Operating and maintaining the JWST Cleanroom attached to JSC's Chamber A during preparations for the OTIS Cryogenic Thermal Vacuum Test

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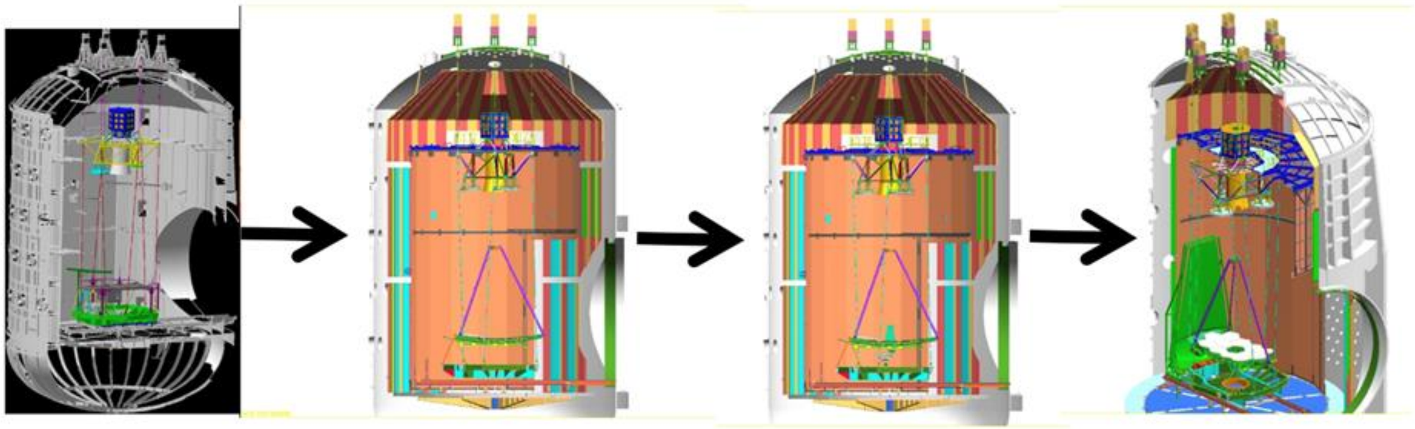
Introduction

- **In order to maintain cleanliness during preparations for JWST's OTIS (Optical Telescope Element-Integrated Science Instrument Module) Cryogenic Thermal Vacuum Test, a cleanroom was built that attached directly to Johnson Space Center's Apollo Era Chamber A.**
- **Both the cleanroom and chamber were outfitted with independent airflow management systems (AFMS) each providing ISO Class 7 air cleanliness and tightly controlled temperature and relative humidity.**
  - While the cleanroom footprint occupied most of the space outside the Chamber A 40' door, it was still considered small in comparison to OTIS and its gigantic test equipment. This made it a constant challenge to maintain cleanliness.
  - The hot, humid climate of Houston Texas was another constant challenge. Exposure to humidity above 60% would have permanently damaged one of the instruments.
  - Balancing the two AFMS systems to ensure the cleanroom was not over or under pressurized was also fun!
- **The cleanroom build and chamber upgrades were completed in 2014 before commencement of the risk reduction Pathfinder (PF) test program, which enabled continued improvements to cleanliness and ECS performance of both facilities.**



Chamber A Commissioning

- Cryo load and stress test of suspension system with payload mass simulator
- Chamber verification
- OGSE vacuum integrity
- OGSE functional testing and thermal characterization
- Cryo shift measurements

OGSE-1

- Pathfinder cryo-vac exposure
- Cryo proof AOS interfaces
- Operated OGSE (CoCOA, PG, DMI) in OTIS-like config
- Checked out BIA in Chamber A
- Thermal Distortion and Dynamics testing
- Vacuum portion of cooldown to check SM model characteristics

OGSE-2

- Added flight AOS and GSE AOS Source Plate.
- Checked out Half-pass and Pass-and-a-half tests
- Used BIA camera as SI simulator
- Thermal Distortion and Dynamics testing

