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Dual Glovebox Thermal Vacuum Chamber: Testing Capabilities for Spacesuit Arms and Gloves

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The development of Extravehicular Activity (EVA) suits and hand mobility EVA tasks are complex, high risk, and difficult to test in a simulated space environment. During the early assembly of the International Space Station (ISS), the Crew and Thermal Systems Division (CTSD) at NASA Johnson Space Center (JSC) was tasked to design a chamber that could use two Extravehicular Mobility Unit (EMU) arms and gloves in a simulated space environment versus testing with a full suit. The Dual Glovebox (DGB) Chamber was built and served to help develop EVA tools and operations to assist with Return to Flight for the Space Shuttle after the Columbia accident. With the recent development of the Exploration Extravehicular Mobility Unit (xEMU) and new commercial suits through the Extravehicular Activities Services (xEVAS) contract, the DGB can support the need to do suit component testing at thermal extremes and EVA operations without the cost of full suit testing. The DGB can simulate realistic delta pressures, vacuum down to 5×10^{-4} Torr (0.066 Pa) with roughing and cryogenic pumps, and a wide range of temperatures achieved via a combination of Liquid Nitrogen (LN_2), conditioned Gaseous Nitrogen (GN_2), Infrared (IR) lamps, and heater cables. Recent developmental work has verified operational status of the chamber and expanded the capabilities of the DGB to include thermal contact testing of suit gloves through two temperature-controlled grab bars. This paper will discuss the history and capabilities of the DGB and the chamber's future role in the development of new spacesuit systems.

Nomenclature

CTSD = Crew and Thermal Systems Division
DGB = Dual Glovebox
EMU = Extravehicular Mobility Unit
EVA = Extravehicular Activity
°F = Fahrenheit
GN_2 = Gaseous Nitrogen
In = inch
IR = Infrared
ISS = International Space Station
JSC = Johnson Space Center
K = Kelvin
kPa = kilopascal
LEO = Low Earth Orbit
LN_2 = Liquid Nitrogen
lx = lux, luminous flux per unit area
m = meter
NASA = National Aeronautics and Space Administration
Pa = Pascal
psi = Pressure per Square Inch
psia = Pressure per Square Inch Absolute
psid = Pressure per Square Inch Delta
TC = thermocouple
W = Watt

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xEMU = Exploration Extravehicular Mobility Unit
xEVAS = Exploration Extravehicular Activity Services

I. Introduction

The Extravehicular Activity (EVA) suits of the past and present, such as the Extravehicular Mobility Unit (EMU), have played a defining role in human space exploration. They were necessary for landing the first human on the Moon and our continued presence on the International Space Station (ISS) for over 20 years.[1] The continued success of space exploration relies heavily on the aerospace industry's ability to develop new and robust spacesuit systems, such as the Exploration Extravehicular Mobility Unit (xEMU) and the Extravehicular Activities Services (xEVAS) suits, quickly and efficiently.[2,3] These suits are critical for the establishment of a lunar base, continued human presence on the Moon, commercial endeavors in Low Earth Orbit (LEO), and landing humans on Mars. Historically, spacesuit development cycles have been lengthy due to the complexity of the technology and the level of performance needed to allow the crew to live and work in the extreme environments of space. A key step in these development cycles is the system- and subsystem-level testing of hardware to evaluate actual performance against requirements. One of the most robust methods used in spacesuit development and validation is thermal vacuum testing, which involves exposing hardware to vacuum and varying thermal environments to simulate their expected operating conditions while collecting necessary data for evaluation. The Crew and Thermal Systems Division's Systems Test Branch (CTSD EC4) at NASA's Johnson Space Center (JSC) specializes in thermal testing of hardware in vacuum and/or reduced pressure conditions.

The Dual Glovebox (DGB) is a thermal vacuum chamber that provides a dual hand glovebox. It can accommodate the use of two elbow-length Class 1 EMU arms and gloves. It is located within a larger chamber, the 11-foot chamber. The internal EMU pressure of 4.3 psia (29.647 kPa) is simulated by the 11-foot chamber. Currently, the DGB is used to test flight hardware and allow test subjects to experience EVA tools within a thermal vacuum environment. The arms and gloves in the chamber allow a test subject to manipulate hardware.

