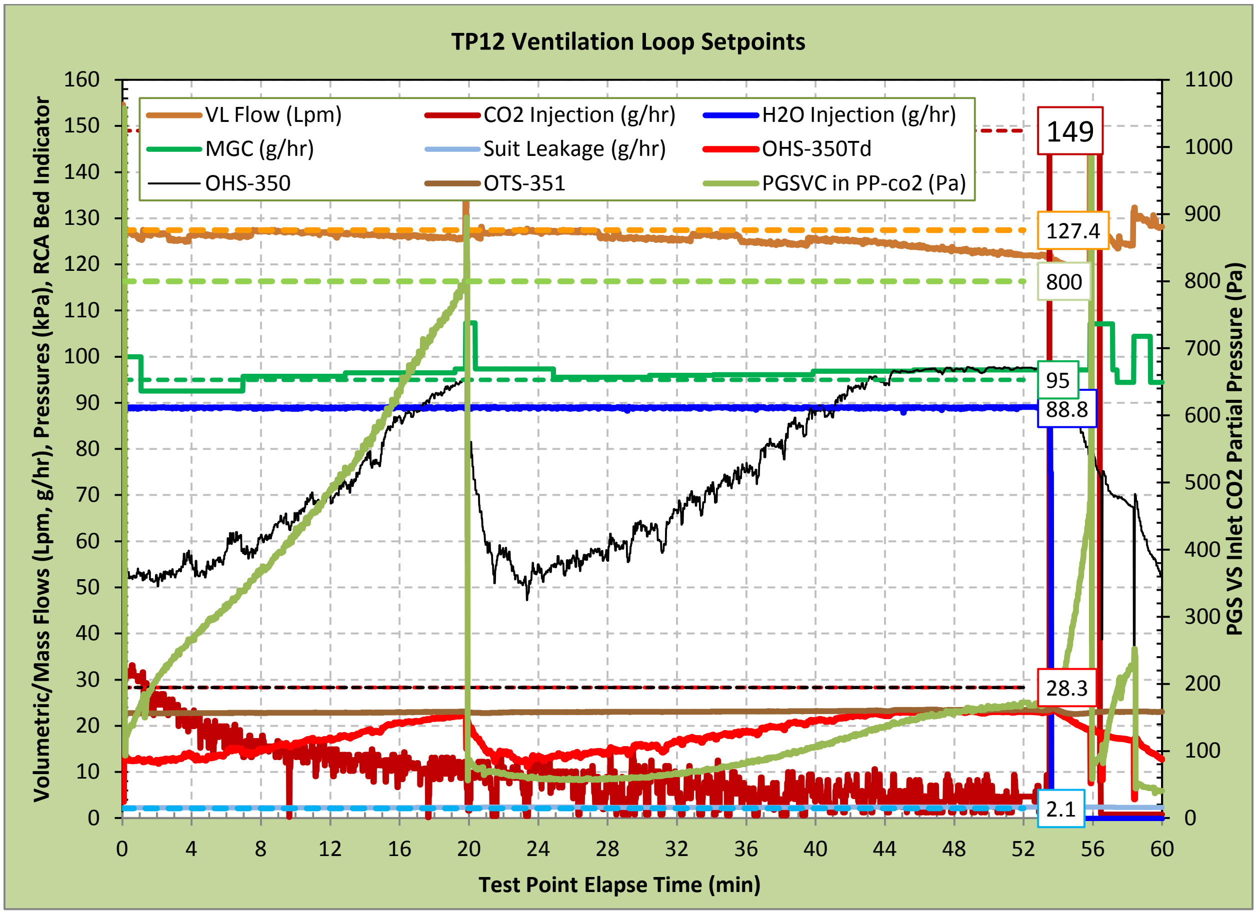


Figure 10. Test Data Plotted Against Ventilation Loop Set-Points for Test Point #12

Though the event documented in Figure 10 did not accomplish the intended objective of TP#12, it did provide extremely interesting and valuable data. After the anomalous condition was identified and steps were taken to reduce the relative humidity and eliminate any liquid water in the ventilation loop, data was recorded as the RCA recovered from the H_2O vapor saturation event. The RCA recovery was not instantaneous, but over the course of several minutes, the unit successfully reduced the relative humidity in the loop and and fully regained its nominal H_2O vapor removal capability. This inadvertent evaluation showed the robustness of the RCA during and after extremely high RH conditions and led to further testing to characterize RCA and ventilation loop performance in a high RH environment.

5.1.1 Oxygen Regulators

Throughout the test series, several interesting observations were made with respect to the oxygen subsystem. The oxygen regulators, the PVR and SOR, performed for the most part as expected. Preliminary observations indicate that the set-point resolution may be affected by regulator reference pressure and/or set-point pressure. At high ventilation loop set-pressure (8 psia), there seemed to be lower set-point resolution than at lower set-pressures; one example of this was observed on 7/13/11. The set-point resolution also seemed lower than normal when the regulator reference pressure was 14.7 psia, as occurred on 6/21/11 and 6/28/11. This could be a result of the high reference pressure or the low gauge set-point pressure.

Interesting results were also observed when the primary oxygen vessel (POV) was allowed to run out of gas and the secondary system provided pressurization and pressure regulation. There is a minimum supply pressure required to ensure proper functionality of the oxygen regulators (approximately 250 psig). When the POV pressure was less than 250 psig, the oxygen subsystem maintained a pressure above the SOR set-point, but below the primary oxygen regulator (POR) set-point.

5.1.2 Ventilation Loop Fan

On the whole, the ventilation loop fan performed very well throughout the PLSS 1.0 test series. The most notable anomalies occurred at extremely high speeds near 70,000 rpm, when the fan was set to achieve a flow rate of 8 ACFM, or approximately 226 standard liters/minute (slm), in the ventilation loop. At this high speed, the fan controller seemed to intermittently lose the ability to maintain the set-point; the fan speed would drop several thousand rpm before recovering. The frequency at which the drops in fan speed occurred increased the longer the high speed condition was allowed to continue. After several occurrences, the test point was terminated. The 8 ACFM ventilation loop flow rate was a requirement during the Constellation Program, but with its cancellation, this requirement was eliminated. The test team wanted to evaluate the high flow condition to push the operational boundaries of the system, but did not want to risk damaging the fan or fan controller at this early point in the PLSS 1.0 testing schedule. It should be noted that the fan controller was COTS hardware and that, later in the test series, it was determined that 8 ACFM was significantly outside the design specification for the hardware.

Table 1. Ventilation Loop Fan Anomalies

Date	Flow Rate (ACFM)	Notes from Test Log Regarding Observed Anomaly
6/21/11	8	Controller cannot seem to effectively control fan speed. Fan speed drops significantly (notably and audibly) at this high speed. Worried about damaging the controller. Terminated test point early.
7/1/11	4.5	Fan speed (as reported in rpm) seems higher than previously observed at 4.5 ACFM.
7/12/11	≈2	Strange noises heard at low speed (20,800 rpm). Sounds like particulates hitting fan impellers (unconfirmed).
7/22/11	6	During simulated RCA failures, vent loop fan anomaly observed. Set-point jumping/falling 10-15 slm.

5.1.3 RCA

Like the aforementioned test articles, the RCA performed as expected throughout the vast majority of PLSS 1.0 testing. Different methods of RCA control were evaluated, including cycling the RCA at constant time intervals as well as at predetermined $ppCO_2$ thresholds at the inlet to the PGSVS. Valuable data was collected regarding the time required for the RCA to desorb, the process of recovery after a CO_2 or H_2O saturation event, and RCA performance with reduced vacuum quality.

Recent CO_2 exposure data indicates that crew members begin becoming symptomatic of CO_2 exposure at levels as low as 3.8 mm Hg inspired CO_2. Analysis indicates that due to the mixing effects that occur inside the space suit helmet, a concentration of 2.2 mm Hg is required at the helmet inlet to yield inspired $ppCO_2$ levels below 3.8 mm. Early in the test series, empirical data was used to confirm the CO_2 concentration that should be used to trigger the RCA to cycle in order to maintain a time averaged CO_2 concentration below 2.2 mm Hg at the PGSVS inlet. After testing several values, it was determined that the RCA should be cycled when the $ppCO_2$ at the PGSVS inlet reached 3 mm Hg (400 Pa). This value was used as the RCA cycle threshold for the majority of test points.

Testing also enabled the evaluation of RCA and system performance as a function of several boundary conditions. On 7/6/11, the RCA was subjected to the highest simulated metabolic rate that this test article has seen over several years of testing, 3071 BTU/hr. During a simulated RCA valve failure, the maximum amount of CO_2 that the RCA sorbent has ever encountered was doubled when the CO_2 concentration was allowed to reach nearly 49 mm Hg (6500 Pa). Before this test, the highest CO_2 concentration the sorbent had seen was approximately 25 mm Hg during testing at Hamilton Sundstrand. While testing at these extreme conditions, the RCA was able to remove significant amounts of CO_2 and water vapor in only a few half cycles. Full recovery of the CO_2 and water vapor removal capabilities took somewhat longer, but was finally achieved after 30-60 minutes.

Finally, several RCA valve anomalies were observed during the test series; these are enumerated in Table 2. It should be noted that the RCA valve incorporated into this test article does not reflect the current prototypic valve concept. The RCA test article used in the PLSS 1.0 test had a pneumatically actuated shuttle valve that differs greatly from the mechanically actuated rotary ball valve that is intended for the next design iteration.

Table 2. RCA Valve Anomalies

Date	Notes from Test Log Regarding Observed Anomaly
7/12/11	RCA valve seems to be dumping more N_2 than usual into the vent loop. Having a hard time maintaining vent loop pressure at conditions where it shouldn't be difficult.
8/4/11	In one position only, RCA doesn't appear to be dumping N_2 into the vent loop. It is unknown how this may impact RCA performance.
8/26/11	In one position only, RCA doesn't appear to be dumping N_2 into the vent loop.
9/27/11	RCA valve dumping more N_2 than usual into the vent loop. Can't maintain vent loop pressure.

5.2 Thermal Subsystem

Like the oxygen and ventilation subsystems, analysis was conducted to evaluate whether the objective for each test point was met. Thermal loop set-point charts were created for each test point to ascertain how well the test data reflected the desired set-points. Figure 11 shows the thermal loop set-points for TP#2; again, dotted lines reflect set-point values from the test point matrix and solid lines are test data. This chart demonstrates that the thermal loop set-points were achieved at roughly t = 7 minutes, after various controls were adjusted. From t = 7 – 60 minutes the test data largely parallels the intended set-points, with a minor thermal event occurring at approximately t = 55 minutes. The thermal event consisted of an increase in the heat load simulating the PLSS electronics and avionics (DT-avi), a slight decrease in the heat load simulating the thermal effect of the crew member (DT-LCVG), and a resultant increase in the SWME outlet temperature (SWME Out). These results may have been caused by fluctuating line voltage in one or both of the heaters, changes in the thermal environment of the laboratory, a manual adjustment of heater or SWME controls, or a combination of these. Regardless of the cause, the thermal event was minor and from t = 7 – 60 minutes, Figure 11 gives a preliminary indication that TP#2 was carried out as expected with respect to the Thermal Subsystem.

