NASA ENGINEERING NETWORK

Lesson Info:

- **Lesson Number:** 1089
- **Lesson Date:** 1992-05-29
- **Submitting Organization:** GSFC
- **Submitted by:** Ronald J. Ploszaj / Eric Raynor

Subject:

TOPEX/POSEIDON Spacecraft Handling Anomaly Special Review Board Final Report of May 29, 1992

Abstract:

Support equipment was damaged during a lift because the fixture assembly used for lifting the spacecraft into the thermal vacuum chamber was unstable in the TOPEX/POSEIDON configuration.

The lesson provides 7 recommendations involving the need for stability analysis, formal mechanical GSE design reviews, peer review of lifting fixture design, high fidelity dry runs, and involvement of host center personnel.

Description of Driving Event:

On Sunday March 8, 1992 the TOPEX/POSEIDON Spacecraft was being prepared for thermal vacuum (T/V) testing by a test team in Building 10 of the Goddard Space Flight Center (GSFC). As part of the procedure, the T/V Fixture Assembly consisting of the spacecraft, thermal test shrouding and instrumentation mounted on the Spacecraft Horizontal Support Structure (SHSS), suspended by four vertical cables from an H-frame spreader bar was lifted and positioned above the T/V chamber. At approximately 11:25 a.m., during final north / south crane positioning maneuvers, the suspended assembly began a slow overturning rotation. The assembly rotated approximately 135 degrees from horizontal before being halted by the entanglement of one of the four suspension cables with the SHSS. After some bouncing and jostling, it came to rest at approximately 115 degrees.

While resting in this anomalous position (+X end up), the Test Team visually determined that the H frame spreader bar assembly had sustained considerable damage during the rotation and might fail. A decision was made by the Spacecraft Manager to remove the vertical load from the overstressed and damaged H frame spreader assembly as quickly as possible by lowering the spacecraft and test fixture to the chamber floor. Within ten minutes of the overturning incident the Test Team, augmented by personnel from a GSFC contractor, lowered the rotated assembly to the chamber floor where it was temporarily secured. During the subsequent visual inspection of the secured assembly it was noted that sections of the thermal test shroud and support fixturing had partially yielded. However, no apparent damage to the spacecraft or to the lower frame of the SHSS could be seen.

An on site "failure review board" of civil servant and contractor personnel was convened to review and discuss the situation. A decision was made by the board that the Spacecraft/SHSS assembly should be removed and reoriented to a horizontal position outside of the chamber to minimize any further yielding of the supporting structures. A rigging crew was on the scene at this time, and was given the go ahead by the board to proceed with the removal of the Spacecraft/SHSS assembly from the chamber.

The damaged H-frame spreader bar and the four suspension cables were removed. A pair of nylon slings were attached from the +X end of the SHSS to the crane hook and the Spacecraft/Thermal Shroud/SHSS assembly was raised vertically out of the T/V chamber and moved directly adjacent to it. The assembly remained there suspended a few inches above the floor while the team attached additional slings from the -X end of the SHSS to a forklift positioned on the -Z side of the load. By alternating operations of the crane and the forklift, the spacecraft and fixture were reoriented horizontally and lowered to the floor. At approximately 6:51 p.m. the operation was completed with the Spacecraft/SHSS assembly safely on the floor in the normal attitude. A video recording of both the anomaly and the recovery operation was made and is available from the TOPEX Project office for viewing.

Lesson(s) Learned:

Root Cause of Problem:

The T/V Fixture Assembly used for lifting the spacecraft into the thermal vacuum chamber was unstable in the TOPEX/POSEIDON configuration.

Contributing Factors:

1. A stability analysis of the total lifted assembly that was used in the T/V lift was not performed.
2. The lifting fixture guidelines contained in JPL900-501, Ground Handling Equipment Design Notebook were not adequately applied.
3. A GSE Review which would have included a review of the T/V handling fixture assembly, was repeatedly postponed, and not held prior to its use for lifting the spacecraft into the T/V chamber.