Since the DGB is in another chamber, this allows for the implementation of nominal delta pressures across the gloves and arms for simulation of realistic arm/hand movement. Not only is it a resource for manipulating flight test hardware and EVA tool practice, the DGB is a valuable chamber for the development of future spacesuit gloves and arms. The specialized design of this chamber enables it to support independent sub-system level testing of spacesuits arms and gloves, which significantly decreases test cost, complexity, time, and required resources when compared to full suit testing.

II. Chamber Capabilities

A. DGB General Layout

The DGB working area is 1.1 m × 1.4 m × 0.4 m. There are horizontal rails at the top and bottom of the chamber, which can be used to support and orient the test articles and test support equipment. As seen in Figure 1, the DGB has two side hatches that are 1.22 m × 0.56 m and one front hatch which is 0.64 m × 1.04 m. The front hatch has a single viewport with two glove ports where the suit arms and gloves are sealed using O-rings, shown in Figure 2. This allows the inside of the arms and gloves to maintain the same pressure as the 11-foot chamber while the outside of the arms and gloves are subjected to the vacuum inside the DGB. In addition, the chamber has fiberoptic interior lighting (100 lx, 5600 K color temperature), and two cameras inside of the chamber with views of the work area. Within the 11-foot chamber, there are multiple cameras to observe the test subject.

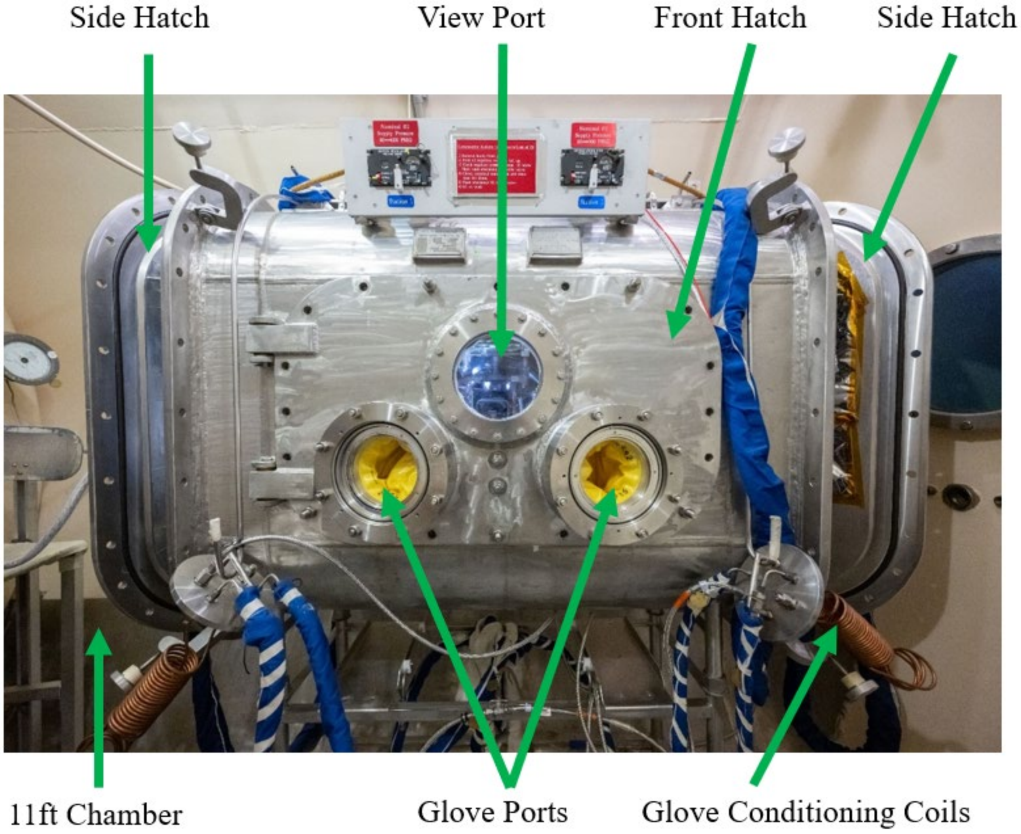

Figure 1. External view of the DGB with EMU gloves installed and side hatches open.