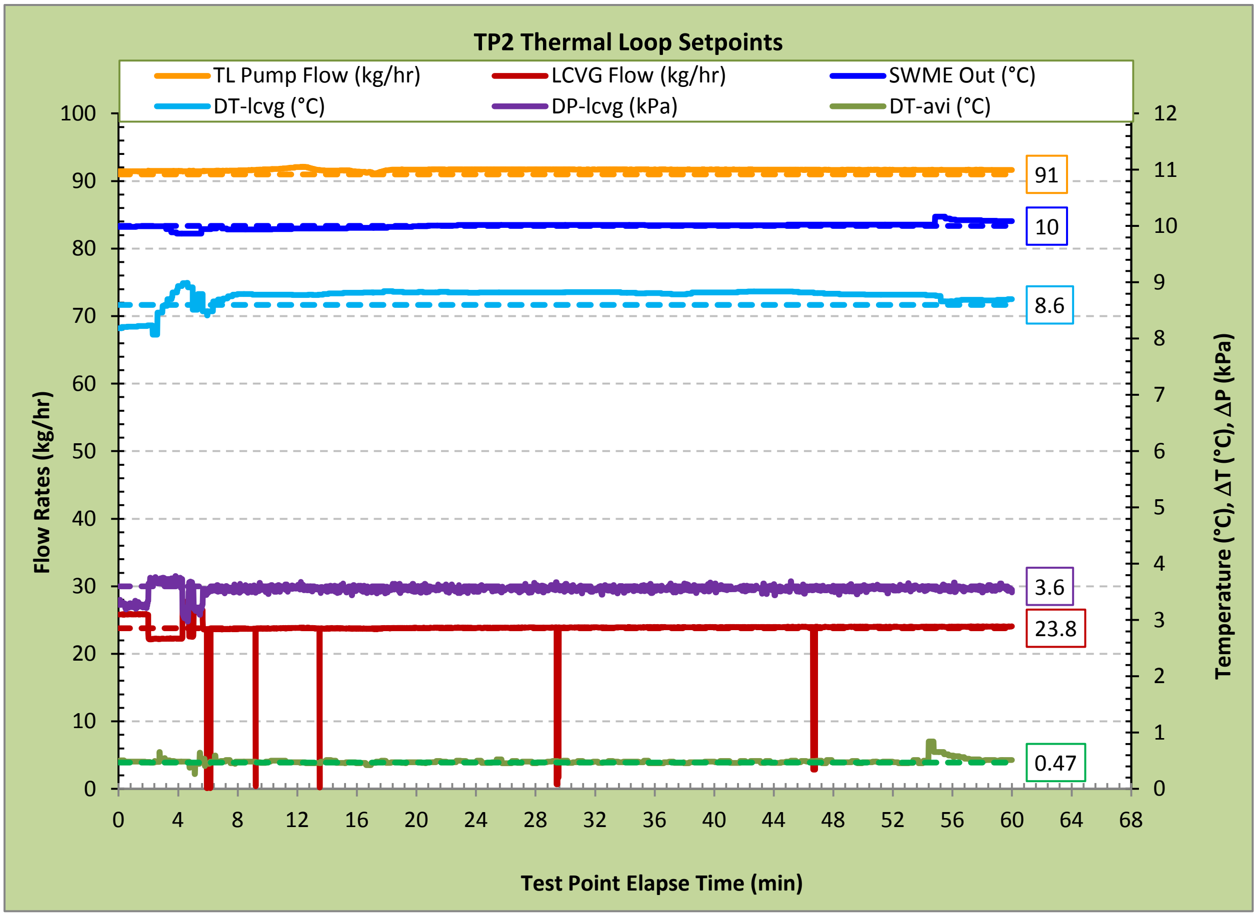


Figure 11. Test Data Plotted Against Thermal Loop Set-Points for Test Point #2

Although the original intent was to operate the thermal loop at subambient pressure in order to simulate functionality of a yet-to-be-developed flight-like water bladder (TK-600 in Figure 1), it was determined early on that this would not be possible due to operational limitations of the COTS pump in conjunction with the pressure drop of the thermal loop. When subambient operation at 4.1 psia was first attempted on 6/17/11, pump cavitation resulted and corrective action was required immediately to avoid damaging thermal loop hardware. For the remainder of the test series, it was determined that the thermal loop should be operated at ambient pressure (roughly 14.7 psia at the "bladder"). Fortunately, previous SWME standalone testing at various subambient pressures verified that SWME performance is largely independent of thermal loop pressure.

It should also be noted that SWME standalone testing was conducted from 3/11/2011 through 5/9/2011 using the thermal loop of the PLSS 1.0 test stand. There was no biocide present in the loop during 2011 SWME standalone testing or PLSS 1.0 testing; furthermore, stringent measures were not taken to avoid corrosion in the thermal loop. As a result, biofilm was presumably generated and products of stainless steel corrosion were introduced into the loop. Because SWME standalone testing and PLSS 1.0 testing were intended to start a lifecycle test of the SWME test article, the water in the thermal loop was not drained and replaced between SWME standalone and PLSS 1.0 testing. Biological and metal corrosion contaminants were allowed to buildup in the loop as testing proceeded, though filter elements were replaced on non-test days to avoid increasing the thermal loop pressure drop beyond acceptable limits for hardware and instrumentation safety. Despite this challenging environment, the thermal loop and SWME test article performed as expected throughout PLSS 1.0 testing.

5.2.1 SWME

As previously noted, the SWME performance was consistent with previous SWME standalone testing for the majority of the PLSS 1.0 test series. Periodically, the SWME maximum heat rejection capability was determined to track the unit's performance over time; this data is shown in Figure 12. SWME maximum heat rejection fluctuated between 725-755 W, with two outlier data points below 700 W. Between June 16 – September 23, 2011, the average value for maximum heat rejection was 736.25 W. The variability in the data set made it difficult to ascertain a clear trend or curve fit. SWME maximum heat rejection will continue to be tracked through the completion of SWME lifecycle testing in order to assess SWME health and to identify performance degradation over time.

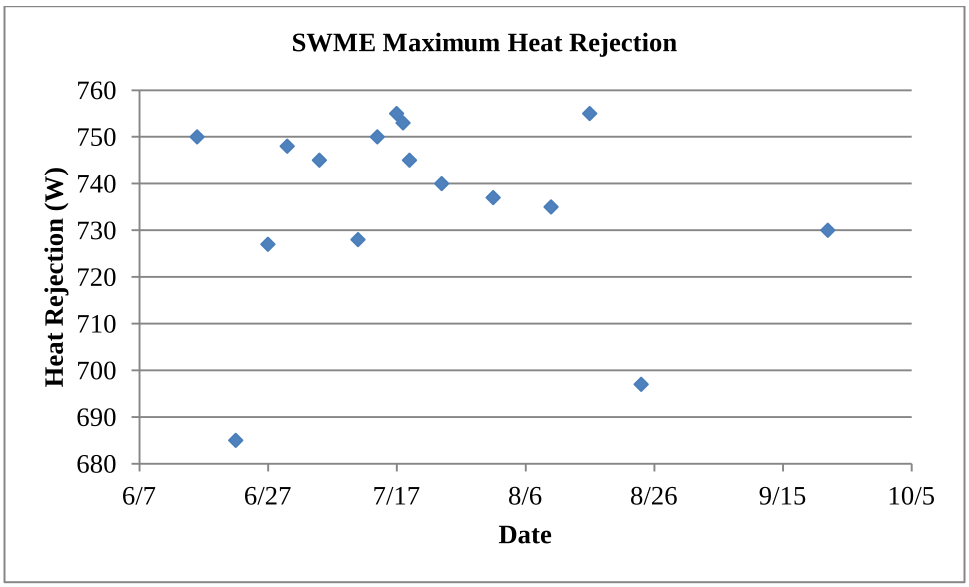


Figure 12. SWME Maximum Heat Rejection Capability As A Function of Time

One of the most interesting observations to occur during PLSS 1.0 testing came during a demonstration of the SWME degassing capability on 7/21/11. Despite previous performance characterization data of SWME's degassing capability, when air was injected into the thermal loop on 7/21/11, SWME failed to eliminate it from the loop on the first pass through the unit. This is the first time this behavior was observed; previous degassing evaluations, the latest of which occurred on 4/28/11, all proved successful. A thorough evaluation was conducted on 8/17/11 to replicate the anomaly and assess the SWME degassing capability. During the evaluation, chamber pressure, thermal loop pressure, flow rate, and filter configuration were varied to determine which of these variables affected the SWME degassing capability. Chamber pressure, thermal loop pressure, and filter configuration did not appear to have a significant effect on the SWME degassing capability. When the flow rate was a nominal 91 kg/hr, no visible degassing occurred. With all other variables held constant, when the flow rate was increased to 156 kg/hr to replicate previous SWME degassing evaluation during standalone testing, roughly 95% of the air bubbles were removed from the thermal loop on the first pass through the SWME unit. This condition was repeated and no apparent degassing was observed. On the third repetition, a small amount of degassing was observed. When a pristine SWME cartridge was installed in the test loop, full degassing capability was restored. This indicates that as some point during the PLSS 1.0 test series, the SWME test article experienced a significant reduction (near elimination) of its degassing capability. Several theories have been proposed, including possible effects of biofilm, loss of polarity of the fibers, and degradation of the hollow fiber hydrophobicity.

In a related observation, as the PLSS 1.0 test series progressed, increased weeping was also observed, first at the SWME inlet and later and both the inlet and outlet. Weeping refers to small amounts of liquid water being expelled through the porous membrane of the SWME hollow fibers and also indicates a reduction in the hydrophobicity of the fiber material.

Additionally, several SWME valve anomalies were observed throughout PLSS 1.0 testing (see Table 3).

Table 3. SWME Valve Anomalies

Date	Notes from Test Log Regarding Observed Anomaly
8/12/11	With Chamber R at vacuum, SWME valve failed to respond to control signal. Could not regain SWME control. Had to repress Chamber R to troubleshoot. At ambient pressure, issue was resolved.
8/26/11	SWME potentiometer voltage temporarily failed to respond to signal. After a short time, voltage started to respond with no stimulus.
9/9/11	SWME valve failed to respond to control signal prior to Chamber R depress. Could not regain SWME control. Troubleshot valve at ambient pressure, regained control, then proceeded with pump down and test.
9/29/11	SWME valve jammed during a test point with Chamber R at vacuum. This was most likely caused by overdriving the valve closed. Could not regain SWME control. Troubleshot and resolved the issue once Chamber R was returned to ambient pressure.

On the last day of the formal PLSS 1.0 test series, 9/30/11, two preliminary automated SWME controller algorithms, one constant gain and the other variable gain, were evaluated. The goal of the controller was to automatically adjust the SWME valve position to reach and maintain a SWME outlet temperature of 10°C. Both algorithms yielded similar, encouraging results. The controller was initially slow to achieve the desired set-point, oscillating around the set-point before maintaining it within the desired tolerance. Once the 10°C was attained, the controller was able to maintain the temperature within +/- 0.1°C, even as the heat load was varied up to 200W. Further controller testing, development, and evaluation is expected.

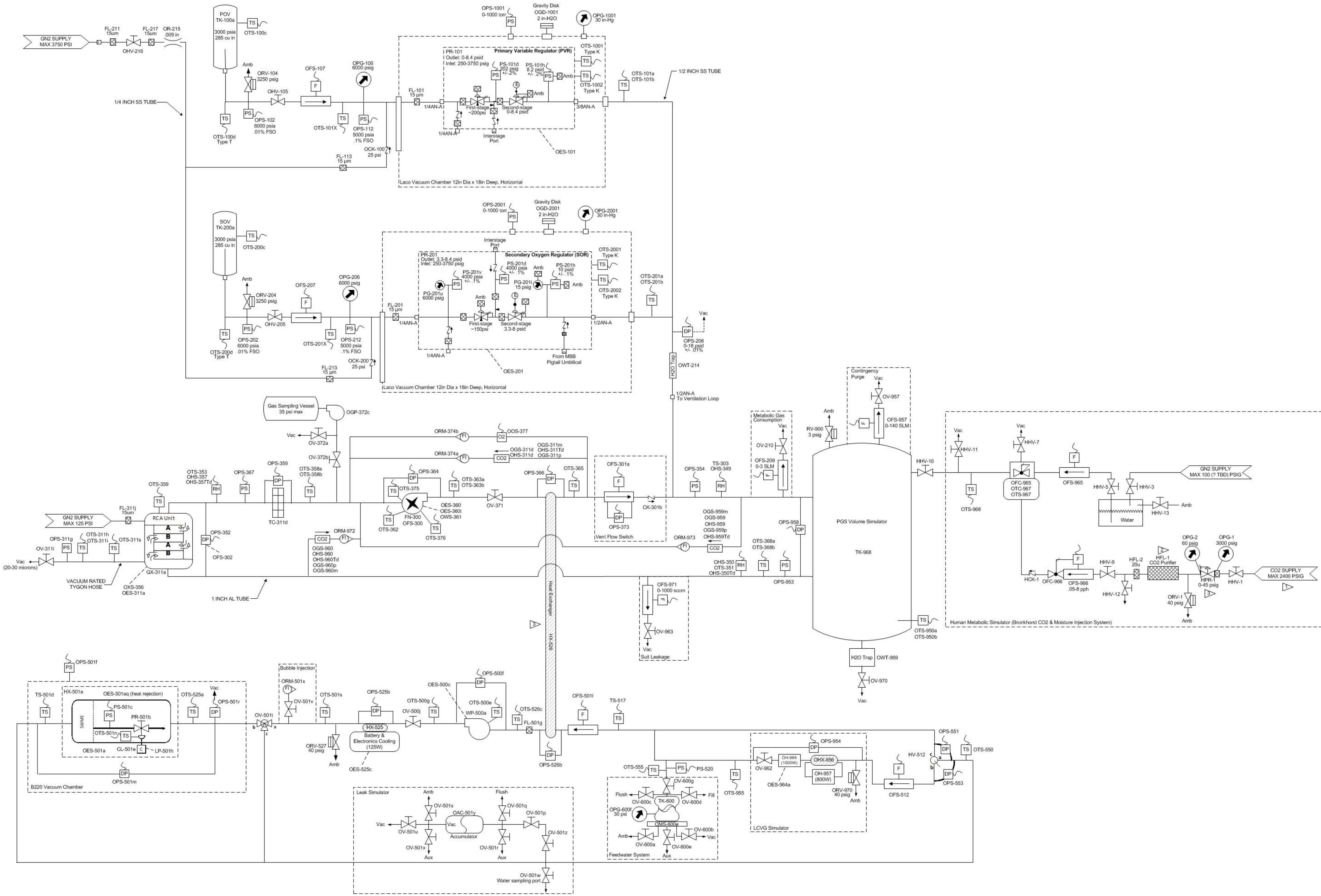
6.0 Conclusion

The PLSS 1.0 test rig, constructed using critical technology development components and COTS hardware, accumulated 233 hours of specific test point data and 397 total hours of operation over 45 days of testing from June

16 to September 30, 2011. On the whole, the PLSS 1.0 testing was successful. The test stand and technology development test articles performed largely as expected, with the exception of a few minor anomalies, to be expected at this phase in the development process. Test data and operational experiences revealed test article design weaknesses and areas for improvement. Furthermore, the lessons learned regarding test stand design, development, and construction were extremely valuable and will contribute significantly to future advanced PLSS development efforts.

