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Shuttle Ground Support Equipment (GSE) T-0 Umbilical to Space Shuttle Program (SSP) Flight Elements Consultation

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January 11, 2007

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- A. ITA/I Request Form (NESC-PR-003-FM-01)
- B. NESC White Paper, *Review of the Space Shuttle T-0 Interface Anomaly Resolution*, 23 Mar 05
- C. NESC Presentation to Shuttle Program Requirements Change Board, *GSE T-0 Umbilical to SSP Flight Elements Assessment*, 31 Mar 05
- D. *Space Shuttle T-0 Umbilical Dynamic Displacements and Forces*, Rocketdyne, 22 Aug 05
- E. Report Q50299FA, *Connector Failure Analysis*, Goddard Space Flight Center Parts Analysis Laboratory
- F. *GSE T-0 Umbilical to SSP Flight Elements Assessment Project Status*, 13 Oct 06
- G. Quad-redundant Failure Analysis

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Volume I: Technical Consultation Report

1.0 Notification and Authorization

The request to conduct a real-time consultation was submitted to the NASA Engineering and Safety Center (NESC) by the NASA Associate Administrator for Safety and Mission Assurance on March 17, 2005. The T-0 umbilical to Space Shuttle Program (SSP) flight elements assessment was approved by the NESC Director in an out-of-board action on March 17, 2005. The NESC previously participated in T-0 review activities while conducting the Space Shuttle Recurring Anomalies assessment (Part I), and this activity is summarized in NESC report RP-05-10, Appendix B.8 [ref. 4].

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3.0 Team List

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4.0 Executive Summary

The NASA Engineering and Safety Center (NESC) was tasked with assessing the validity of an alternate opinion that surfaced during the investigation of recurrent failures at the Space Shuttle T-0 umbilical interface. The most visible problem occurred during the Space Transportation System (STS) -112 launch when pyrotechnics used to separate Solid Rocket Booster (SRB) Hold-Down Post (HDP) frangible nuts failed to fire. Subsequent investigations recommended several improvements to the Ground Support Equipment (GSE) and processing changes were implemented, including replacement of ground-half cables and connectors between flights, along with wiring modifications to make critical circuits quad-redundant across the interface. The alternate opinions maintained that insufficient data existed to exonerate the design, that additional data needed to be gathered under launch conditions, and that the interface should be further modified to ensure additional margin existed to preclude failure.

The NESC reviewed the data gathered during the various investigations, including the results of vibration tests and a finite element analysis performed by the Space Shuttle Program (SSP). Four initial recommendations were documented in a white paper released March 23, 2005 (see Appendix B). These focused on implementing hardware and process control improvements, changing interface assembly procedures to increase the force margin on the mated interface connection, collecting data to anchor the finite element models, and performing a high-fidelity system-level test of an assembled interface connector to establish the design margin. In lieu of the system-level test, the NESC undertook a follow-on effort to expand the finite element analysis the SSP had already performed. Failure analysis of GSE cabling removed from the T-0 interface was also conducted and an independent risk assessment performed.

The expanded finite element analysis indicated that sufficient margin existed at the interface and the failure analysis was successful at duplicating a corrosion-induced intermittent electrical failure. Consequently, the NESC concurred with launching STS-114 and subsequent vehicles with no redesign of the T-0 interface.

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5.0 Consultation Plan

The scope of this consultation was initially limited to a review of the documentation and test and analysis results collected in conjunction with the STS-112 T-0 interface failure investigation [ref. 1 through 9]. The scope was later expanded to include additional modeling of the T-0 interface, failure analysis of a T-0 interface cable including testing to duplicate a corrosion-induced intermittent connection, and an independent risk assessment. Boeing-Rocketdyne performed the initial T-0 modeling work in support of the SSP and was contracted by the NESC to perform the expanded analysis [ref. 10]. The T-0 cable failure analysis was undertaken by the Goddard Space Flight Center (GSFC) [ref. 11]. The risk assessment was performed by Dr. K. Preston White of the University of Virginia [ref. 12].

