



Environmental Test Laboratory

HESSI Spacecraft Incident - March 21, 2000

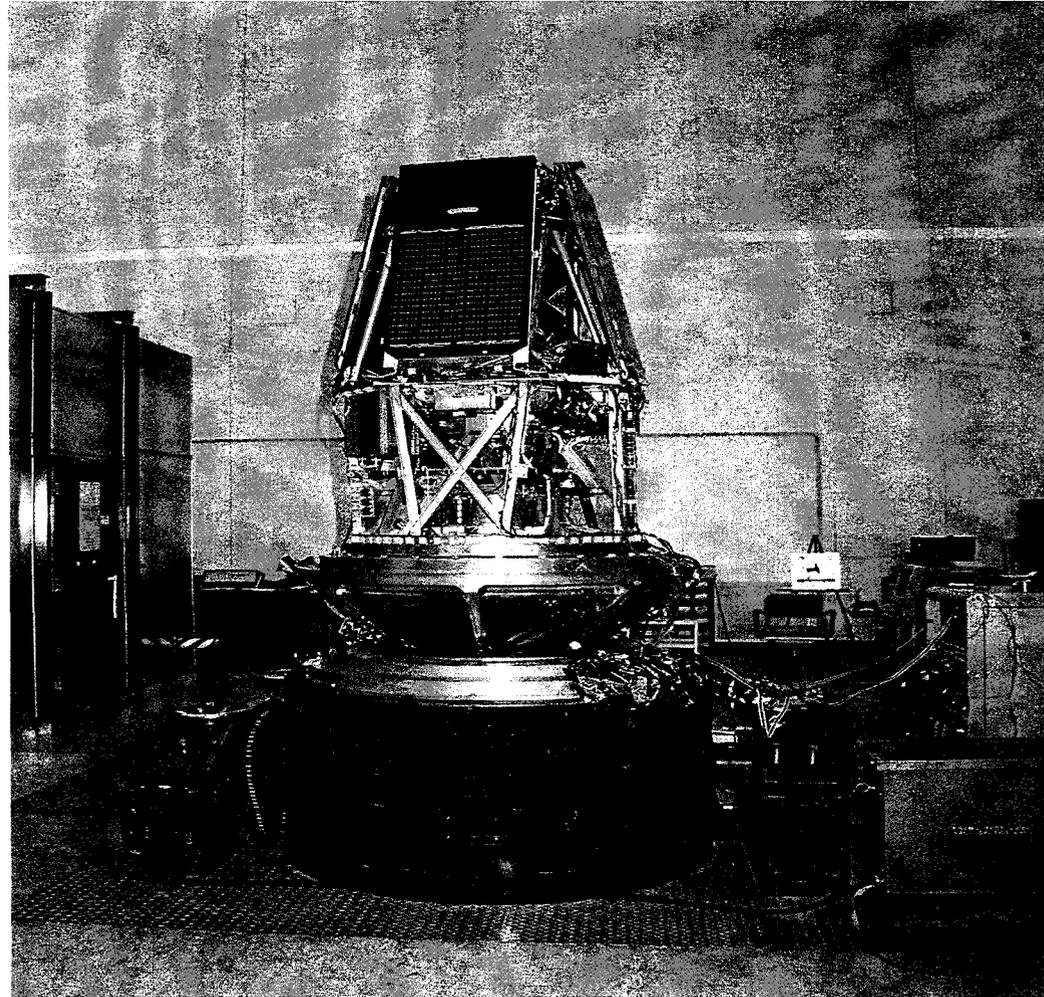
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HESSI Spacecraft

- The High Energy Spectroscopic Imager (HESSI) spacecraft primary mission objective is to explore the basic physics of particle acceleration and explosive energy release in solar flares. The HESSI spacecraft was scheduled for a July, 2000, launch on a Pegasus vehicle as part of the Small Explorer Program (SMEX). On March 21, 2000, the HESSI spacecraft was being subjected to a series of vibration tests at JPL as a part of its flight certification program. The structural qualification test, denoted as the sine-burst test, subjected the spacecraft to a major over-test that resulted in significant structural damage to the spacecraft. The incident was designated as a Class A mishap by NASA since the damage exceeded \$1 million

