Orion ECLSS/Suit System – Ambient Pressure Integrated Suit Test

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The Ambient Pressure Integrated Suit Test (APIST) phase of the integrated system testing of the Orion Vehicle Atmosphere Revitalization System (ARS) technology was conducted for the Multipurpose Crew Vehicle (MPCV) Program within the National Aeronautics and Space Administration (NASA) Exploration Systems Mission Directorate. Crew and Thermal Systems Division performed this test in the eleven-foot human-rated vacuum chamber at the NASA Johnson Space Center. This testing is the first phase of suit loop testing to demonstrate the viability of the Environmental Control and Life Support System (ECLSS) being developed for Orion. APIST is the first in a series, which will consist of testing development hardware including the Carbon dioxide and Moisture Removal Amine Swing-bed (CAMRAS) and the air revitalization loop fan with human test subjects in pressure suits at varying suit pressures. Follow-on testing, to be conducted in 2013, will utilize the CAMRAS and a development regulator with human test subjects in pressure suits at varying cabin and suit pressures. This paper will discuss the results and findings of APIST and will also discuss future testing.

I. Introduction

The Orion project has baselined CAMRAS as the technology for carbon dioxide (CO_2) and water vapor (H_2O) removal for the life support system in the MPCV. Unmanned tests conducted at both Hamilton Sundstrand (the manufacturer) and the Crew and Thermal Systems Division facilities at NASA/Johnson Space Center (JSC) demonstrate how the CAMRAS technology may meet several ECLSS requirements. Testing the hardware with human test subjects, who generate significantly more varied metabolic loads than those generated by a human metabolic simulator (HMS), is another important aspect of demonstrating the technology's capabilities. Integrating the CAMRAS unit with pressure suits connected by umbilicals requires human testing because the test subjects' individual responses to the way the ARS functions could directly impact the final design of the system for Orion.

The CAMRAS test series evaluated the performance of the CAMRAS under various conditions with simulated metabolic loads in order to recommend implementation details for the Orion spacecraft and to characterize the system for refinements in system modeling. Extensive testing of earlier hardware designs and various operating conditions was completed in Phases 1, 2, and 3 in previous years, and recommended operations were developed for ambient-pressure atmospheres. Phase 4A testing examined a third iteration of the hardware design and particularly studied the effects of the CAMRAS on trace contaminants expected in a spacecraft environment. Phase 4B was the first test of this technology in reduced-pressure cabin environment.

The CAMRAS/Constellation Suit Integrated Test (CCSIT) series evaluated the impact of suits, umbilicals, and humans on the development-level ECLSS test articles to identify vehicle design changes needed to address issues that are revealed. CCSIT activities consisted of three distinct phases, with each phase progressing with increased complexity and rigor. Phase 1 was completed in May 2008. It consisted of testing the CAMRAS technology in a sealed chamber, similar in size to the habitable volume of the Orion, with human test subjects as the source of metabolic activity under ambient conditions. Test subjects varied their metabolic activity by sleeping, performing nominal activities, exercising, or donning and doffing an in-line emergency breathing apparatus. Pressure drops through prototype umbilicals were also tested. Phase 2 was completed in April 2009, and consisted of testing the CAMRAS in a vacuum environment with simulated metabolic loads. The plumbing was a simulated suit-loop, and

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nominally operated at 4.3 psia in an oxygen-enriched environment. CAMRAS performance was evaluated by varying different operating parameters (flow rate, cycle time, temperature, etc.). Umbilical flow and pressure drop performance were evaluated as well using different types of mating connectors and umbilical lengths.

Due to funding limitations, CCSIT Phase 3 is being broken into multiple test series. The first series is APIST, which consisted of testing the CAMRAS and additional development hardware with human test subjects in pressure suits at ambient cabin pressure and varying suit pressures. Follow-on series will consist of testing the system with human test subjects in pressure suits at reduced pressures.

III. Test Setup and Description

A. General Setup

The APIST is an extension of the CAMRAS and CCSIT testing. APIST incorporated two human test subjects wearing sealed pressure suits connected to an ARS loop utilizing available Orion development components. Components of the test setup are described in more detail in the sections below. A single blower provided airflow through the entire suit loop. For regeneration, the CAMRAS had both a vacuum source to simulate a link to space vacuum and a purge air source to simulate prelaunch operations. The ARS suit loop was configured to support two suited subjects. They were responsible for introducing low and medium rate metabolic gas loads into the loop. The whole test rig was outfitted with various sensors to monitor test conditions and experimental results. Sensor data was generally recorded at 1 Hertz. Four key pressure sensors were configured to record data at a rate of 1000 Hertz for short periods during key test events.

B. Test Chamber

APIST was performed in the 11 Foot Chamber located in the JSC Building 7 Highbay. The test buildup was located in the Cabin and Inner Lock sections of the chamber. The chamber remained at site ambient pressure throughout all test phases.

A suit interface panel located in the Inner Lock provided connections between the ARS loop and the suited human test subjects via flexible umbilicals. Three-way valves on the panel allowed for the selection of Advanced Crew Escape Suit (ACES) or Pressure Garment Assembly Test Article (PGATA) suit at either of the two suit interface locations. The panel also housed communication interfaces, and another array of sensors to measure ARS loop parameters and the test subject environment. Cooling water for test subject comfort was supplied separately via one or more Multiple User Cooling Units (MUCUs), provided by the suit engineers, and completely independent of the facility.

The doors to the Outer Lock and the Inner lock remained open during the all testing. The interconnect door between the Inner Lock and the Cabin remained closed during all manned tests to provide a physical safety barrier between most of the ARS buildup and the manned portion of the loop. Loop tubing passed from one test volume to the other via an interface plate installed in place of one of the existing cabin viewports, as shown in Figure 1. Figure 2, Figure 3 and Figure 4 shows actual photos of the test setup.

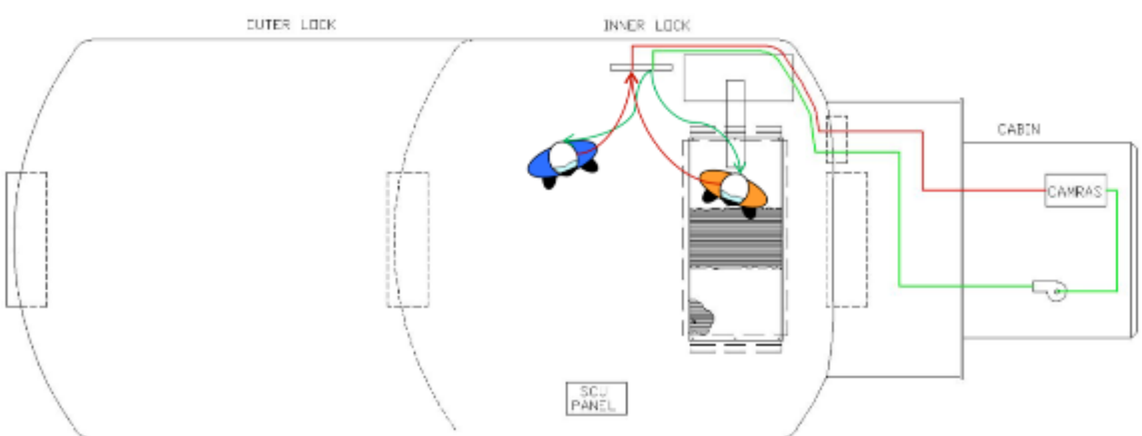

Figure 1 - Cabin and Inner Lock Separation


Figure 2 – APIST Test Rig Photo (Front View)

