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ACCELERATION TESTING-A BETTER, FASTER, CHEAPER ALTERNATIVE FOR STRENGTH QUALIFICATION TESTING

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ABSTRACT

This paper addresses the advantages of utilizing a centrifuge test over the conventional static load test methods to structurally qualify aerospace structures. Three recent test cases are reviewed and used as examples to highlight these benefits. In addition, the overall capability of Goddard's High Capacity Centrifuge (HCC) is outlined along with some unique features that were designed specifically to reduce costs, test turn around time, and increase test item safety.

INTRODUCTION

A strength qualification test as referenced by this paper is defined as the method used to demonstrate that the test item remains structurally sound under simulated conditions more severe than expected from ground operations, launch, orbital operations and landing (ref. 1). There are basically three methods for strength qualification testing: acceleration testing, static load testing , and vibration testing. There are many issues to consider in deciding which method fits test item requirements the best. This paper will assume that vibration testing is not an option or will be used as a supplemental test. Therefore only static load and acceleration testing are considered.

Static Load Testing:

For static load testing the loads are applied at selected points in an effort to simulate some uniform load distributed over the entire structure. If desired, specific points may be selectively loaded while leaving others unloaded. At Goddard Space Flight Center (GSFC), static load testing requirements are implemented using hydraulic actuators that are attached to designated load application points on the test item, and controlled manually with a mechanical hand pump. The load is controlled by monitoring load cells and hydraulic pressure. Occasionally, load application points will be tied together and controlled by a single load line (one hydraulic actuator, one load cell). This method of testing works well in applying the required loads, but it can be very labor intensive in terms of test design, fabrication, and set up. For static load testing the test item remains fixed and the load source is moved to get the desired effect.

Acceleration Testing:

During acceleration testing the load is essentially uniformly distributed throughout the structure. This is accomplished by fixturing the test item on an acceptable centrifuge and allowing the centrifugal force to load the structure. An acceptable centrifuge has a large enough payload radius to minimize the centrifugal force gradient over the entire test item. Passive restraints are used to minimize damage in the event of a structural failure since the test item cannot be unloaded quickly at high speed (however, passive restraints have never been needed). Therefore, for acceleration testing the test item is fixtured and the resulting centrifugal force applies the proper load vector. In addition, at GSFC all facility fixturing for static load and acceleration testing is designed to a safety factor of three on the material yield strength, and proof tested to a factor of 1.5 on the maximum loading condition.

ADVANTAGES -Acceleration Testing:

- The structural load distribution is much more representative of the actual flight loading condition than a static load test.
- Problems with load application point identification and location go away since there is no load line attachment to the test item.
- Load application control and coordination is no longer an issue.
- Use of the innovative fixturing minimizes test reconfiguration time.
- The total cost of the test can be reduced since that an HCC test can be far less labor intensive than a static load test.
- Changes in the load vector can be easily accommodated.

ADVANTAGES -Static Load Testing:

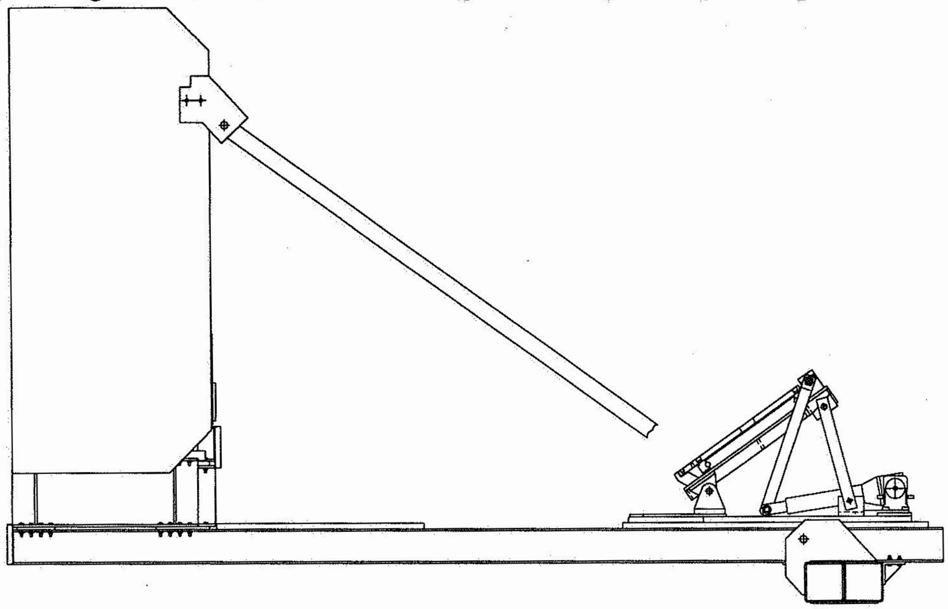
- If a problem arises the test item can be unloaded quickly.
- Particulate contamination is not a concern (a stirring of the air during acceleration testing has raised questions about particulate contamination, but it has never been a problem).
- The ability to apply a load to selected points while leaving other points essentially unloaded.

GENERAL INFORMATION:

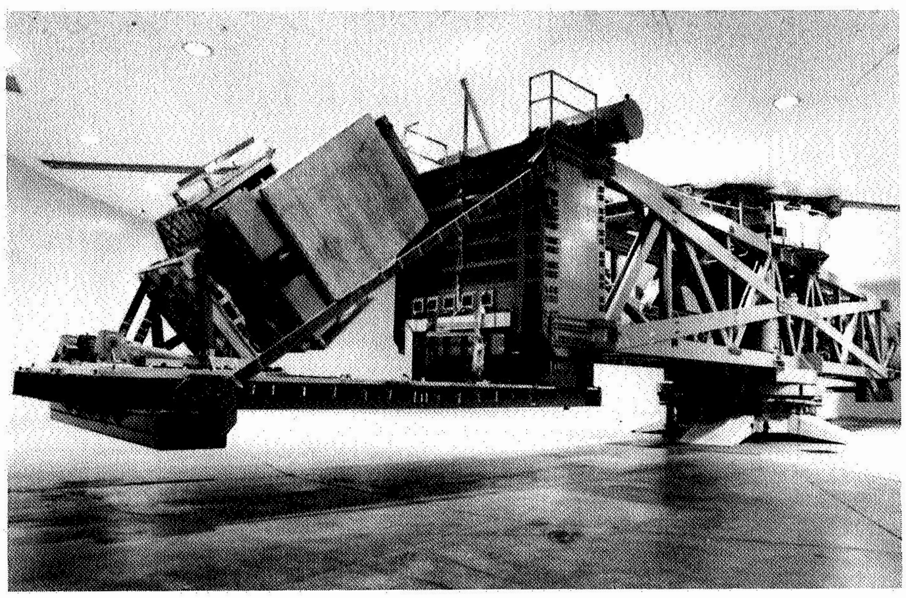
The High Capacity Centrifuge (HCC) is a Goddard Space Flight Center (GSFC) facility used to qualify aerospace structures for flight by subjecting them to a centrifugal force field.

- 38m (125 ft) diameter
- 18m (60 ft) nominal payload radius

- Powered by two 1250 HP DC motors
- Top speed of 38 rpm- 30 g's at the payload interface
- Designed to handle a moment of 846,000Nm (7,500,000 lb.in) or a shear load of 668kN (150,000 lb) at the platform interface.
- Instrumentation capability of 192 channels
- Large enough that the acceleration field gradient is generally not a problem.