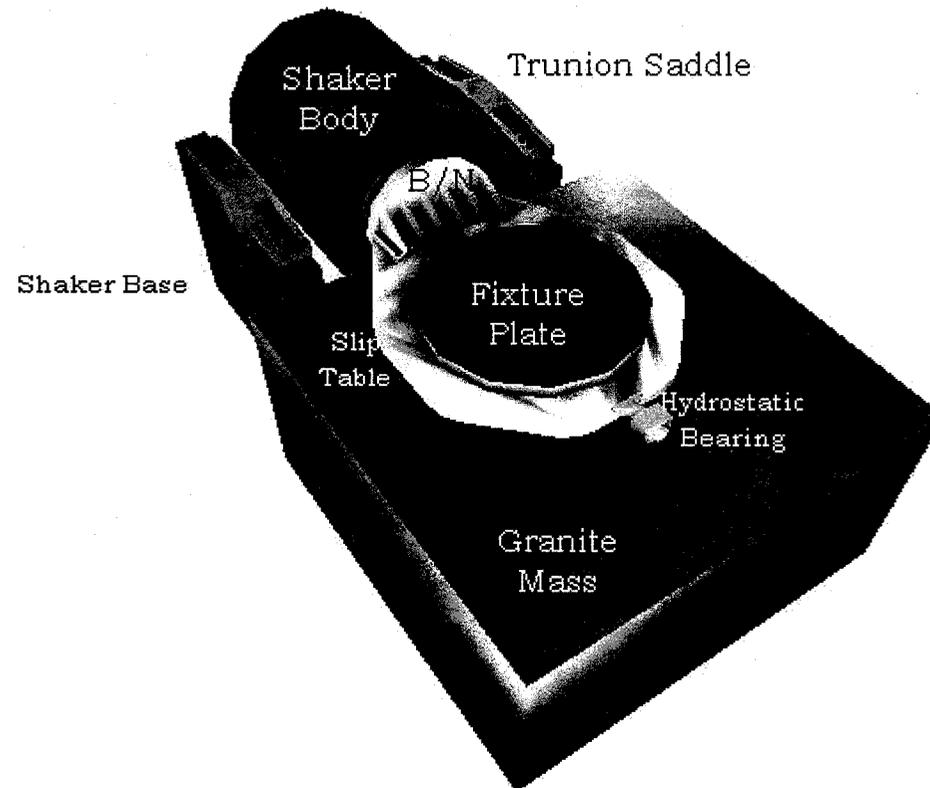
HESSI Spacecraft in Vertical Test Axis



HESSI Incident

- The HESSI Spacecraft was mounted on the Environmental Test Laboratory (ETL) Ling A-249 shaker slip-table for vibration testing
- During the sine burst test the shaker and spacecraft were driven at a higher level than programmed
- Cause of the HESSI Over Test
 - Slip table misalignment
 - Broken trunion bearing
 - Inadequate self-check resulting in a poor transfer function estimate

HESSI Test Set up



HESSI Spacecraft Damage

- +X and -X Solar Arrays damaged
- -Y Solar Array 3 solar cells damaged
- Imager Support Ring cracked
- Main Deck inserts damaged
- Solid State Recorder bracket bent
- Imager Cable Harness insulation abrasion

Recovery Plan

- Implement the “Recommendations” of the HESSI Mishap Investigation Board
 - Repair Ling 249 shaker and repeat the HESSI sine burst test, verifying adequate self-check and transfer function.
 - Develop and Validate Operational Procedures to perform the following:
 - Operate shaker/control system for all test scenarios using a test article mockup or mass simulator.
 - Validate and record all control functions such as amplifier gain, programmed self-check level, signal integrity, drive signal, and transfer function where applicable.
 - During conduct of a sine burst test verify adequate self-check and transfer function before proceeding.