Finally, it should be noted that the PLSS 1.0 testing program contributed significantly to the current Advanced PLSS Schematic work. While the PLSS 1.0 test configuration was based on the Advanced PLSS Schematic Revision C, changes were made during the testing program to address key hardware issues and to investigate potential schematic improvements. Configuration changes include the following: modified CO_2 sensor configuration in the ventilation subsystem; modified thermal subsystem line routing, particularly with respect to the TCV and feedwater supply system; replaced ventilation subsystem flow switch with a flow meter; incorporated a relief valve around the thermal subsystem pump; and removed the negative pressure relief valve. These changes are considered to be material improvements to the overall Advanced PLSS design and are captured in the Revision D Schematic. In addition, the Advanced EMU (AEMU) PLSS baseline captures these changes.

Appendix A. PLSS 1.0 Test Schematic



Appendix B. Test Point Matrix

Test Point	Comments	Ventilation Loop Absolute Pressure (kPa)	FN-300: Ventilation Loop Flow Rate using OFS-301a (Lpm)	POR Laco Vacuum Chamber Pressure (kPa)	SOR Laco Vacuum Chamber Pressure (kPa)	O_2 (N_2) source	POR setting using OPS-208 (kPa)	SOR setting use OPS-208 (kPa)	WP-500a: Pump flow rate using OFS-501l (kg/hr)	OV-210: Metabolic Consumption using OFS-209 (kg/hr)	OV-963: Suit Leakage Valve using OFS-971 (kg/hr)	OV-957: Suit Purge Valve using OFS-957 (kg/hr)	OV-962: LCVG Pressure Drop using OPS-954 (kPa-d)	HV-512: LCVG Water Flow Rate OFS-512 (kg/hr)	HX-501a: SWME Control	OH-964: LCVG Simulator Heater (W)	LCVG Delta Temp [OTS-550 - OTS-955] (°C) +/- 0.06 °C	HX-525: Battery and Electronics Simulator Heater (W)	Battery and Electronics Delta Temp [OTS-526c - OTS-501s] (°C) +/- 0.02 °C	GX-311a: RCA Cycle Threshold via OGS-969 (Pa)	RCA Back Pressure using OPS-311g (Pa)	HMS: Metabolic Rate (BTU/hr)	HMS: Carbon Dioxide Injection Rate using OFC-966 (kg/hr)	HMS: Carbon Dioxide Injection Rate using OFC-966 (SLPM-CO_2)	HMS: Water Vapor Injection Rate using OLC-965 (g/hr)	Thermal Environment	Duration (hrs)	Objective
1	Nominal EVA	102.8	127.4	101.4	101.4	Primary	1.4	Offψ	91	0.024	0.0025	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0τ	467	0	400	0.037	0.317	44.267	Nominal	1.5	Primary
1.Sec	Nominal EVA	102.8	127.4	101.4	101.4	Secondary	Offψ	1.4	91	0.024	0.0025	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0τ	467	0	400	0.037	0.317	44.267	Nominal	1.5	Primary
2	Nominal EVA	102.8	127.4	101.4	101.4	Primary	1.4	Off ψ	91	0.059	0.0025	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	0.5	Primary
3	Nominal EVA	102.8	127.4	101.4	101.4	Primary	1.4	Offψ	91	0.095	0.0025	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	800	0	1600	0.149	1.267	88.821	Nominal	2	Primary
3R400	Nominal EVA	102.8	127.4	101.4	101.4	Primary	1.4	Offψ	91	0.095	0.0025	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	0	1600	0.149	1.267	88.821	Nominal	1.25	Primary
4	Nominal EVA	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.024	0.0021	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	800	0	400	0.037	0.317	44.267	Nominal	2	Primary
4.65	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.024	0.0021	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	400	65	400	0.037	0.317	44.267	Nominal	2	Tertiary
4.275	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.024	0.0021	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	400	275	400	0.037	0.317	44.267	Nominal	1	Tertiary
4.300	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.024	0.0021	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	400	300	400	0.037	0.317	44.267	Nominal	1	Tertiary
4.325	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.024	0.0021	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	400	325	400	0.037	0.317	44.267	Nominal	1	Tertiary
4.375	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.024	0.0021	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	400	375	400	0.037	0.317	44.267	Nominal	1	Tertiary
4R400	Nominal EVA	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.024	0.0021	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	400	0	400	0.037	0.317	44.267	Nominal	2.5	Primary
5	Nominal EVA	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	1	Primary
5.65	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	400	65	1000	0.093	0.792	82.649	Nominal	1	Tertiary
5.275	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	400	275	1000	0.093	0.792	82.649	Nominal	1	Tertiary
5.300	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	400	300	1000	0.093	0.792	82.649	Nominal	1	Tertiary
5.325	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	400	325	1000	0.093	0.792	82.649	Nominal	1	Tertiary
5.375	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	400	375	1000	0.093	0.792	82.649	Nominal	1	Tertiary
5R400	Nominal EVA	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	400	0	1000	0.093	0.792	82.649	Nominal	1	Tertiary
5R400W	Nominal EVA	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	0.0	23.8	Manualπ	237	N/A	50	N/A	400	0	1000	0.093	0.792	82.649	Nominal	1.5	Primary
5R800W	Nominal EVA	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	0.0	23.8	Manualπ	237	N/A	50	N/A	800	0	1000	0.093	0.792	82.649	Nominal	1.5	Primary
6	Nominal EVA	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	800	0	1600	0.149	1.267	88.821	Nominal	0.75	Primary
6.65	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	65	1600	0.149	1.267	88.821	Nominal	1	Tertiary
6.85	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	85	1600	0.149	1.267	88.821	Nominal	1	Tertiary
6.125	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	125	1600	0.149	1.267	88.821	Nominal	1	Tertiary
6.175	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	175	1600	0.149	1.267	88.821	Nominal	1	Tertiary
6.225	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	225	1600	0.149	1.267	88.821	Nominal	1	Tertiary
6.275	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	275	1600	0.149	1.267	88.821	Nominal	1	Tertiary
6.300	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	300	1600	0.149	1.267	88.821	Nominal	1	Tertiary
6.375	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	375	1600	0.149	1.267	88.821	Nominal	1	Tertiary
6R400	Nominal EVA	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	0	1600	0.149	1.267	88.821	Nominal	1	Primary
7	Nominal EVA-Cold	28.3	127.4	vacuumΩ	vacuumΩ	Secondary	Offψ	28.3	91	0.024	0.0021	0	0.5	3.2	Manualπ	N/A	1.4	N/A	0.47	467	0	400	0.037	0.317	44.267	Cold	1.5	Primary
8	Nominal EVA-Cold	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	2.8	18.6	Manualπ	N/A	8.2	N/A	0τ	800	0	1000	0.093	0.792	82.649	Cold	0.75	Primary
9	Nominal EVA-Cold	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	10.7	71.0	Manualπ	N/A	4.3	N/A	0.47	800	0	1600	0.149	1.267	88.821	Cold	0.5	Primary
9R400	Nominal EVA-Cold	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	10.7	71.0	Manualπ	N/A	4.3	N/A	0.47	400	0	1600	0.149	1.267	88.821	Cold	1	Primary
10	Nominal EVA-Hot	28.3	127.4	vacuumΩ	vacuumΩ	Secondary	Off ψ	28.3	91	0.024	0.0021	0	1.9	12.3	Manualπ	N/A	18.4	N/A	0.47	467	0	400	0.037	0.317	44.267	Hot	1.5	Primary
11	Nominal EVA-Hot	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	5.8	38.6	Manualπ	N/A	9.0	N/A	0τ	800	0	1000	0.093	0.792	82.649	Hot	0.5	Primary
12	Nominal EVA-Hot	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	5.6	N/A	0τ	800	0	1600	0.149	1.267	88.821	Hot	0.75	Primary
12R400	Nominal EVA-Hot	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	5.6	N/A	0.47	400	0	1600	0.149	1.267	88.821	Hot	1	Primary
13	Nominal EVA	41.4	127.4	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.024	0.0031	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	800	0	400	0.037	0.317	44.267	Nominal	2	Primary
14	Nominal EVA	41.4	127.4	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.059	0.0031	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	0.75	Primary
14R400	Nominal EVA	41.4	127.4	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.059	0.0031	0	0.0	23.8	Manualπ	N/A	8.6	N/A	0.47	400	0	1000	0.093	0.792	82.649	Nominal	1.5	Primary
14R800	Nominal EVA	41.4	127.4	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.059	0.0031	0	0.0	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	1.5	Primary
15	Nominal EVA	41.4	127.4	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.095	0.0031	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	800	0	1600	0.149	1.267	88.821	Nominal	2	Primary
15R400	Nominal EVA	41.4	127.4	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.095	0.0031	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	0	1600	0.149	1.267	88.821	Nominal	1	Primary
16	Nom EVA + DCS on vacuum	55.2	127.4	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	0.024	0.0042	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0τ	800	0	400	0.037	0.317	44.267	Nominal	1.5	Primary
17	Nom EVA + DCS on vacuum	55.2	127.4	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	0.059	0.0042	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	0.5	Primary
17R400	Nom EVA + DCS on vacuum	55.2	127.4	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	0.059	0.0042	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	400	0	1000	0.093	0.792	82.649	Nominal	1.5	Primary

