PERFORMING A LAUNCH DEPRESSURIZATION TEST ON AN INFLATABLE SPACE HABITAT

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ABSTRACT

In July, 2014 JPL's Environmental Test Laboratory successfully performed a launch depressurization test on an inflatable space habitat proposed to be installed on the International Space Station. The inflatable habitat is to be launched in the SpaceX Dragon Trunk. During the launch, the unpressurized Dragon Trunk will rapidly change from ground level atmospheric pressure to the vacuum of space. Since the inflatable habitat is tightly folded during launch with multiple layers of bladder, Kevlar fabric sections, and micro-meteoroid shielding, it was not possible to analyze or simulate how the residual air pockets would behave during the launch. If the inflatable habitat does not vent adequately and expands, it could rupture the payload bay of the launch vehicle. A launch depressurization test was chosen as the best way to qualify the inflatable habitat. When stowed, the inflatable habitat measured approximately 241 cm (95 inches) in diameter by 152 cm (60 inches) high and weighed close to 1361 kg (3,000 pounds).

Two vacuum chambers connected by a large vacuum line were used to perform this test. The inflatable habitat was mounted in the smaller chamber, which was 396 cm (13 feet) in diameter and 1128 cm (37 feet) high. The larger chamber, which was 823 cm (27 feet) in diameter and 2,591 cm (85 feet) high, was rough pumped and used as a vacuum reservoir. A two stage axial type compressor and ten Stokes vacuum pumps were also used during the depressurization. Opening a butterfly valve on the vacuum line, at the smaller chamber, was manually controlled so that the smaller chamber's depressurization rate matched the launch pressure profile.

INTRODUCTION

The most critical phase of a depressurization profile for a typical large vehicle launch occurs within the first 120 seconds when the pressure vents from 760 Torr (14.7 psi) at sea level to the vacuum of space. The launch depressurization test required a large vacuum chamber with a tremendous vacuum pumping capacity. From the late-1960s until 1982, JPL's Environmental Test Lab (ETL) had the capability to perform launch depressurization tests in the large vacuum chambers because a vacuum line connected the chambers to the powerful compressors located in JPL's wind tunnel facility. The wind tunnel supplied the pumping capacity using four 5,000 horsepower compressors and one 500 horsepower axial compressor. With the wind tunnel pumping facility, JPL had the ability to perform launch depressurization tests in the large Space Simulator Chamber and in the 10ft Vertical Chamber.

THE PROBLEMS

NASA decommissioned JPL's wind tunnel in 1982. The wind tunnel's four large 5,000 horse power compressors were removed, and were no longer available for supporting testing in the ETL vacuum chambers. But, the ETL was able to acquire the wind tunnel's small 500 horsepower axial compressor for use in the Space Simulator facility. At that time, eight Stokes mechanical pumps and five roots blowers were added to the rough pumping system in the pump room at the Space Simulator facility.

The engineers who designed this system for the ETL had the foresight to include large underground vacuum lines connecting the 25ft Space Simulator Chamber (in Building 150), the 10ft Vertical Vacuum Chamber (in Building 248), and the 7ft Horizontal Vacuum Chamber (in Building 144). Thus, the mechanical roughing pumps in the Space Simulator facility could be used to pump down the chambers in all three building.

Using the axial compressor from the Space Simulator facility, it had been possible to successfully perform launch depressurization tests on smaller Inflatable Space Habitats in the 7' Horizontal Vacuum Chamber which is 211 cm (83 inches) diameter x 345 cm (136 inches) deep. Unfortunately, the 7ft Horizontal Chamber was not large enough to accommodate the larger Inflatable Space Habitat. The 10ft Vertical Vacuum Chamber was large enough to accommodate the larger Inflatable Space Habitat, but the Space Simulator's rough pumping facility did not have the pumping capacity to meet the launch depressurization profile requirements for a chamber of this size.