Figure 2. The DGB front hatch viewport with EMU gloves installed.

B. Vacuum Capabilities

The DGB vacuum capabilities leverage a roughing pump to reduce pressure to at least 0.43 Torr (57.32 Pa) and a cryogenic pump to achieve a pressure of 5×10^{-4} Torr (0.066 Pa). The pressure of the DGB, the inside of the suit arms and gloves, and the 11-foot chamber can be controlled independently as seen Figure 3. This allows for temperature preconditioning of the test articles within the DGB while maintaining the 11-foot chamber at atmospheric pressure. Once the test articles are conditioned to acceptable soak temperatures, the 11-foot chamber can be pumped down to any given pressure below 14.7 psia (4.3 psia (29.647 kPa) for the EMU) so the test subject can begin manipulating the hardware. To control the pressure inside of the suit arms and gloves, isolation plates are installed on the glove ports and a glove pressure control system is used to control a pressure delta (4.3 psi (29.647 kPa) delta for the EMU).

As seen in Figure 3, the differential pressure between the inside of the arm and glove is maintained using a combination of a GN_2 in-bleed and a vacuum source provided by 11-foot chamber roughing pumps. Glove conditioning coils can also be installed to maintain ambient temperatures within the EMU arms and gloves by using a Glove Heating/Cooling Cart flowing a water/glycol mixture. This ensures the inside of the arms and gloves stay at ambient temperature for the test subject.

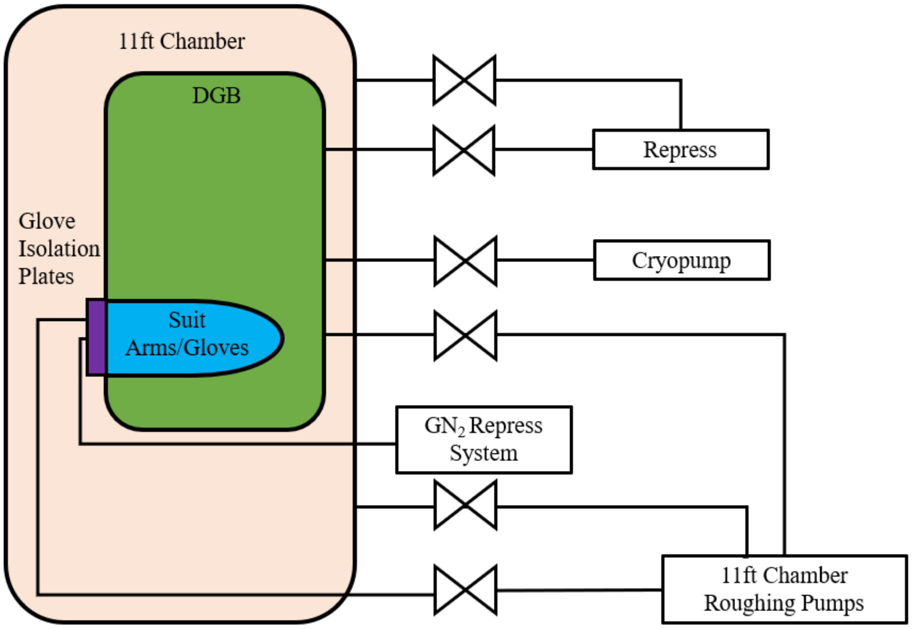

Figure 3. Pressure control for the facility.

C. Thermal Capabilities

Table 1 shows all of the environment temperatures that can be achieved within the DGB. A shroud surrounding the work area and the work surface (excluding the hatches) can provide an environment as low as –250°F (116 K) with LN_2. Conditioned GN_2 supplied to the shroud can heat the environment up to 150°F (338 K). Any intermediate temperature between 150°F (338 K) and –250°F (116 K) can be achieved within ± 10°F (±5.5 K) by mixing GN_2 and LN_2.