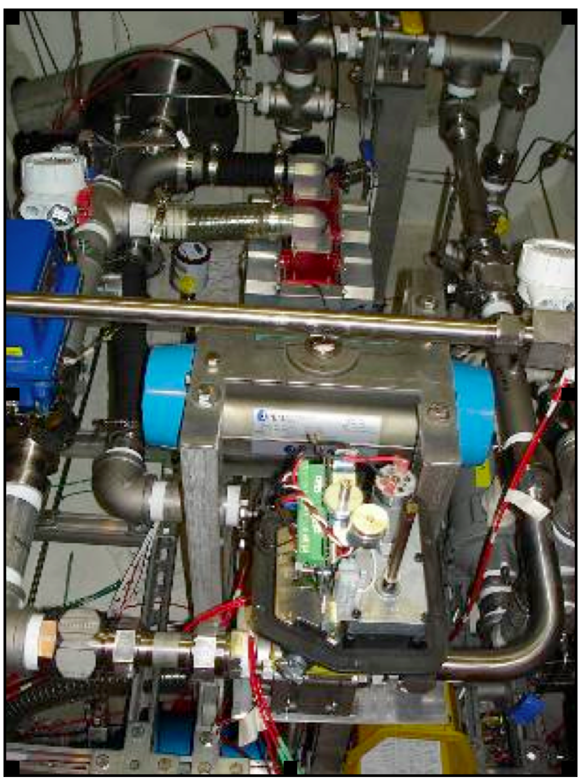
Figure 3 – APIST Test Rig Photo (Top View)

Figure 4 – APIST Umbilical Panel Photo

C. ARS loop

The system also incorporated two methods of CAMRAS bed regeneration. A CAMRAS vacuum source was used to regenerate the amine beds by exposing them to vacuum, thus removing captured CO_2 and water. Additionally, a purge air system was integrated into the system to regenerate the CAMRAS beds using dry breathing air. This method of regeneration was used to simulate launch pad operations where a vacuum source is not feasible or available.

The ARS loop, shown in Figure 5, consisted of a variable speed blower to provide airflow, a heat exchanger to condition the air in the loop and remove the heat load from the blower, trace contaminant filters, and a multitude of sensors to measure temperature, pressure, flow rate, and gas concentrations. In addition, two pumps external to the chamber permitted periodic sampling for purposes of trace gas measurements.

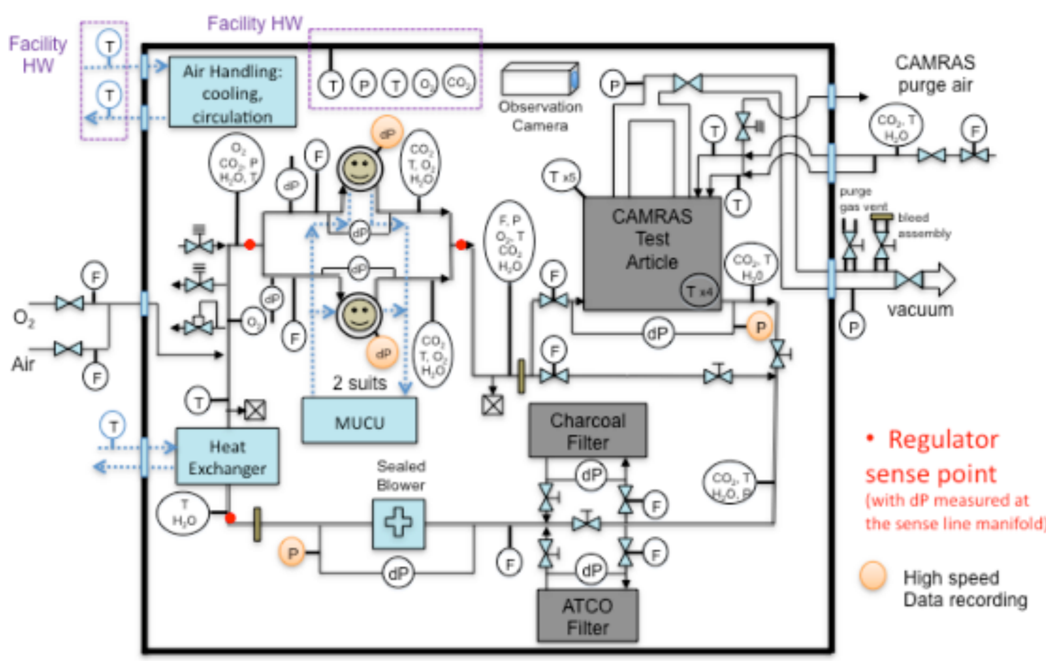

Figure 5 – APIST Loop Schematic

The CAMRAS requires a motive force for the airflow, so a blower was included in the test rig, and the blower flow rate was variable to allow a range of test conditions. The ARS loop process air system was also outfitted with instruments to analyze the test performance. Air flowed from the suits into the CAMRAS via a debris-filtered line. Air coming out of the CAMRAS flowed through parallel charcoal and Ambient Temperature Catalytic Oxidizer (ATCO) beds for trace contaminant control, then through the blower, through a heat exchanger that could help remove excess heat added by the blower, and back into the suits. Airflow through the loop could be controlled within a range of rates, depending on the experimental scenario, and it was designed to overcome the pressure drop caused by the plumbing fixtures and the CAMRAS beds. The air flow rates for this test were typically in the 8 cfm to 10 cfm range. An array of sensors, including those measuring temperature, moisture, CO_2, and airflow rate, were tapped into this plumbing stream.

D. Loop Pressure and O_2 Concentration Control

The gas supply system was comprised of a breathing air and oxygen injection system, located downstream of the heat exchanger. This system was designed to control the loop pressure for the various test points of APIST, and to make up for the oxygen depletion due to breathing. The loop pressure was intended to be controlled automatically using regulators located on sensing lines connected to one of three possible locations in the system. Operating the system while sensing the pressure at different locations, helped evaluate the effects of the sensor location on the system. Different sense locations could see minor variations in loop pressures, and could cause variations in cycling of the regulators. By evaluating these three locations the team had hoped to gain a better understanding of the loop pressure and the effect of the sensor location. For the gas concentration control, the system used breathing air as the default gas. O_2 could be selected if the loop atmosphere approached oxygen-depleted levels. Once the appropriate O_2 concentration was reached, the system could be switched back to breathing air, as this test was not permitted to operate in an O_2 enriched state. If required, the O_2 could be placed in a "trickle" mode to continuously inject a small amount of O_2 to match the test subjects' usage rate.