Recovery Plan (Continued)

- Investigate possible internal and external safety controls for Sine-Burst testing
- Develop procedures for validating self-checks
- Replace the 40+ year old Ling vibration test system
 - Proposed FY03 CoF Project (NASA Funded)
 - Obtain FY01 Infrastructure Funding if possible

What to Expect from an Investigation Board

- The Mishap Investigation Board will be made up of experts in many different fields
- The board will require that the test configuration not be disturbed until they can assemble their team and observe the scene of the incident
- The board will conduct oral interviews with all participants and witnesses
 - All statements will be typed by the board's secretary and will be signed
- The board will review all facility maintenance and repair records

What to Expect from an Investigation Board

- The board will review all personnel training records
- The board will inquire about past problems and failures with the equipment and facility
- Each board member will review the mishap and surrounding conditions from their own field of expertise, i.e, mechanical, QA, electrical, thermal, safety
- The board will issue findings, constraints to return to operations and corrective action recommendations

Mishap Investigation Board Report

- Definitions
 - A finding is a conclusion based on facts established during the investigation by the investigating authority.
 - The root cause of a failure is the mechanism that directly caused the mishap.
 - Contributing factors are events or conditions that if identified, could have been used to prevent the mishap.
 - Observations are items that did not directly affect the mishap but could potentially cause a mishap or subject the flight hardware to undue risk.
 - Recommendations are included for each contributing factor and observation.

Mishap Investigation Board Report

- **Finding:** The HESSI spacecraft was subjected to a significant sine-burst overttest condition that resulted in damage to the spacecraft. Stiction (static friction) between the granite reaction mass and the slip plate of the shaker-system combined with a self-check performed at very low force input levels resulted in the calculation of an inappropriate drive signal. The resulting pulse was significantly higher in amplitude than expected, thus yielding the subject overttest.

Root Cause: Stiction caused by misalignment of the shaker and slip table was the root cause of this mishap.

Mishap Investigation Board Report

- **Contributing Factors:**

- Misalignment caused the slip table to exhibit non-linear behavior in that it would bind at low levels of force input.
 - *Recommendation:* Develop metrics for routinely assessing the mechanical “health” of the shaker and slip table systems. This would include mechanical measurements as well as periodic test runs of the system under defined input levels. This data could be compared to the same data from previous measurements to identify any changes to the test setup that might cause an improper test condition.

Mishap Investigation Board Report

- **Contributing Factors (Continued):**
 - The test personnel did not have knowledge that data was available to assess the quality of the transfer function calculated from the self-check prior to initiating the sine-burst test.
 - *Recommendation:* Additional steps should be added to the test procedure for sine-burst and shock testing to review the transfer function and calculated drive voltage after the completion of the self-check and prior to initiating the sine-burst test. While it is not possible to set absolute standards for the transfer function and drive voltage values, as a minimum this data should be reviewed to ensure that the results are consistent with similar data from previous tests and/or a validation test for sine-burst and shock.

Mishap Investigation Board Report

- **Contributing Factors (Continued):**
 - A facility validation test using the sine-burst on the shaker table was not conducted before the spacecraft was mounted.
 - *Recommendation:* Prior to arrival of the test article, all proposed tests should be simulated using levels which replicate as closely as possible the expected test input conditions. The validation test should be done in such a way as to closely replicate actual test conditions. Control software setup, amplifier gains, control charge amplifier settings, self-check amplitude, test hardware gravity loading and any unique conditions that affect the response of the system should all be representative of the actual test conditions.

Mishap Investigation Board Report

- **Contributing Factors (Continued):**
 - The shaker, a Ling A-249, shifted in its support cradle after being coupled to the slip table in preparation for this test. The shift resulted in a misalignment that brought one area of the slip plate into contact with the granite reaction mass creating a much larger frictional drag than normal.
 - *Recommendation:* Refurbish or replace the Ling Model A-249 shaker.