Additional Observations:

1. The overall review process, at all levels (peer review to formal review) failed to identify the lifting fixture deficiency.
2. No precursor run through (dry run) of the T/V lifting exercise, using either the actual or a high fidelity simulation of the lifted assembly, was run prior to the lift with the flight spacecraft. There was a low fidelity dry run with the TOPEX/POSEIDON handling fixture, but it was performed without a spacecraft mass simulation and at different locations and orientations than the flight spacecraft handling. (The stated purpose for the dry run was to check the SHSS and thermal shroud interfaces and clearances to the T/V chamber, not to dry run the actual spacecraft lift.)
3. Just prior to the final crane move, the T/V Fixture Assembly was lifted by the crane and a "rocking test" was performed on the assembly by the test team to assess its stability. The T/V Fixture Assembly appeared to be stable at that time because the lifting clevis friction was not exceeded during the rocking test.

Lessons Learned:

1. GSE Review - Ground support handling equipment should always be reviewed/approved by experienced designers and handling personnel prior to handling operations.
2. Review material - Released drawings, analysis, and procedures for handling equipment should be available for review at least 60 days before a test to permit adequate evaluation.
3. Lifting Equipment Stability Analysis - No lifting equipment should ever be used without a complete stability analysis of the equipment with the load in its complete configuration.
4. Precursor Handling Experience - On protoflight spacecraft, the only precursor handling experience is with a dry run and mass mockups. The mass mockups handling dynamics, geometries, and sequences used for the dry run should simulate the protoflight spacecraft. Analysis and procedural checks are not always adequate to ensure surprises won't occur.
5. Project overview of contract - Project support from the cognizant JPL (or other NASA Center) divisions should ensure, for the area of overview of their organization, that the contractor is adhering to all applicable requirements. All contractual documents (such as JPL 900-501) relating to potentially hazardous operations should be clearly identified and should receive special attention.
6. Dedicated Briefing - A detailed and dedicated briefing structured to review the wording, text, diagrams, etc. is also a mandatory part of any functional demonstration. This briefing serves to inform the personnel who may not have had the opportunity to read or review the written material or see the diagrams, etc. More importantly it is an opportunity for anyone who does not understand his assignment to have a clarification. If there are any reservations with regard to the technical approach of the upcoming activity this forum is the place to discuss them.
7. Functional Demonstration - A functional demonstration of all critical lifts, handling or maneuvers should be performed just prior to any event involving flight hardware. It may be judged too costly or redundant to a detailed procedure, but the value of such an exercise is particularly worthwhile if a high value item such as a one of a kind spacecraft is involved.

The actual demonstration (dry run), will reveal discrepancies in the written procedure. When the procedure lacks detail, the demonstration affords the opportunity to try out, or practice, different variations to the step-by-step approach. The unwritten or unspoken, yet implied instruction must be practiced and executed by the actual personnel involved. Where coordinated actions are required the exercise will help assure that everyone has the same response and timing to obtain the same end result.

An exact physical and mass mock up would be an ideal item to use for the demonstration, but it is rarely a possibility because of resource or other limitations. The importance of the duplication of the center of gravity with a mass mock up is self evident. The interface points or pickup points of the load can usually be replicated or borrowed from the flight article. However, in no case should they be overloaded or mispositioned from the designated lifting pattern. All shackles, rings, slings, chains, and everything in the load line should be assembled from a sketch or a pictorial equivalent in the procedure which identifies each item as to capacity, size or other details. All parts should carry a dated tag stating the level of proof load sustained, and witnessed by the appropriate project official. Loadlines should not be torn down after a proof or demonstration load test to the levels and conditions stated in the procedure. If a partial tear down is required, the exact reassembly must be assured. This is particularly important with multiple joint assemblies using what appears to be identical hardware, but may have different loadings. Clevis pins must never be mixed from assembly to assembly. One final note on the load line drawings. It has been shown on numerous occasions that the facility does not fit the load line or vice versa even though everyone's opinion was to the contrary. It is prudent to include key dimensions on the load line sketch for later use.

8. Tilt Angle Requirements - Although it did not contribute to the TOPEX overturning incident, the yielding of the spreader bar at a tilt angle of only 8 degrees to 10 degrees raises an important point. Historically, there has been no design requirement for lifting equipment to tolerate a specified tilt angle. Lifting equipment requirements should be revised so the usual safety factors must be met at a specified, tilt angle.
9. Host Center Review of Hazardous Procedures - Host center personnel should perform a review of all hazardous

procedures/operations planned by outside user organizations. In addition, development of requirements for advance notification of the host center safety organization of the expected date and time of the actual performance of each hazardous operation should be considered.