While the chamber remained at site pressure throughout all test phases, the ARS loop pressure was elevated to different pressures, depending on test point. The three pressures used in the loop for APIST testing were 14.7 psia, 15.5 psia (0.8 psig), and 16.7 psia (2.0 psig). At these pressures, the loop environment was at the following O_2 concentrations:

14.7 psia	21.0% O_2 (160 mmHg ppO_2)
15.5 psia	19.9% O_2 (160 mmHg ppO_2)
16.7 psia	18.5% O_2 (159 mmHg ppO_2)

E. CAMRAS Test Article

The CAMRAS technology uses a pair of interleaved-layer beds filled with sorbent beads to remove carbon dioxide (CO_2) and water (H_2O) vapor from a spacecraft cabin atmosphere or closed suit loop. In the CAMRAS unit, shown in Figure 6, a valve directs airflow through the adsorbing bed, while isolating the desorbing bed, which is open to vacuum. The valve also equalizes pressure between the two beds as it transitions from one bed to the other. In order to simulate launch pad operations where a separate vacuum source would be impractical, a gas purge of dry pressurized air can be used to purge or "sweep" the accumulated H_2O and CO_2 out of the desorbing beds.

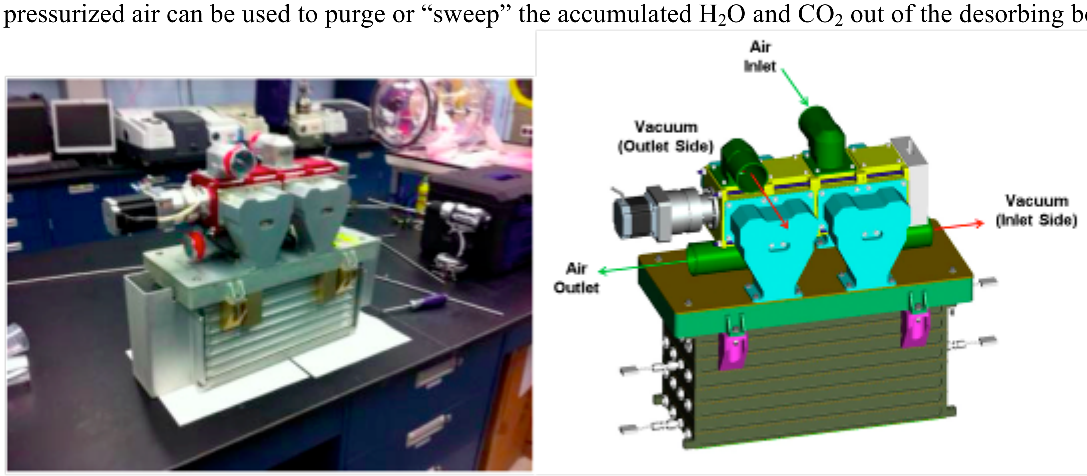

Figure 6 – CAMRAS Unit

The highly porous plastic beads in this device are coated with a liquid amine, which becomes immobilized in the bead pores. In this sorbent formulation, known as SA9T, the amine adsorbs both carbon dioxide and water. Due to this design, adsorption of CO_2 and H_2O can occur simultaneously and somewhat independently. The adsorption reaction generates some heat, while the desorption reaction consumes heat; the interleaving of bed layers helps conserve the overall system thermal energy.

A single CAMRAS assembly was used for this phase of testing. Because the projected nominal MPCV configuration will have two CAMRAS units working in parallel for a crew of four, this test only required a single CAMRAS unit for a crew of two.

The facility data system controlled the actuator of the CAMRAS test article and provided the Test Conductors with the ability to set valve cycle times for various experimental scenarios. For the APIST the cycle time was targeted at 20 minutes for all test points. The exterior of the unit was outfitted with surface temperature sensors and the interior with temperature probes to gather data about the thermal performance of the adsorbing and desorbing beds.

F. Orion Development ARS Fan

The ARS fan, designed by Hamilton Sundstrand and based on ball bearing centrifugal flow technology similar to the Shuttle Inertial Measuring Unit (IMU) fan, was used in the APIST loop as part of the hardware evaluation. The ARS fan is shown in Figure 7. The test unit is a development fan used for early performance mapping by Hamilton Sundstrand. The unit consists of an aluminum impeller, a nylon housing and a commercially available motor. The fan motor speed is controlled to provide 4.0 to 5.0 cfm to the suited test subjects.

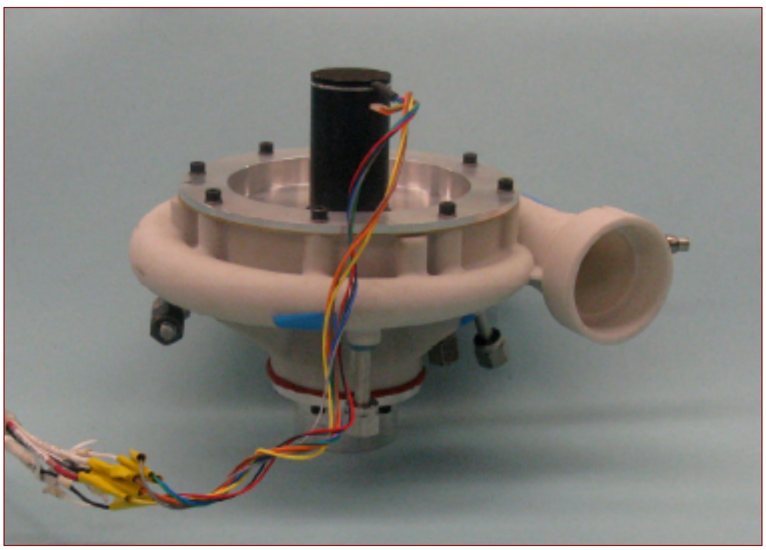

Figure 7 - ARS Development Fan

G. Pressure Suits

The two types of pressure suits used for the APIST consisted of an Altered Advanced Crew Escape Suit (ACES) and a Pressure Garment Assembly Test Article (PGATA). Both of these suits are soft suits and have been designed to operate in a closed loop system. They are full pressure suit assemblies that consist of a coverall assembly, gloves, helmet, liquid cooling garment, and boots. The main difference between the suits is that the ACES provides individual attachment points for the umbilical lines, and the PGATA uses a ganged umbilical connector. These suits do not provide a portable life support system, so environmental control and safety features were integrated into the ARS suit loop, including pressure control and oxygen delivery control as previously discussed.. Two-way audio communication was provided for the test subjects to communicate with the test team.

The Internal Vehicular Activity (IVA) umbilical for the Altered ACES is 11.5 feet long, and represents the length of the current flight design. The gas hoses are 1-1/4 inch inner diameter, incorporating a smooth-bore silicone design to minimize pressure loss. The cooling fluid hoses are 3/16 inch inner diameter and are part of the suit cooling loop Ground Support Equipment (GSE).

The IVA umbilical for the PGATA is also 11.5 feet long. The gas hoses are 5/8 inch inner diameter, incorporating a smooth-bore Teflon design to minimize pressure loss. The cooling fluid hoses are 3/8 inch inner diameter and are connected to the suit cooling loop GSE.

H. Modified Advanced Crew Escape Suit (ACES)
The ACES/Modified ACES design is a pressure garment optimized for non-pressurized activities such as those encountered during launch, dynamic on-orbit events, landing, and post-landing scenarios. The Modified ACES shown in Figure 8, is a development prototype and converts the ACES from an open loop demand based system to a closed loop life support system.

