JAMES WEBB SPACE TELESCOPE (JWST) INTEGRATED SCIENCE INSTRUMENTS MODULE (ISIM) CRYO-VACUUM (CV) TEST CAMPAIGN SUMMARY

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ABSTRACT

JWST Integrated Science Instruments Module (ISIM) completed its system-level space simulation testing program at the NASA Goddard Space Flight Center (GSFC). In March 2016, ISIM was successfully delivered to the next level of integration with the Optical Telescope Element (OTE), to form OTIS (OTE + ISIM), after concluding a series of three cryo-vacuum (CV) tests. During these tests, the complexity of the mission has generated challenging requirements that demand highly reliable system performance and capabilities from the Space Environment Simulator (SES) vacuum chamber. The first test served as a risk reduction test; the second test provided the initial verification of the fully-integrated flight instruments; and the third test verified the system in its final flight configuration following mechanical environmental tests (vibration and acoustics). From one test to the next, shortcomings of the facility were uncovered and associated improvements in operational capabilities and reliability of the facility were required to enable the project to verify system-level requirements. This paper: (1) provides an overview of the integrated mechanical and thermal facility systems required to achieve the objectives of JWST ISIM testing, (2) compares the overall facility performance and instrumentation results from the three ISIM CV tests, and (3) summarizes lessons learned from the ISIM testing campaign.

INTRODUCTION

The James Webb Space Telescope (JWST) is a multi-billion dollar space-based telescope (Figure 1a) aimed to enable insights into the formation of galaxies and planets after the "Big Bang." The objective will be achieved using four science instruments (SI) that operate in short to medium wavelengths: Mid-InfraRed Instrument (MIRI), Fine Guidance Sensor (FGS), Near-InfraRed Spectrometer (NIRSpec), and Near-InfraRed Camera (NIRCam). The composite structure housing the SIs, shown in Figure 1b, is called the Integrated Science Instruments Module (ISIM).

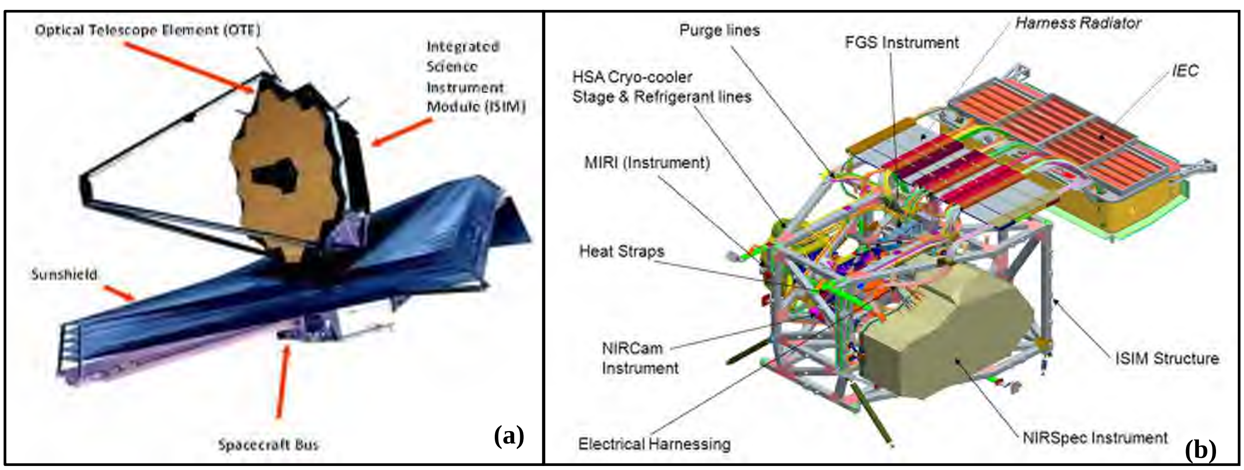

Figure 1 (a) Diagram of the entire JWST observatory (b) ISIM elements

Using an incremental integration and testing approach, the JWST ISIM system underwent a series of three cryo-vacuum (CV) tests, CV1 to CV3. Each SI was developed and tested independently prior to delivery for ISIM-level integration. CV1 included the MIRI and FGS flight instruments and served as a risk reduction test. CV2 tested all four flight SIs with an objective of measuring baseline optical, thermal, electrical, and software performance. CV3 also consisted of the four SIs, but the primary objective was to verify the system-level requirements after replacement of selected components (i.e. detectors) in the instruments, provide a post mechanical environmental testing verification, and validate any repairs of non-conforming items. This mandated ISIM de-integration and removal of instruments after the CV2 test and re-integration to final flight configuration. After this process, the ISIM was thermally retested in the CV3 test to verify proper performance prior to delivery of ISIM to integration and vibration testing with the Optical Telescope Element (OTE). ISIM and the OTE form the OTIS element. After vibration testing at Goddard, OTIS will be delivered to Johnson Space Center (JSC) for thermal vacuum testing where the facility is large enough to accommodate the large OTIS hardware.

This paper serves to deliver and document the efforts involved with the evolution of chamber readiness and development during the CV1 through CV3 tests at GSFC. The intent is to present an overview of the chamber requirements and test configuration for ISIM CV testing, comparison of facility performance capabilities from each test, and the plan forward to surmount future testing using the chamber to improve reliability and performance.

OVERVIEW OF CHAMBER REQUIREMENTS AND TEST CONFIGURATION

The Space Environment Simulator (SES) chamber shown in Figure 2, Facility 290, at NASA GSFC underwent several modifications in order to provide a platform by which the thermal specifications required of the JWST ISIM CV testing program could be successfully achieved. In 2012, the paper *James Webb Space Telescope Integrated Science Instrument Module Cryogenic Vacuum Test Planning* was presented in the 27th Space Simulation Conference and covers the finer details with a comprehensive overview of the changes and upgrades involved to prepare the SES for ISIM-level testing. Furthermore, in 2014 at the 28th Space Simulation Conference, the paper *James Webb Space Telescope Integrated Science Instrument Module Cryo-Vacuum Testing at GSFC* described the SES modifications since the initial commissioning and the results of the CV1 test. In this paper, therefore, only the high-level SES facility capabilities are listed below. The remaining part of this chamber overview section documents the changes (if any) of supporting instrumentation for the three CV tests.