10. Video Recording of Hazardous Operations - All hazardous operations should be video recorded. The video recording of the overturning anomaly and the preceding and following activities was extremely helpful in the investigation and evaluation of this incident. Since mishaps may also occur during normal operations, consideration should be given to video recording all operations involving unique high value equipment. Use of inexpensive, off-the-shelf video cameras and recorders would permit very economical routine video recording of all activities
11. The TOPEX/POSEIDON overturning incident had the potential for being classified as a NASA Type A Mishap. Only a series of uncontrolled, but fortunate occurrences prevented this from initially being a much more serious anomaly with severe consequences.

Major damage to both the spacecraft and the T/V chamber were avoided only because the T/V Fixture Assembly was lifted higher than necessary to clear the lip of the chamber. This was done in the erroneous belief that the higher lift (shorter crane to assembly distance) would improve stability by reducing swaying of the load. If the lift had been at the same height as the dry run, the T/V Fixture Assembly might have struck the chamber lip during the rollover resulting in major damage to both the Spacecraft and the chamber. The H-Frame spreader bar was severely damaged, and probably would have failed completely if one of the suspension cables had not snagged on one of the upper SHSS clevis lugs. Complete failure of the spreader bar would have dropped the 8000 pound load approximately equal to 40 feet to the floor of the T/V chamber, destroying both the Spacecraft and the chamber.

The Spacecraft fortuitously rolled with the -X side down, where a significant amount of GSE structure was mounted. If the Spacecraft had rotated with the +X side down (or if it had fully inverted) placing it on the floor of the T/V chamber to relieve the loads on the H-Frame spreader bar might not have been possible without significant additional damage to the spacecraft.

Following the anomaly only the quick and professional response of the test team and contractor personnel prevented further (and potentially severe) damage to the Spacecraft and chamber facility.

Recommendation(s):

FINDINGS AND RECOMMENDATIONS

Root Cause of Problem.- The T/V Fixture Assembly used for lifting the spacecraft into the T/V chamber was unstable in the TOPEX/POSEIDON configuration.

Contributing Causes

1. Lack of Stability Analysis - A stability analysis of the total T/V Fixture Assembly (T/V Lift Fixture, Cables, SHSS, Satellite, supporting thermal shrouds, and instrumentation) was not performed, reviewed, or approved prior to the overturning incident.

Recommendation: A Stability analysis must be performed on all lifting devices in all lift configurations and must be repeated with each new application assigned. A stability factor of 1.5 or greater should be analytically demonstrated to cover possible differences between analysis and the actual lifted assembly. The stability analysis should be treated as a formal mandatory item in the same manner that stress analysis is addressed.

2. Inadequate Stability Testing - Stability testing was done during the proof loading tests of the lifting fixture, and again with the complete T/V Fixture Assembly. Because the impact of clevis friction was not taken into account, neither of these tests revealed the underlying instability. The two "rocking" tests were not analyzed for their adequacy in determining fixture instability.

Recommendation: Detailed review of all elements of planned testing must be done to assure the testing will accomplish the goals of the test. Stability analysis of lifted assemblies should be done whether or not stability testing is planned. This analysis is essential to determine the need for and the adequacy of any stability testing.

3. Continued Postponement of GSE Review - A GSE Review which would have included a review of the T/V Fixture Assembly was repeatedly Postponed, and not held prior to use of the Assembly for lifting the spacecraft into the T/V chamber. (In preparation for thermal vacuum testing an Environmental Test Readiness Review was held November 20-21, 1991. There was one page that addressed the entire mechanical GSE in the review documentation. This page was simply a listing of the mechanical GSE and its status.) A supplemental handout available at the November 20, 1991, Environmental Test Readiness Review (ETRR) included an assembly drawing of the lift configuration, but the drawing reproduction did not clearly show the cable attach points. A viewgraph of the lift configuration drawing was not shown at the ETRR. However, it was shown at the previous Monthly Status Review (MSR).