The Goddard Space Flight Center High Capacity Centrifuge (HCC)
Test Platform

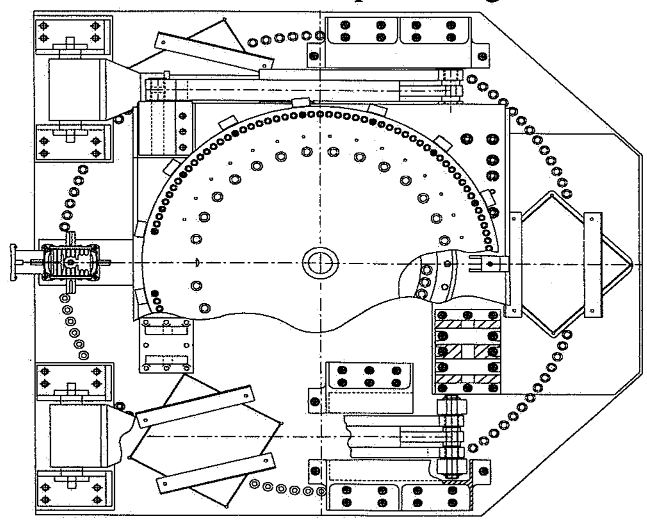


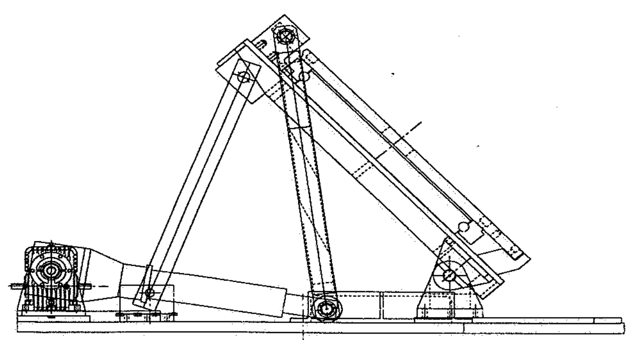
High Capacity Centrifuge-Overall View

FIXTURING

The Low Profile Tilt Fixture (LPTF) allows aerospace structures to be lifted and mounted vertically, secured and rotated into position. Subsequent reconfiguration to other load cases without unbolting and moving the spacecraft minimizes the handling risk and greatly reduces the reconfiguration time.

The LPTF allows three degrees of freedom. The first degree comes from rotating the entire payload tilt fixture assembly about the vertical axis via air bearings. This allows an inboard or outboard tilting attitude. The second degree of freedom is achieved by rotating the test item on the bearing mounted top plate, and the third degree is attained by tilting the top plate to the desired angle. Low profile comes from the fact that this fixture is less than 50cm (20 in) thick. The tilt fixture top plate is moved by two ball screw actuators coupled together and driven by an electric motor through a 60:1 gear reduction interface mechanism. Once the test configuration is achieved, custom stanchions are put into place to take the driving mechanism out of the load path during the test.





Low Profile Tilt Fixture

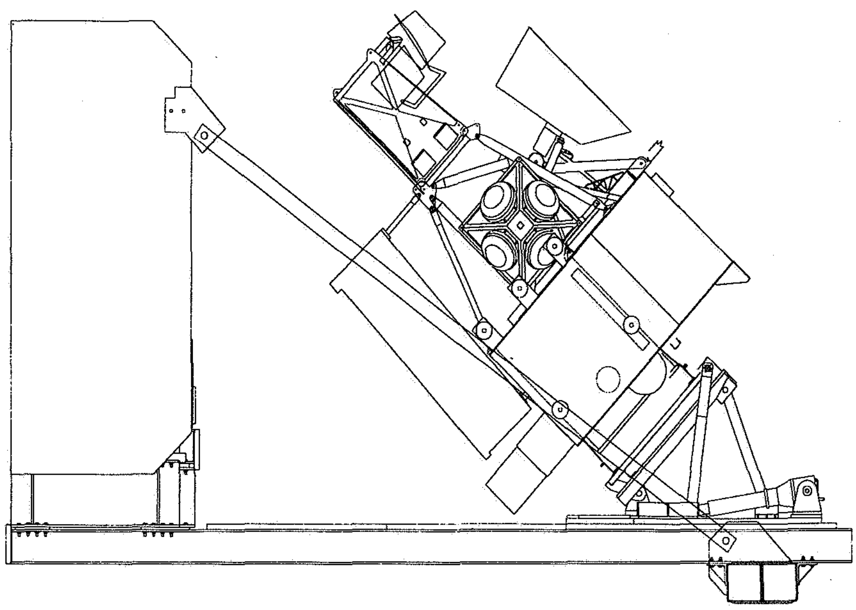
TEST CASES

Tropical Rainfall Measuring Mission (TRMM)