Figure 8 - Modified ACES

The ACES delivers air to the crewmember for breathing and suit pressurization to maintain crewmember's body at full inflation. The ACES has an inner pressure bladder that encompasses the crewmember's body and an outer covering. The ACES incorporates a pressure-sealing zipper at the back for donning and doffing, a neck ring to attach the helmet, and wrist rings to attach the pressurized gloves. The pressurization components of the ACES consist of an oxygen distribution manifold on the upper left leg of the suit, a positive pressure breathing regulator just below the neck ring, a dual suit controller on the right side of the chest, and a relief valve.

Air enters the pressure garment at the interface connection and is then routed through soft tubing along the interior of the pressure garment. The breathing air lines terminate approximately 2 inches. above the neck ring and in front of the helmet vent pad. The return air (exhalant) is removed from the suit at the return air connection. The suit relief valve is set to open when suit pressure reaches 5.5 ± 0.2 psid. Once open, the relief valve will remain open until suit pressure drops to 3.5 psid.

The Modified ACES can also connect to the ACES helmet and communications carrier assembly (CCA) for communications. The helmet attaches to the ACES via a locking neck ring and provides a pressurized breathing volume and head protection to the crewmember. A sense port on the back of the helmet will allow for the installation of a differential pressure sensor to monitor pressure changes in proximity of the test subject's head.

I. Pressure Garment Assembly Test Article (PGATA) suit
The Pressure Garment Assembly Test Article (PGATA), shown in Figure 9, was fabricated by the Crew Safe Accommodation for Exploration (C-SAFE) Team to closely represent the features and elements of the current suit

architecture. The PGATA is a continuous loop breathing suit. The air inlet hose is routed to the suit via a penetration on the upper right chest. The air flow is then routed up around the neck ring to an inlet at the back of the neck. The air outlet penetration is located next to the air inlet and accommodates the addition of a vent tree to assist in suit ventilation. The suit is equipped with a neck ring to interface a helmet for pressurized operations. An interface analogous to the ACES one was used for a pressure sensor during test. A separate CCA incorporates a detachable vent as well as communications for suited evaluations.

The PGATA is equipped with a “U” entry Pressure Sealing Closure (PSC), a convoluted waist joint and belly bar. These mobility features enable improved bending at the waist and a more comfortable seated position. The waist is also equipped with circumferential waist take ups to decrease the free volume of the suit after it is donned.

The PGATA suit features tucked fabric elbow joints, convoluted knee joints, low profile bicep bearings and link net shoulders to provide pressurized mobility and subject comfort. The arms and leg incorporate drum style lacing in order to size the suit for various subjects. Commercially available military style jump boots are used with the suit to protect the boot bladders and to provide pressure restraint and ankle stability.

Cooling is provided from an external source and penetrates the suit on the left chest. Quick disconnects are located on the inside of the suit and a can accommodate the C-SAFE liquid cooling garment.

The PGATA gloves are United States Air Force pilot protective assembly style gloves.

Figure 9 - PGATA Suit

IV. Test Conditions and Objectives

This section details the specific test conditions that were to be used for the suit-loop configuration. These tests gathered pressure drop variation and flow data at various test conditions. This test series was performed with two suits. The suits were pressurized to various levels: 0.8 and 2.0 psid above a chamber pressure of 14.7 psia. The objectives of this test series were to:

1) Determine effect on suit pressure control due to regulator control sensing points at different locations within the loop
2) Test flow variations of the loop as a result of test subject position or motion
3) Measure pressure effects at multiple points around the suit loop during testing to validate analysis models

4) Obtain qualitative feedback from test subjects with regard to pressure effects due to CAMRAS bed cycling and test subject motion.
5) Obtain preliminary sound level data within the suit loop

A. Unmanned Performance Tests

This short test series focused on testing the hardware and facility using an unmanned suit configuration. The facility was configured with the suits installed and leak checks were performed. Once the leak checks were complete, tests for fan performance, CAMRAS bed cycling and system check out were performed per the Unmanned Priority Test Sequence in Table 1.

Table 1 - Unmanned Test Priority Sequence

Priority Class	Priority Sequence Number	Suit Pressure (psid)	CAMRAS Regeneration	Sense Point	Metabolic Load Type	CAMRAS Flow	Suit Config[1]
1	1	0.8	Vacuum	HX Inlet	Unmanned	100%	2A
1	2	0.8	Purge Gas	HX Inlet	Unmanned	100%	2A
1	3	2.0	Vacuum	HX Inlet	Unmanned	100%	2A
1	4	2.0	Purge Gas	HX Inlet	Unmanned	100%	1A, 1P

Note(s):
1. Suit Configuration: A=ACES, P=PGATA; 2A = 2 ACES; 1A, 1P = 1 ACES & 1 PGATA

B. Baseline Sound Level Testing

During the unmanned performance tests, the team performed a baseline sound level test. The primary purpose of this test was to gather baseline data on noise levels inside the suit and to verify levels below Occupational Safety and Health Association (OSHA) limits for test subject protection. Acoustic levels were measured at various locations including inside the suit during suit-pressurization using the Orion prototype ARS fan. A secondary objective was to attempt to quantify how much of the noise is flow-noise as opposed to fan noise. The set up included several microphones and accelerometers simultaneously to try to separate the flow noise from the fan noise using a signal-coherence method. Figure 10 shows the microphone with a windscreen inside the helmet.

Figure 10 - Microphone insert through the helmet sensor port

Helmet interior A-weighted Overall Sound Pressure Levels varied from 74.0 dBA to 75.4 dBA (Figure 11 and Figure 12), which is well below OSHA and NIOSH (National Institute for Occupational Safety and Health) requirements (90 and 85 dBA for 8-hour exposures, respectively) and therefore deemed acceptable for the test subjects. The measured data also provided information on the dominant noise source (airflow noise) and indicated possible noise reduction solutions. In the flight system, the swingbed provides attenuation on one side of the fan, but not on the other side. There will be a muffler on the other side of the fan in the flight system, and this will provide some noise reduction.