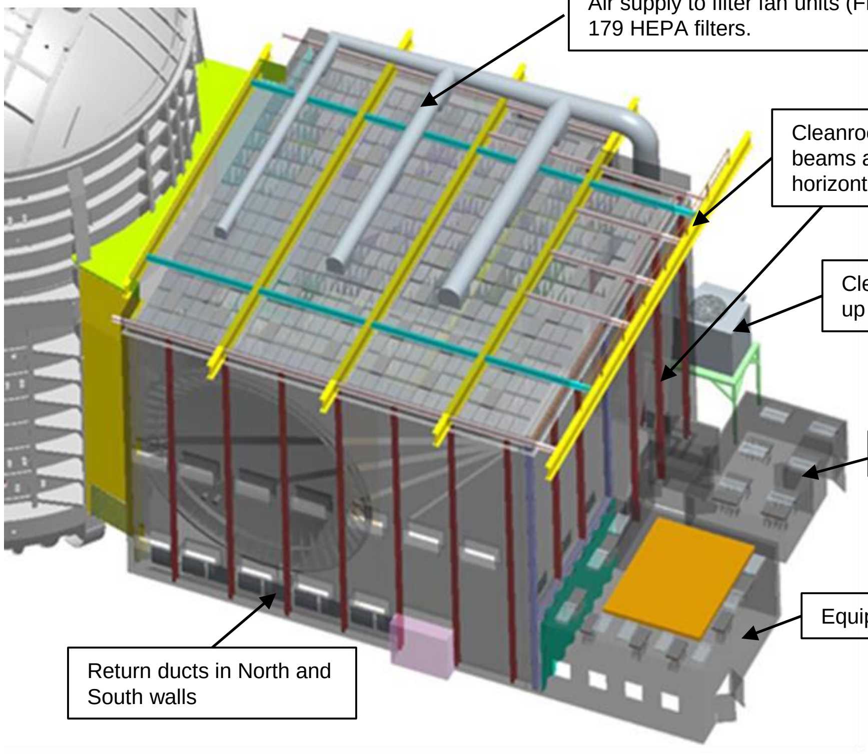
Thermal Pathfinder

- Thermal GSE Checkout (including SVTS, DSERS)
- Dry run cooldown, practiced warmup tests
- Backplane Thermal Balance (design validation off critical path)
- Thermal Distortion and Dynamics testing

Objective

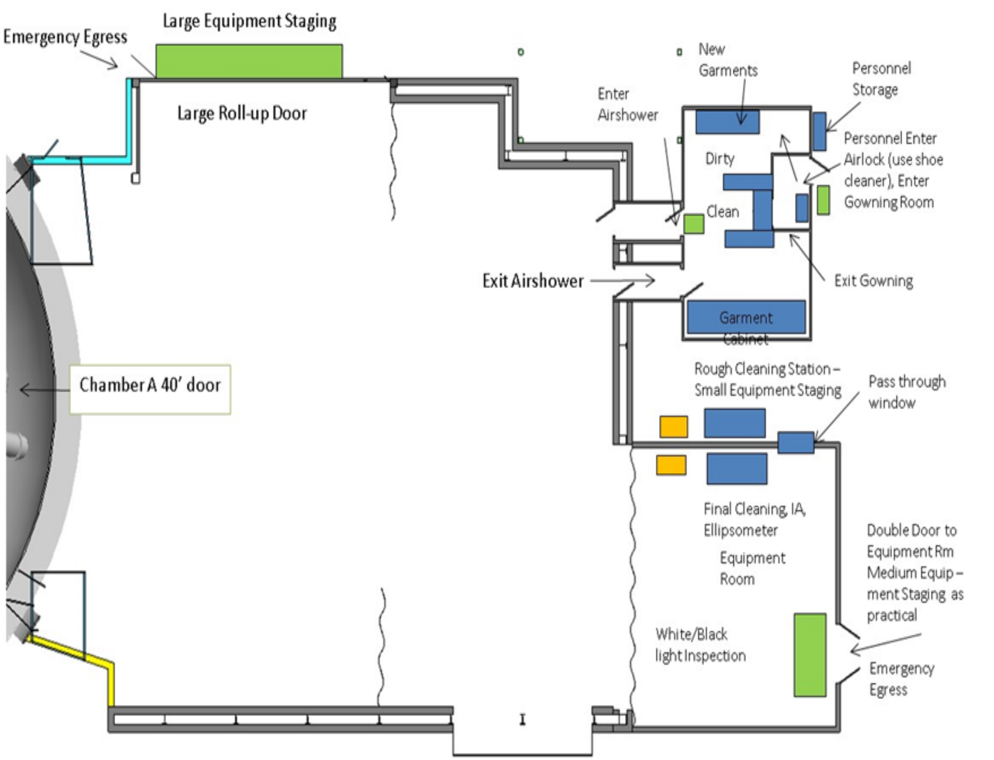
- This manuscript tells how the massive challenges of this test program were overcome, describing the facilities, processes and protocols put in place. These sufficiently mitigated contamination sources and enabled the cleanroom and chamber AFMS systems to consistently meet tight temperature (T) and relative humidity (RH) requirements.