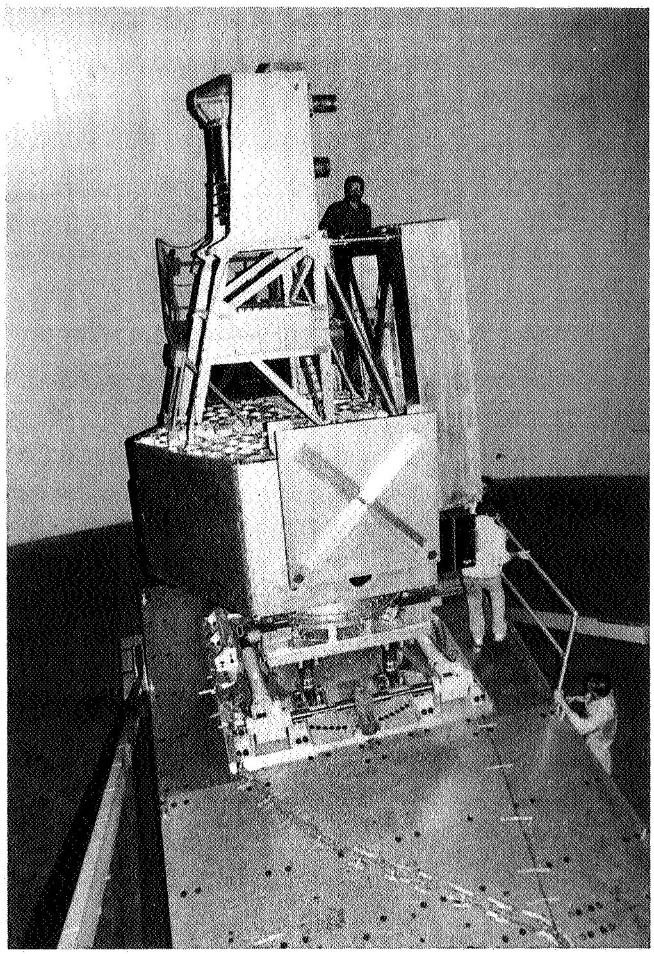
The TRMM spacecraft will be launched on a Japanese H-2 rocket in 1997.

TRMM is a large spacecraft structure at 3627kg (7980 lb) and a height of about 5m (17 ft) including a simulated internal fuel load of 909 kg (2000 lb). A feasibility study determined that an acceleration test was the most cost effective method of achieving the desired test loading. There were a number of difficult to access load application points on the spacecraft and dimensional restrictions on our Static Load Test facility that contributed to the acceleration testing decision. One of the most difficult loads to simulate was the internal spacecraft fuel load.

The load cases were performed in a sequence that allowed for the quickest turn around time between tests. Figures 1 and 2 show the TRMM Spacecraft on the HCC configured for testing. The inboard oriented load cases 1 and 3 were run at 19.60 rpm corresponding to a 7.28 g centrifugal force on the test item. Load case 2, oriented outboard was run at 13.94 rpm with a resultant 4.13 g loading.