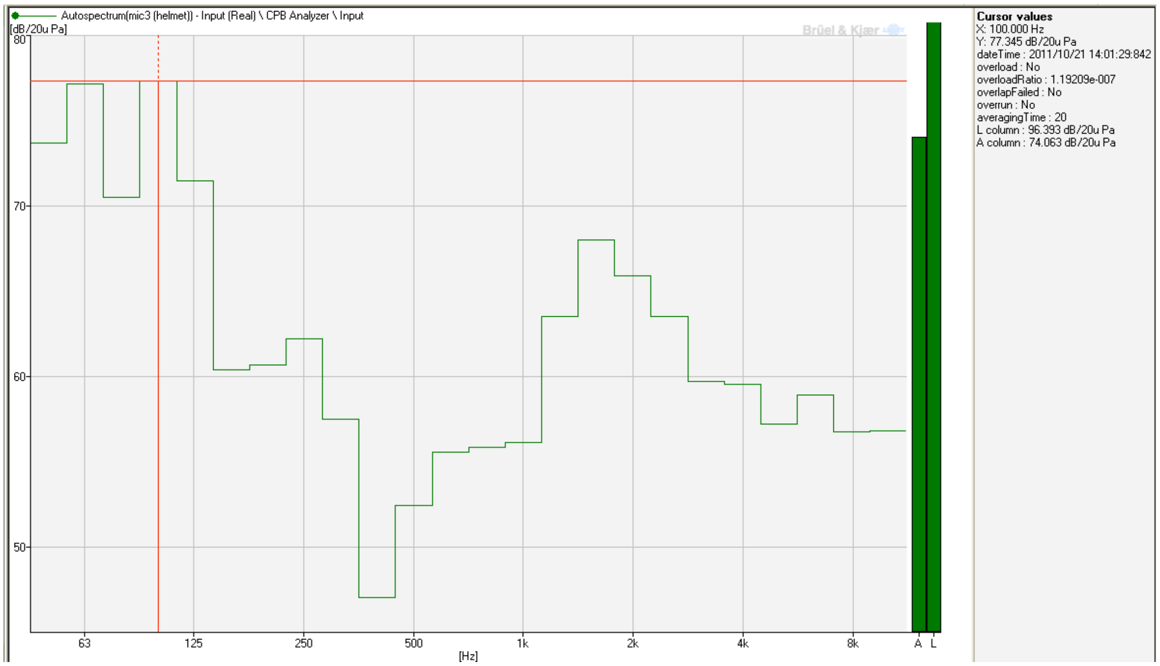

Figure 11 – Sound Spectrum with Suit Pressure at Ambient

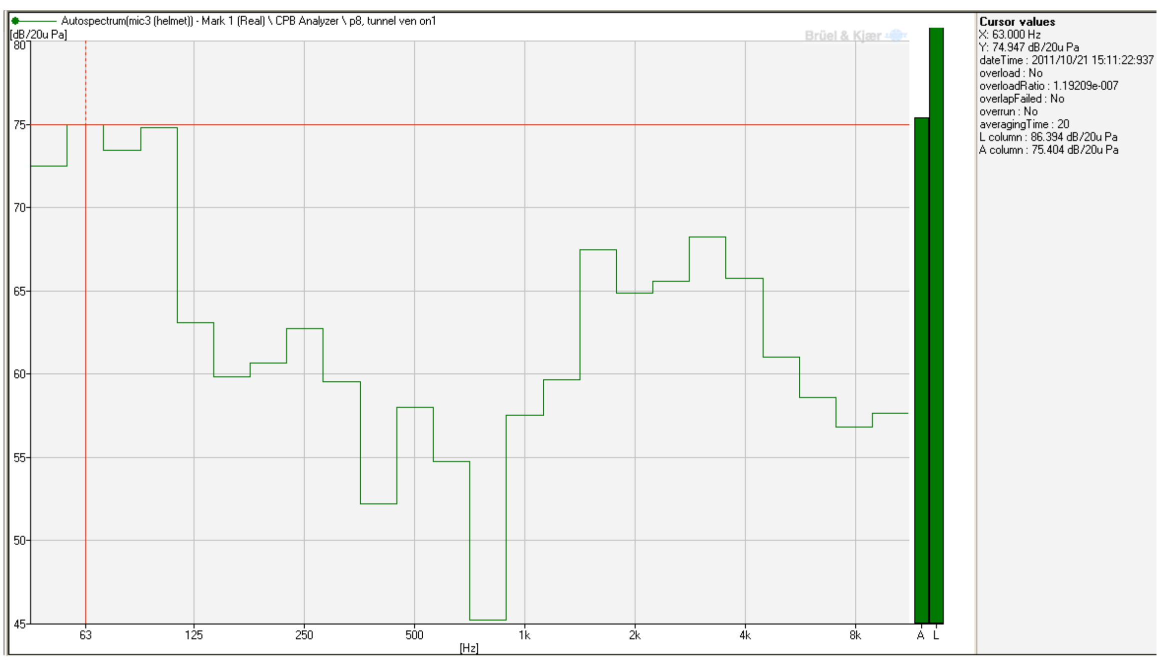

Figure 12 - Sound Spectrum with Suit Pressure at 0.8 psi above Ambient

C. Manned Performance Tests

The remainder of the test series focused on integrated testing with human test subjects.. The facility was configured, suited test subjects were integrated into the loop, and leak checks were performed. Once the leak checks were complete, tests for fan performance, CAMRAS bed cycling and varying metabolic loads were performed per the Manned Priority Test Sequence in Table 2. The table shows the parameters that were varied during the test series to simulate different suit loop operational conditions.

Table 2 - Manned Test Priority Sequence

Priority Class	Priority Sequence Number	Suit Pressure (psid)	CAMRAS Regeneration	Sense Point[2]	Metabolic Load Type[3]	CAMRAS Flow	Suit Config[1]
2	5	0.8	Vacuum	HX Inlet	Low/Low	100%	2A
2	6	0.8	Vacuum	HX Inlet	Low/Medium	100%	2A
2	7	0.8	Vacuum	HX Inlet	Medium/Medium	100%	2A
2	8	0.8	Purge Gas	HX Inlet	Medium/Medium	100%	1A, 1P
2	9	2.0	Vacuum	HX Inlet	Low/Low	100%	1A, 1P
3	10	0.8	Vacuum	Suit Inlet	Low/Low	100%	1A, 1P
3	11	0.8	Vacuum	Suit Inlet	Low/Medium	100%	1A, 1P
3	12	0.8	Vacuum	Suit Inlet	Medium/Medium	100%	1A, 1P
3	13	0.8	Purge Gas	Suit Inlet	Medium/Medium	100%	1A, 1P
3	14	2.0	Vacuum	Suit Inlet	Low/Low	100%	1A, 1P
4	15	0.8	Vacuum	Suit Outlet	Low/Low	100%	1A, 1P
4	16	0.8	Vacuum	Suit Outlet	Low/Medium	100%	1A, 1P
4	17	0.8	Vacuum	Suit Outlet	Medium/Medium	100%	1A, 1P
4	18	0.8	Purge Gas	Suit Outlet	Medium/Medium	100%	1A, 1P
4	19	2.0	Vacuum	Suit Outlet	Low/Low	100%	1A, 1P
4	20	2.0	Vacuum	Suit Outlet	Seat P/Low	100%	1A, 1P
5	21	0.8	Vacuum	Fixed	Low/Low	50%	1A, 1P
5	22	0.8	Vacuum	Fixed	Low/Medium	50%	1A, 1P
5	23	0.8	Vacuum	Fixed	Medium/Medium	50%	1A, 1P
5	24	0.8	Purge Gas	Fixed	Medium/Medium	50%	1A, 1P
5	25	0.8	Purge Gas	Fixed	Seat A/Med	50%	1A, 1P
6	26	0.8	Vacuum	Fixed	Low/Low	33%	1A, 1P
6	27	0.8	Vacuum	Fixed	Low/Medium	33%	1A, 1P
6	28	0.8	Vacuum	Fixed	Medium/Medium	33%	1A, 1P
6	29	0.8	Purge Gas	Fixed	Medium/Medium	33%	1A, 1P
6	30	0.8	Purge Gas	Fixed	Seat A/Med	33%	1A, 1P
7	31	2.0	Purge Gas	Fixed	Medium/Medium	100%	1A, 1P
7	32	2.0	Vacuum	Fixed	Medium/Medium	100%	1A, 1P
8	33	2.0	Vacuum	Fixed	Low/Low	50%	1A, 1P
8	34	2.0	Vacuum	Fixed	Low/Medium	50%	1A, 1P
8	35	2.0	Vacuum	Fixed	Medium/Medium	50%	1A, 1P
8	36	2.0	Purge Gas	Fixed	Medium/Medium	50%	1A, 1P
9	37	2.0	Vacuum	Fixed	Low/Low	33%	1A, 1P
9	38	2.0	Vacuum	Fixed	Low/Medium	33%	1A, 1P
9	39	2.0	Vacuum	Fixed	Medium/Medium	33%	1A, 1P
9	40	2.0	Purge Gas	Fixed	Medium/Medium	33%	1A, 1P