The general SES-facility capabilities and configuration include:

- Internal volume: 27' diameter x 40' high
- Payload support weight: 26,000 lbs
- Temperature: 83K to 348K (-190°C to +75°C)
- Vacuum pressure: 10^{-7} Torr
- Hardware access: 6' high x 5'wide personnel access door; 15 ton crane capacity for hardware loading through the top dome of the chamber
- A 1.0 kW (at 20K) helium refrigeration system with 10-zones (one supply and ten individually valved return line) for gaseous He circulation

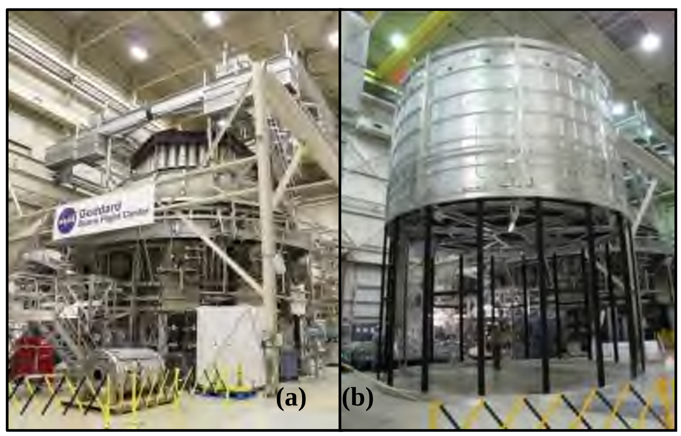

Figure 2 (a) GSFC SES Chamber (b) Helium Shroud

Figures 3 & 4 depict the JWST ISIM full configuration within the SES using required facility and GSE capabilities. Refer to the 2014 conference paper for descriptions of the GSE shown in Figure 3.

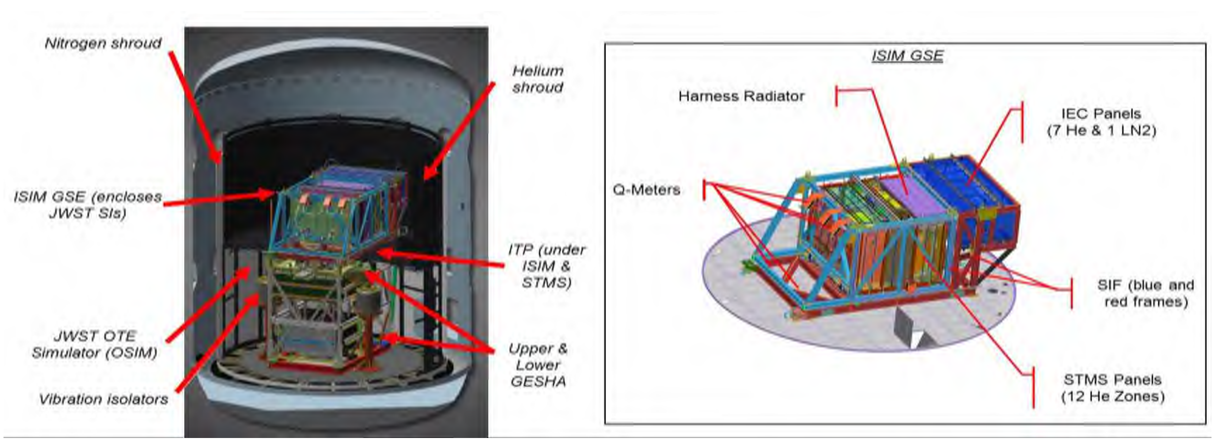

Figure 3. Configuration of ISIM and ground support equipment (GSE) for CV tests

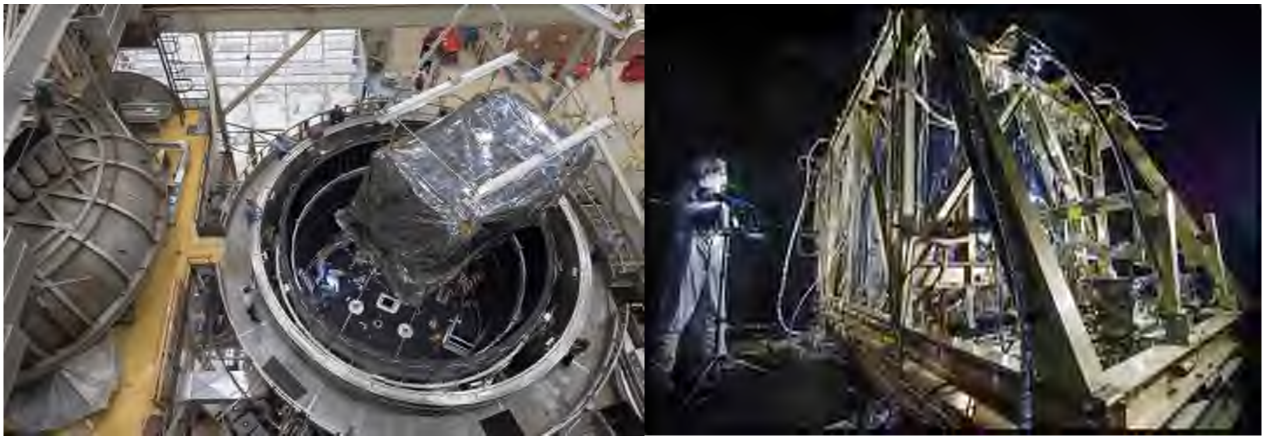

Figure 4. Actual configuration (a) Successful lift of ISIM element into SES for CV3 test; (b) ISIM element inside helium shroud for CV1 test

SUPPORT EQUIPMENT CHANGES FROM CV1 – CV3

Additional ground support equipment (GSE), summarized in Table 1, improved or were upgraded from CV1 to CV3 in order to address deficiencies and/or increase the effectiveness of their measurements.

Table 1. Additional Facility GSE Instrumentation Improvements for JWST ISIM CV Testing in the SES

GSE	Description	CV1	CV2	CV3
Quartz Crystal Microbalances (QCM) 	A QCM quantifies the outgassing rate of spacecraft materials by measuring the changes in frequency of a cooled quartz crystal as the mass flow of gases that intercept and condense onto the crystal increases (with increasing levels of contamination)	A total of 8 QCMs for contamination monitoring was used. Four TQCMs remained the same for all CV tests: ISIM Electronics Compartment (IEC) shroud volume, Upper Optical Telescope Element Simulator (OSIM) shroud, Lower OSIM shroud, SES chamber. Four CQCM locations: 2 on the Surrogate Thermal Management System (STMS) (one centered and one off-set), helium shroud and the MIRI SI. The CQCMs drifted or were controlled to 243K (-30°C). Between CV1 & CV2, the two STMS CQCMs were changed from QCM Research to CrystalTek to improve performance.		
Residual Gas Analyzers (RGA) 	An RGA is used to measures the partial pressure of ionized gas molecules for given mass ranges in real time.	One RGA monitored the general chamber volume.	Added a second RGA to detect residual gases in helium volume via a 20' flex line.	Installed two new & upgraded RGAs in the same locations as CV2; changed 20' flex line to a SS line.
Micro Ion Gauges (IG) 	A micro IG provides a compact, reliable, and cost-effective means to measure vacuum pressure in small, local volumes based on the amount of ion current generated when energized electrons collide with gas molecules in the gauge.	Three micro IGs were installed: one for the OSIM volume and two in the helium shroud volume.	The same three micro IGs from CV1 were used, but one of the two from the helium shroud volume moved into the IEC volume.	An additional, redundant micro IG was added to monitor the IEC volume, for a total of four micro IGs in the test.