TRMM Load Case #3
Fig. 1



TRMM Load Case #2
Fig. 2

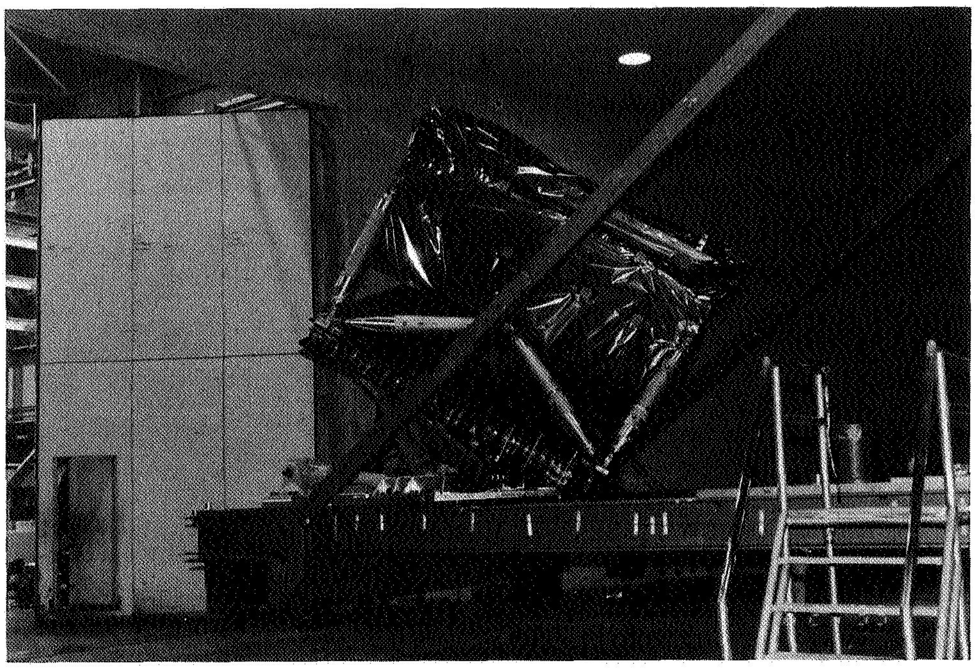
The TRMM spacecraft was instrumented with 93 strain gages, 4 string potentiometers, and 1 Linear Variable Differential Transformer (LVDT). Also, 3 accelerometers were mounted on the HCC platform at the TRMM Center of Gravity (C.G). location to obtain a direct measurement of acceleration vector components. In addition, 32 strain gages, 4 string potentiometers and 1 LVDT was mounted on the HCC structure itself. The allowable test tolerances were -5% to +1% on g load.

Initial test runs up to 40% of maximum load were done for the first two load cases to review the data and to remove any hysteresis. Data was acquired to disk and printed out at each load increment. Also, 20 channels were monitored and 6 others graphed in real time. The entire test was successfully completed in less than 4 days.

Hubble Space Telescope (HST) Axial Scientific Instrument Protective Enclosure (ASIPE)

The ASIPE will be used as a protective enclosure for an upgraded instrument on the upcoming second HST servicing mission.

This test required an unusual fixturing to simulate the load distribution of eight "load isolators" intended to act as shock absorbers during the launch environment. The ASIPE was tested on the HCC primarily because the instrument mass simulator was located inside the ASIPE and was inaccessible for the direct application of external forces. Acceleration testing afforded the ability to load the ASIPE internal instrument attachment points. In addition, the quick reconfiguration time resulted in a short overall test and completely eliminated the need for potentially hazardous load application hardware adjustments in close proximity to flight hardware. Figure 3 shows the HST ASIPE in one test configuration.