Mishap Investigation Board Report

- **Contributing Factors (Continued):**
 - The self-check used for this test was at a very low level.
 - *Recommendation:* Perform self-checks at appropriate levels such that the transfer functions at various amplitudes can be compared for linearity

Mishap Investigation Board Report

- **Observations:**
 - The sine-burst test setup does not currently include independent over-test protection methods, such as a trip circuit based upon acceleration or displacement limits. By contrast, the random vibration test includes redundant control accelerometers, acceleration trip circuits, and a third monitor accelerometer..
 - *Recommendation:* JPL shall implement overtest protection methods for sine-burst testing. Protection methods for this type of testing have been satisfactorily implemented at other NASA test facilities.

Mishap Investigation Board Report

- **Observations (Continued):**
 - The HESSI project was not fully aware of the risks associated with the sine-burst testing.
 - *Recommendation:* Projects electing to perform sine-burst testing at the “all-up” spacecraft level should be made aware of the risks associated with this approach. Strength qualification, especially using the sine-burst test method, should be performed at the lowest level of assembly as possible to eliminate the risk of damaging sensitive flight components.

Mishap Investigation Board Report

- **Observations (Continued):**
 - The sine-burst frequency was not specified in the test plan. As indicated in the test plan, the frequency was selected after reviewing the sine sweep test data.
 - *Recommendation:* A sine-burst frequency should be included in the test plan. This will support the conduction of an accurate validation test. This frequency selection should be made using the best structural analysis model available at the time. While the behavior of the actual structure may differ from the analytical model, the differences should not be significant enough to negate the validity any pre-test simulation of the sine-burst test by the test facility. In addition, selecting the sine-burst frequency in advance of the test allows for more time to weigh all factors in selecting the appropriate test frequency.

Mishap Investigation Board Report

- **Observations (Continued):**
 - The following three observations address concerns with the JPL test procedures and their execution:
 - (1) It is currently JPL practice to allow the Project Representative to determine if an independent check is required to verify that all critical steps have been completed prior to conduct of a test.
 - *Recommendation:* JPL should reassess their policy that permits the omission of critical checks that are intended to reduce or preclude the potential of single point errors that could damage or destroy high value or critical hardware.

Mishap Investigation Board Report

- **Observations (Continued):**
 - (2) The written test procedure for the HESSI sine-burst test did not include the critical steps of turning on the low pressure and high pressure oil pumps. It should be noted that everyone involved in this test is quite certain that the pumps were turned on and as a result did not contribute to the test anomaly.
 - *Recommendation:* These steps should be added to the procedures critical step list. In addition, the incorporation of system interlocks that would prevent running the table without the pumps turned on should be considered.

Mishap Investigation Board Report

- **Observations (Continued):**
 - (3) The written procedures generally did not have full coverage of the pretest setup and post-test teardown phases of the process.
 - *Recommendation:* Expand the written procedures to fully cover the pretest and post-test phases for flight hardware testing. This should include all electrical, fluid and data hook-ups.

Mishap Investigation Board Report

- **Observations (Continued):**
 - The flight hardware, while in the JPL test facility, was not consistently protected against inadvertent mishaps to the same level as JPL in-house projects.
 - *Recommendations:* JPL should assure their equipment is being used in a safe manner and all flight hardware is adequately protected.

Mishap Investigation Board Report

- **Lessons Learned:**
 - Test facilities must be maintained such that the test equipment is in good working order. Metrics must be developed and tracked that assess the mechanical health of the systems.
 - “Canned” tests should be developed and periodically utilized to provide a trended database for the test systems’ response. Any deviations in the system response should be investigated.
 - Critical control system response data such as the transfer function or inverse transfer functions, and calculated drive voltage must be evaluated real-time during testing to ensure that they are reasonable and do not indicate system maladies.

Mishap Investigation Board Report

- **Lessons Learned (Continued):**
 - **Facility validation test should be done for each planned test series that are representative of the actual test conditions before flight or critical hardware is mounted.**
 - **Self-checks should be done that provide a representative response for the forcing range of the planned test. For higher force shock tests, shaker systems and test fixtures often do not respond in a linear fashion. It is also foolhardy to assume that test facilities are always in perfect working order.**
 - **All test requirements should be defined in the test plan for a particular test. The test operators must have adequate data to enable complete verification testing before testing critical hardware.**