Recommendation: Formal mechanical GSE design reviews must be held to assure adequate design evaluation of the proposed lifting configurations. Discussions must include a detailed review of the proposed drawings and procedures for

specific attach points, stability analyses, direction of motion, and expected accelerations for all moves.

4. Lack of Designer Experience and Peer Reviews - The Principal Engineer was not familiar with stability analysis of lifting fixtures for loads lifted below the C.G. and did not follow the lifting fixture guidelines contained in JPL900-501, Ground Handling Equipment Design Notebook. Furthermore, no peer review, internal contractor review, or project review of the total T/V Fixture Assembly occurred. The review process failed.

Recommendation: Accepted guidelines should be followed in the design of all lifting fixtures. This is especially true when the designer has not designed a lifting fixture before and is unfamiliar with the shortfalls of various lifting fixture configurations. In all cases, a review of the design and margins should be held with peers and supervision to assure the design meets all requirements. A checklist which includes all aspects of the design e.g., stability, loads analysis, proof loading, etc. should be developed.

GSE Project reviews should be held and attended by personnel who are capable of assessing the adequacy of the design being reviewed.

5. Lack of Functional Demonstration - A functional demonstration (dry run) of the chamber lift activities was not performed prior to the incident. However, a lift of the T/V Fixture Assembly (without the spacecraft) was done earlier for a form fit of the SHSS and thermal shrouds. There were significant, differences in C.G., fixture alignment, and personnel assignments between this lift and the actual spacecraft lift.

Recommendation: A high fidelity dry run, using the lifting fixture with the proper mass and C.G. simulator and following the procedures that will be used for the actual lift should be conducted. A formal briefing before the dry run and debriefing after the dry run of the personnel involved should be made for all high value one of a kind spacecraft and equipment.

On protoflight spacecraft, the only precursor handling experience is with a dry run and mass mockups. The mass mockups handling dynamics, geometries, and sequences used for the dry run should simulate the protoflight spacecraft. Analysis and procedural checks are not always adequate to ensure surprises won't occur.

6. Lack of Host Center Review of Hazardous Operations Procedures - The host center (GSFC) did not review the hazardous procedures/operations planned by the outside user organizations. Also the GSFC did not require advance notification of the Center Code 205 or 302 safety organizations of the expected date and time of the actual performance of each hazardous operation.

Recommendation: Host center personnel should be required to review all hazardous procedures/operations planned by outside user organization. Host center personnel are much more familiar with the characteristics (and quirks, if any) of their equipment and facilities. Also, they are more likely than the visiting organization to be highly experienced in the type of operations involved. A requirement for formal Host Center "Buy-Off" (signature of concurrence) would help ensure proper visibility and attention to hazardous procedures/operations.

In addition, the development of requirements for advance notification of the host center safety organization of the expected date and time of the actual performance of each hazardous operation should be considered. Advance notification would allow the safety organization the option of monitoring or witnessing selected hazardous activities and ensuring that all internal and external safety requirements are being satisfied.

7. Remaining Spacecraft Handling Operations: At this time the T/V spacecraft handling equipment has been redesigned, tested, analyzed, reviewed and used to move the spacecraft back into the T/V Chamber.

Recommendation: The TOPEX Project must examine and approve the stability analysis for all remaining handling configurations, including those at the launch site. A GSE review should be conducted for all remaining handling operations as soon as possible.

Evidence of Recurrence Control Effectiveness:

N/A

Documents Related to Lesson:

N/A

Mission Directorate(s):

- Science

Additional Key Phrase(s):

- Administration/Organization
- Environment
- Facilities
- Flight Equipment
- Flight Operations
- Ground Equipment
- Ground Operations
- Hardware
- Hazardous/Toxic Waste/Materials
- Industrial Operations
- Lifting Devices
- Logistics
- Mishap Reporting
- Packaging Handling Storage
- Payloads
- Policy & Planning
- Spacecraft

Approval Info:

- **Approval Date:** 2002-02-12
- **Approval Name:** Jay Liebowitz
- **Approval Organization:** GSFC
- **Approval Phone Number:** 301-286-4467