Infrared (IR) lamps and Type HLT self-regulating heater cable can be installed within the chamber in custom configurations to heat the test article beyond 150°F (338 K) as seen in Figure 5. The maximum temperature the test articles can be heated to is determined by the type, amount, and location of the heating elements. The shroud, test article, suit arm, and suit glove temperatures are measured using Type T thermocouples (TCs). The desired data from the sensors and instruments are displayed on custom-built displays for the test team and test requester to review during live testing. The data are also logged and provided to the requester after completion of the test.

Table 1. Heating/Cooling Method in the DGB

Heating/Cooling Method	**Temperature**
LN_2 Fluid in Shroud	–250°F (116 K)
GN_2 Fluid in Shroud	150°F (338 K)
GN_2 and LN_2 Fluids in Shroud	150°F (338 K) and –250°F (116 K)
Additional Heating Elements	Over 150°F (338 K)

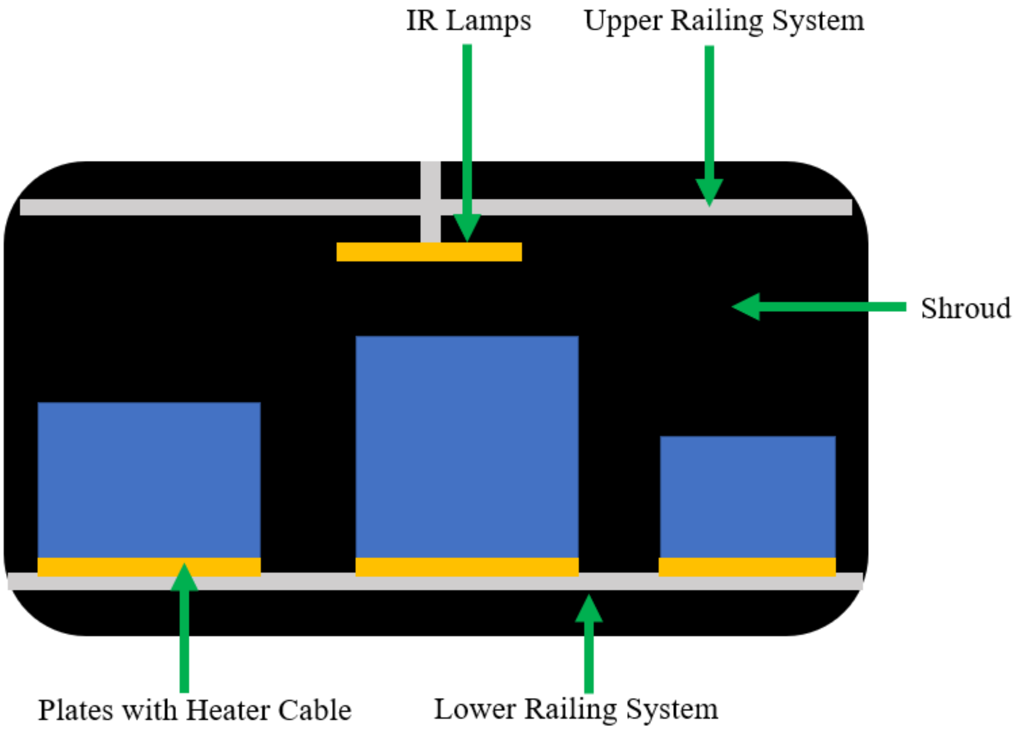

Figure 4. Internal view of the DGB.

D. Facility Safety

Within the facility, multiple safety measures are in place to protect the test subject. The 11-foot chamber is equipped with emergency repress capability which will repress the chamber to site pressure under 30 seconds. In addition, the chamber is equipped with fire suppression system. The test subject is supplied facility oxygen and an emergency carry-around oxygen bottle as seen in Figure 5. The emergency bottle provides 30 minutes of oxygen in case the test subject is disconnected from facility oxygen. In addition, the test subject always has communication with the test team through the oxygen mask microphone and communication cap. Biomedical data for the test subject such as heart rate is provided and recorded by medical specialists throughout the test. Medical specialists have an assigned station to monitor the test subject the entirety of the test.