Cleanroom description



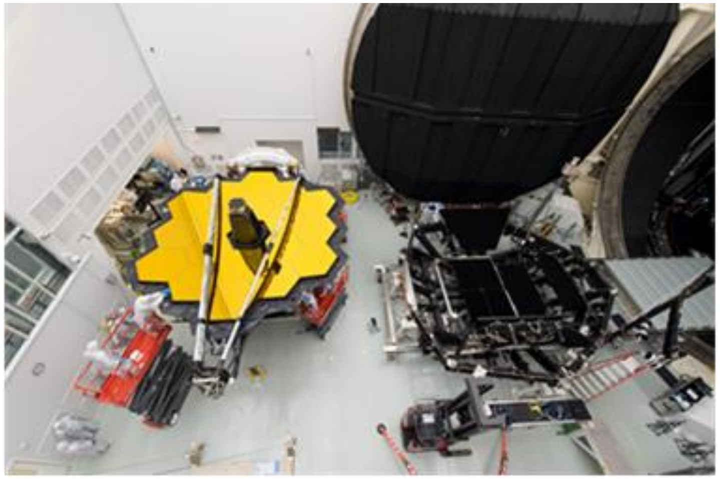
- **Vertical, laminar flow ISO 7 cleanroom**
- **Included charcoal filtration**
- **Airflow rate was 160,000 cfm with 40 air changes/hour.**
- **Due to existing floor trenches, cleanroom is supported primarily by yellow horizontal I-beams attached to building 32's vertical supports columns.**
- **Cleanroom is attached directly to Chamber A and accommodates the swing of it's 12 m (40 ft) diameter door.**

Cleanroom floorplan and OTIS equipment



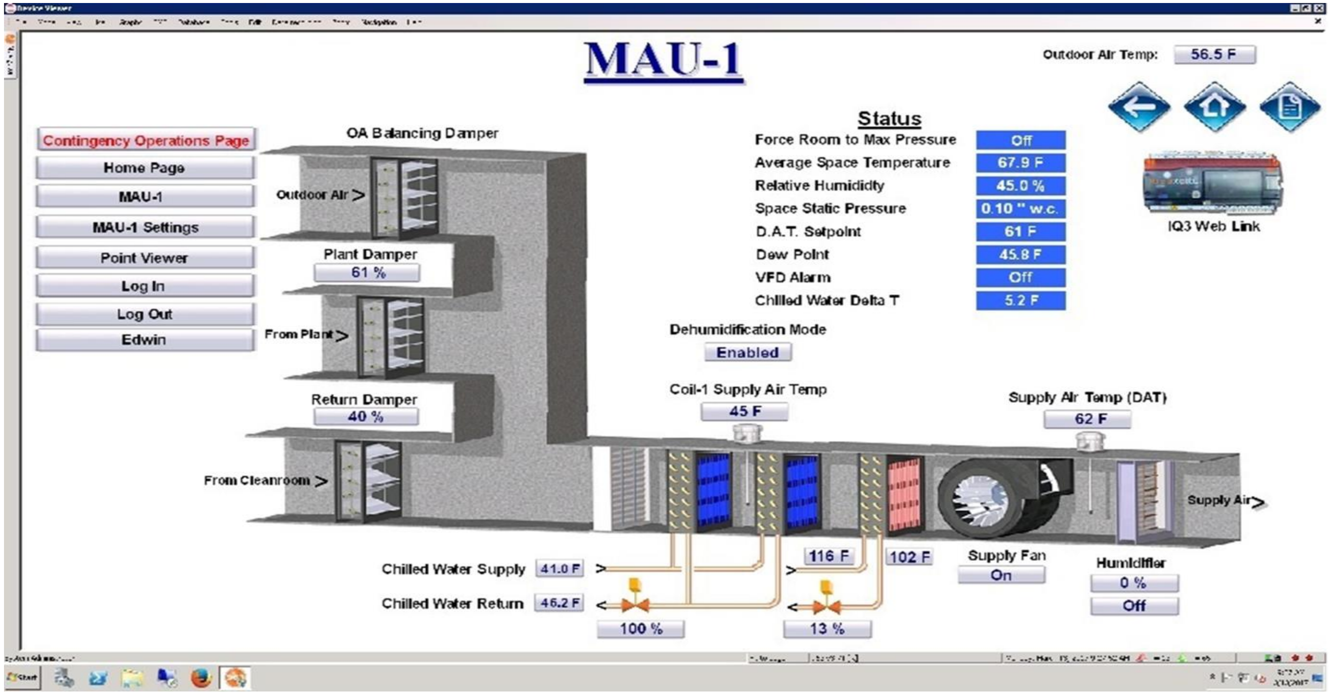
Very crowded conditions during PF and OTIS I&T operations in cleanroom!

(Diagram and photo credit: NASA)



Cleanroom AFMS

- Program required 20-32 Celsius (C) (68-73 degrees Fahrenheit (F)) and 40-60% relative humidity.
- A centralized building automation system (BAS, pictured below) modulated chilled and hot water valves, plant air dampers, and the cleanroom humidifier to required set points.
- When opening the cleanroom roll up door the BAS had a user select mode to force the room to maximum pressure, without waiting for the system to respond to a pressure drop.