Test Point	Comments	Ventilation Loop Absolute Pressure (kPa)	FN-300: Ventilation Loop Flow Rate using OFS-301a (Lpm)	POR Laco Vacuum Chamber Pressure (kPa)	SOR Laco Vacuum Chamber Pressure (kPa)	O_2 (N_2) source	POR setting using OPS-208 (kPa)	SOR setting use OPS-208 (kPa)	WP-500a: Pump flow rate using OFS-501l (kg/hr)	OV-210: Metabolic Consumption using OFS-209 (kg/hr)	OV-963: Suit Leakage Valve using OFS-971 (kg/hr)	OV-957: Suit Purge Valve using OFS-957 (kg/hr)	OV-962: LCVG Pressure Drop using OPS-954 (kPa-d)	HV-512: LCVG Water Flow Rate OFS-512 (kg/hr)	HX-501a: SWME Control	OH-964: LCVG Simulator Heater (W)	LCVG Delta Temp [OTS-550 - OTS-955] (°C) +/- 0.06 °C	HX-525: Battery and Electronics Simulator Heater (W)	Battery and Electronics Delta Temp [OTS-526c - OTS-501s] (°C) +/- 0.02 °C	GX-311a: RCA Cycle Threshold via OGS-969 (Pa)	RCA Back Pressure using OPS-311g (Pa)	HMS: Metabolic Rate (BTU/hr)	HMS: Carbon Dioxide Injection Rate using OFC-966 (kg/hr)	HMS: Carbon Dioxide Injection Rate using OFC-966 (SLPM-CO_2)	HMS: Water Vapor Injection Rate using OLC-965 (g/hr)	Thermal Environment	Duration (hrs)	Objective
17R400.POV	Empty POV	55.2	127.4	vacuumΩ	vacuumΩ	Primary&Sec	55.2	25.5	91	0.059	0.0042	0	3.6	23.8	Disabled (valve jammed, chiller cart on)	0	N/A	0	N/A	400	0	1000	0.093	0.792	82.649	Nominal	3.5	Secondary
17R400.SWM.full	SWME valve full open/close sweep	55.2	127.4	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	0.059	0.0042	0	3.6	23.8	Disabled	0	N/A	0	N/A	400	0	1000	0.093	0.792	82.649	Nominal	0.25	Tertiary
18	Nom EVA + DCS on vacuum	55.2	127.4	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	0.095	0.0042	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	800	0	1600	0.149	1.267	88.821	Nominal	0.75	Primary
18R400	Nom EVA + DCS on vacuum	55.2	127.4	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	0.095	0.0042	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	0	1600	0.149	1.267	88.821	Nominal	1	Primary
19	Nominal EVA	28.3	169.9	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.024	0.0021	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	800	0	400	0.037	0.317	44.267	Nominal	2	Primary
20	Nominal EVA	28.3	169.9	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	1	Primary
20x.275	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.035	0.0021	0	0.0	8.5	Manualπ	135	N/A	50	N/A	400	275	600	0.056	0.475	60.641	Nominal	1	Tertiary
20.300	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.035	0.0021	0	0.0	8.5	Manualπ	135	N/A	50	N/A	400	300	600	0.056	0.475	60.641	Nominal	1	Tertiary
20.325	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.035	0.0021	0	0.0	8.5	Manualπ	135	N/A	50	N/A	400	325	600	0.056	0.475	60.641	Nominal	1	Tertiary
20.375	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.035	0.0021	0	0.0	8.5	Manualπ	135	N/A	50	N/A	400	375	600	0.056	0.475	60.641	Nominal	1	Tertiary
20R400W	Nominal EVA	28.3	169.9	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	0.0	23.8	Manualπ	237	N/A	50	N/A	400	0	1000	0.093	0.792	82.649	Nominal	1.5	Primary
20R800W	Nominal EVA	28.3	169.9	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	0.0	23.8	Manualπ	237	N/A	50	N/A	800	0	1000	0.093	0.792	82.649	Nominal	1.5	Primary
21	Nominal EVA	28.3	169.9	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	800	0	1600	0.149	1.267	88.821	Nominal	0.75	Primary
21R400	Nominal EVA	28.3	169.9	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	0	1600	0.149	1.267	88.821	Nominal	1	Primary
22	Nominal EVA	41.4	169.9	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.024	0.0031	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0τ	800	0	400	0.037	0.317	44.267	Nominal	2	Primary
23	Nominal EVA	41.4	169.9	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.059	0.0031	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	0.75	Primary
23R400	Nominal EVA	41.4	169.9	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.059	0.0031	0	0.0	23.8	Manualπ	N/A	8.6	N/A	0.47	400	0	1000	0.093	0.792	82.649	Nominal	1.5	Primary
23R800	Nominal EVA	41.4	169.9	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.059	0.0031	0	0.0	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	1.5	Primary
24	Nominal EVA	41.4	169.9	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.095	0.0031	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	800	0	1600	0.149	1.267	88.821	Nominal	0.5	Primary
24R400	Nominal EVA	41.4	169.9	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.095	0.0031	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	0	1600	0.149	1.267	88.821	Nominal	1	Primary
25	Nom EVA + DCS on vacuum	55.2	169.9	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	0.024	0.0042	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0τ	800	0	400	0.037	0.317	44.267	Nominal	1.5	Primary
26	Nom EVA + DCS on vacuum	55.2	169.9	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	0.059	0.0042	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	1	Primary
27	Nom EVA + DCS on vacuum	55.2	169.9	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	0.095	0.0042	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	800	0	1600	0.149	1.267	88.821	Nominal	0.75	Primary
27R400	Nom EVA + DCS on vacuum	55.2	169.9	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	0.095	0.0042	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	0	1600	0.149	1.267	88.821	Nominal	1	Primary
29	Nominal EVA (Buddy mode?)	28.3	226.5	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	0.75	Primary
32	Nominal EVA (Buddy mode?)	41.4	226.5	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	0.059	0.0031	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	800	0	1000	0.093	0.792	82.649	Nominal	0.5	Primary
37	Nom EVA using Secondary O_2	25.5	127.4	vacuumΩ	vacuumΩ	Secondary	Offψ	25.5	91	0.024	0.0020	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0τ	467	0	467	0.037	0.317	44.267	Nominal	2	Secondary
38	Nom EVA using Secondary O_2	25.5	127.4	vacuumΩ	vacuumΩ	Secondary	Off ψ	25.5	91	0.059	0.0020	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0τ	467	0	1000	0.093	0.792	82.649	Nominal	0.5	Secondary
39	Nom EVA using Secondary O_2	25.5	127.4	vacuumΩ	vacuumΩ	Secondary	Offψ	25.5	91	0.095	0.0020	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	467	0	1600	0.149	1.267	88.821	Nominal	1.5	Secondary
42R400	POR Fail LOW (3.7 psia)	25.5	127.4	vacuumΩ	vacuumΩ	Primary	25.5	Offψ	91	0.095	0.0023	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	0	1600	0.149	1.267	88.821	Nominal	1	Secondary
46	High Suit Leakage	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.024	0.0107	0	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	400	0	400	0.037	0.317	44.267	Nominal	1	Secondary
47	High Suit Leakage	28.3	127.4	vacuumΩ	vacuumΩ	Secondary	Off ψ	28.3	91	0.059	0.0107	0	3.6	23.8	Manualπ	N/A	8.6	N/A	0τ	467	0	1000	0.093	0.792	82.649	Nominal	1	Secondary
48	High Suit Leakage	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0107	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	0	1600	0.149	1.267	88.821	Nominal	1	Secondary
50	Failed thermal loop flow (blocked)	28.3	127.4	vacuumΩ	vacuumΩ	Secondary	Off ψ	28.3	0	0.059	0.0021	0	0.0	0.0	Disabled	N/A	0.0	N/A	0τ	467	0	1000	0.093	0.792	82.649	Nominal	1	Secondary
52.1	Power failure simulation - suit purgeΦ	28.3	0.0	vacuumΩ	vacuumΩ	Primary	28.3	25.5	0	0.000	0.0000	2.04	0.0	23.8	Manualπ	N/A	8.6	N/A	0.47	Off	0	400	0.000	0.000	0.000	Nominal	0.5	Secondary
52.2	Power failure simulation - suit purgeΦ	28.3	0.0	vacuumΩ	vacuumΩ	Primary	28.3	25.5	0	0.000	0.0000	1.02	0.0	23.8	Manualπ	N/A	8.6	N/A	0.47	Off	0	400	0.000	0.000	0.000	Nominal	1	Secondary
52.3	Power failure simulation - suit purgeΦ	28.3	0.0	vacuumΩ	vacuumΩ	Primary	28.3	25.5	0	0.000	0.0000	0.52	0.0	23.8	Manualπ	N/A	8.6	N/A	0.47	Off	0	400	0.000	0.000	0.000	Nominal	1	Secondary
52.4	Power failure simulation - suit purgeΦ	28.3	0.0	vacuumΩ	vacuumΩ	Primary	28.3	25.5	0	0.000	0.0000	Variable	0.0	23.8	Manualπ	N/A	8.6	N/A	0.47	Off	0	400	0.000	0.000	0.000	Nominal	4	Secondary
57R400	Evaluate 3.7 psia vent loop pressure	25.5	127.4	vacuumΩ	vacuumΩ	Primary	25.5	Offψ	91	0.095	0.0020	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400	0	1600	0.149	1.267	88.821	Nominal	1	Secondary

Test Point	Comments	Ventilation Loop Absolute Pressure (kPa)	FN-300: Ventilation Loop Flow Rate using OFS-301a (Lpm)	POR Laco Vacuum Chamber Pressure (kPa)	SOR Laco Vacuum Chamber Pressure (kPa)	O_2 (N_2) source	POR setting using OPS-208 (kPa)	SOR setting use OPS-208 (kPa)	WP-500a: Pump flow rate using OFS-501l (kg/hr)	OV-210: Metabolic Consumption using OFS-209 (kg/hr)	OV-963: Suit Leakage Valve using OFS-971 (kg/hr)	OV-957: Suit Purge Valve using OFS-957 (kg/hr)	OV-962: LCVG Pressure Drop using OPS-954 (kPa-d)	HV-512: LCVG Water Flow Rate OFS-512 (kg/hr)	HX-501a: SWME Control	OH-964: LCVG Simulator Heater (W)	LCVG Delta Temp [OTS-550 - OTS-955] (°C) +/- 0.06 °C	HX-525: Battery and Electronics Simulator Heater (W)	Battery and Electronics Delta Temp [OTS-526c - OTS-501s] (°C) +/- 0.02 °C	GX-311a: RCA Cycle Threshold via OGS-969 (Pa)	RCA Back Pressure using OPS-311g (Pa)	HMS: Metabolic Rate (BTU/hr)	HMS: Carbon Dioxide Injection Rate using OFC-966 (kg/hr)	HMS: Carbon Dioxide Injection Rate using OFC-966 (SLPM-CO_2)	HMS: Water Vapor Injection Rate using OLC-965 (g/hr)	Thermal Environment	Duration (hrs)	Objective
58.23	Constant RCA Cycle Time-Transient 8-hour runs	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	Variable*	0.0021	0	3.6	23.6	Manualπ	Variable*	N/A	50	N/A	23 sec	0	Variable*	Variable*	Variable*	Variable*	Nominal	3	Tertiary
58.25._(1,2)	Constant RCA Cycle Time-Transient 8-hour runs	28.3/41.4	127.4	vacuumΩ	vacuumΩ	Primary	28.3/41.4	25.5	91	Variable*	0.0021/0.0031	0	3.6	23.6	Manualπ	Variable*	N/A	50	N/A	25 sec	0	Variable*	Variable*	Variable*	Variable*	Nominal	5	Tertiary
58.40._(1,2)	Constant RCA Cycle Time-Transient 8-hour runs	28.3/41.4	127.4	vacuumΩ	vacuumΩ	Primary	28.3/41.4	25.5	91	Variable*	0.0021/0.0031	0	3.6	23.6	Manualπ	Variable*	N/A	50	N/A	40 sec	0	Variable*	Variable*	Variable*	Variable*	Nominal	8	Tertiary
58.60._(1,2,3)	Constant RCA Cycle Time-Transient 8-hour runs	28.3/41.4	127.4	vacuumΩ	vacuumΩ	Primary	28.3/41.4	25.5	91	Variable*	0.0021/0.0031	0	3.6	23.6	Manualπ	Variable*	N/A	50	N/A	60 sec	0	Variable*	Variable*	Variable*	Variable*	Nominal	8	Tertiary
67	Variable RCA Cycle Time-Transient 8-hour runs	28.3	127.4	vacuumΩ	vacuumΩ	Secondary	Offψ	28.3	91	Variable*	0.0021	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	467	0	Variable*	Variable*	Variable*	Variable*	Nominal	7	0
68	Variable RCA Cycle Time-Transient 8-hour runs	41.4	127.4	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	Variable*	0.0031	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Nominal	7	0
69	Variable RCA Cycle Time-Transient 8-hour runs	55.2	127.4	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	Variable*	0.0042	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Nominal	7	0
70	Variable RCA Cycle Time-Transient 8-hour runs	28.3	169.9	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	Variable*	0.0021	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Nominal	7	0
71	Variable RCA Cycle Time-Transient 8-hour runs	41.4	169.9	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	Variable*	0.0031	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Nominal	7	0
72	Variable RCA Cycle Time-Transient 8-hour runs	55.2	169.9	vacuumΩ	vacuumΩ	Primary	55.2	25.5	91	Variable*	0.0042	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Nominal	7	0
84	Suit Port 8.3 psia decay to 4.1	Decay 55.2-28.3	127.4	vacuumΩ	vacuumΩ	Secondary	Off ψ	Decay (55.2-28.3)	91	0.095	Decay 0.0042-0.0021	0	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	467	0	1600	0.149	1.267	88.821	Nominal	1.5	Tertiary
93	Nominal EVA-low flow	28.3	85.0	vacuumΩ	vacuumΩ	Primary	28.3	25.5	10	0.024	0.0021	0	6.5	4.7	Manualπ	N/A	15.8	N/A	4.31	400	0	400	0.037	0.317	44.267	Nominal	2	Tertiary
94	Nominal EVA-low flow	28.3	85.0	vacuumΩ	vacuumΩ	Primary	28.3	25.5	10	0.059	0.0021	0	13.6	10.0	Manualπ	N/A	20.4	N/A	4.31	400	0	1000	0.093	0.792	82.649	Nominal	1	Tertiary
95	Nominal EVA-low flow	28.3	85.0	vacuumΩ	vacuumΩ	Primary	28.3	25.5	10	0.095	0.0021	0	13.6	10.0	Manualπ	N/A	25.0	N/A	4.31	400	0	1600	0.149	1.267	88.821	Nominal	0.5	Tertiary
96	lo met rate	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.018	0.0021	0	0.5	3.1	Manualπ	N/A	17.6	N/A	0.47	800	0	300	0.028	0.238	34.739	Nominal	2	Tertiary
96.275	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.018	0.0021	0	0.5	3.1	Manualπ	N/A	17.6	N/A	0.47	400	275	300	0.028	0.238	34.739	Nominal	1	Tertiary
96.300	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.018	0.0021	0	0.5	3.1	Manualπ	N/A	17.6	N/A	0.47	400	300	300	0.028	0.238	34.739	Nominal	1	Tertiary
96.325	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.018	0.0021	0	0.5	3.1	Manualπ	N/A	17.6	N/A	0.47	400	325	300	0.028	0.238	34.739	Nominal	1	Tertiary
96.375	High RCA Back Pressure	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.018	0.0021	0	0.5	3.1	Manualπ	N/A	17.6	N/A	0.47	400	375	300	0.028	0.238	34.739	Nominal	1	Tertiary
97	high met rate EVA	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.118	0.0021	0	13.6	90.7	Manualπ	N/A	5.1	N/A	0.47	400	0	2000	0.186	1.584	75.041	Nominal	1	Tertiary
98	very hi met rate EVA	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.177	0.0021	0	13.6	90.7	Manualπ	N/A	7.8	N/A	0.47	400	0	3000	0.280	2.376	77.111	Nominal	0.75	Tertiary
114	Transient 8-hour runs	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	Variable*	0.0021	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Cold	7	Tertiary
117	Transient 8-hour runs	41.4	127.4	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	Variable*	0.0031	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Cold	7	Tertiary
143._(1,2)	Higher LCVG Humidity-Transient 8-hour runs	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	Variable*	0.0021	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Nominal	9	Tertiary
144._(1,2)	Higher LCVG Humidity-Transient 8-hour runs	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	Variable*	0.0021	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Cold	7.25	Tertiary
145._(1,2)	Higher LCVG Humidity-Transient 8-hour runs	28.3	127.4	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	Variable*	0.0021	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Hot	7.25	Tertiary