The most notable improvement attempts made for the additional support instrumentation implemented between the three JWST ISIM CV tests were those related to the RGAs and micro IGs. The motivation for upgrading RGA capabilities was to meet critical verification requirements for the MIRI cooler, the SI instrument with a high sensitivity to any helium levels in the chamber; the details of the MIRI-related verification test requirements and associated RGA analysis and results are detailed in the "Evaluation of Helium Leaks within the Helium Shroud Volume" section of this paper. The motivation for improving the micro IG use was to keep hardware, namely the IEC, and its operations safe. Figure 5 below shows the evolution of RGA changes made in pictorial form; and Figure 6 depicts the micro IG changes specifically for the IEC volume throughout CV testing. Micro IGs were added into this volume to provide the knowledge necessary to understand the local pressure within a tightly enclosed volume with limited venting, so as to prevent premature activation of cooling loops that could result in ice formation without a high enough vacuum.

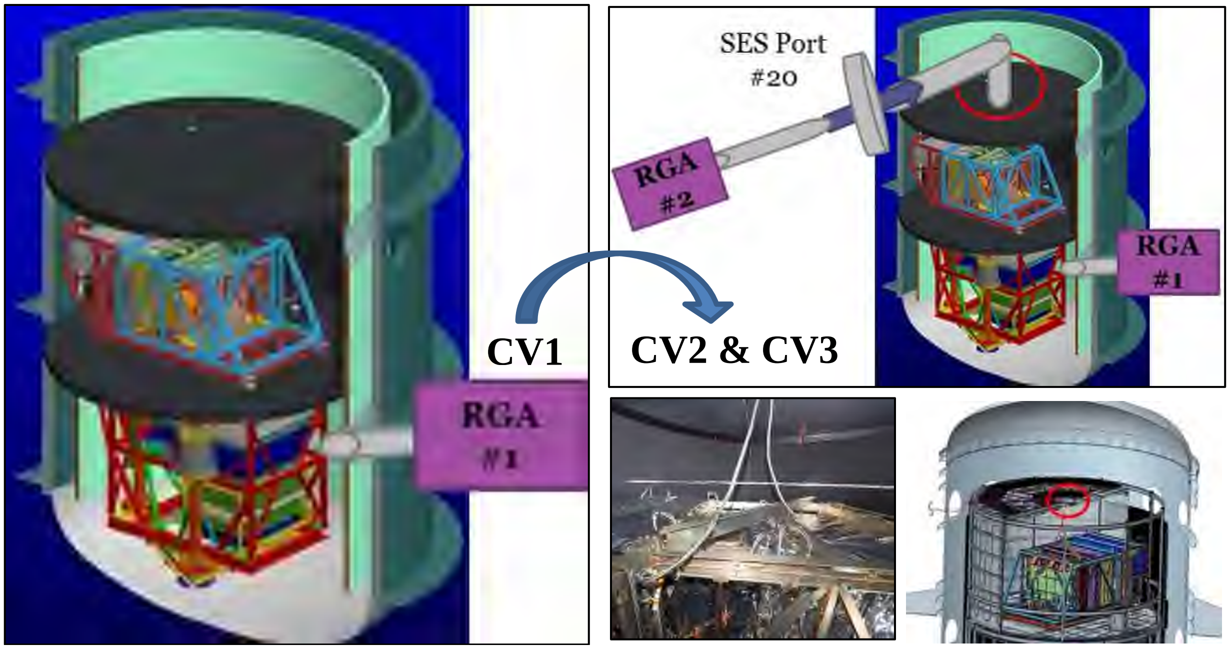

Figure 5. Evolution of RGA configuration and upgrades during CV testing

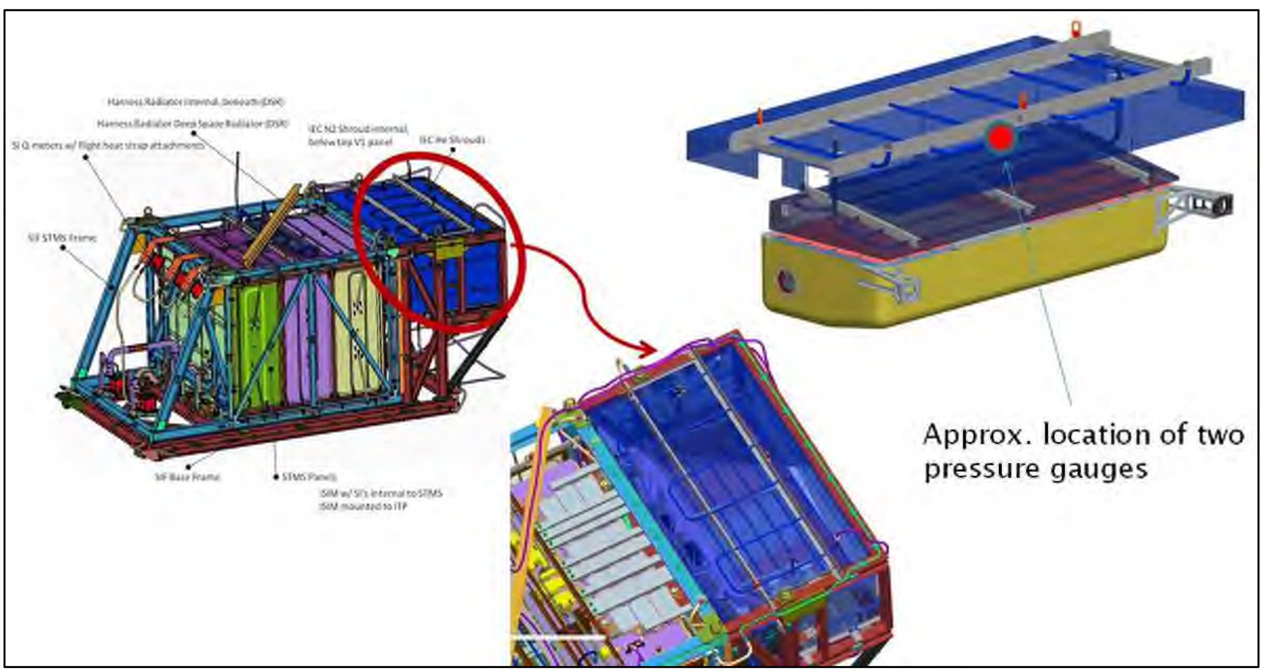

Figure 6. Configuration of IEC micro IGs for CV testing

COMPARING RESULTS FROM THE JWST ISIM CV TESTS

Overall Facility Performance

To achieve the objectives of the CV test campaign, the facility had to provide reliable performance while being pushed to the limits of its capabilities. The test campaign aimed to ultimately verify system-level requirements in a flight-like environment. In light of these test objectives, the overall performance of the SES in support of CV testing activities was outstanding. For each of the CV tests, the chamber provided the environment required to achieve target temperatures so that the planned SI and facility check-out procedures associated with each test could be performed successfully. A general summary of the overall test statistics are outlined in Table 2:

Table 2. CV General Test Summary

Item		CV1	CV2	CV3
Pump-down Date		8/29/2013	6/17/2014	10/27/2016
He skid Shutdowns		6	3	1
Power outages		1	3	0
Total days of testing		73	116	109
Total consumables	LN_2 (gallons)	520K	1.03M	935K
	Helium	20 bottles	20 bottles	20 bottles

Facility Temperature Performance

The nitrogen and helium shroud systems proved capable of maintaining required nominal operating temperatures. The nitrogen shroud operated at 182K ± 4K (-91°C ± 4°C) during every test at steady state GN_2 conditions, while the helium shroud achieved 24K ± 1K (-249°C ± 1°C) for the same test duration (Figure 7). The steady state temperatures reported here neglect the temperature fluctuations that resulted from facility-related issues, such as helium skid compressor shutdowns or power outages that would result in temperature spikes. Despite several