THE SOLUTION

It was decided to attempt a novel approach. The test article would be mounted in the 10ft Vertical Vacuum Chamber, the large Space Simulator would be pumped to roughing pressure, and volume of the Space Simulator would be used as a vacuum reservoir in tandem with the mechanical pumps of the rough pumping facility. Since the volume of the Space Simulator was approximately ten times the volume of the 10ft Vertical Chamber, it could greatly enhance the pumping capacity of the axial compressor and Stokes mechanical pumps. The butterfly valve, on the vacuum line connecting the chambers to the Space Simulator's roughing pumps, would be manually controlled to limit the pumping rate of the 10ft Vertical Chamber to track the requirements of the launch depressurization profile. A block diagram of the test setup is shown in Figure 1 below.

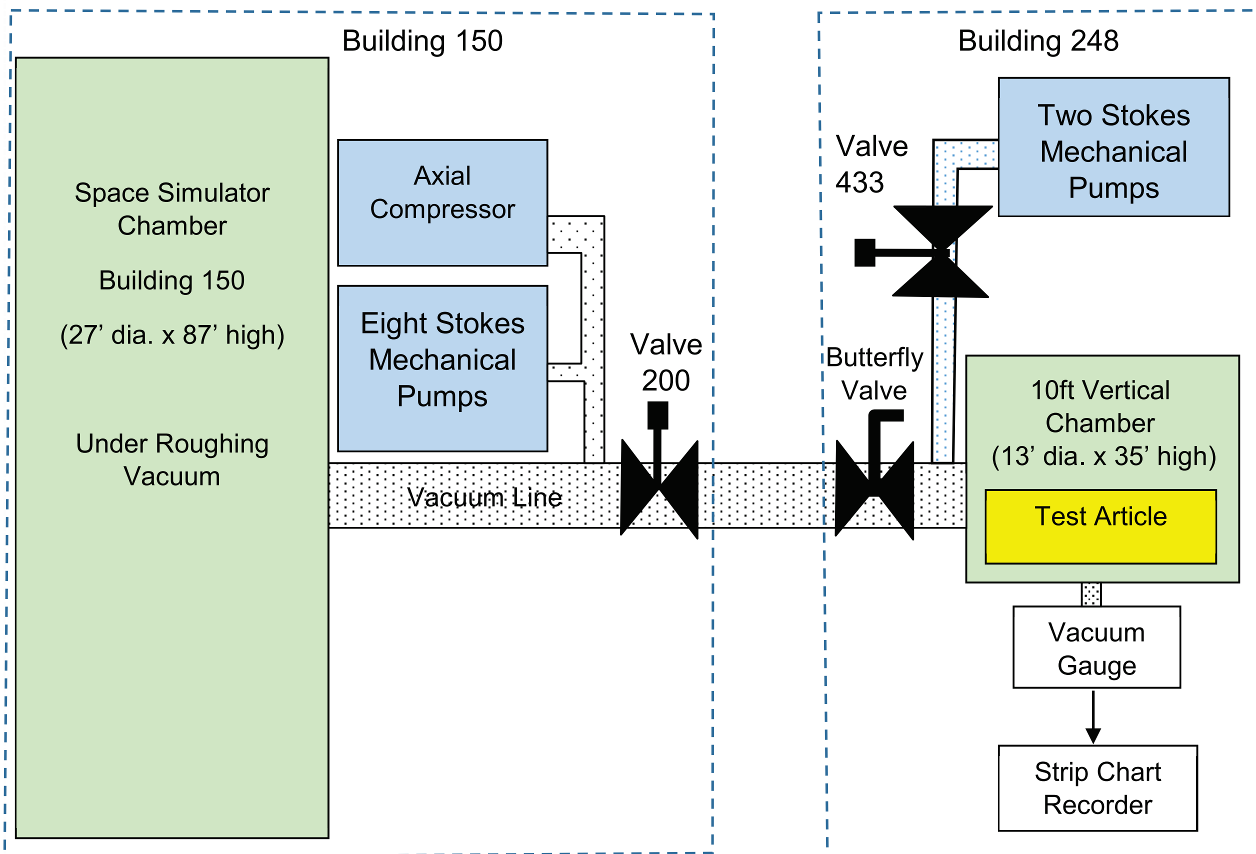


FIGURE 1: TEST SETUP BLOCK DIAGRAM