HST ASIPE
Fig. 3

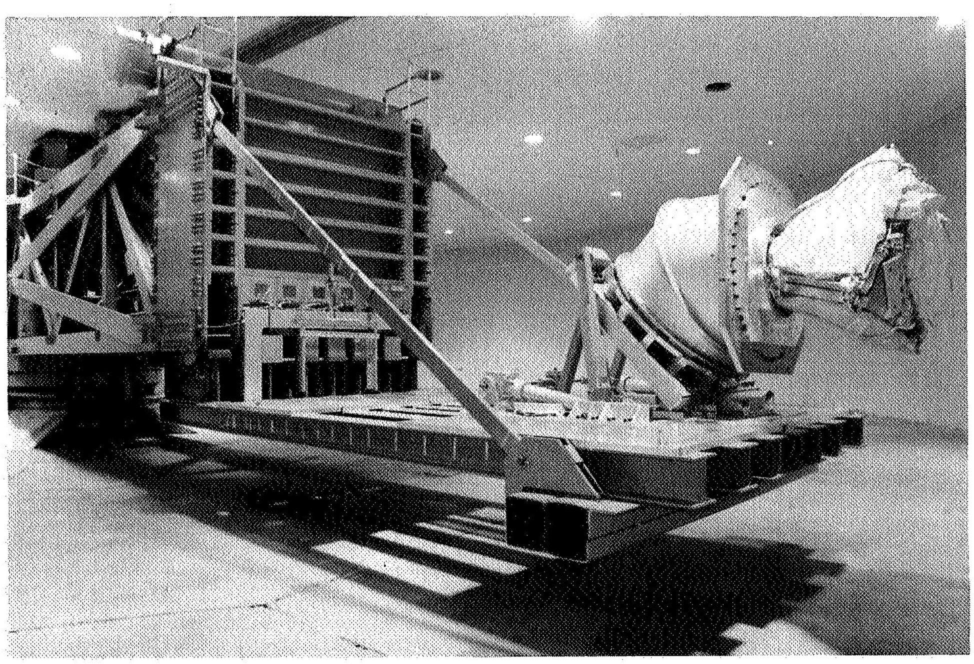
The two ASIPE test configurations both oriented inboard, were run at 18.96 and 19.40 rpm. The resulting centrifugal force was measured at 7.09 and 7.37 g's respectively. The ASIPE was instrumented with 88 strain gages; 32 evenly divided among the 8 struts, 16 on the clevises and 40 on the ASIPE. An LVDT was used to monitor movement and an accelerometer was mounted for a direct measurement of acceleration components. The weight of the ASIPE and struts was 887 kg (1930 lb) and the weight of the fixturing was 1803 kg (3968 lb) for a total test weight of 2690 kg (5898 lb).

Mars Pathfinder

The Mars Pathfinder will be launched in late 1996 and arrive on Mars in July 1997.

The complete test program from initial contact with the project until completion was accomplished in a total of 9 days. It would have been extremely difficult to design a static load test to meet the requirements in such a short time. The acceleration loads achieved during this test were the highest in recent experience (26g's). The Mars Pathfinder project was very interested in the acceleration effects on the stowed gas bags and restraint system. This information was unobtainable with conventional static load testing. Once all the test and interface requirements were known, the Pathfinder/facility interface hardware needed to be proof tested to 1.5 times the maximum test load. The LPTF allowed facility fixturing to the Mars Pathfinder quickly and between test reconfiguration without delay. The addition of a conventional tilt fixture to the LPTF gave the capability to attach the Pathfinder to the HCC in the vertical and configure for a 90 outboard run.

The test item weighed 227 kg (500 lb) and the fixturing an additional 993 kg (2185 lb) for a total test eight of 1220 kg (2685 lb). Figure 4 shows the Mars Pathfinder in the outboard test configuration. The inboard load case was run at 24.82 rpm resulting in an 11.6 g loading. The outboard case was run at 33.64 rpm and resulted in a 26 g loading.



Mars Pathfinder
Fig. 4

SUMMARY

The HCC is capable of simulating loading conditions which cannot be duplicated by conventional static load testing. Experience has shown that this method of strength qualification testing can be superior in terms of cost, test fidelity, and overall test completion time. Not all aerospace structures are candidates for centrifuge testing because of size, fixturing constraints, or other unique requirements. However, acceleration testing should not be dismissed without serious consideration.

References:

1. Milne, J. S., 1990, "General Environmental Verification Specification for STS Payloads, Subsystems, and Components," NASA Goddard Spaceflight Center p.1-5