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6.0 Problem Description and NESC Initial and Follow-On Activities

6.1 Problem Description

The T-0 umbilicals provide fluid and electrical connections between the Shuttle Orbiter and the ground. One umbilical on the left-hand side of the Orbiter aft carries liquid hydrogen (LH₂) and related fluid lines along with a set of electrical connections. One umbilical on the right-hand side carries liquid oxygen (LO₂) and a second set of electrical connections. Connectors on each side pass through a ground-side umbilical carrier plate and mate to flight-half connectors on an Orbiter-side plate. The umbilicals are disconnected at launch by commands from the Orbiter Primary Application Software Set (PASS) through General Purpose Computers (GPC). Redundant (Systems A and B) signals across the LH₂ and LO₂ interfaces also arm and fire pyrotechnic charges that release the SRB HDP frangible nuts and disconnect the External Tank Vent Arm System (ETVAS). Refer to Figures 6.1-1 and 6.1-2. The LH₂ side T-0 interface is depicted in Figure 6.1-3 and a typical electrical connector assembly is depicted in Figure 6.1-5.

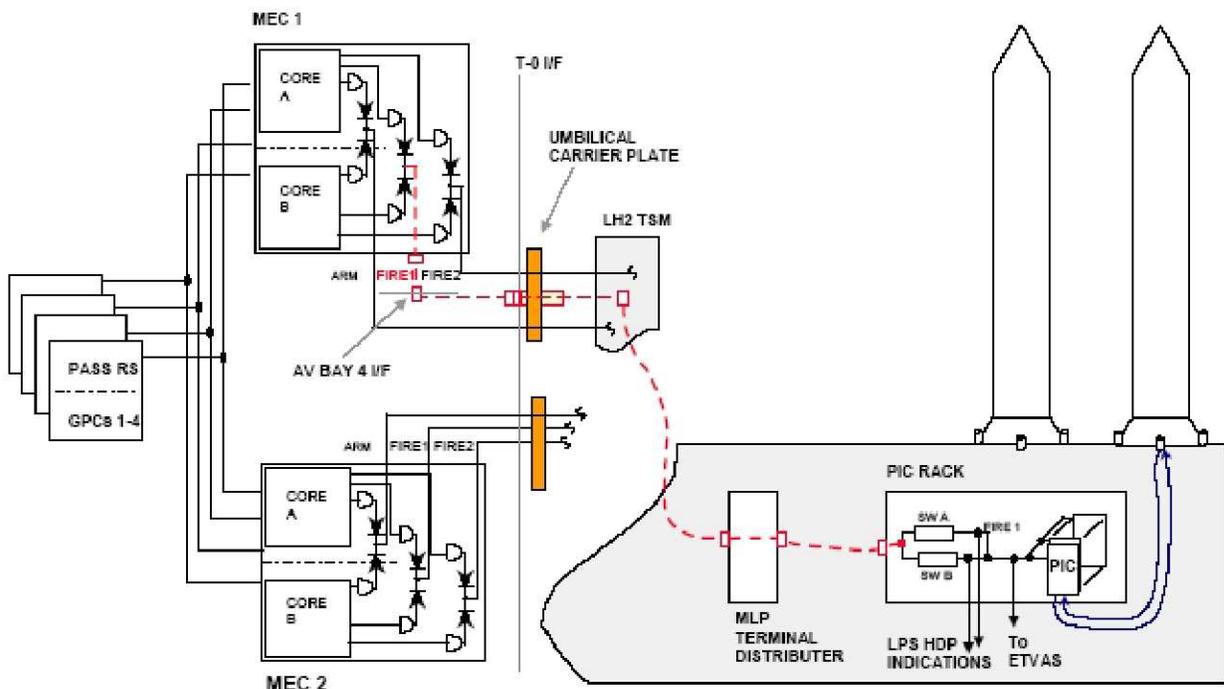


Figure 6.1-1. SRB HDP Pyrotechnic Interfaces



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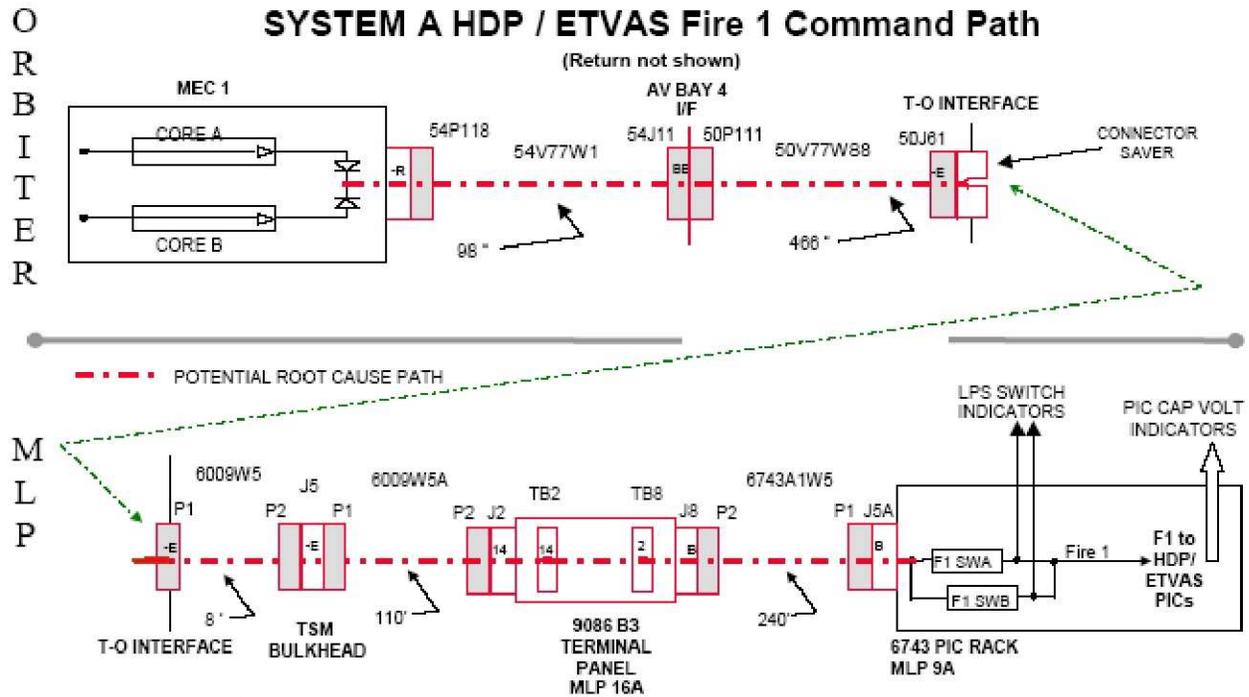


Figure 6.1-2. HDP/ETVAS Command Path

During the STS-112 launch, System A pyrotechnics failed to fire the release mechanism of the HDP frangible bolts and ETVAS. System B functioned normally and the launch was successful. However, failure of one-half the redundant system was considered a “near-miss” launch failure and a Standing Accident Investigation Board (SAIB) was convened at KSC to determine the root cause. The problem was closed as an unexplained anomaly and attributed to an intermittent failure at the T-0 interface [ref. 2]. An Independent Assessment Team (IAT) was formed to review the SAIB report and to provide recommendations [ref. 3]. The SSP Program Requirements Change Board (PRCB) subsequently directed Systems