EASY ENGINEERING

Easy Engineering – June 2024

Problem Solved
How Are Minus K Products/Solutions Used In Overcoming Challenging Situations

The National Aeronautics and Space Administration (NASA) had a serious problem. The James Webb Space Telescope (JWST) was designed to work in space where the disturbances are highly controlled and only come from the spacecraft. While the telescope was on Earth being tested all the ground-based disturbances, such as the pumps and motors, and even traffic driving by could affect the testing.

All of the JWST systems-level cryogenic vacuum tests were to be performed in NASA Johnson Space Center's (JSC) Chamber-A. Chamber A is the largest high-vacuum, cryogenic-optical test chamber in the world, and made famous for testing the space capsules for NASA's Apollo mission, with and without the mission crew. It is 55 feet (16.8 meters) in diameter by 90 feet (27.4 meters) tall. The air in the chamber weighs 25 tons, when all the air is removed the mass left inside will be the equivalent of half of a staple.

NASA JSC engineers spent three years building and remodeling the chamber's interior for the temperature needed to test the James Webb Space Telescope. Chamber A was retrofitted with the helium shroud, inboard of the existing liquid-nitrogen shroud and is capable of dropping the chamber's temperature farther down than ever, which is 11 degrees above absolute zero (11 Kelvin, -439.9 Fahrenheit or -262.1 Celsius).

All of these improvements would make Chamber A an ideal environment for ground testing of JWST, if NASA could remove external vibration sources and create a near flight-like disturbance environment within the chamber.

NASA approached Minus K Technology to solve this issue. Minus K's commercially available Negative-Stiffness vibrations isolators have a natural frequency of 0.5 Hz, both vertical and horizontally*, mechanically passive, requiring no air or electricity to function. (with some versions at 1.5 Hz horizontally). (*Note that for an isolation system with a 0.5 Hz natural frequency, isolation begins at 0.7 Hz and improves with increased vibration frequency. The natural frequency is more commonly used to describe the system performance.)

Minus K designed and manufactured six custom 10,000 lb. Negative-Stiffness vibrations isolators with patented passive mechanical thermal compensator device to support JWST, test structure and all test equipment within Chamber A for the ground testing at JSC.

Some of the key engineering challenges for Minus K when scaling up their standard isolators to the 10,000 lb. isolators were:

a. Ensuring the vertical (Z) natural frequency of the suspended mass would be 0.50 Hz ± 0.05 Hz.
b. Ensuring the horizontal (X-Y) natural frequency would be 2.0 Hz ± 0.10 Hz (allowing for the support rod inside the chamber be at less than 1 Hz.).
c. Internal modes vertical and horizontal natural frequencies of isolators were above 75 Hz
d. Each isolator would remain within < 0.010 in (< 0.254 mm) of its original floated position over a period of 1 hour

The six Minus K Negative-Stiffness vibration isolators were installed on top of Johnson Space Center's Thermal Vacuum Chamber A in March 2014.

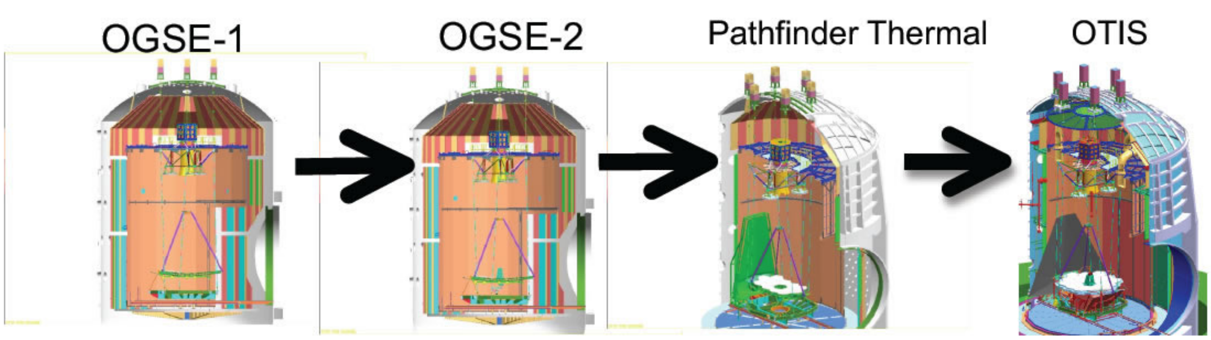
Suspended OTIS Test Set (SOTS), which included the test and support equipment used in the testing of the Optical Telescope Element / Integrated Science Instrument Module (OTIS), one of these units were required at each of the six primary structural interfaces to the test facility. Its purpose is to provide structural support and vibration isolation of the SOTS during test operations. Vibration isolation was required with the chamber interior at both ambient temperature and pressure, and cryogenic temperature and vacuum conditions.