efforts to locate a known leak in the nitrogen shroud prior to ISIM testing, these efforts were unsuccessful. As a result, during the steady state portions of the CV test campaign, the nitrogen shroud operated in GN_2 mode, to prevent the cold leak in the shroud to worsen in a flooded LN_2 shroud situation. To facilitate the initial cool-down stage of the test, however, the nitrogen shroud was flooded with LN_2. Upon achieving a helium shroud temperature around 50K (-223°C) and under the direction of the JWST thermal test director, the switchover to GN_2 was performed.

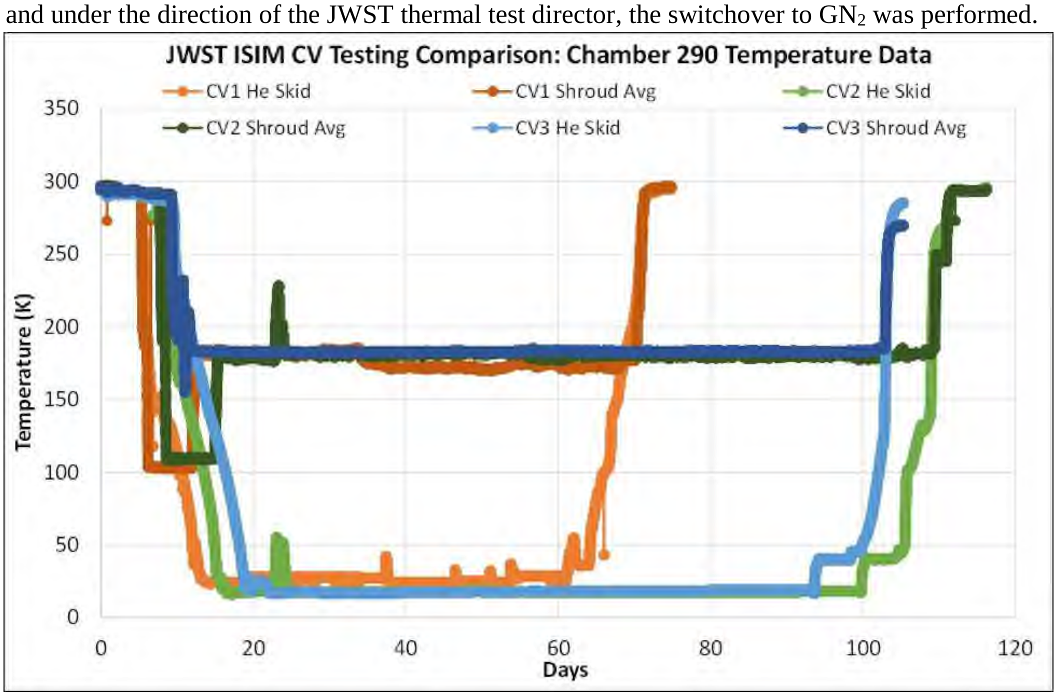

Figure 7. ISIM CV Facility N_2 and He Shroud Temperature Results

Facility Vacuum Performance

The SES chamber vacuum system performed exceptionally consistently for the entire CV test campaign, with incremental improvements in vacuum levels with each test (Figure 8). In CV1, the chamber vacuum system successfully held a nominal pressure of 3.0 x 10^{-7} Torr for the steady state portions of the test. In CV2 and CV3, the facility maintained a nominal pressure of 1.7 x 10^{-7} Torr and 1.4 x 10^{-7} Torr, respectively. The standard operating philosophy for maintaining the nominal pressure is to keep 5 of the 7 cryopumps online with the other 2 in reserve. When a cryopump requires regeneration, therefore, an easy swap of cryopumps can be made without fluctuations in the pressure. Deviations from the nominal pressure occurred whenever there was a momentary power outage or a helium skid shutdown. The pressure spikes in these cases result from the sublimation of nitrogen off of the helium shroud due to higher pressures.

The small improvements in vacuum pressure with each CV test can be attributed to a couple of factors. Between CV1 and CV2, JWST implemented more stringent leak checking practices during I&T activities in the cleanroom prior to lifting into the chamber. There were about three dozen flex line connections that needed to be leak-checked prior to the start of the test. In CV1, the requirements for leak-check levels was to evacuate each line to 10^{-8} Torr range, spray helium at the external joints, and ensure same vacuum levels are maintained in each line prior to spraying with helium. For CV2, the standard leak check levels were enforced down to the 10^{-9} Torr range, and the vacuum performance subsequently improved. JWST, therefore, adopted the same leak checking procedures during preparations leading up to CV3. The higher vacuum performance in CV3 may be explained by the fact that the nitrogen shroud failed to flood in LN_2 mode due to facility issues, so the chamber shroud operated in GN_2 for the entire CV3 test duration. Although this slowed down the cool-down rate for the test, it could have increased vacuum performance since it also eliminated the concern of introducing and exasperating the nitrogen shroud leak, which is an effect that is characteristic of going into LN_2 mode.