Test Point	Comments	Ventilation Loop Absolute Pressure (kPa)	FN-300: Ventilation Loop Flow Rate using OFS-301a (Lpm)	POR Laco Vacuum Chamber Pressure (kPa)	SOR Laco Vacuum Chamber Pressure (kPa)	O_2 (N_2) source	POR setting using OPS-208 (kPa)	SOR setting use OPS-208 (kPa)	WP-500a: Pump flow rate using OFS-501l (kg/hr)	OV-210: Metabolic Consumption using OFS-209 (kg/hr)	OV-963: Suit Leakage Valve using OFS-971 (kg/hr)	OV-957: Suit Purge Valve using OFS-957 (kg/hr)	OV-962: LCVG Pressure Drop using OPS-954 (kPa-d)	HV-512: LCVG Water Flow Rate OFS-512 (kg/hr)	HX-501a: SWME Control	OH-964: LCVG Simulator Heater (W)	LCVG Delta Temp [OTS-550 - OTS-955] (°C) +/- 0.06 °C	HX-525: Battery and Electronics Simulator Heater (W)	Battery and Electronics Delta Temp [OTS-526c - OTS-501s] (°C) +/- 0.02 °C	GX-311a: RCA Cycle Threshold via OGS-969 (Pa)	RCA Back Pressure using OPS-311g (Pa)	HMS: Metabolic Rate (BTU/hr)	HMS: Carbon Dioxide Injection Rate using OFC-966 (kg/hr)	HMS: Carbon Dioxide Injection Rate using OFC-966 (SLPM-CO_2)	HMS: Water Vapor Injection Rate using OLC-965 (g/hr)	Thermal Environment	Duration (hrs)	Objective
146._(1,2)	Higher LCVG Humidity-Transient 8-hour runs	41.4	127.4	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	Variable*	0.0031	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Nominal	7.25	Tertiary
147._(1,2)	Higher LCVG Humidity-Transient 8-hour runs	41.4	127.4	vacuumΩ	vacuumΩ	Primary	41.4	25.5	91	Variable*	0.0031	0	Variable*	Variable*	Manualπ	Variable*	N/A	50	N/A	400	0	Variable*	Variable*	Variable*	Variable*	Cold	7.25	Tertiary
176	Failed RCA-only	28.3	169.9	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.024	0.0021	1	0.7	4.7	Manualπ	N/A	15.8	N/A	0.47	Off	0	400	0.037	0.317	44.267	Nominal	1.5	Tertiary
177	Failed RCA-only	28.3	169.9	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.059	0.0021	1	3.6	23.8	Manualπ	N/A	8.6	N/A	0.47	Off/800 Pa for recovery	0	1000	0.093	0.792	82.649	Nominal	1	Tertiary
178	Failed RCA-only	28.3	169.9	vacuumΩ	vacuumΩ	Primary	28.3	25.5	91	0.095	0.0021	1	13.6	90.7	Manualπ	N/A	3.9	N/A	0.47	400/Off/800	0	1600	0.149	1.267	88.821	Nominal	1.5	Tertiary
SWME.controller.eval	Eval of 1st gen SWME controller	N/A	N/A	N/A	N/A	N/A	N/A	N/A	91	N/A	N/A	N/A	0.0	90.7	Automated Control	Variable*	Variable*	Variable	Variable	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	Secondary

* See Transient Data Table

α Allow p□essure to decay to simulate tran□ition from 57 to 28 kPA (8.3 to 4.1 psia)

β Slowly s□ep down regulator 6 mmHg (0.1 psia) e□ery□5 minutes

δ Swap beds at 6 mmHg (0.1 psia) of CO_2 measured □t OGS-959

ψ Swap bed every 1.5 minutes

η Implemented via LVCG H□ater OH-664

Ω Vacuum is defined for test purposes a□ < 1 torr (.02 psia)

Φ Wait 5 seonds after f□iling the power before purging

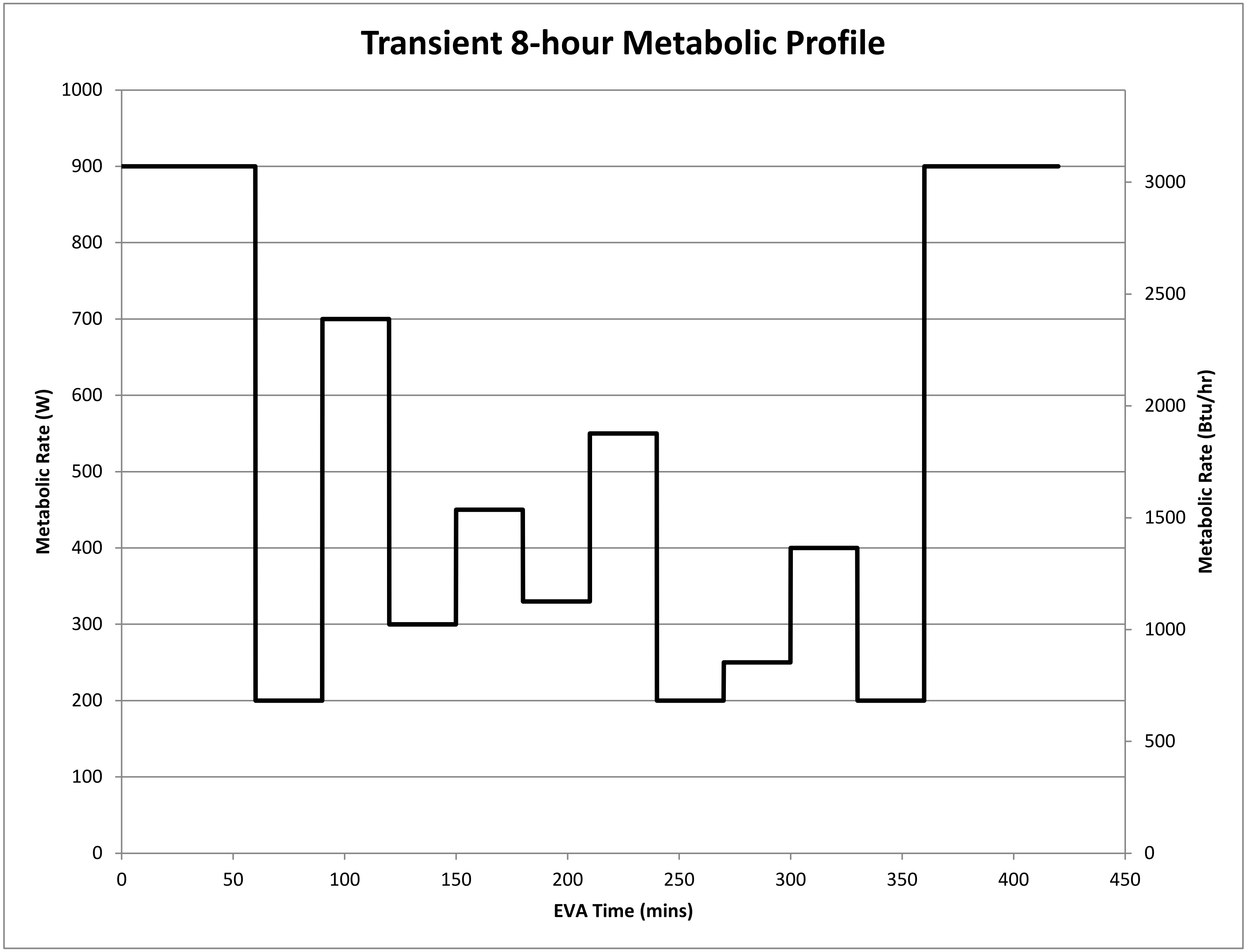
π Manually control SWME valve position to maintain 10 deg.□C outlet temp +/- 0.05 deg. C

τ Due to an unresolved hardware failure, HX-525 was not functional wh□n these test points were run

ψ When a regulator is set to 'Off' this indicates that not only is the regulator set to control to 0 psid, but als□ that the□appropriate POV/SOV isolation valve is also closed.