There were two primary functions of the Isolator Units. The first function is to provide the structural support link between the load formed by the suspended elements of the SOTS / OTIS assembly and structures that transfer the load to the test chamber. The second function was to provide this suspended load with isolation from environmentally induced chamber vibrations, in the vertical (Z) direction and in the lateral (X-Y) direction. The term "environmental" is intended to encompass any source of vibration originating exterior to the test chamber, either natural or as the result of human activity.

JWST needed a support structure inside the vacuum chamber to hold equipment for the testing. Engineers installed a massive steel platform suspended from the six vibration isolators via steel rods about 60 feet long (18.2 meters) each and about 1.5 inches (or 38.1 mm) in diameter, to hold the telescope and key pieces of test equipment. The sophisticated optical telescope test equipment included an interferometer, auto-collimating flat mirrors, and a system of photogrammetry 'precision surveying' cameras in precise relative alignment inside the chamber while isolated from any sources of vibration, such as the flow of nitrogen and helium inside the shroud plumbing and the rhythmic pulsing of vacuum pumps.

To allow the engineers could keep an eye on JWST while being tested, additional test support equipment including mass spectrometers, infrared cameras and television cameras were also connected to the support structure that was being suspended and isolation from vibrations by the Minus K Negative-Stiffness isolators.

JWST Pathfinder tests were planned into 3 major test campaigns prior to the final cryogenic vacuum test of the fully assembled flight Optical Telescope Elements (OTE) and the integrated Science Instrument Module (ISIM). The three Pathfinder tests were, OGSE1, OGSE2, and the 'Thermal-Pathfinder' (TPF).



Pathfinder tests stages OGSE1, OGSE2, 'Thermal-Pathfinder' (TPF) and the fully assembled flight Optical Telescope Elements (OTE) and the integrated Science Instrument Module (ISIM) called (OTIS).

These tests were incremented to be more complex to fully characterize the test facility including the cryogenic test chamber and the Ground Support Equipment (GSE). The 'flight-like' test articles within the Pathfinder tests were designed to understand the thermal behaviors within the cryogenic environment.

The 30-day OGSE1 test was completed in May 2015 after the JSC Chamber-A was successfully commissioned in 2014 for JWST use. The 35-day OGSE2 cryo-vacuum test completed in October 2015 where all Primary, Secondary, Tertiary Test Objectives were all met. The successful completion of the OGSE2 marked a major milestone for JWST. This test was the first major cryogenic test with the actual flight telescope optical elements and a specialized fiber-fed optical equipment. It was the first test with the Aft-Optics-Subsystem (AOS) Source Plate Assembly or ASPA, designed to illuminate the telescope's optics through the focal planes. The flight Tertiary Mirror (TM) and the Fine Steering Mirror (FSM) packaged in a bundle called the Aft-Optics-Subsystem was optically tested in an integrated configuration in its operational cryogenic environment.

In June 2015 after the OGSE1 and OGSE2 tests and before the 'Thermal-Pathfinder' (TPF) test, L3Harris (formerly ITT Exelis) who commissioned and installed the six negative-stiffness vibration isolators on top of Chamber A, made adjustments with the assistance of Minus K to the chamber isolators, setting them to their designed 0.5 Hz natural frequency. This allowed the isolators to provide an improvement in vibration reduction on the two primary mirror segments of TPF test.