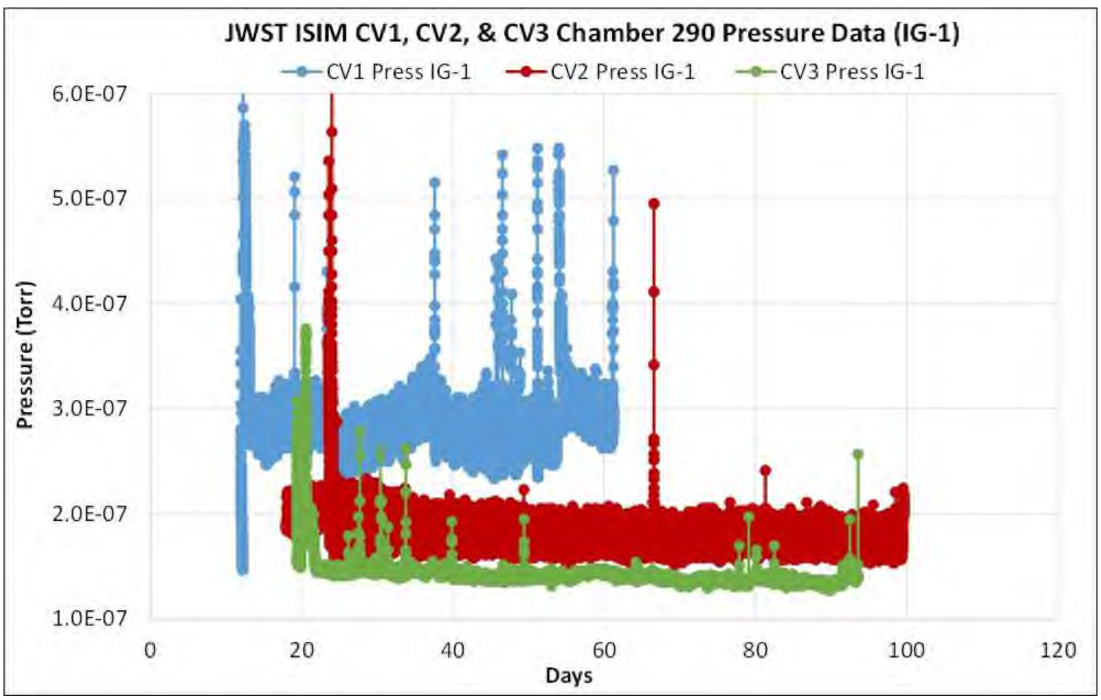

Figure 8. ISIM CV Facility 290 Pressure Results

Facility Temperature Sensors Instrumentation Performance

Similar to the chamber's incremental improvement in vacuum performance with each successive CV test, the temperature sensor reliability reports a similar trend as well. The temperature sensors for CV testing included a combination of Type-T thermocouples, both calibrated and uncalibrated silicon diodes, platinum resistance thermometers (PRTs), and Cernox sensors. Table 3 reports the quantitative breakdown of temperature sensors by type for each CV test, and also tabulates the total quantity of sensors. Although the number of sensors increased with each successive CV test, from 1121 in CV1 to 1172 in CV3, the cumulative failure rate of sensors at the end-of-test dropped each time. As hardware accessibility and project schedule permitted, sensors that the thermal team deemed as critical were repaired and/or replaced in between tests. This increased the reliability and robustness of the temperature sensors from one test to the next. The failure rates can be attributed to a wide range of issues including: damaged wire leads, loosened connectors, broken sensors, etc. It was crucial to ensure that the handling of the delicate wire leads, especially thin 36 awg PhBr wire, was done with care and performed using cognizant workmanship skills.

Table 3. CV Testing Temperature Sensor Inventory and Performance Summary

Temp Sensors	CV1	CV2	CV3
T Thermocouples	366	396	375
Silicon Diodes	242	246	248
Platinum Resistance Thermometers (PRTs)	242	248	248
Cernox sensors	80	80	108
Heater control sensors	191	193	193
Total:	**1121**	**1163**	**1172**
% Failure:	**4.6**	**3.2**	**1.9**

Although the thermal and vacuum performance of the SES chamber was sufficient to achieve the objectives of the JWST ISIM CV testing, the two primary avenues to improve the ability to achieve some specific verification test goals depended highly on facility performance capabilities in the areas of: (1) increasing performance reliability of the helium skid; and (2) improving helium leak detection capabilities within the helium shroud volume. The last two sections of the paper focuses on these two specific areas of the chamber capabilities for the entire test campaign.

Evaluation of Helium Skid Performance

The 1.0 kW helium skid system was not originally designed to cool items as large as the 25 ft diameter x 15 ft high helium shroud plus five other large helium zones. The CV test campaign was, therefore, pushing the operation levels of a test-critical facility system beyond its intended range for optimal performance. Any failures of the helium skid system introduces not only cost and schedule risk regarding the associated delay of testing activities, but also the risk of damaging flight hardware should the facility be unable to maintain the specified pressure and temperature requirements.

Providing a recap of the helium skid performance, therefore, will provide insight into potential challenges with operating facility systems at the upper end of its limits and also documents ways to improve reliability when caught in such operational modes. A summary of helium skid shutdowns and consequential effects of each on the pressure and temperature stability for the entire CV test campaign are outlined in Table 4. Each shutdown resulted in an immediate pressure spike and rise in the helium shroud temperature. The duration of the pressure spike and temperature rise was affected by the operational status of the other systems as well as the ability for the helium skid to be put back online.

For CV1, the helium skid system experienced a total of six shutdowns. The two direct causes for all of the shutdowns are: #1 – low turbine bearing gas return temperature alarm; and #2 – compressor low oil level / high temperature alarm. After CV1, the Dunham Bush helium compressor was replaced entirely to mitigate and improve helium skid reliability since the majority of the disruptions for CV1 were caused by compressor performance issues.

For CV2, despite the fact that a new helium compressor was brought online, there was a faulty temperature sensor for the compressor oil that trips the alarm to shut down the compressor. The vendor replaced the sensor and the helium skid operated seamlessly afterwards. During warm-up there was a human operational error that was mitigated post-test by refreshing operations personnel of standard helium skid operations procedure and where they can be easily accessed in the future.