Note(s):

1. Suit Configuration: A=ACES, P=PGATA; 2A = 2 ACES; 1A, 1P = 1 ACES & 1 PGATA
2. Sense Points: Fixed – Will decide based on early test results where to leave the sense point (HX inlet, Suit Inlet, or Suit Outlet).
3. Metabolic Load Type: Low – Sitting or standing with minimal movement. Medium – Moving arms or legs to increase met rate over sitting. Seat P – PGATA Seat with PGATA suit subject strapped into seat. Seat A – ACES Seat with ACES suit subject strapped into seat. Metabolic loads will not be calculated during this event.

During the two weeks of testing, four unmanned and thirty-two manned test points were completed. The test day consisted of morning and afternoon test sessions. Multiple test points from the matrix were included in each test session. Figure 13 shows test subjects in the chamber during test operations.

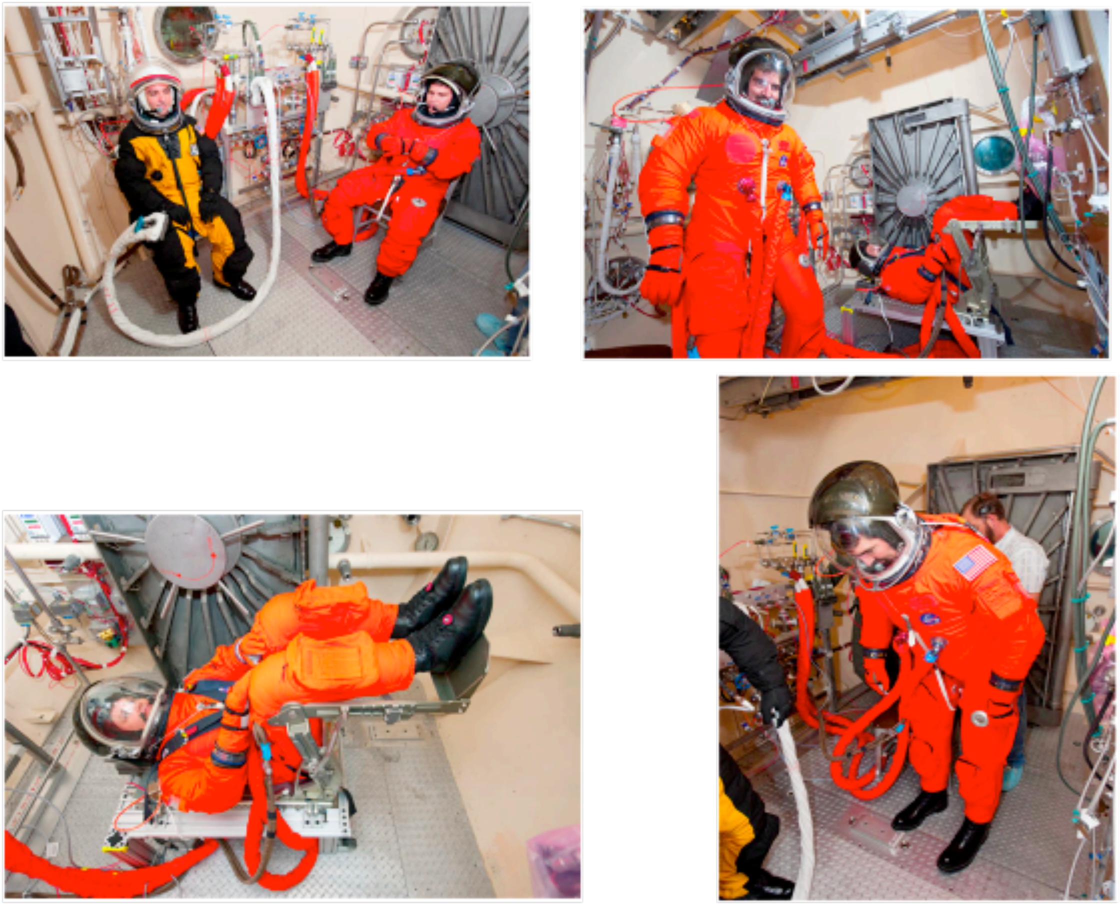

Figure 13 - Test Subjects During Testing

V. Test Results

A. Fan Performance

The baseline ARS fan design was based on suit requirements of the PGATA suit and umbilical. The total pressure loss across the PGATA is higher than the ACES, therefore manual valves were incorporated into the test rig to increase the pressure loss across the ACES leg to achieve balanced flow to both suits. This was done immediately at the beginning of each test point. The test points were performed primarily using one ACES and one PGATA. Only one set of test points were performed using two ACES. Table 3 is a comparison of the fan performance with two ACES in the loop vs one ACES and one PGATA.

For the purpose of this comparison, steady state conditions are desirable. However, since this was not possible during the test, the test data was averaged (by visual approximation) when necessary to approximate steady state conditions. The results are shown in Table 4.

Table 3 - APIST Fan Performance, Selected Four Priority Sequence Number Cases.

Priority Sequence Number (PSN)	Suit Pressure	CAMRAS Regeneration	PCS Supply Gas Sense Point	Metanolic Load Category	Percent CAMRAS Flow	Suit Configuration
	(psid)					
7	0.8	Vacuum	HX Inlet	Medium/Medium	100%	ACES/PGATA
8	0.8	Purge gas	HX Inlet	Medium/Medium	100%	ACES/PGATA
31	0.8	Purge gas	Fixed	Medium	100%	ACES/ACES
32	0.8	Vacuum	Fixed	Medium	100%	ACES/ACES

Table 4 - APIST Fan Performance, Fan Inlet Volumetric Flow Rates and Fan Pressure Rise.

Priority Sequence Number	Average Fan Inlet Volumetric Flow Rate	Sum of Suit 1 and Suit 2 Inlet Flow Rates	Average Pressure Rise Across Fan	Fan Speed
	(acfm)	(acfm)	(inches of H_2O)	(rpm)
7	9.2	9.4	23.5	17,300
8	9.25	9.4	23.55	17,300
31	9.25	10.0	15.75	14,500
32	9.75	10.2	16.3	14,500

B. Pressure Control Sense Point

The test regulators were installed with three remote sense locations at the suit inlets, suit outlets and the heat exchanger inlet, which are noted on the schematic in Figure 5. The objective was to determine the effect on suit pressure control due to regulator control sensing points at different locations within the loop. The early test points were run with the sense point locations changing between locations as per Table 2. The primary objective to determine the best control point was not met due to the test regulator's wide tolerances and relatively slow response times. However, the heat exchanger inlet was found to be the best position of the three locations. That point exhibited the most stable control as it was less influenced by pressure fluctuations imparted by test subject movement. Figure 14 shows the pressures around the loop during one test run that incorporated changing the sense point locations.