Appendix C. Transient 8-Hour Metabolic Profile Data

Time (mins)	Met Rate (W)	Cold Thermal Env. LCVG Heat Load (W)	Nominal Thermal Env. LCVG Heat Load (W)	Hot Thermal Env. LCVG Heat Load (W)	WP-500a: Pump flow rate using OFS-501l (kg/hr)	OV-210: Metabolic Consumption using OFS-209 (kg/hr)	HMS: Carbon Dioxide Injection Rate using OFC-966 (SLPM-CO_2)	HMS: Water Vapor Injection Rate using OLC-965 (g/hr)	OV-500j: Thermal Loop Pressure Drop using OPS-500f (kPa-d) Thermal Env.			OH-964: LCVG Simulator Heater (W) Thermal Env.			OV-962: LCVG Pressure Drop using OPS-954 (kPa-d) Thermal Env.			HV-512: LCVG Water Flow Rate OFS-512 (kg/hr) Thermal Env.		
									Cold	Nom.	Hot	Cold	Nom.	Hot	Cold	Nom.	Hot	Cold	Nom.	Hot
0	900	778	836	894	91	0.181	1.43	83.72	26.07	26.07	26.07	778	836	894	13.61	13.61	13.61	91	91	91
29.9	900	778	836	894	91	0.181	1.43	83.72	26.07	26.07	26.07	778	836	894	13.61	13.61	13.61	91	91	91
30	900	778	836	894	91	0.181	1.43	83.72	26.07	26.07	26.07	778	836	894	13.61	13.61	13.61	91	91	91
59.9	900	778	836	894	91	0.181	1.43	83.72	26.07	26.07	26.07	778	836	894	13.61	13.61	13.61	91	91	91
60	200	87	159	320	91	0.040	0.54	66.35	9.63	10.13	12.19	87	159	320	1.23	1.61	3.16	8	11	21
89.9	200	87	159	320	91	0.040	0.54	66.35	9.63	10.13	12.19	87	159	320	1.23	1.61	3.16	8	11	21
90	700	580	642	819	91	0.141	1.89	77.11	26.07	26.07	26.07	580	642	819	13.61	13.61	13.61	91	91	91
119.9	700	580	642	819	91	0.141	1.89	77.11	26.07	26.07	26.07	580	642	819	13.61	13.61	13.61	91	91	91
120	300	185	256	411	91	0.060	0.81	83.50	11.97	13.06	15.73	185	256	411	3.00	3.82	5.82	20	25	39
149.9	300	185	256	411	91	0.060	0.81	83.50	11.97	13.06	15.73	185	256	411	3.00	3.82	5.82	20	25	39
150	450	334	401	573	91	0.091	1.22	89.70	20.48	24.03	26.07	334	401	573	9.40	12.08	13.61	63	80	91
179.9	450	334	401	573	91	0.091	1.22	89.70	20.48	24.03	26.07	334	401	573	9.40	12.08	13.61	63	80	91
180	330	215	285	442	91	0.067	0.89	86.62	13.10	14.49	17.35	215	285	442	3.85	4.90	7.05	25	32	47
209.9	330	215	285	442	91	0.067	0.89	86.62	13.10	14.49	17.35	215	285	442	3.85	4.90	7.05	25	32	47
210	550	432	497	682	91	0.111	1.49	80.82	26.07	26.07	26.07	432	497	682	13.61	13.61	13.61	91	91	91
239.9	550	432	497	682	91	0.111	1.49	80.82	26.07	26.07	26.07	432	497	682	13.61	13.61	13.61	91	91	91
240	200	87	159	320	91	0.040	0.54	66.35	9.63	10.13	12.19	87	159	320	1.23	1.61	3.16	8	11	21
269.9	200	87	159	320	91	0.040	0.54	66.35	9.63	10.13	12.19	87	159	320	1.23	1.61	3.16	8	11	21
270	250	136	207	363	91	0.050	0.68	76.23	10.57	11.29	13.66	136	207	363	1.94	2.49	4.27	13	16	28
299.9	250	136	207	363	91	0.050	0.68	76.23	10.57	11.29	13.66	136	207	363	1.94	2.49	4.27	13	16	28
300	400	284	352	518	91	0.081	1.08	90.24	16.77	19.22	22.58	284	352	518	6.61	8.46	10.98	44	56	73
329.9	400	284	352	518	91	0.081	1.08	90.24	16.77	19.22	22.58	284	352	518	6.61	8.46	10.98	44	56	73
330	200	87	159	320	91	0.040	0.54	66.35	9.63	10.13	12.19	87	159	320	1.23	1.61	3.16	8	11	21
359.9	200	87	159	320	91	0.040	0.54	66.35	9.63	10.13	12.19	87	159	320	1.23	1.61	3.16	8	11	21
360	900	778	836	894	91	0.181	1.43	83.72	26.07	26.07	26.07	778	836	894	13.61	13.61	13.61	91	91	91
389.9	900	778	836	894	91	0.181	1.43	83.72	26.07	26.07	26.07	778	836	894	13.61	13.61	13.61	91	91	91
390	900	778	836	894	91	0.181	1.43	83.72	26.07	26.07	26.07	778	836	894	13.61	13.61	13.61	91	91	91
419.9	900	778	836	894	91	0.181	1.43	83.72	26.07	26.07	26.07	778	836	894	13.61	13.61	13.61	91	91	91
420	900	778	836	894	91	0.181	1.43	83.72	26.07	26.07	26.07	778	836	894	13.61	13.61	13.61	91	91	91



Transient 8-hour Metabolic Profile
Metabolic Rate (W)
Metabolic Rate (Btu/hr)
EVA Time (mins)
0
100
200
300
400
500
600
700
800
900
1000
0
500
1000
1500
2000
2500
3000
0
50
100
150
200
250
300
350
400
450

Appendix D. Transient Profile for Test Point #58

SWME/ Thermal Loop Met Rate (Btu/hr)	Vent Loop Met Rate (Btu/hr)	Vent Loop Absolute Pressure (psia)	Nominal Thermal Env. LCVG Heat Load (W)	WP-500a: Pump flow rate using OFS-501l (lbm/hr)	O_2 Resp Quotient	CO_2 Resp Quotient	OV-210: Metabolic Consumption using OFS-209 (lbm/hr)	HMS: Carbon Dioxide Injection Rate using OFC-966 (lbm/hr)	HMS: Water Vapor Injection Rate using OLC-965 (lbm/hr)	OV-500j: Thermal Loop Pressure Drop using OPS-500f (psid)	OH-964: LCVG Simulator Heater (W)	OV-962: LCVG Pressure Drop using OPS-954 (psid)	HV-512: LCVG Water Flow Rate OFS-512 (lbm/hr)
1000	400	4.1	237	200	0.82	0.90	0.052	0.08	0.10	1.85	237	0.52	52
1000	400	4.1	237	200	0.82	0.90	0.052	0.08	0.10	1.85	237	0.52	52
1000	400	4.1	237	200	0.82	0.90	0.052	0.08	0.10	1.85	237	0.52	52
1000	400	4.1	237	200	0.82	0.90	0.052	0.08	0.10	1.85	237	0.52	52
1000	1000	4.1	237	200	0.82	0.90	0.130	0.21	0.18	1.85	237	0.52	52
1000	1000	4.1	237	200	0.82	0.90	0.130	0.21	0.18	1.85	237	0.52	52
1000	1000	4.1	237	200	0.82	0.90	0.130	0.21	0.18	1.85	237	0.52	52
1000	1000	4.1	237	200	0.82	0.90	0.130	0.21	0.18	1.85	237	0.52	52
1000	1600	4.1	237	200	0.82	0.90	0.208	0.33	0.20	1.85	237	0.52	52
1000	1600	4.1	237	200	0.82	0.90	0.208	0.33	0.20	1.85	237	0.52	52
1000	1600	4.1	237	200	0.82	0.90	0.208	0.33	0.20	1.85	237	0.52	52
1000	1600	4.1	237	200	0.82	0.90	0.208	0.33	0.20	1.85	237	0.52	52
1000	2400	4.1	237	200	0.82	0.90	0.313	0.49	0.17	1.85	237	0.52	52
1000	2400	4.1	237	200	0.82	0.90	0.313	0.49	0.17	1.85	237	0.52	52
1000	2400	4.1	237	200	0.82	0.90	0.313	0.49	0.17	1.85	237	0.52	52
1000	2400	4.1	237	200	0.82	0.90	0.313	0.49	0.17	1.85	237	0.52	52
1000	2400	4.1	237	200	0.82	0.90	0.313	0.49	0.17	1.85	237	0.52	52
1000	2400	6.0	237	200	0.82	0.90	0.313	0.49	0.17	1.85	237	0.52	52
1000	2400	6.0	237	200	0.82	0.90	0.313	0.49	0.17	1.85	237	0.52	52
1000	2400	6.0	237	200	0.82	0.90	0.313	0.49	0.17	1.85	237	0.52	52
1000	1600	6.0	237	200	0.82	0.90	0.208	0.33	0.20	1.85	237	0.52	52
1000	1600	6.0	237	200	0.82	0.90	0.208	0.33	0.20	1.85	237	0.52	52
1000	1600	6.0	237	200	0.82	0.90	0.208	0.33	0.20	1.85	237	0.52	52
1000	1600	6.0	237	200	0.82	0.90	0.208	0.33	0.20	1.85	237	0.52	52
1000	1000	6.0	237	200	0.82	0.90	0.130	0.21	0.18	1.85	237	0.52	52
1000	1000	6.0	237	200	0.82	0.90	0.130	0.21	0.18	1.85	237	0.52	52
1000	1000	6.0	237	200	0.82	0.90	0.130	0.21	0.18	1.85	237	0.52	52
1000	1000	6.0	237	200	0.82	0.90	0.130	0.21	0.18	1.85	237	0.52	52
1000	1000	6.0	237	200	0.82	0.90	0.130	0.21	0.18	1.85	237	0.52	52
1000	400	6.0	237	200	0.82	0.90	0.052	0.08	0.10	1.85	237	0.52	52
1000	400	6.0	237	200	0.82	0.90	0.052	0.08	0.10	1.85	237	0.52	52
1000	400	6.0	237	200	0.82	0.90	0.052	0.08	0.10	1.85	237	0.52	52
1000	400	6.0	237	200	0.82	0.90	0.052	0.08	0.10	1.85	237	0.52	52

Appendix E. High Humidity Test Conditions

TP	VL Flow Rate (Lpm)	VL Pressure (kPa)	Metrate (W)	Metabolic Gas Consumption (kg/hr)	Suit Leakage (kg/hr)	LCVG Heat Load (W)	CO_2 Injection Rate (g/hr)	H_2O Vapor Injection Rate (g/hr)	Duration (hours)
143	127.4	28.3	117	0.024	0.0021	237	37	13.6	1.75
								72.6	1.75
								131.5	1.75
								190.5	1.75
144	127.4	28.3	293	0.059	0.0021	237	93	13.6	1.75
								72.6	1.75
								131.5	1.75
								190.5	1.75
145	127.4	28.3	469	0.095	0.0021	237	149	13.6	1.75
								72.6	1.75
								131.5	1.75
								190.5	1.75
146	127.4	41.4	117	0.024	0.0031	237	37	13.6	1.75
								72.6	1.75
								131.5	1.75
								190.5	1.75
147	127.4	41.4	293	0.059	0.0031	237	93	13.6	1.75
								72.6	1.75
								131.5	1.75
								190.5	1.75
148	127.4	41.4	469	0.095	0.0031	237	149	13.6	1.75
								72.6	1.75
								131.5	1.75
								190.5	1.75

Note: Thermal Loop set to nominal 293 W conditions, RCA Bed Switch $ppCO_2$ = 400 Pa (3 mm Hg)

Appendix F. Schedule of Test Points

Test Point	Date	Start Time	End Time	Comments
5	6/17/2011	10:30 AM	11:29 AM	
20	6/17/2011	11:34 AM	12:35 PM	
29	6/17/2011	12:42 PM	1:25 PM	
32	6/17/2011	1:32 PM	2:01 PM	
23	6/17/2011	2:03 PM	2:51 AM	Human error. Wrong metabolic consumption rate. Repeated test point on 6/20/2011.
14	6/17/2011	2:53 PM	3:32 PM	
17	6/17/2011	3:50 PM	4:02 AM	Incomplete test point. Repeated test point on 6/20/2011.
26	6/20/2011	8:41 AM		DAQ program froze ≈ 9:15 AM; troubleshot this until ≈ 10:10 AM, then needed to recondition water temperature in loop & reconfigure some settings. Note: used preset '100 Btu/hr' instead of entering CO_2 & H_2O manually. CO_2 flow rate was 0.8085 slm CO_2, H_2O flo wrate was 0.0816 kg/hr.
26	6/20/2011	10:30 AM	11:34 AM	OPS-953 still not working Note: used preset '100 Btu/hr' instead of entering CO_2 & H_2O manually. CO_2 flow rate was 0.8085 slm CO_2, H_2O flo wrate was 0.0816 kg/hr.
8	6/20/2011	12:20 AM	1:10 PM	Note: when we switch vent loop set pressure, we turn off the HMS & the RCA. Note: used preset '100 Btu/hr' instead of entering CO_2 & H_2O manually. CO_2 flow rate was 0.8085 slm CO_2, H_2O flo wrate was 0.0816 kg/hr.
23	6/20/2011	1:47 PM	2:22 PM	Note: used preset '100 Btu/hr' instead of entering CO_2 & H_2O manually. CO_2 flow rate was 0.8085 slm CO_2, H_2O flo wrate was 0.0816 kg/hr.
17	6/20/2011	2:44 PM	3:09 PM	O2 repress performed after this TP. .Note: used preset '100 Btu/hr' instead of entering CO_2 & H_2O manually. CO_2 flow rate was 0.8085 slm CO_2, H_2O flo wrate was 0.0816 kg/hr.
11	6/20/2011	4:28pm	4:56 PM	Note: used preset '100 Btu/hr' instead of entering CO_2 & H_2O manually. CO_2 flow rate was 0.8085 slm CO_2, H_2O flo wrate was 0.0816 kg/hr.
2	6/21/2011	7:54 AM	8:36 AM	Note: Can't get to set pressure of 1.4 kPa. 1 step on POR goes from 0-3 kPa
3	6/21/2011	9:37 AM	10:24 AM	Note: messed with the plots at 10:26 ish
6	6/21/2011	10:56 AM	11:40 AM	
21	6/21/2011	11:47 AM	12:24 PM	Ended this test point because 1) we thought we had enough data & 2) started watching fan anomaly (fan speed dropping down 2-4k)
15	6/21/2011	1:37 PM	2:09 PM	Resuming test points after being down for a while to troubleshoot the fan anomaly.
24	6/21/2011	2:15 PM	2:45 PM	
18	6/21/2011	3:03 PM	3:55 PM	