Figure 5. Test subject within the 11-foot chamber and operating hardware with EMU gloves in the DGB.

III. Concept of Operations

Below is an example procedure that could be conducted to test flight hardware within the DGB[4]:

1. Place test articles into the chamber and complete all pretest functionals as required.
2. Install heating elements and instrumentation into the DGB as needed.
3. Turn on data recording, video recording, and lighting within chamber.
4. Close the front hatch of the DGB.
5. Install EMU arm and gloves within the DGB glove ports.
6. Close the side hatches of the DGB.
7. Turn Glove Heating/Cooling cart and set to ambient temperature.
8. Pump down the DGB and stop at 620 Torr (82.66 kPa). Hold down on the arm bearings to establish the initial seal during depress.
9. Install glove conditioning coils and isolation plates.
10. Continue depress of the DGB while maintaining the Glove-to-DGB differential pressure of 4.3 psid (29.647 kPa).
11. Once the DGB is at 1 Torr (133.32 Pa), begin thermal conditioning by flowing liquid through the shroud and turning on the heater elements as needed.
12. Once the chamber is below 0.43 Torr (57.32 Pa), turn on cryopump and continue depress to 5×10^{-4} Torr (0.066 Pa).
13. While maintaining the temperature and pressure in the DGB, the test subject will begin donning the oxygen mask, emergency carry-around oxygen bottle, the communications cap, and biomedical sensors.
14. Once a good mask seal and oxygen flow has been verified, prebreathe can begin for 4.5 hours.
15. After the 4.5 hours prebreathe, close the 11-foot chamber door.
16. Depress the 11-foot chamber to 4.3 psia (29.647 kPa).
17. Once at 4.3 psia (29.647 kPa), the test subject will remove the glove conditioning coils and isolation plates.
18. The test subject will place their hands into the EMU arms and gloves and begin evaluation of the test articles.
19. After the end of the evaluation, the test subject will place the glove conditioning coils and isolation plates back. The heater elements and the shroud are adjusted as needed within the DGB.
20. Repress the 11ft chamber to site pressure 14.7 psia (101.325 kPa) while the inside of the gloves is maintained at 4.3 psia (29.647 kPa).
21. The test subject will doff the oxygen mask, emergency carry-around oxygen bottle, the communications cap, and biomedical sensors.

22. Repress the DGB to site pressure while maintaining the Glove-to-DGB differential pressure of 4.3 psid (29.647 kPa).
23. Open the front hatch and remove the EMU arms and gloves from the DGB.
24. Open the side hatches and remove the test articles.

IV. DGB Additional Testing Capabilities

Recent developmental work has expanded the capabilities of the DGB to include thermal contact testing of spacesuit gloves. This was achieved through the development of two temperature-controlled grab bars which can be grabbed, brushed against, and/or tapped during testing to evaluate performance. In the future, to quantify the applied loads placed on the bar, a pressure sensor will be installed. Although no space suit gloves have been tested with the grab bars yet, multiple functional tests have been conducted within the chamber to ensure the bars work as expected. Multiple TCs were placed along the bars to verify temperature during these functionals.

As seen in Figure 5, the cold grab bar consists of a 2-in (0.0508 m) diameter and 9-in (0.2286 m) long solid copper 101 rod with LN_2 and GN_2 flowing through it. This bar is tied directly into the DGB shroud and can achieve any temperature the shroud can see (refer to Table 1). The hot grab bar has the same dimensions as the cold grab bar. As seen in Figures 5 and 6, it consists of a 500 W IR lamp within a 2-in (0.0508 m) outer diameter copper 122 tube. The design of the hot bar enables it to rapidly increase temperature as needed and can achieve up to 400°F (477.59 K). The IR lamp is completely covered by the copper tube so there is no risk of gloves contacting the heating element. Higher power IR lamps can be swapped in if hotter temperatures need to be achieved.