(Diagram credit: Performance Controls)

Cleanroom environmental control reliability and cleanliness

- **Lesson learned from 2015 weather event:**
  - When a major thunderstorm caused a power outage, the variable fan drive (VFD) fuses blew, and the cleanroom Main Air Handler (MAU) shut down.
  - Once power resumed, the cleanroom power started prior to that of the chamber, causing lower pressure in the cleanroom, resulting in the need for 100% make-up air from the cleanroom MAU. At 100% make-up air, the cleanroom MAU struggled to control the RH.
  - As a result, special protocols were developed requiring chamber man lock doors to be closed and access through the large cleanroom roll up door was not allowed until the chamber AFMS system restored nominal operation. A spare VFD was also procured.
- **Chilled water supply**
  - The cleanroom chilled water was single-sourced from a central supply. Due to Center-wide chilled water demand in the humid conditions of Houston, chilled water flow rate and temperature fluctuated frequently.
  - To reduce the probability of unacceptable humidity, a specialized control program was written within the BAS software to monitor the chilled water temperature (T) for excursions above 7.2 C (45 F). When the chilled water supply exceeded 7.2 C, a 5-minute software timer was triggered. If, at the expiration of the timer the chilled water had not fallen below 7.2 C, the control program sent a shutdown command to the MAU. With the MAU shut down, there is typically a 2-hour window that enabled troubleshooting before humidity exceeded specifications.

Cleanroom alarms

- **Continuous monitoring would activate alarms for off-nominal conditions, alerting facility manager, who was on call 24-7**
  - Particle counts, T, RH
  - Room pressure
  - MAU, VFD on/off status
  - Utility supply status
    - Chilled water supply T
    - Hot water supply T
- **Electronic call tree:**

Email: [redacted] cleanroom-alarms-bounces@lists.nasa.gov

on behalf of

[redacted]@nasa.gov

Sat 12/31/2016 5:09 PM

James Webb Clean Room/INC/MAU-1 Cleanroom MAU-1 Status (I1) Clear Digital Input [last value was 1.00]->Saturday` December 31` 2016 5:08:51 PM

Cleanroom environmental control redundancy

- **Instability in the critical utility delivery to cleanroom air handlers due to severe weather prompted the development of a stand-alone redundant system that could provide conditioned air in the event of equipment failure, utility disruption, or other system failure.**
  - The back up system was located just outside the building housing Chamber A and was connected directly to the cleanroom MAU intake when needed.

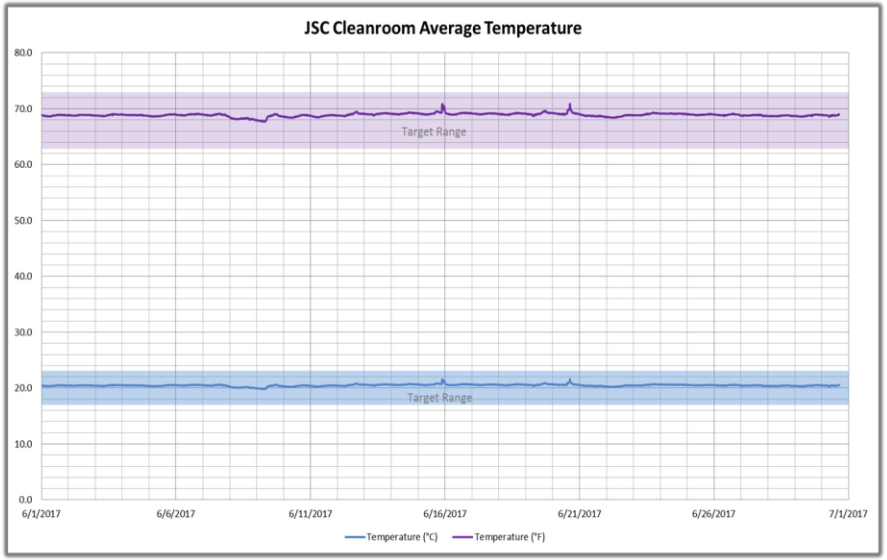
(Photo credit: NASA)