Photo 1: Space Simulation Chamber
View with the Chamber Door Open

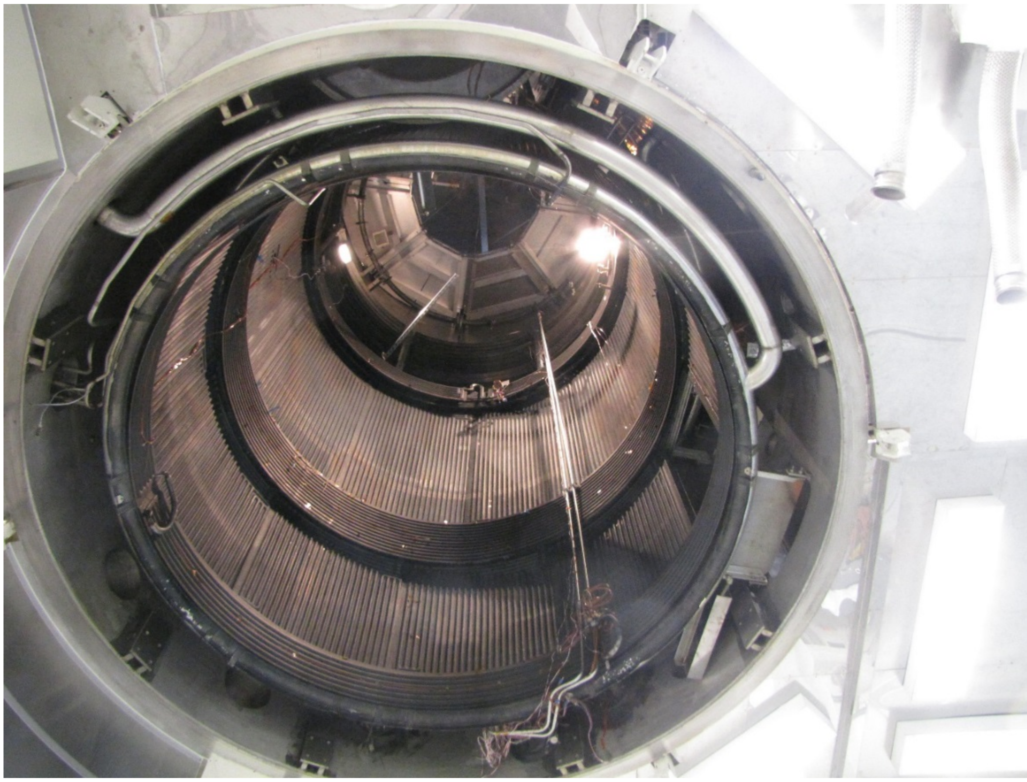


Photo 2: 10ft Vertical Vacuum Chamber Bottom View without End Bell

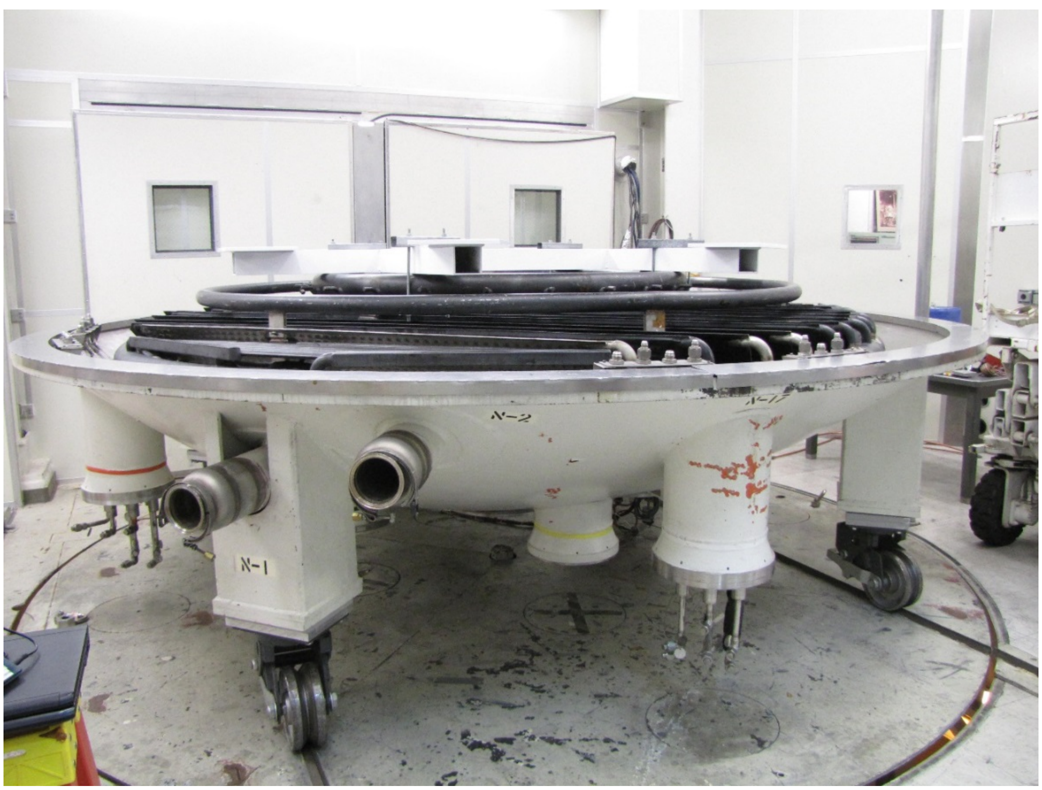


Photo 3: End Bell on the Hydraulic Ram below the Chamber

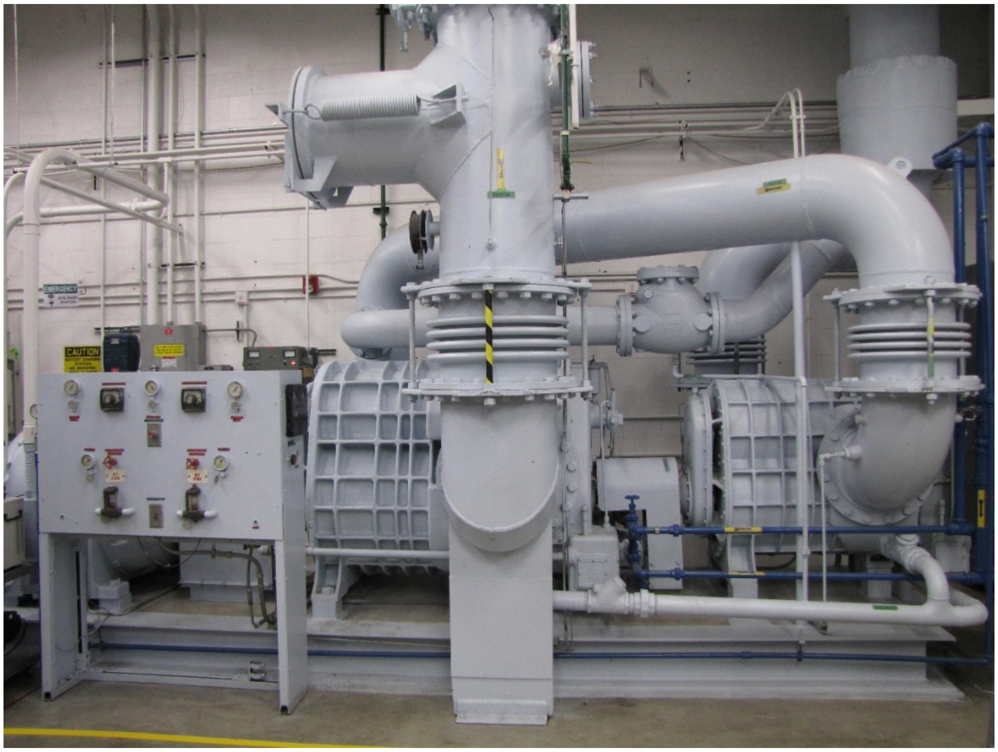


Photo 4: Axial Compressor in Building 150 Pump Room

Photo 5: Stokes Mechanical Pumps in Building 150 Pump Room
Note: The Roots blowers were not used for this test.