Engineering and Integration (SE&I) to form and lead a Tiger Team to address all findings related to GSE interfaces with Space Shuttle flight elements, including not only the STS-112 failure, but other intermittent signal dropouts that had been documented and attributed to connections through the T-0 [ref. 5]. The Tiger Team’s charter included identifying common failure causes, understanding the multiple environments, and developing corrective actions. An NESC Recurring Anomalies Splinter Team was formed to participate in a review of the SSP’s response to the consultation team’s findings (held at KSC on 28 October and 3 November 2004) [ref. 4].

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LH2 T-O Interface
showing J61



Figure 6.1-3. LH₂ T-0 Interface showing J61

The various investigations eventually pointed to an electrical connection at the T-0 interface as the most likely point of the STS-112 failure. Visual inspection using 10X magnification detected contamination and missing gold plating on the ground-side connector pins. Laboratory failure analysis showed isolated areas of discontinuity and pin degradation (Figure 6.1-4). In addition, a spring used to apply force to the mated contact assembly and hold the ground and flight halves together was found out-of-tolerance with a spring constant of 30.5 lbs/in versus a minimum required of 34.9 lbs/in. (see Figure 6.1-5). Finally, it was determined the mating procedure being employed had potential for misalignment of the connector mating halves. Testing showed that a misaligned connector can result in individual signal dropout at the outer connector pins during vibration. A course of action to address these issues was outlined by the PRCB Tiger Team and a plan for corrective action implemented. The plan included not only specific procedural changes to address the potential for corrosion and connector mis-assembly, but also component-level vibration testing and finite element modeling of the interface. The NESC Recurring Anomalies Splinter Team concurred with the actions proposed [ref. 4].