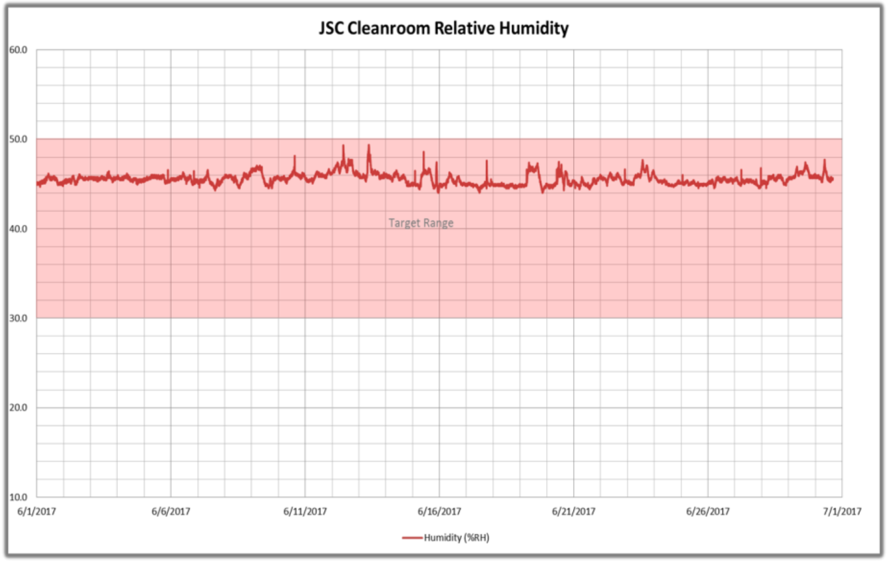
Cleanroom and Chamber protocols

- **Monitoring**
  - Airborne particles – three continuous, automated particle counters in cleanroom and chamber. Chamber also included air supply and return particle counters.
  - Nonvolatile Residue (NVR) – foils place throughout chamber and cleanroom, analyzed monthly by gravimetric analysis and Gas Chromatography Mass Spectrometry (GCMS) – analyzed
  - Particle fallout – wafers, analyzed by image analysis on a monthly basis.
  - Periodic measurement of airborne hydrocarbons, sulfur dioxide and hydrogen sulfide.
- **CC Tech Team on site 6 days/week, 3-4 on each 10-hour shift**
  - Daily floor, horizontal surface, and support equipment cleaning. Entire cleanroom cleaned just prior to PF testing and OTIS delivery. Lift equipment inspected and cleaned before each lift.
  - Entire chamber was cleaned from top to bottom once during PF testing and again just prior to the OTIS CV test, by a team of 20 CC technicians.
  - Trained to screen materials for cleanroom and vacuum compatibility.
  - Trained in cleaning techniques and solvent/material compatibility and hardware sensitivity.
- **Monthly (or as needed) white and black light inspections.**
- **Full bunny suits changed out twice/week. Approved gloves sealed with cuff tape.**

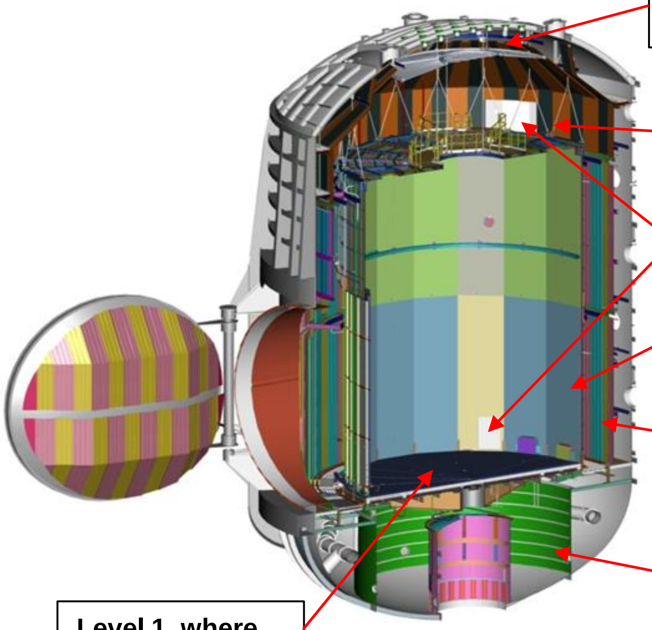
Cleanroom performance

Test Method	Limit or Goal	Data Collection Frequency	Typical Results
Airborne Particles	ISO 7	continuous	ISO 6 or better
Airborne Hydrocarbons	15 ppm	prior to test	$\leq$ 5 ppm
Silicon wafer fallout	< 0.001 PAC/day	monthly	$\leq$ 0.0002 PAC/day
NVR foil	< 15 angstroms/month	monthly	$\leq$ 6 angstroms/month





Chamber A Description



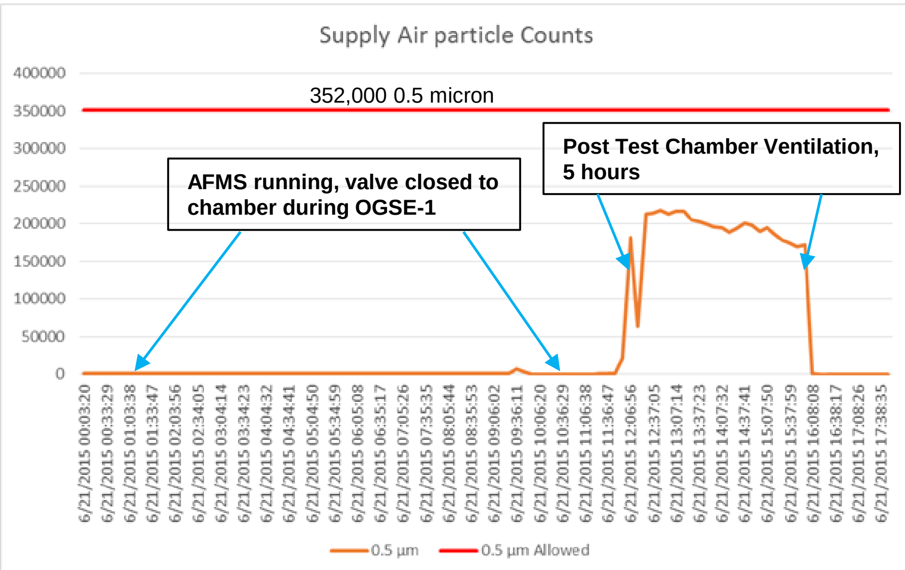
(Diagram credit: NASA)

- Chamber A is a 7-story high vacuum chamber used during the Apollo Era.
- New helium shroud was installed for JWST measuring 14 m (45 ft) in diameter, and 24 m (80 ft) tall.
- Turbo molecular and cryogenic pumps replaced original diffusion pumps.
- The Chamber AFMS supplied ISO 7 charcoal filtered air (during ambient operations) through ducting that fed into the chamber at the 7^{th} story and interfaced with the top of the helium shroud.
- Chamber underwent a high temperature bake-out at 60 C for 25 days to reduce volatiles.