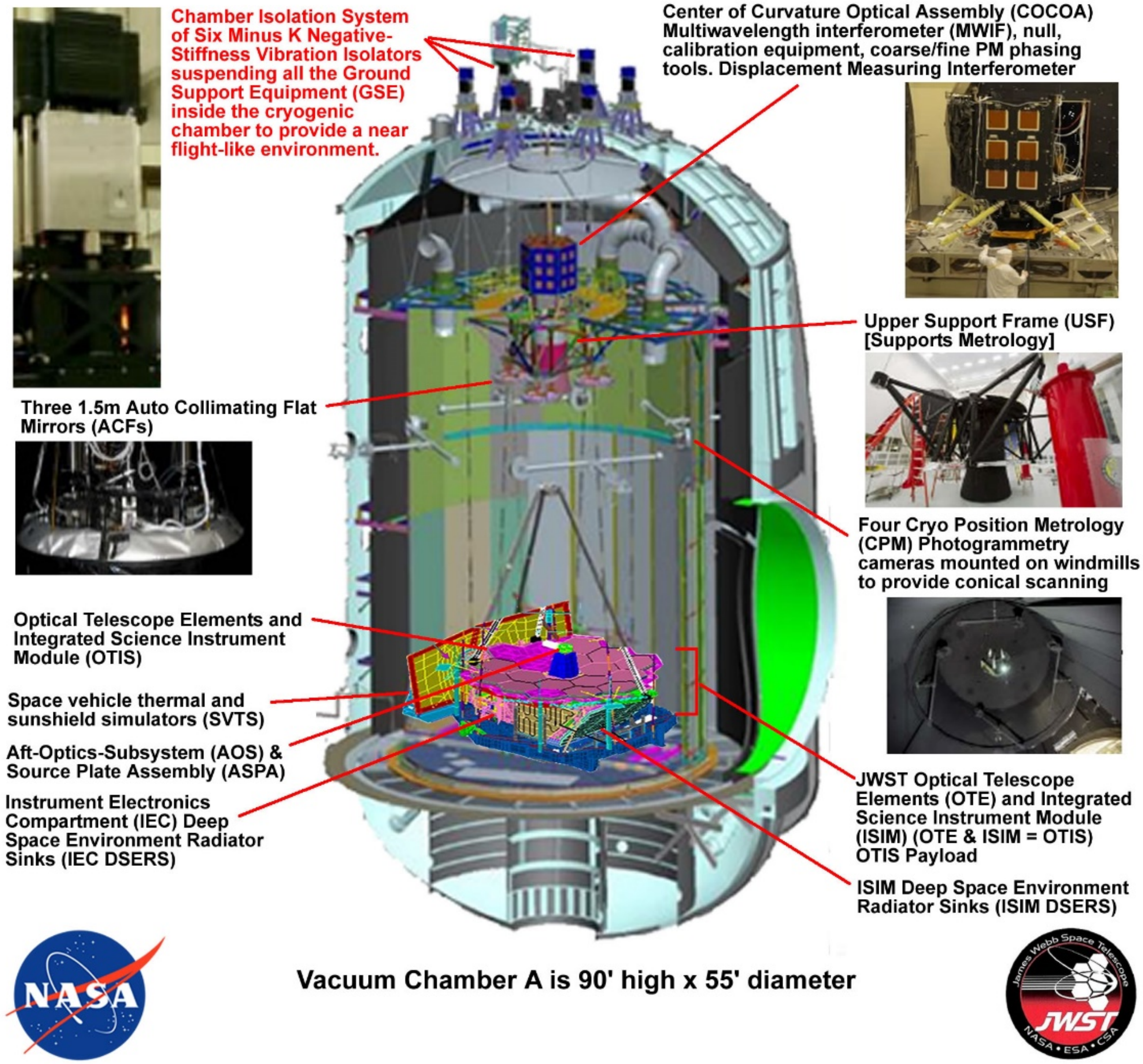
The 35-day Thermal Pathfinder (TPF) cryogenic test was completed in October 2016. TPF included two spare flight-rated beryllium mirrors (one gold-coated) and ten non-flight gold-coated aluminum test segments functioning as thermal simulators. During the optical tests the mirrors had to be "phased" or aligned to a distance less than the wavelength of light, thousands of times smaller than the thickness of a human hair at a temperature hundreds of degree below zero. Thermal Pathfinder underwent all thermal and vacuum tests that the actual JWST was planned to also go through in 2017.

The 93-day final test of the fully assembled JWST Optical Telescope Elements and Integrated Science Instrument Module (OTIS) started in July 2017. It took about 10 days to pull the air from the chamber, and then about one month to lower the temperatures of the JWST telescope and its scientific instruments to the levels required for testing.

These tests included an important alignment check of JWST's 18 primary mirror segments, to make sure all of the gold-plated, hexagonal segments acted like a single, monolithic mirror. This required all 132 hexapod actuators to be tested for 6 degrees of freedom (DOF) and radius of curvature for each mirror segment. This was the first time the telescope's optics and its instruments were tested together.

It was a long and complicated testing process to test JWST. The conditions it would encounter within the cold vacuum of space were simulated on the ground, ensuring the optics and instruments will perform perfectly after launch. This testing was very necessary since JWST would be close to a million miles away from Earth orbiting at L2. This will be too far away for repairs to be made as were done with the Hubble Space telescope.

OTIS Testing Ground Support Equipment (GSE) Architecture and Subsystems



When engineering the design for the JWST isolators Minus K determined that there might be a need for a secondary horizontal isolation stage with a different resonant frequency. It was a contingency plan that was ultimately never needed. However, a spacer structure was added into the JWST isolators supplied to NASA so it could be implemented later with minimal impact to the overall system design.

NASA was very pleased with the vibration isolation system that was used for JWST. Minus K has been told that without our isolators, it would have been nearly impossible to test the optics to the level they achieved.

Minus K are quite proud of the isolators that were provided for the JWST project. The engineers worked through a very intense design process, with a lot of analysis and verification testing. Minus K Technology is grateful to been a small, but important part of such a remarkable project, and has already been contacted by NASA for future space telescopes.