For CV3, the helium skid performed exceptionally with only one shutdown during the chamber pumpdown phase of the test. The shutdown for CV3, therefore, had minimal effect on both the test time and environmental stability since it occurred much prior to achieving steady state. The shut-down was attributed to an air leak in the purifier, introducing contamination that caused the differential pressure across it to increase rapidly when operating in bypass mode. The bypass mode of operation was performed to pre-cool the gas rather than introducing warm gas that exceeds the limits of the turbine expander wheel, which is required to operate in normal turbine mode. Due to the rapid rise in pressure differential, the valve to the turbine was opened when the inlet temperature to the turbine was at 140K, instead of waiting for it to get to 100K. As a result, the higher inlet gas temperature corresponded to an inlet pressure that exceeded the limits of the expander wheel and consequently shut-down the turbine. In response, the turbine throttle valve immediately failed closed to 0%, and the bypass valve opened to almost 50%. The system (valve positioning) was restored to its configuration (prior to the turbine shutdown) well within 15 minutes. The result was a 10K spike in the expander outlet temperature (helium shroud inlet temperature), but the spike was back to its pre-shutdown temperature within 15 minutes. The effect on the helium shroud average temperatures was less than 0.5K.

Table 4. Summary of Helium Skid Shutdowns for JWST ISIM CV Test Campaign

*Duration for pressure to return to 10^{-7} Torr

**Duration for helium shroud average temperature to return to temp before shut-down

CV Test #	Shutdown #	Date	Cause	Pressure Spike	Duration*	He Temp Spike	Duration**
1	1	09/10/13	#1	4.1×10^{-6} Torr	4.0 hrs	52K (+16K)	11.2 hrs
	2	10/05/13	#1	2.8×10^{-4} Torr	5.3 hrs	42K (+15K)	8.5 hrs
	3	10/15/13	#2	1.1×10^{-4} Torr	1.1 hrs	33K (+9K)	14.0 hrs
	4	10/19/13	#2	9.3×10^{-5} Torr	1.1 hrs	32K (+8K)	6.5 hrs
	5	10/22/13	#2	9.2×10^{-5} Torr	6.1 hrs	37K (+13K)	N/A
	6	11/05/13	#2	6.8×10^{-6} Torr	2.1 hrs	N/A (warm-up)	N/A (warm-up)
2	1	06/24/14	#2	3.0×10^{-6} Torr	N/A	199 (<1K)	<15 min
	2	06/26/14	#2	2.8×10^{-6} Torr	N/A	166 (<1K)	<15 min
	3	10/01/14	#3	2.0×10^{-6} Torr	~1 hr	N/A (warm-up)	N/A (warm-up)
3	1	11/7/15	#4	N/A (during pumpdown)	N/A	<0.5K	N/A

The causes for the helium skid shutdowns are defined as:

- Cause #1: low turbine bearing gas temperature alarm
- Cause #2: compressor oil level/temp alarm
- Cause #3: human error
- Cause #4: turbine shutdown

Evaluation of Background Gas within the Helium Shroud Volume

As described in the previous several sections, the SES-facility was configured to simulate the overall flight environmental conditions that ISIM will encounter at its location within the JWST observatory. As in flight, the MIRI instrument is required to operate at a nominal temperature much lower than the passive thermal environment of ISIM.

One of the most challenging SI requirements for JWST to achieve in flight, and verify in a simulated space environment, is the nominal 6.2K (-266.8°C) operating temperature of the MIRI detectors. Additional active local cooling is required to maintain this lower temperature. This is achieved in flight and in test with a dedicated dual-element, "hybrid," cryocooler consisting of a long Joule-Thomson (JT) loop and a coupled pre-cooler. Engineering models of the JT loop components attached to ISIM were used in the CV1 and CV2 configurations, but were replaced by the flight components for CV3. Ground support versions of the precooler and remaining components of the JT loop were used in configurations for all three test programs. Of note are the long in-vacuum GSE refrigerant lines of the JT loop referred to below by the flight designation, Refrigerant Line Deployable Assembly (RLDA).

The cooler is configured to lift heat at two heat-load interfaces along the remote JT loop within the ISIM element: one on the MIRI Optics Module (OM) at 6K and another on the MIRI Radiation Shield at a nominal 18K. Cooler heat-lift requirements are derived from expected heat loads at those interfaces as well as from heat loads on the cooler components themselves. Verification of MIRI and cryocooler flight requirements in the SES chamber can be complicated by free-molecular heat transfer (FMHT), through background gases, from the warmer ISIM environment – primarily to the MIRI shield and OM. Accurate determination of any such test-generated heat load is required in order to remove it from verification results.

First indications of possible FMHT came during CV1 when measured cooler heat lift from the MIRI OM was 13 mW higher than expected. Since this amounts to over 20% of the margined end-of-life (EOL) heat-lift requirement for the 6K cooler stage, it was critical that actual MIRI OM heat loads be distinguished from test artifacts in order to verify cooler margins for flight. If these higher heat loads were internal to MIRI, rather than test parasitics, MIRI would begin to consume system-level heat-load margins.

At operating temperatures, helium gas would be the presumed medium for any FMHT within the SES. CV1 RGA data (Figure 9) shows partial pressures of helium, at the RGA location along the warm outer chamber wall, at levels approaching 10-7 Torr. If this had represented the correct pressures at ISIM, then the FMHT to MIRI would have been in the 0.2 to 2 mW range. However, the two possible sources of helium, the facility helium shrouds and the cryocooler, resided inside the shroud or STMS enclosures. Actual helium pressure is expected to be higher in those volumes than measured at the RGA due to the pumping impedance through small openings in the enclosures.