Priority Sequence Numbers 8, 13, and 18: Oct 28 2011 12:50 to 15:44 PM.

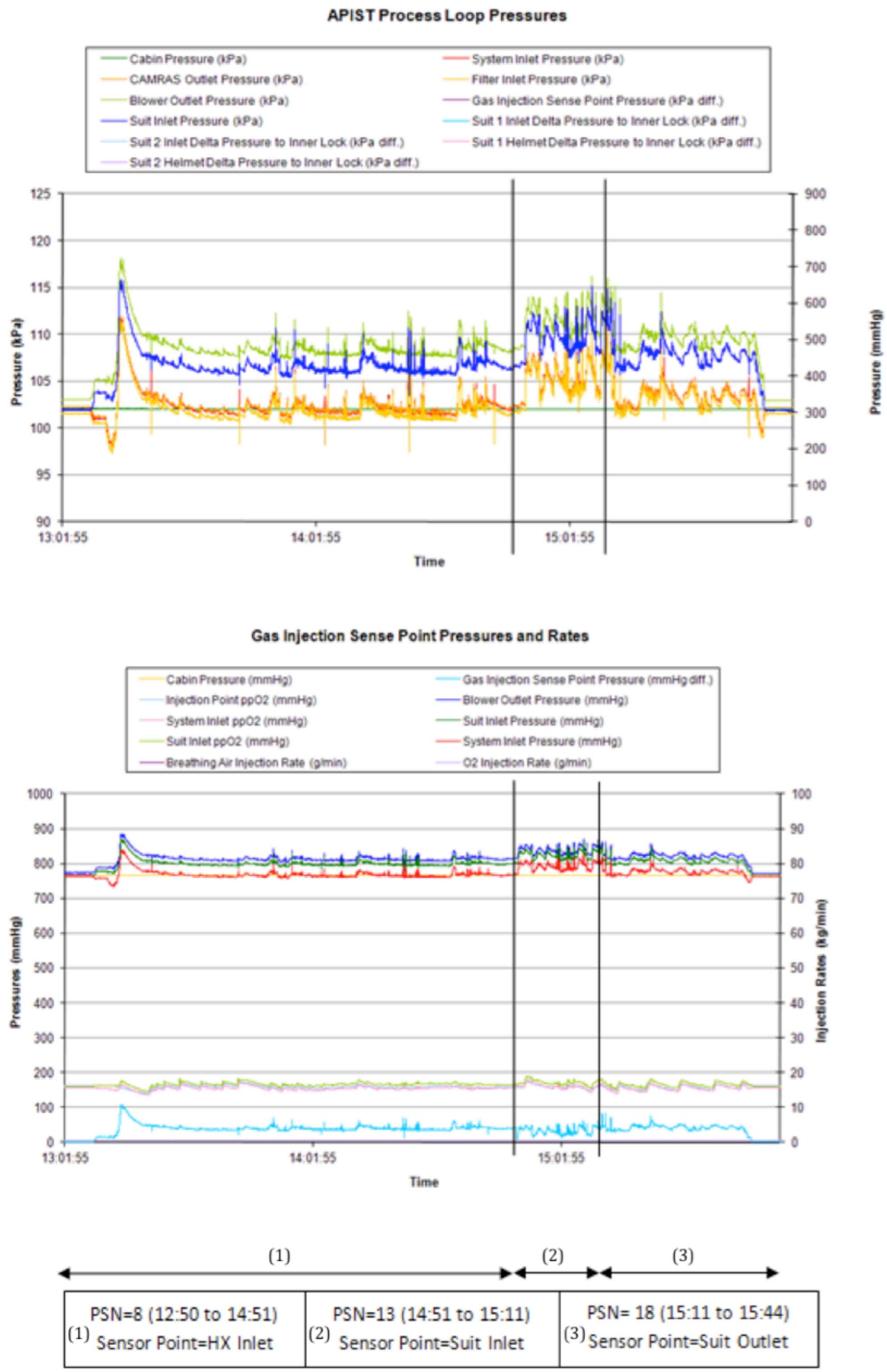

Figure 14 - Pressure Control Stability Comparison

C. Loop Pressure Fluctuations

The objective from this test series with the largest potential impact on the Orion design was the evaluation of pressure fluctuations due to bed cycling and crew motion, thereby determining the worst-case magnitudes and rate of change. In both cases, rapid pressure changes within suit helmets and suit torso volumes were monitored in this study as a measure of severity of pressure fluctuations. High rate data with a frequency of 0.001 seconds was captured during each CAMRAS bed cycle for this purpose.. Four APIST Test Priority Sequence Numbers (PSN) were chosen to evaluate pressure pulses in the APIST Loop due to CAMRAS cycling based on different APIST Loop configurations available during these PSN's. The worst case rates of change are summarized in Table 5. The need to characterize these fluctuations is driven by Human Systems Integration Requirements (HSIR) concerning crew exposure to rapid pressure transients. The limit specified is -13 psid/min for depressurization.

Table 5 - Sample Pressure Fluctuations

Priority Sequence Number	Suit Pressure (psid)	Metabolic Load Type	CAMRAS Flow	Suit Config	PGATA* Worst Pressure Decay Rate (psi/min)	PGATA* Change in Pressure During Cycling (psi)	ACES Worst Pressure Decay Rate (psi/min)	ACES Change in Pressure During Cycling (psi)
7	0.8	Medium/Medium	100%	1A, 1P	-52	0.26	-78	0.38
9	2.0	Low/Low	100%	1A, 1P	-53	0.25	-79	0.38
23	0.8	Medium/Medium	50%	1A, 1P	-39	0.11	-27	0.10
28	0.8	Medium/Medium	33%	1A, 1P	-41	0.12	-27	0.09
32	0.8	Medium/Medium	100%	2A**	-62	0.17	-70	0.20

*** "A" indicates ACES suit, "P" indicates PGATA suit**
**** PGATA used for except for PSN 32 where ACES is used for both Suit 1 and 2**

While the rate of change noted in the table exceeds the HSIR limits for all occurrences, the durations of these changes were less than 0.4 seconds. However, no instantaneous or intervals less than one minute are specified in the requirements. The pressure control lead for NASA Orion ECLSS is working with the Flight Surgeons to clarify the HSIR depressurization rate of change requirements and how these short exceedances are handled.

During the test, the test subjects were asked for feedback on the any sensations they experienced during bed cycles due to the pressure fluctuations. No discomfort was noted by any of the test subjects in this test. The theme of the comments was that the fluctuations were noticeable but no discomfort was experienced. However unless test subjects were sitting very still or specifically informed that a CAMRAS valve cycle was approaching, they frequently did not even notice. Feedback was that when detected, valve cycle changes were manifested as a momentary loss/change in flow.

Further feedback from the test subjects was that their motions were significantly more noticeable than the bed cycles. If one test subject was sitting still and the other quickly compressed their posture, the suit of the sitting test subject would visibly inflate. Raw data analyses of these fluctuations show larger magnitude pressure changes, but. But high rate data was not taken during the test to capture test subject motion. These fluctuations will be captured with high rate data in the next series of tests to quantify the rate of change.