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Figure 6.1-4. T-0 Connector Corrosion and Pin Degradation

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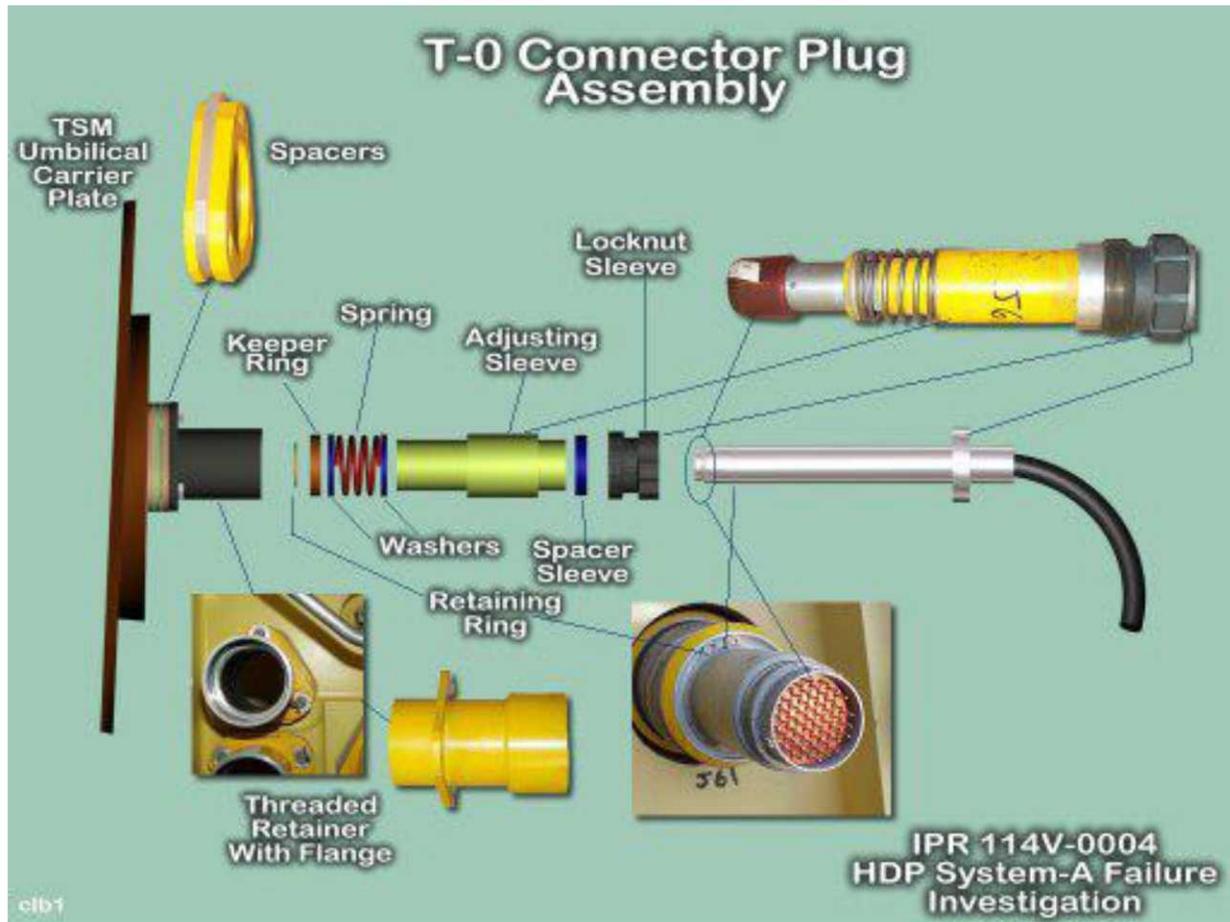


Figure 6.1-5. T-0 Connector Plug Assembly

Two IAT members responsible for reviewing the original SAIB investigation and findings generated an alternate opinion (below) in response to the SSP’s proposed corrective actions. The opinion was based on weaknesses in the original certification testing program and a general lack of data regarding the behavior of the interface at launch [ref. 10, pg 1]:

“Many umbilical mechanical retention system improvements have resulted from this Independent Assessment and the SE&I Tiger Team activity, which adds rigor, controls, and robustness. However, after reviewing the Shuttle Program’s final SE&I Tiger Team actions and responses to the IAT’s risk mitigation recommendations, the IAT has concluded that there still remains a level of uncertainty due to the undetermined root cause by the Tiger Team / Standing Accident Investigation Board (SAIB) and lack of controls for the [Ground

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Support Equipment] GSE T-0 umbilical to SSP flight element interfaces posing high risk to future Shuttle flights. Primary residual risks / concerns include: (1) Vibration testing non-representative of flight configuration; (2) Inadequate connector pin/socket electrical engagement design margin; (3) Finite Element Model (FEM) modeling deficiencies; (4) Inadequate qualification / certification of electrical umbilical portion of [Tail Service Mast] TSM umbilical system; (5) Risk documentation inadequate to address causes for T-0 signal losses; (6) Lack of adequate instrumentation to quantify and certify the TSM T-0 system; (7) Inadequate full scale flight verification.”