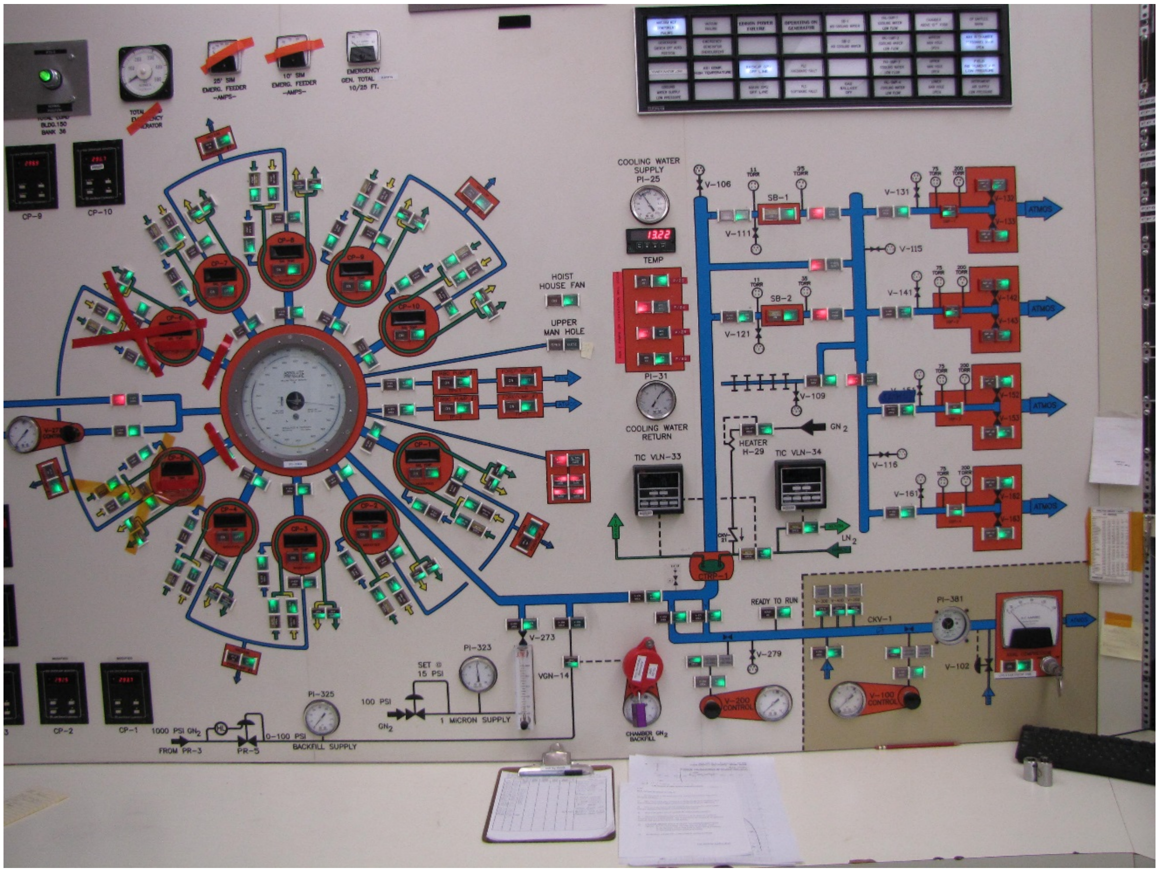


Photo 6: Space Simulator Chamber Vacuum Control Panel

THE CHANLLENGES

A number of issues made this test challenging for the team:

Time Constraints

Since the proposed test method, using these two large chambers in tandem for a launch depressurization, had not been performed before, NASA and JPL contracts administrators would not open a contract until a dry run had been performed to assure them of the likelihood of success. Once the test method has been successfully demonstrated and approved, it normally would take about 30 days to open the contract. Because the Space Simulator Chamber was being used to test the SMAP Observatory, the Space Simulator chamber did not become available for performing our dry runs until late June of this year. On the other end of the schedule, the 10ft Vertical Vacuum chamber was scheduled to support testing of the Mars 2020 Sample Return starting the first of August. Only one month was available to determine how to do something that had not been done before, reconfigure the facilities, perform the dry runs, open the contract, write the test procedure, practice with the crew to develop proficiency, setup the instrumentation, perform the test, and vacate the facility.