Chamber A environmental control reliability and cleanliness

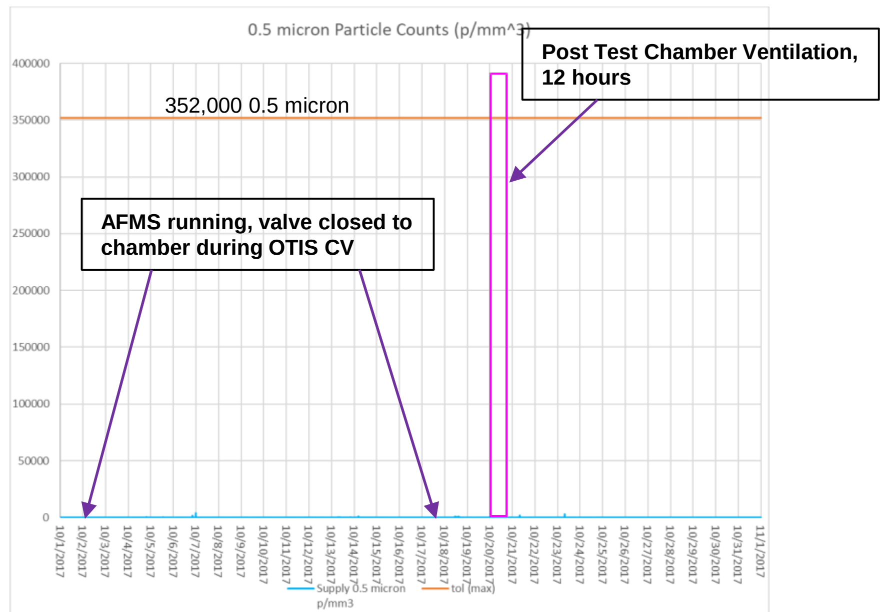
- **Lessons learned after OGSE-1 and the 2015 weather event**
  - Noted elevated particle counts while purging nitrogen from the chamber after OGSE-1. Found later to be due to slight leaks in one segment of the AFMS ducting.
  - Due to a power outage caused by a 2015 weather event, the MAU shut down causing negative pressure in the AFMS ducting and high T & RH levels.
- **To improve particle counts:**
  - "Due diligence" cleanliness inspection conducted of accessible AFMS surfaces, including the MAU, filter boxes, and accessible system ducts, vents, and valves. All issues found were mitigated.
  - Chamber operation modes were optimized to consistently maintain a positive pressure. For OTIS CV, AFMS was operated constantly, even with AFMS valve closed to chamber while under vacuum (in bypass mode).
  - Pressure transducers were added to the chamber AFMS and continuously monitored.
- **Chamber alarms**
  - Particle counts, T, and RH were monitored and alarmed to the same specifications as the cleanroom with a chamber systems engineer on call 24-7. The AFMS pressure transducers were also alarmed.
  - A redundant AFMS system, like that implemented for the cleanroom, was situated next to the chamber MAU. It was also connected directly to the MAU intake for use in the event of a system or facility infrastructure failure caused by weather.