D. Loop Dew Point/Humidity

During the manned tests, the test team noted that the dew point at the suit inlets were remaining stable and at a higher level than expected. Plotting of the early test cases showed that the trace contaminate control system (TCCS) beds were providing a buffer from the CAMRAS beds. Although the dew point at the outlet of the CAMRAS unit was very low at the beginning of a cycle and increased during the cycle, the dew points on the downstream side of the TCCS remain relatively stable. This is shown in Figure 15. Since humidity levels immediately downstream of the CAMRAS are cyclical as a result of the water vapor removal process within the CAMRAS, a method was used to capture “average” humidity levels in the test data at the CAMRAS outlet during the test. Shaded columns in Table 6 are of interest due to apparent humidity addition downstream of the TCCS.. Test subjects commented that the moisture level in the suit loop during the tests was noticeably drier than normal but was not uncomfortable. These findings are useful for the flight systems team because there have been concerns that the atmosphere would be over dried during suited operations.

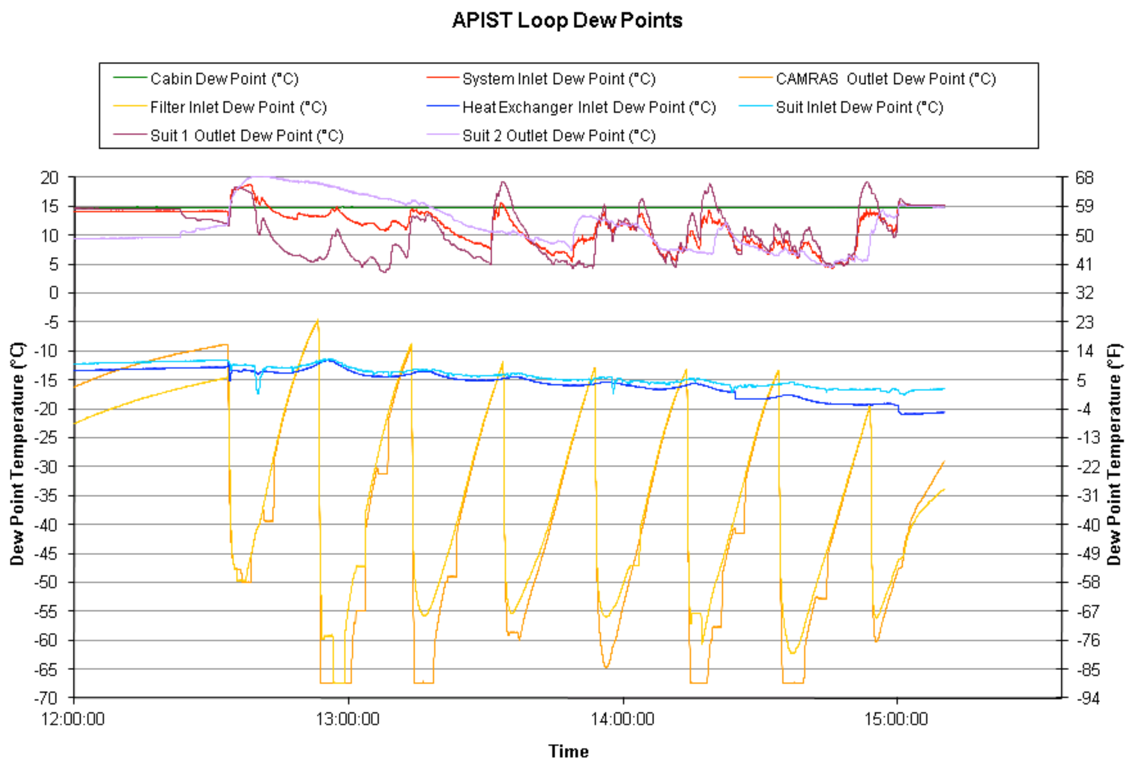

Figure 15 – ARS Loop Dew Points

Table 6 - APIST Loop Dew Point Temperatures at specified “midpoints”

Test day & Date	1 am 10_27_11 10:24:15	1 pm 10_27_11 13:31:15	2 am 10_28_11 11:03:49	2 pm 10_28_11 14:54:43	3 am 10_31_11 10:30:17	3 pm 10_31_11 14:02:46	4 am 11_01_11 10:08:42	4 pm 11_01_11 13:35:53	5 am 11_02_11 9:55:18	5 pm 11_02_11 14:42:08	6 am 11_03_11 10:42:07	6 pm 11_03_11 14:24:11	7 am 11_04_11 10:44:58	7 pm 11_04_11 14:37:47
Dew Point (°C)														
Cabin	14.77	14.77	13.03	12.46	13.13	12.96	13.41	13.43	14.32	14.22	10.65	8.67	4.60	5.15
System Inlet	5.07	10.22	1.26	2.98	5.64	2.74	5.58	6.56	9.29	8.61	8.86	11.85	8.32	9.61
CAMRAS Outlet	-27.03	-17.91	-27.60	-14.89	-32.37	-26.80	-55.14	-56.76	-52.07	-32.06	-14.06	-13.33	-53.72	-38.81
Filter Inlet	-26.65	-17.75	-27.14	-14.56	-31.73	-26.64	-5.54	-1.55	-2.15	-2.59	0.99	3.29	-0.13	0.83
Heat Exchanger Inlet	-10.09	-15.06	-22.28	-21.83	-20.71	-24.38	-12.23	-3.17	-2.85	-1.82	0.12	3.38	1.65	1.21
Suit Inlet	-10.45	-14.24	-19.78	-19.75	-18.22	-21.43	-12.04	-4.80	-5.05	-3.77	-2.40	-0.19	-1.35	-1.64
Suit 1 Outlet	3.11	8.33	3.85	5.47	0.82	4.81	5.36	4.85	11.01	11.58	11.97	11.98	9.59	10.09
Suit 2 Outlet	7.15	10.66	-1.24	0.96	9.78	1.30	6.89	8.72	8.16	6.09	5.90	12.36	7.67	9.72

VI. Conclusion

This test proved basic functionality of Orion suit and ECLSS integration. The development hardware performed nominally for the entire test. The development fan provided sufficient flow to both the modified ACES and the PGATA suit configurations. Data analysis and test subject feedback indicate that the pressure effects of the CAMRAS amine swing-bed and from human movement in the suit, while noticeable, were not detrimental to the test subjects. This data will enable removal of the valve assembly that directly injected oxygen into the CAMRAS beds in the Orion ECLSS, as it is not needed for pressure equalization during bed cycles. Test subject feedback on humidity levels was acceptable, as no negative comments were made regarding discomfort due to dryness of the eyes or oral/nasal membranes. Dew point data shows the TCCS bed acts as a moisture capacitor in the suit loop and keeps the loop from being over dried by the amine swing-bed. Acoustic levels in the suit did not interfere with communication between test subjects and test team. In addition, suit umbilical pressure drop variation does have effect on fan speed, however is not proportional to the delta in umbilical/suit flow resistance.

The second test series is currently in planning for spring of 2013. The chamber pressure will be reduced to 10.2 psia to simulate the Orion MPCV operating pressure. Additional development hardware including higher fidelity fan, a development suit loop regulator and suit hardware will be incorporated into the test loop to bring the system closer to flight configuration. The final phase of testing, currently planned for August 2014, will be performed at vacuum conditions.

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