In order to accommodate our test schedule, the Space Simulator Chamber was turned over to us as soon as the SMAP Observatory test was completed and the Observatory had been removed from the chamber. Removing the SMAP fixtures and ground support equipment from the Space Simulator Chamber was postponed until after dry runs for the launch depressurization test had been completed. Eight dry runs were conducted between late June and early July. The NASA and JPL contracts administrators were then challenged to open the contract in time to support installation of the support test fixture in the 10ft Vertical Chamber by mid-July. To the credit of the contract administrators, the contract was opened in time to support our tight test schedule.

Test Setup and Dry Runs

Normally only one test is conducted at a time in either the Space Simulator Chamber or the 10ft Vertical Chamber. A vacuum interlock needed to be bypassed so that the valves between the chambers could be opened. Control of the butterfly valve was changed from a slow responding pressure regulator to a faster responding Jamesbury hand valve. A Barotron pressure gauge was installed on the chamber to monitor the chamber pressure. The output of the Barotron gauge was fed to a strip chart recorder. A second Barotron gauge was installed so that our customers could observe the chamber pressure from the deck where their monitoring instrumentation was to be setup.

Eight dry runs were conducted. The dry runs allowed us to optimize our test method and provided the chamber operators the hands-on experience necessary to accurately control the depressurization and track the depressurization profile. The ETL crew consisted of two chamber operators in Building 150 and three chamber operators in Building 248. Two way radios were used to communicate and coordinate activities in five locations.

TEST METHOD

From the dry runs, it was determined that the optimum test method was to start by rough pumping the Space Simulator Chamber to less than 45 torr using the axial compressor and 8 Stokes mechanical pumps in Building 150. We discovered that by valving off the axial compressor, we could achieve better vacuum in the Space Simulator Chamber with the Stokes pumps, but it was advantageous to keep the axial compressor on line since it greatly enhanced the rate at which the 10ft Vertical Chamber could be evacuated.

The required launch depressurization profile was traced onto the paper of the strip chart recorder before the paper was loaded into the recorder. During the test, the pen on the strip chart recorder plotted the chamber pressure from the Barotron gauge. The operator of the butterfly vacuum valve manually adjusted the valve position so that the pen on the strip chart recorder followed the traced launch depressurization profile line on the strip chart paper.

As the pressure in the 10ft Vacuum Chamber came down, the pressure in the Space Simulator rose. As the two chambers approached equilibrium, Valve 433 in Building 248 was opened to bring on line the two Stokes mechanical pumps in Building 248. A few seconds after that, Valve 200 in Building 150 was closed to isolate the Space Simulation Chamber and the roughing pumps in Building 150. The two Stokes mechanical pumps in Building 248 were used to continue the launch depressurization profile and to maintain the 10ft Vertical Vacuum Chamber under vacuum for a minimum of 15 minutes.

The most critical period of the launch depressurization profile corresponds to the period when the launch vehicle goes transonic and the maximum rate of pressure decay occurs. Upon reviewing the initial dry run data, the Project Chief Engineer from Johnson Space Center requested that our launch depressurization profile be modified so that the transonic slope occurred earlier in the profile. This was to insure that transonic slope of the profile occurred when our pumping capacity was at maxim controllability. The profile was modified accordingly, and additional dry runs were performed to assure proficiency.