Chamber A Particle Count Improvement

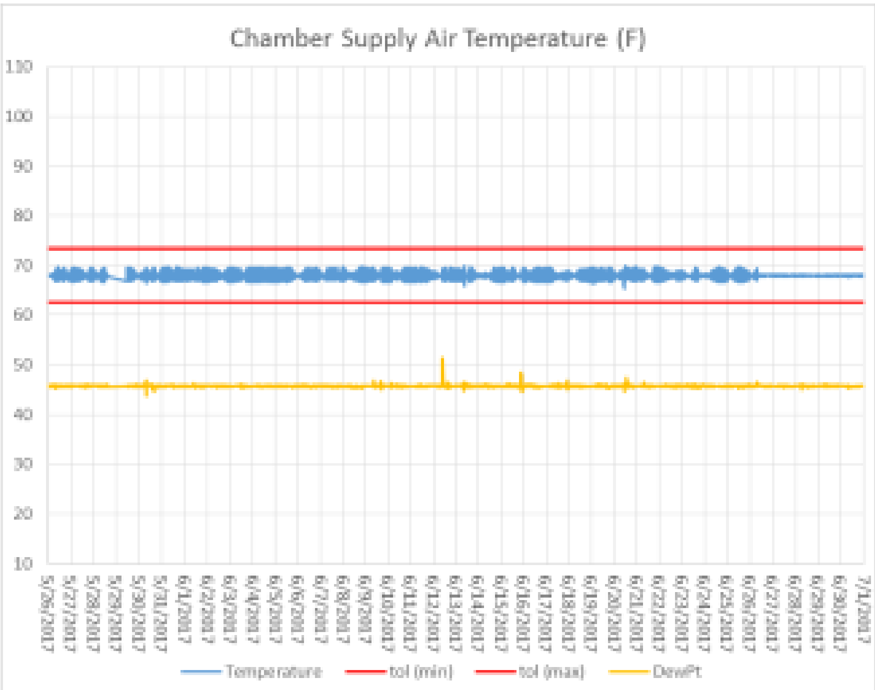


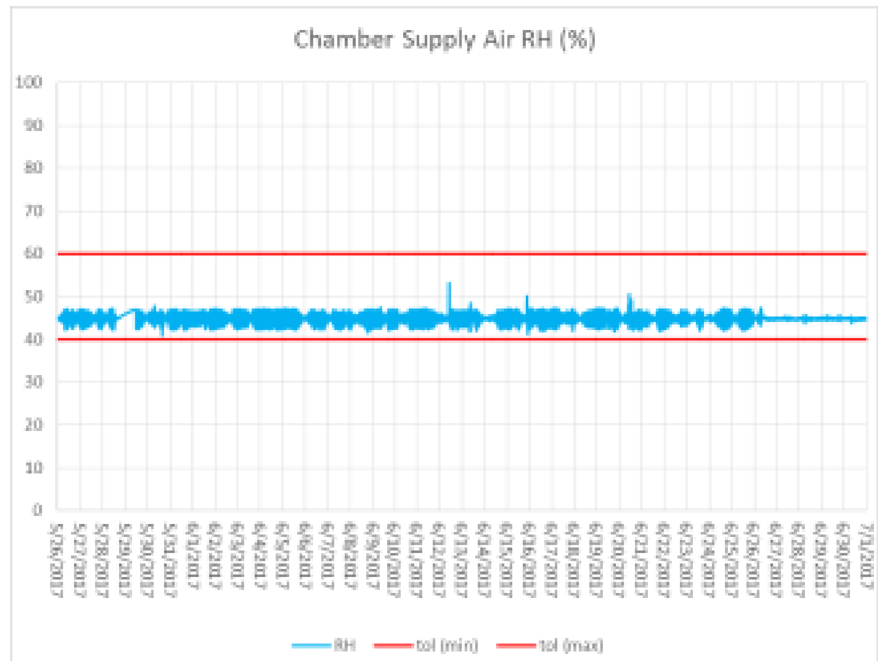
OGSE-1

OTIS CV



Chamber A Temp and RH performance





Tri-phenyl phosphate (TPP)

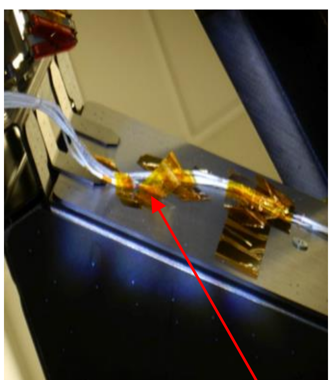
- **TPP Contamination from newly painted Chamber hardware**
  - The new helium shroud and much of the support equipment utilized inside the helium shroud were painted with Z307 black thermal paint.
  - Chemical analysis of samples from painted support equipment surfaces showed that the coating system contained TPP. Further investigation revealed that the source was a two-part primer used on the substrate under the paint, which seeped through the black topcoat.
  - The subsequent chamber bake-out and cleanings reduced the TPP levels to acceptable levels.

Balancing Cleanroom and Chamber A to maintain positive pressure

- **When Chamber A's 40-foot door was open to the cleanroom, dramatic swings in cleanroom pressure would occur when:**
  - The exterior chamber manlock doors were open too far or completely closed
  - The chamber AFMS was down, or not operating at the desired flow rate.
  - Either or both of the above conditions resulted in diminished positive pressure (and high particle counts) or over-pressurization of the cleanroom with billowing and potential damage to the large cleanroom roll up door.
- **Strict protocols were put in place to avoid pressure issues:**
  - Manlock doors were to be open no more than 6 inches during ambient test operations to ensure pressure of 0.5 – 1.0 inches w.c. Cleanroom pressure was checked prior to each roll up door opening.
  - Both the chamber and cleanroom systems needed to operate simultaneously with the chamber at a pre-established flow rate. If the chamber AFMS system was shut down, chamber manlock doors were completely closed (with personnel entering only through the cleanroom gown room) to help maintain positive pressure.
  - If further balancing or additional flow was necessary (i.e., for a prolonged cleanroom door-open period) cleanroom facility manager coordinated with the chamber AFMS operator.