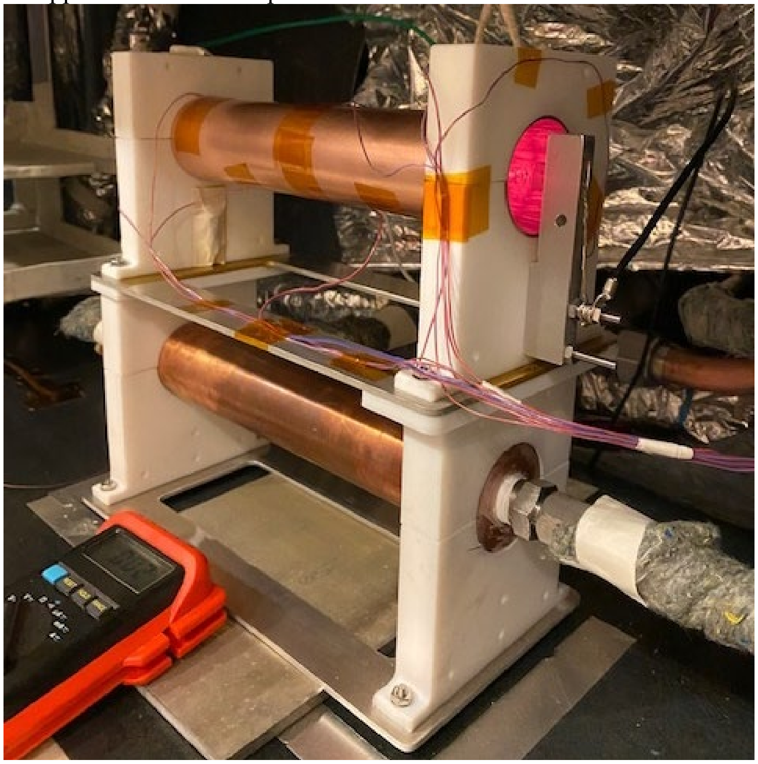

Figure 5. Hot grab bar above and cold grab bar below inside the DGB.

Figure 6. IR lamp inside of the hot grab bar.

V. Conclusion

The DGB has had a long history of testing flight hardware, developing EVA tools, and training crew members. In support of STS-114 “Return to Flight” Space Shuttle mission, multiple tests were conducted within the DGB to make repairs on reinforced carbon-carbon (RCC) samples. These tests were done if RCC damage was detected during post ascent wing leading edge inspections, and crew members needed to conduct a repair EVA. The DGB was the ideal location for testing and to allow crew members to practice for the potential EVA task. In addition to supporting the Shuttle program, the DGB was used to test hand controllers for the Orion spacecraft. The objective of the test was to perform a thermal vacuum cycle of the multiple Orion hand controllers at different temperature extremes. The test articles were evaluated pre-test, during test with manipulation from a test subject, and post test to determine any change in performance from exposure to the temperature and vacuum extremes.

As the outlook of the space industry includes the development of new spacesuits, the DGB will play a significant role. The DGB expands new suit development testing capabilities with significant reductions in cost, complexity, and time to test. The chamber potential applications for new suit development range from component-level verification to crew training and system-level validation. For component verification, the DGB can be utilized for structural pressure testing of spacesuit gloves—the gloves can be thermally cycled while a maximum delta pressure is simulated. Furthermore, the two new grab bars can be used within the DGB to develop and/or ground thermal models and validate thermal performance of the gloves. The DGB grab bars can be used to determine new touch temperature requirements for gloves as well.

Each test does require at least 3 weeks of preparations to ensure the systems are checked out, all the instruments are calibrated, and the consumables are replaced. This would not include time for buildup that is required for the specific tests. Currently, the 11-foot chamber and DGB has much availabity to assist in the development of new suit arms and gloves. In the future, it can be used for both acceptance and qualification tests once the suit arms and gloves are more developed.

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