Test Point	Date	Start Time	End Time	Comments
27	6/21/2011	4:01 PM	4:44pm	
9	6/21/2011	5:10 PM	5:40 PM	
12	6/23/2011	9:15 AM	9:56 AM	From 8-8:45, didn't have CO_2 flow, we were oversaturating with H_2O. Relative humidities reached nealry 90%. 34 psi upstream pressure on H_2O. 32 psi upstream pressure on CO_2.
4	6/23/2011	10:40 AM	12:54 PM	
19	6/23/2011	1:06 PM	3:03 PM	OES-525c heater dying. Turned off heater at 2:08pm to troubleshoot.
22	6/23/2011	3:21 PM	5:25 PM	At 4:48, transitioned to SWME full open while leaving the ventilation conditions the same
13	6/28/2011	8:38 AM	11:02 AM	
16	6/28/2011	11:13 AM	12:56 PM	
25	6/28/2011	1:02 PM	2:41 PM	
1	6/28/2011	3:34 PM		Couldn't get enough resolution to get down to 1.4 kPa. Could only get to about 2.4 kPa
37	7/1/2011	9:29 AM	11:30 AM	
1	7/1/2011	12:04 PM	1:22 PM	
38	7/1/2011	2:21 PM	2:49 PM	
47	7/1/2011	3:06 PM	3:57 AM	Using secondary regulator for all test points today instead of primary regulator (due to primary O_2 subsystem anomaly)
50	7/1/2011	4:03 PM	5:02 PM	
7	7/5/2011	8:50 AM	10:23 AM	Installed new PAS simulator heater (OES-252c). Still have primary O_2 subsystem isolated because of anomaly noted on Friday. Running test points today off of secondary O_2 subsystem/regulator.
10	7/5/2011	11:07 AM	12:30 PM	
39	7/5/2011	1:14 PM	2:31 PM	
84	7/5/2011	2:59 PM	5:36 PM	8.3 psia suit port decay down to 4.1 psia. Ran at 8.3 psia for about 30 mins to simulate suit port ops (suit checkout, etc.) before going down to 4.1 psia, as indicated by the "SOR Position" (Colin's software).
67	7/6/2011	8:43 AM	3:12 PM	Terminated test point early (3:12 instead of 3:45) because RCA couldn't keep up with MET rate/RCA dumping gas into the vent loop.
		3:12 PM	5:17 PM	Playing with MET rate to see at which MET rate RCA can recover
68	7/12/2011	8:21 AM	3:21 PM	Cycling RCA at 3 mmHg CO_2 (400 Pa)
69	7/13/2011	7:57 AM	2:45 PM	Cycling RCA at 3 mmHg CO_2 (400 Pa)
70	7/15/2011	8:29 AM	3:29 PM	Cycling RCA at 3 mmHg CO_2 (400 Pa)
71	7/18/2011	8:33 AM	3:33 PM	Cycling RCA at 3 mmHg CO_2 (400 Pa)

Test Point	Date	Start Time	End Time	Comments
72	7/19/2011	8:38 AM	3:38 PM	Cycling RCA at 3 mmHg CO_2 (400 Pa)
96	7/21/2011	9:26 AM	11:32 AM	Cycling RCA at 6 mmHg CO_2 (800 Pa)
46	7/21/2011	11:41 AM	1:01 PM	Cycling RCA at 3 mmHg CO_2 (400 Pa)
176	7/21/2011	1:10 PM	2:38 PM	Intentionally failing RCA to see what happens with CO_2 & humidity
93	7/21/2011	2:04 PM	4:12 PM	normal ops: low flow
94	7/22/2011	8:25 AM	9:29 AM	
177	7/22/2011	10:02 AM	11:10 PM	Intentionally failing RCA to see what happens with CO_2 & humidity
48	7/22/2011	11:32 AM	12:32 PM	Cycling RCA at 3 mmHg CO_2 (400 Pa)
178	7/22/2011	12:47 PM	2:25 PM	Cycling RCA at 400 Pa before simulated RCA failure & 800 Pa after
95	7/22/2011	3:06 AM	3:42 AM	Cycling RCA at 400 Pa
5	7/26/2011	8:57 AM	10:20 AM	Repeating test point #5 because it's our baseline performance test. Cycling RCA at 800 Pa (6 mm Hg CO_2)
97	7/26/2011	10:58 AM	11:51 AM	High met rate case (2000 BTU/hr), cycling RCA at 400 Pa (3 mm Hg CO_2)
98	7/26/2011	12:00 PM	12:50 PM	Very high met rate case (3000 BTU/hr), cycling RCA at 400 pa (3 mm Hg CO_2)
58.60.1	7/26/2011	1:29 PM	3:29 PM	Constant RCA cycle time = 60 sec Transient met rate case 1:29-2:29…thermal met rate = 1000 btu/hr, vent loop met rate = 400 btu/hr 2:29-3:29…thermal met rate = 1000 btu/hr, vent loop met rate = 1000 btu/hr
58.60.2	7/28/2011	8:02 PM	3:30 PM	Constant RCA cycle time = 60 sec Transient met rate case 8:02-9:02…thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr 9:02-10:02…thermal met rate = 1000 btu/hr, vent loop met rate = 2400 btu/hr 1:30-2:30…thermal met rate = 1000 btu/hr, vent loop met rate = 400 btu/hr 2:30-3:30…thermal met rate = 1000 btu/hr, vent loop met rate = 1000 btu/hr
58.60.3	8/2/2011	8:19 AM	10:19 AM	Constant RCA cycle time = 60 sec Transient met rate case 8:19-9:19…thermal met rate = 1000 btu/hr, vent loop met rate = 2400 btu/hr 9:19-10:19…thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr
58.40.1	8/2/2011	10.34 AM	4:15 PM	Constant RCA cycle time = 40 sec Transient met rate case 10:34-11:34…thermal met rate = 1000 btu/hr, vent loop met rate = 400 btu/hr, vent loop pressure = 4.1 psia 11:34-12:34…thermal met rate = 1000 btu/hr, vent

Test Point	Date	Start Time	End Time	Comments
				loop met rate = 1000 btu/hr, vent loop pressure = 4.1 psia 12:43-1:43…thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr, vent loop pressure = 4.1 psia 1:43-2:43…thermal met rate = 1000 btu/hr, vent loop met rate = 2400 btu/hr, vent loop pressure = 4.1 psia 1:43-2:43…thermal met rate = 1000 btu/hr, vent loop met rate = 2400 btu/hr, vent loop pressure = 6 psia 2:58-4:15…thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr, vent loop pressure = 6 psia
58.40.2	8/3/2011	8:15 AM	11:15 AM	Constant RCA cycle time = 40 sec Transient met rate case 8:15-9:15…thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr, vent loop pressure = 6 psia 9:15-10:15…thermal met rate = 1000 btu/hr, vent loop met rate = 1000 btu/hr, vent loop pressure = 6 psia 10:15-11:15…thermal met rate = 1000 btu/hr, vent loop met rate = 400 btu/hr, vent loop pressure = 6 psia
58.23	8/3/2011	12:45 AM	4:15 PM	Constant RCA cycle time = 23 sec Transient met rate case 12:45-1:45…thermal met rate = 1000 btu/hr, vent loop met rate = 400 btu/hr, vent loop pressure = 4.1 psia 1:50-2:50…thermal met rate = 1000 btu/hr, vent loop met rate = 1000 btu/hr, vent loop pressure = 4.1 psia 3:15-4:15…thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr, vent loop pressure = 4.1 psia
58.25.1	8/4/2011	10:21 AM	3:42 PM	Constant RCA cycle time = 25 sec Transient met rate case 10:21 - 11:21 …thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr, vent loop pressure = 4.1 psia 11:25-12:25…thermal met rate = 1000 btu/hr, vent loop met rate = 2400 btu/hr, vent loop pressure = 4.1 psia 12:25-1:25…thermal met rate = 1000 btu/hr, vent loop met rate = 2400 btu/hr, vent loop pressure = 6 psia 1:40-2:40…thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr, vent loop pressure = 6 psia 2:42-3:42…thermal met rate = 1000 btu/hr, vent loop met rate = 1000 btu/hr, vent loop pressure = 6 psia
143.1	8/5/2011	8:57 AM	2:12 PM	High humidity conditions, cyling RCA at 3 mm Hg CO_2, thermal met rate = 1000 btu/hr, vent loop met

Test Point	Date	Start Time	End Time	Comments
				rate = 400 btu/hr, vent loop pressure = 4.1 psia 8:57 - 10:42…. H_2O Injection Rate = 13.6 g/hr 10:42 -12:27 …. H_2O Injection Rate = 72.6 g/hr 12:27 - 2:12…. H_2O Injection Rate = 100 g/hr
58.25.2	8/5/2011	2:33 PM	3:33 PM	Constant RCA cycle time = 25 sec Transient met rate case 2:33 - 3:33 …thermal met rate = 1000 btu/hr, vent loop met rate = 400 btu/hr, vent loop pressure = 4.1 psia
114	8/11/2011	8:20 AM	3:20 PM	7 hr transient met rate case Cold thermal environment Cycling RCA at 400 Pa (3 mm Hg)
117	8/12/2011	9:05 AM	4:05 PM	Cycling RCA at 400 Pa (3 mm Hg)
Eval	8/17/2011	7:00 AM	11:45 AM	SWME bubble eval
Eval	8/17/2011	12:23 PM	3:33 PM	HMS Eval ("Old/Breadboard" Bronkhorst, "New/Vent" Bronkhorst, combined) 12:23 - 1:23 Vent Bronkhorst 1:31 - 2:31 Breadboard + Vent Bronkhorst 2:33 - 3:33 Breadboard Bronkhorst
143.2	8/18/2011	8:40 AM	12:15 PM	Test point #143 high and extra high humidity cases, splinting CO_2 /H20 between HMSs 8:40 - 10:25 131.5 H20 10:30 - 12:15 190.5 H20
144.1	8/18/2011	12:30 PM	4:01 AM	12:30 - 2:15 13.6 kg/hr H20 Breadboard Bronkhorst only 2:16 - 4:01 72.6 kg/ hr H20 Breadbiard Bronkhorst only
144.2	8/19/2011	8:15 AM	11:50 AM	High humidity conditions, cyling RCA at 400 Pa CO_2, thermal met rate = 1000 btu/hr, vent loop met rate = 1000 btu/hr, vent loop pressure = 4.1 psia 8:15 - 10:00…. H_2O Injection Rate = 131.5 g/hr 10:05 -11:50 …. H_2O Injection Rate = 190.5 g/hr
145.1	8/19/2011	11:56 AM	3:39 PM	High humidity conditions, cyling RCA at 400 Pa CO_2, thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr, vent loop pressure = 4.1 psia 11:56 - 1:41…. H_2O Injection Rate = 13.6 g/hr 1:54 -3:39 …. H_2O Injection Rate = 72.6 g/hr
5	8/22/2011	1:10PM	3:25PM	Baseline Nom Ops
145.2	8/23/2011	8:36 AM	12:53 PM	"High humidity conditions, cyling RCA at 400 Pa CO_2, thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr, vent loop pressure = 4.1 psia 8:36 - 10:16…. H_2O Injection Rate =131.5 g/hr (split) 11:08- 12:53…. H_2O Injection Rate = 190.5 g/hr (split)
146.1	8/23/2011	1:05 PM	4:43 PM	"High humidity conditions, cyling RCA at 400 Pa CO_2, thermal met rate = 1000 btu/hr, vent loop met rate = 400 btu/hr, vent loop pressure = 6 psia 1:05 - 2:50…. H_2O Injection Rate =13.6 g/hr 2:58 - 4:43…. H_2O Injection Rate =72.6 g/hr