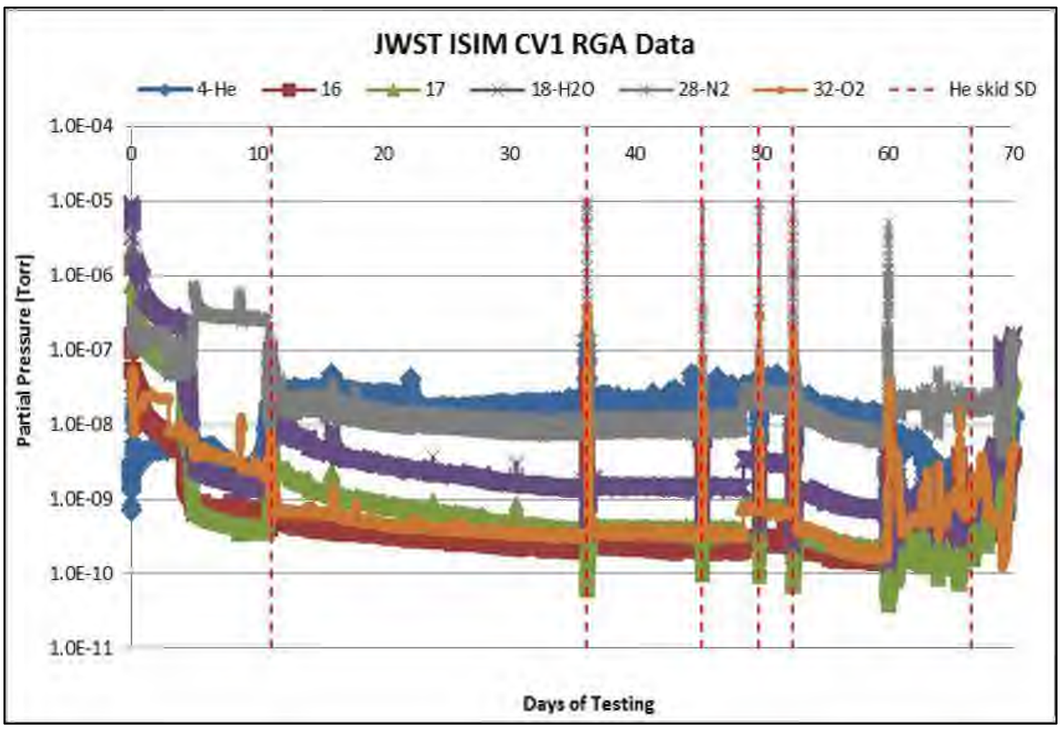

Figure 9. ISIM CV1 chamber RGA data results

For CV2, a second RGA was added to the test configuration in an attempt to understand helium background levels in closer proximity to MIRI. Helium sampling for the second RGA was attained by routing a ½” flex line from an upper chamber port (Port 20) into the STMS through an opening at the top of the helium shroud. This second, or Port 20 RGA, was mounted outside the chamber (ref. Figure 5) and connected to the vacuum-side flex line at a Port 20 feedthrough.

The team decided to begin CV2 by monitoring the helium background during cooler cooldown, but before helium shroud activation, looking for indications of a gross cold-leak in the cooler. No spikes in helium background were detected. While any gross leak would have been detected, the high helium background measured at the two RGAs prior to cooldown obviated verification of cooler requirements for the entire test duration.

In addition to efforts described above to eliminate helium-shroud leaks and to improve the accuracy and sensitivity to helium measured by the RGA configuration, the MIRI team decided to make the following changes prior to final verification opportunities in CV3:

- Replace the RGA's with new models for better accuracy
- Replace the plumbing used for the Port 20 RGA with all metal-sealed plumbing
- Integrate a calibrated helium leak with the Port 20 RGA system for correlation measurements
- Install a helium leak detector on foreline of the chamber turbopump

The restated goals for CV3 were two-fold: (1) to determine test parasitic heat load on MIRI due to helium background pressure – as distinguished from flight-like loads; and (2) to verify, post-vibe, the MIRI cooler helium leak rate requirement (sub-allocation for flight cooler components on ISIM) of 6.6×10^{-7} sccs at operating temperature (4.2×10^{-8} sccs at room temperature).

Average daily helium partial pressures, covering most of the CV3 test campaign, are presented in Figure 10 and show evidence of a helium cold-leak within the helium-shroud or STMS enclosures. The inverse relationship between partial pressure and temperature may be the result of actual cold-leaks in addition to the effects of thermal transpiration on partial pressure measurements at each RGA. While it is difficult to quantify thermomolecular pressure increases over actual cold-volume values, due to the latter effect, they are presumed, from ideal theory, to be equivalent for corresponding RGA measurements. Therefore, pressure *differences* between Port 2 RGA and Port 20 RGA values are taken as physical and the result of leaks. One may wish to advance a caveat after considering warm partial pressure measurements at the beginning and end of CV3. Port 2 and Port 20 RGA values were nearly identical over the two days in February just prior to the helium skid being shut down and evacuated while the values are noticeably different for comparable conditions early in the test – comparable within cleanliness changes over months in vacuum.

Heat loads to the MIRI instrument and radiation shield due to FMHT in this helium background were found to be well within requirements and the anomalous loads seen in CV1 had been alleviated through better attention to detail.

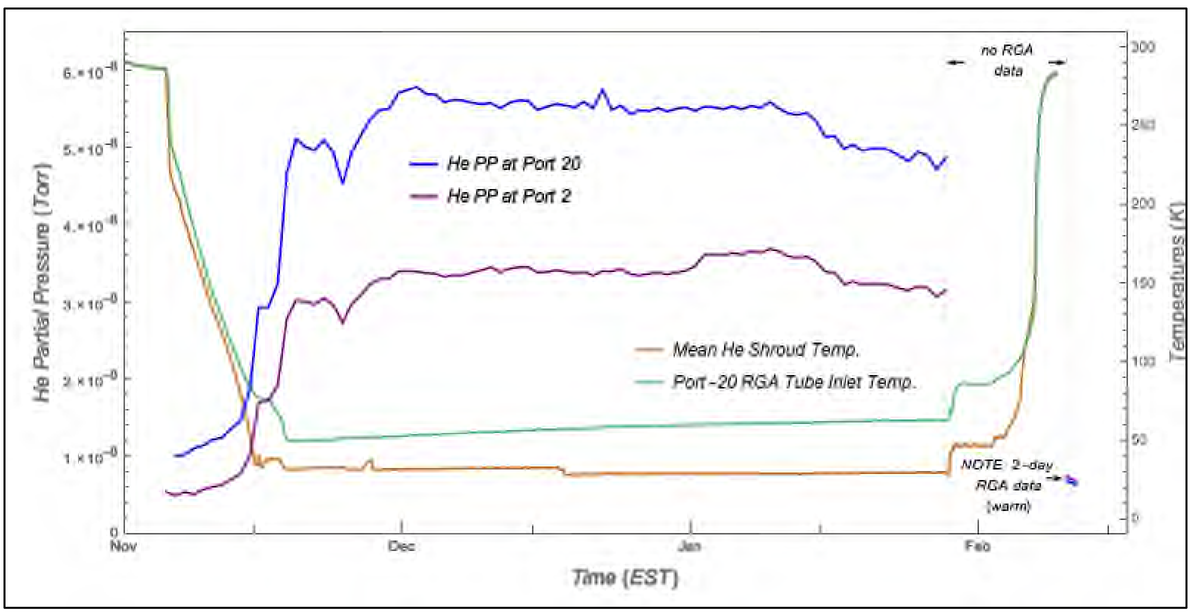

Figure 10. Average daily helium partial pressure measured at Ports 2 and 20 in relation to the mean helium shroud temperature and the inlet temperature of the Port 20 sampling tube.