Acrylic adhesive contamination

- **Acrylic Adhesive Contamination**
  - During inspection of support equipment after one of the initial cryogenic risk reduction tests before the OTIS CV test, acrylic adhesive was discovered on various surfaces.
  - With a glass transition temperature of -40^{o}C, 966 became brittle at cryogenic temperatures, fractured, and generated particles during vacuum operations. Black Kapton tape was found to be worse than regular Kapton tape.
  - Mitigation techniques included adhesive cleaning/removal, thoroughly cleaning substrate prior to adhering to surface, burnishing tape securely to surface and using tie wraps around beams and circular structures.



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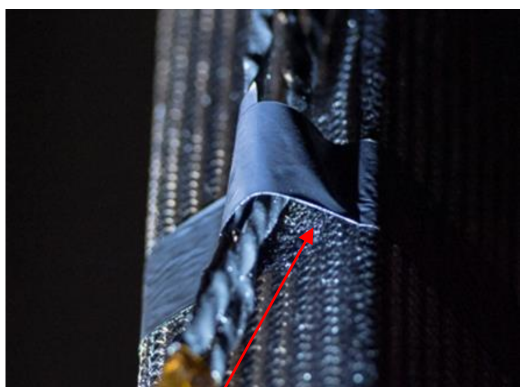

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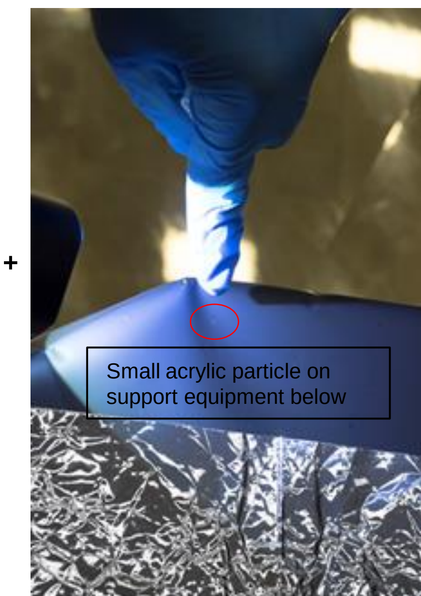
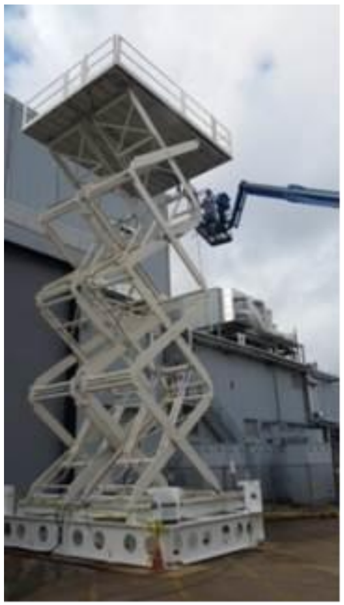


Tape loosened after exposure to cryogenic temperatures

Acrylic "shard" missing after exposure to cryogenic temperatures

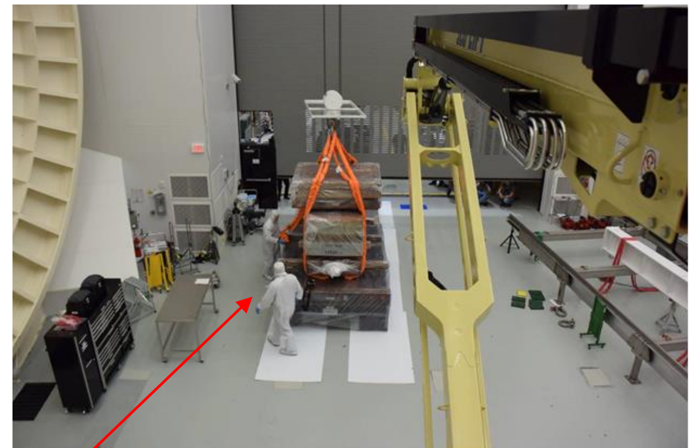
(Photo credit: NASA)

Large support equipment ingress through truck lock



The 40 ft Pentalift! Too large to be cleaned inside building and not designed for cleanroom use!

Preparing to back truck into cleanroom for crane load testing!



Tons of scaffolding – each pole cleaned inside and outside

(Photo credit: NASA)

Conclusion

- **The JWST CC teams (including GSFC, and JSC) were extremely successful in meeting CC requirements during OTIS I&T operations at JSC!**
  - Witness samples monitoring OTIS while in the cleanroom and Chamber A show that the OTIS Primary Mirror met its allocation requirements with margin: the average PAC was 0.04 PAC vs. an allocation requirement of 0.20 PAC, and the NVR was <2 angstroms against an allocation requirement of 55 angstroms for operations at JSC.
  - T and RH remained within specification!
- **The key to this successful contamination control program was vigilance in inspections, monitoring, daily maintenance cleaning, and having a well-trained CC technician team that operated as the front-line defense against contamination ingress with hardware, and contamination created in the cleanroom or chamber.**

Acknowledgments

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Thank you SPIE!