Test Point	Date	Start Time	End Time	Comments
146.2	8/25/2011	8:16 AM	11:47 AM	High humidity conditions, cyling RCA at 400 Pa CO_2, thermal met rate = 1000 btu/hr, vent loop met rate = 400 btu/hr, vent loop pressure = 6 psia 8:16 - 10:01…. H_2O Injection Rate = 131.5 g/hr 10:02 -11:47 …. H_2O Injection Rate = 190.5 g/hr
147.1	8/25/2011	11:52 AM	3:31 PM	High humidity conditions, cyling RCA at 400 Pa CO_2, thermal met rate = 1000 btu/hr, vent loop met rate = 1000 btu/hr, vent loop pressure = 6 psia 11:52 - 1:37…. H_2O Injection Rate = 13.6 g/hr 1:46 -3:31 …. H_2O Injection Rate = 72.6 g/hr
147.2	8/26/2011	8:20 AM	12:00 PM	High humidity conditions, cyling RCA at 1000 Pa CO_2, thermal met rate = 1000 btu/hr, vent loop met rate = 400 btu/hr, vent loop pressure = 6 psia 8:20 - 10:05…. H_2O Injection Rate = 131.5 g/hr 10:15 - 12:00 …. H_2O Injection Rate = 190.5 g/hr
148.1	8/26/2011	12:11 PM	4:05 PM	High humidity conditions, cyling RCA at 400 Pa CO_2, thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr, vent loop pressure = 6 psia 12:30 - 2:15 …. H_2O Injection Rate = 13.6 g/hr 2:20 -4:05 …. H_2O Injection Rate = 72.6 g/hr
148.2	8/30/2011	8:15 AM	11:56 AM	High humidity conditions, cyling RCA at 400 Pa CO_2, thermal met rate = 1000 btu/hr, vent loop met rate = 1600 btu/hr, vent loop pressure = 6 psia 8:17 - 10:03 …. H_2O Injection Rate = 131.5 g/hr (split) 10:10 - 11:55…. H_2O Injection Rate = 190.5 g/hr
52.1	8/30/2011	12:26 PM	12:53 PM	Suit Purge 4.5 kg/hr (ended test with Primary Tank and Secondary tanks both at zero psi)
52.2	8/30/2011	1:43 PM	2:44 PM	Suit Purge 2.5 kg/hr (ended test with Primary Tank and Secondary tanks both at zero psi)
52.3	8/30/2011	3:12 PM	4:17 PM	Suit Purge 1.15 kg/hr (ended test with Primary Tank at zero and Secondary Tank at ~1750psi)
52.4	9/1/2011	8:33 AM	12:35 PM	Suit Purge 0.5 kg/hr (ended test with Primary Tank and Secondary tanks both at zero psi)
4R400	9/1/2011	1:24 PM	4:00 PM	Met rate: 400 Pa
5R400	9/2/2011	8:40 AM	9:40 AM	Nominal baseline performance test. Cycling RCA at 400 Pa
6R400	9/2/2011	9:49 AM	10:42 AM	Nominal baseline performance test. Cycling RCA at 400 Pa
6.65	9/2/2011	10:51 AM	11:53 PM	RCA Back Pressure Test (65 Pa on OPS-311g) Vent and Thermal Loops at 1600 btu/hr
5.65	9/2/2011	12:37 PM	1:31 PM	RCA Back Pressure Test (65 Pa on OPS-311g) Vent and Thermal Loops at 1000 btu/hr
4.65	9/2/2011	1:45 PM	3:45 PM	RCA Back Pressure Test (65 Pa on OPS-311g) Vent and Thermal Loops at 400 btu/hr
6.85	9/8/2011	8:07 AM	9:07 AM	RCA Back Pressure Test (85 Pa on OPS-311g) Vent and Thermal Loops at 1600 btu/hr
6.125	9/8/2011	9:15 AM	10:15 AM	RCA Back Pressure Test (125 Pa on OPS-311g)

Test Point	Date	Start Time	End Time	Comments
				Vent and Thermal Loops at 1600 btu/hr
6.175	9/8/2011	10:30 AM	11:30 AM	RCA Back Pressure Test (175 Pa on OPS-311g) Vent and Thermal Loops at 1600 btu/hr
6.225	9/8/2011	11:40 AM	12:40 PM	RCA Back Pressure Test (225 Pa on OPS-311g) Vent and Thermal Loops at 1600 btu/hr
6.275	9/8/2011	12:44 PM	1:44 PM	RCA Back Pressure Test (275 Pa on OPS-311g) Vent and Thermal Loops at 1600 btu/hr
6.375	9/8/2011	2:45 PM	3:45 PM	RCA Back Pressure Test (325 Pa on OPS-311g) Vent and Thermal Loops at 1600 btu/hr
4.325	9/9/2011	9:35 AM	10:35 AM	RCA Back Pressure Test (325 Pa on OPS-311g) Vent and Thermal Loops at 400 btu/hr
4.300	9/9/2011	10:42 AM	11:42 AM	RCA Back Pressure Test (300 Pa on OPS-311g) Vent and Thermal Loops at 400 btu/hr
4.275	9/9/2011	12:25 PM	1:25 PM	RCA Back Pressure Test (275 Pa on OPS-311g) Vent and Thermal Loops at 400 btu/hr
4.375	9/9/2011	1:33 PM	2:33 PM	RCA Back Pressure Test (375 Pa on OPS-311g) Vent and Thermal Loops at 400 btu/hr
5.375	9/9/2011	2:40 PM	3:40 PM	RCA Back Pressure Test (375 Pa on OPS-311g) Vent and Thermal Loops at 1000 btu/hr
5.325	9/13/2011	8:12 AM	9:12 AM	RCA Back Pressure Test (325 Pa on OPS-311g) Vent and Thermal Loops at 1000 btu/hr
5.300	9/13/2011	9:18 AM	10:18 AM	RCA Back Pressure Test (300 Pa on OPS-311g) Vent and Thermal Loops at 1000 btu/hr
5.275	9/13/2011	10:25 AM	11:25 AM	RCA Back Pressure Test (275 Pa on OPS-311g) Vent and Thermal Loops at 1000 btu/hr
6.375	9/13/2011	11:40 AM	12:40 PM	RCA Back Pressure Test (375 Pa on OPS-311g) Vent and Thermal Loops at 1600 btu/hr
6.300	9/13/2011	12:48 PM	1:48 PM	RCA Back Pressure Test (300 Pa on OPS-311g) Vent and Thermal Loops at 1600 btu/hr
96.375	9/13/2011	2:00 PM	3:00 PM	RCA Back Pressure Test (375 Pa on OPS-311g) Vent and Thermal Loops at 300 btu/hr
96.325	9/13/2011	3:03PM	4:03 PM	RCA Back Pressure Test (325 Pa on OPS-311g) Vent and Thermal Loops at 300 btu/hr
96.300	9/14/2011	9:07 AM	10:07 AM	RCA Back Pressure Test (300 Pa on OPS-311g) Vent and Thermal Loops at 300 btu/hr
96.275	9/14/2011	10:14 AM	11:14 AM	RCA Back Pressure Test (275 Pa on OPS-311g) Vent and Thermal Loops at 300 btu/hr
20x.275	9/14/2011	11:28 AM	12:28 PM	RCA Back Pressure Test (275 Pa on OPS-311g) Vent and Thermal Loops at 600 btu/hr
20x.300	9/14/2011	12:37 PM	1:37 PM	RCA Back Pressure Test (300 Pa on OPS-311g) Vent and Thermal Loops at 600 btu/hr
20x.325	9/14/2011	1:48 PM	2:48 AM	RCA Back Pressure Test (325 Pa on OPS-311g) Vent and Thermal Loops at 600 btu/hr
20x.375	9/14/2011	2:57 PM	3:57 PM	RCA Back Pressure Test (375 Pa on OPS-311g) Vent and Thermal Loops at 600 btu/hr

Test Point	Date	Start Time	End Time	Comments
5R400W	9/15/2011	8:20 AM	9:50 AM	Rerunning the test points from test day 1 (6/17). Starting with TP#5. Running it without the SWME valve at full open (just normal SWME operation), controling heat inputs in the thermal loop via wattage not delta T, LCVG delta P = 0, & cycling the RCA at 400 Pa. Running test point for 1.5 hrs.
5R800W	9/15/2011	9:55 AM	11:25 AM	TP#5 without the SWME valve at full open (just normal SWME operation), controling heat inputs in the thermal loop via wattage not delta T, LCVG delta P = 0, & cycling the RCA at 800 Pa. Running test point for 1.5 hrs.
20R800W	9/15/2011	11:45 AM	1:15 PM	Same conditions as TP# 5R800, except increased the vent loop fan flow rate to 169.9 slm (6 acfm). Cycling RCA at 800 Pa.
20R400W	9/15/2011	1:21 PM	3:00 PM	Same conditions as TP# 20R800, except cycling RCA at 400 Pa.
23R800	9/19/2011	9:37 AM	11:07 AM	Same conditions as TP#23, except eliminated LCVG DP. Cycling RCA at 800 Pa. Controling heat inputs in thermal loop via delta T, not wattage.
23R400	9/19/2011	11:10 AM	12:40 PM	Same conditions as TP#23, except eliminated LCVG DP. Cycling RCA at 400 Pa. Controling heat inputs in thermal loop via delta T, not wattage.
14R400	9/19/2011	12:58 AM	2:28 PM	Same conditions as TP#14, except eliminated LCVG DP. Cycling RCA at 400 Pa. Controling heat inputs in thermal loop via delta T, not wattage.
14R800	9/19/2011	2:30 PM	4:00 PM	Same conditions as TP#14, except eliminated LCVG DP. Cycling RCA at 800 Pa. Controling heat inputs in thermal loop via delta T, not wattage.
39	9/21/2011	8:15 AM	9:45 AM	Redoing this TP because we did not reach full steady state the first time we ran it.
57R400	9/21/2011	10:12 AM	11:11 AM	
42R400	9/21/2011	11:45 AM	12:45 PM	
6R400	9/21/2011	1:20 PM	2:20 PM	
48	9/21/2011	2:42 PM	3:42 PM	
21R400	9/23/2011	10:40 AM	11:40 AM	
9R400	9/23/2011	11:58 AM	12:58 AM	
12R400	9/23/2011	1:22 PM	2:22 PM	
15R400	9/27/2011	8:18 AM	9:18 AM	Same conditions as TP#15. Cycling RCA at 400 Pa. Controling heat inputs in thermal loop via delta T, not wattage.
24R400	9/27/2011	10:00 AM	11:00 AM	Same conditions as TP#24. Cycling RCA at 400 Pa. Controling heat inputs in thermal loop via delta T, not wattage.
18R400	9/27/2011	11:26 AM	12:26 PM	Same conditions as TP#18. Cycling RCA at 400 Pa. Controling heat inputs in thermal loop via delta T, not wattage.

Test Point	Date	Start Time	End Time	Comments
27R400	9/27/2011	12:29 PM	1:29 PM	Same conditions as TP#27. Cycling RCA at 400 Pa. Controling heat inputs in thermal loop via delta T, not wattage.
17R800	9/27/2011	2:18 PM	3:48 PM	Same conditions as TP#17. Cycling RCA at 800 Pa. Controling heat inputs in thermal loop via delta T, not wattage.
3R400	9/29/2011	8:27 AM	9:43 AM	
17R400	9/29/2011	10:58 AM	12:30 PM	
17R400.SWME.full	9/29/2011	12:50 PM	1:16 PM	Matt's SWME valve characterization eval. Heaters are off, SWME valve at 350 steps, chiller cart on at 20 deg C. Opened the SWME valve to 4100 steps, waited about 5 mins, closed the valve back to 350 steps.
17R400.SWME.half	9/29/2011	1:20 PM	N/A	Matt's SWME valve characterization eval, part 2. Heaters are off, SWME valve at 350 steps, chiller cart on at 20 deg C. Opened the SWME valve to 2200 steps, waited a few mins, opened the valve to 4100 steps,
17R400.POV	9/29/2011	12:42 PM	4:00 PM	Testing what happens when the POV runs out of gas & the SOP has to take over.
5	9/30/2011	2:27 PM	3:07 PM	TP#5 without the SWME valve at full open (just normal SWME operation), controling heat inputs in the thermal loop via delta T, & cycling the RCA at 800 Pa.
SWME.controller.eval	9/30/2011	3:00 PM	4:00 PM	Aaron's SWME controller eval