Full verification of the MIRI cooler leak-rate requirement was again beyond reach in CV3. Helium partial pressure levels as seen, for example, in Figure 11 correlate to flow rates on the order of 2×10^{-4} sccs, as measured with a helium leak detector plumbed in the fore-line of the chamber turbopump. The corresponding flow rate profile, on an arbitrary scale, is also shown in Figure 11 for a period before and during decontamination of the RLDA and connected hardware. This correlation was verified through a procedure involving the rapid release of a known amount of helium, accumulated from a standard leak, into the SES chamber and observed with continuous measurements by both RGAs and the helium leak detector.

While steady-state pumping of helium is accomplished by the chamber turbopump, the chamber cryopumps can have significant effects on the partial pressure of helium. Whereas steady cooler leaks above requirements would have been obscured by the background rate, sudden changes at requirement level had the potential to be observed, as was the case during decontamination of the RLDA. That potential depended on which trio of cryopumps was on-line at any one time. Large fluctuations in partial pressure, as seen to the left in Figure *XX*, surely obscured changes that could be seen at more quiet times. This was clearly were not measurement noise since concurrent profiles from the two RGAs and leak detector match fluctuations perfectly, each to the other. Notice how features in the coldhead temperature profile for Cryopump 2 clearly match changes in the helium background when Cryopump 3 is off-line and are obscured when on-line. Cryopump 3 is an older Œrlikon-Leybold COOLVAC 60k BL-V LN2, with dual GM refrigerators, while Cryopumps 2, 4, and 5 are newer PHPK/CVI TorrMaster TM1200 pumps, with single GM refrigerators. None of these features has been investigated further for causes; however, one can clearly follow the hours-long progression to helium saturation of the cryoadsorption arrays of Cryopump 5, after it was brought back on line following regeneration.

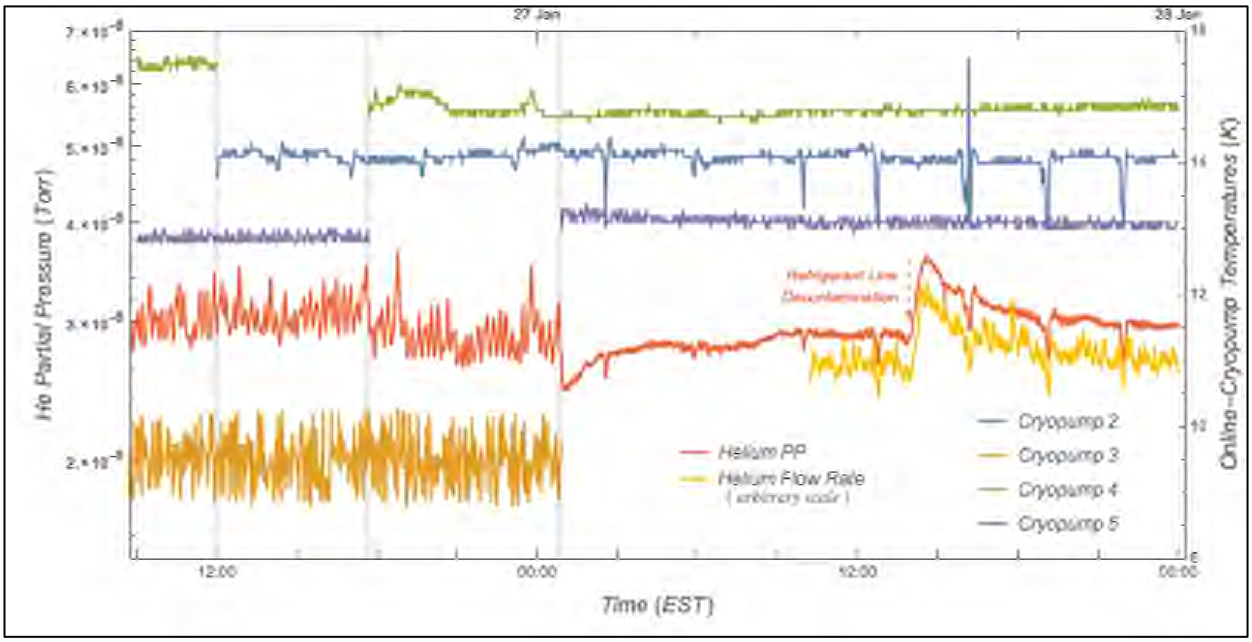

Figure 11. Plot of cryopump temperatures and Helium partial pressure during a period of various online cryopump combinations (trios) and initiation of cryocooler refrigerant line decontamination (exterior surface). Also shown is the flow rate profile from a Helium leak detector – plumbed in parallel with a mechanical pump and, together, backing the main chamber turbopump – during decontamination

LESSONS LEARNED FROM JWST ISIM CV TEST CAMPAIGN

The requirements of the JWST ISIM mission introduced an incredibly complex system into the realm of space simulation testing that challenges the capabilities and truly pushes the limits of the SES chamber at GSFC. With such an extensive test campaign, there were many lessons learned along the way. Table 5 highlights some of the top lessons learned from the CV tests.

Table 5. Top 4 JWST ISIM CV Test Campaign Lessons Learned

#	Lesson Learned	Recommended Actions
1	Project personnel touching and/or changing facility configuration (esp. in between tests) must be verified / communicated	• Test engineer verifies with project before start of test whether the project made any facility changes • Test engineer requests that the project informs facility team when items are changed, esp. feedthrough plates and during chamber breaks
2	Stringent leak checking is possible and effective	• Continue adopting the more stringent leak checking techniques to meet high leak-tight requirements • Standard leak check levels were made more stringent for CV2, requiring that measured leaks did not exceed 10-9 Torr range
3	Helium leak rate detection is a difficult endeavor for high sensitivity measurement requirements	• Determine the helium background requirement beforehand to gauge whether or not it would be achievable in test • Characterize helium background levels and leak tightness of facility prior to executing leak rate measurements
4	Do not assume reliability of the SES LN_2 skid, or any test-critical facility system from one test after another	• Check programmable logic control (PLCs) before major tests • Consider adopting standard operations to include a check-out of major facility systems (i.e. perform a dry-run)

Successful completion of the JWST ISIM CV test campaign in March 2016 demonstrated that the procedures and operational capabilities of the SES are sufficient for a technically challenging program as marked by JWST ISIM-level requirements verification with all four SIs will be performed. The ISIM hardware is currently at the next level of integration with the OTE (Figure 10).

Figure 10. Fully integrated OTIS (OTE + ISIM) in the NASA GSFC Class 10,000 cleanroom

REFERENCES

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