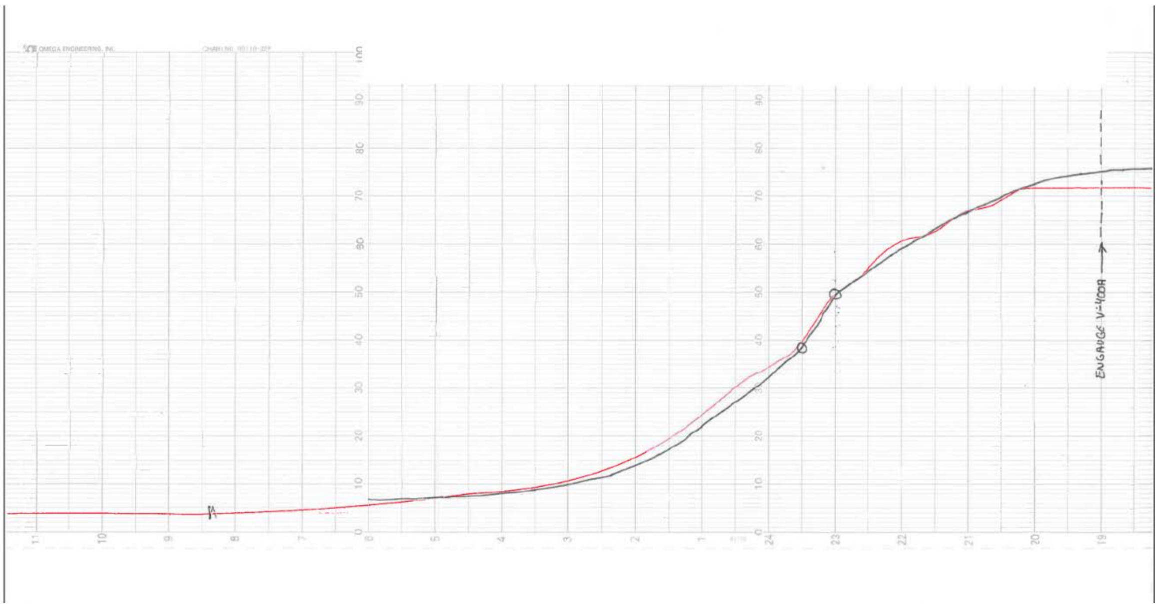
TEST PERFORMANCE AND RESULT

In late July, the customer delivered the test article. The test article was installed on the end bell of the 10ft Vertical Vacuum Chamber. Four cameras were installed in the chamber with views of the test article during the test. Launch Depressurization Test Run # 1 was conducted, and control of the chamber evacuation met the launch depressurization requirements as determined by the JSC Project Engineer. The chamber's end bell was lowered, and a post-test visual inspection of the test article was performed. The customer reported that the test article had not expanded and no damage to the test article had been observed. The test was successful, but the customer's data acquisition system did not operate properly during the test, and it was decided a second test run would be required.

The next day, the test article was reloaded into the chamber, and a pre-test check of the customer's data acquisition system was performed during which the chamber pressure was briefly reduced by 40 torr. After verification that the data acquisition system was functioning properly, the chamber was backfilled to room ambient pressure.

Thirty minutes after the backfill, launch depressurization Test Run # 2 was performed. The launch depressurization test requirements were successfully achieved and the customer's data acquisition system worked properly.

The chamber's end bell was lowered, and the customer again performed a post-test visual inspection of the test article. The customer reported that the test article had not expanded during the test and that no visual damage had been observed. The test article was removed from the end bell, loaded into the customer's shipping container. The test article was delivered to JPL on a Monday morning, and by Tuesday afternoon is was on its way back to the customer's facility.



Plot of Launch Depressurization Chamber Pressure
Note: The two circles bound the transonic pressure slope.

CONCLUSION

The test was successfully conducted on schedule, within tolerance, and well within the estimated budget. Per feedback from the customer and the JSC Project Manager, the test successfully demonstrated that the Inflatable Space Habitat should not pose a risk of inflation during the launch.

The test also demonstrated JPL's capability of using the two chamber method of performing a launch depressurization test on a large test article. The ability to perform a launch depressurization test on such a large test article is a unique capability.

Doing something that had not been done before under narrow schedule constraints inspired a lot of creativity from all of our team members. And we had great fun performing this test.

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