The IAT made eight recommendations to address these concerns [ref. 10, pg. 19]:

“(1) Increase the electrical pin length 1 mm to accommodate the unknown dynamic extraction potential; (2) Maximize effort to obtain suitable instrumentation and certify it for use during launch; (3) Perform T-0 Umbilical Electrical System Delta Certification; (4) Update the [Finite Element Model] FEM to include considerations of the issues identified; (5) Continuation of the mandatory instrumentation / data review of the T-0 signals active across the T-0 Umbilical from T-7 seconds to T-0. A subset of these measurements that are relatively stable during this time period [should] be recorded at 100 or 200 samples per second; (6) Install [Linear Voltage Displacement Transducers] LVDT’s on the LO₂ electrical connectors J56, J60, & J64 for the [STS-114] tanking test; (7) Reclassify GSE associated with the SRB HDP system to a different criticality category because it performs CRIT 1 and CRIT 1R launch functions; (8) Properly update risk documentation to reflect the deficiencies noted.”

The SSP objected to several of these recommendations, especially the first and third which would have required a full-up, system-level test of the T-0 interface before flight. The NESC was asked to review the data already collected and make pertinent recommendations.

6.2 Initial NESC Activity

The initial NESC effort is summarized in the white paper which is provided in Appendix B. The NESC concurred with the SSP’s efforts and with the corrective actions already implemented to address weaknesses in the processing and flight-to-flight hardware maintenance. The NESC T-0 Assessment Team concluded those actions were adequate to address the most probable cause of the failures observed at the interface (corrosion of electrical connections leading to intermittent contact) and, given the redundancy designed into the system, sufficient to ensure

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safe flight. At the same time, the NESC T-0 Assessment Team concurred with several of the concerns voiced in the IAT alternate opinion and noted that the modeling conducted to that point was not test-validated and did not address at the excitations due to Space Shuttle Main Engine (SSME) startup. The SSP's vibration testing was found adequate to characterize performance of an individual connector, but not representative of the integrated, dual carrier plate assembly being flown. Four recommendations to the SSP were generated as a result of the initial NESC work:

- R-1.** Fully implement planned hardware and process control changes.
- R-2.** Revisit the 0.25-inch connector nut gap requirement and consider increasing to 0.38 - 0.5 inches to increase force margin on the mated connector assembly.
- R-3.** Collect data suitable for anchoring system-level finite element models, optimally by instrumenting the ground-side of the T-0 interface through launch.
- R-4.** Verify the connector frequency response is in the 300-500 Hz range and conduct a conservative vibration test of the assembled connector using a composite spectrum that bounds both the 16C and 21 environments. The use of instrumented nominal and undersized pins of varying lengths across the full spectrum will help establish design margin.

6.3 Follow-On NESC Activity

After release of the initial white paper and consultation with stakeholders, the NESC undertook three additional activities:

1. Conduct finite element modeling to help characterize the response of the T-0 interface to the launch startup transient. The NESC T-0 Assessment Team agreed that a well-developed finite element analysis that incorporated all system elements and addressed low-frequency response (less than 20 Hz) could be conducted in lieu of the system-level test recommended in the white paper (Recommendation R-4).
2. Conduct failure analysis and testing of a cable assembly removed from the Mobile Launch Platform (MLP) at KSC to better understand the corrosion-induced failure postulated for STS-112.
3. Develop a quantitative risk estimate assuming failure of the entire HDP firing circuit (i.e., a quad-redundant failure).

In the initial review, the NESC T-0 Assessment Team noted that although the finite element

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modeling prepared by the SSP was well-formulated, the model did not: couple the vehicle and ground carrier plates, incorporate cryogenic quick disconnects, or address the system response to frequencies below 20 Hz.

In the follow-on activity, Boeing-Rocketdyne was asked to perform a more comprehensive analysis by building an integrated model coupling the LH₂ umbilical carrier plate (ground-side) and the LH₂ umbilical Orbiter plate (vehicle-side). All mass elements including cryogenic quick disconnects and electrical connectors would be included. Low frequency response of the system was to be evaluated and the sensitivity to modeling assumptions assessed. Results of the Boeing-Rocketdyne finite element modeling are provided in Appendix D and are discussed in Section 7.0.

A T-0 cable assembly was removed from the KSC MLP and transferred to GSFC where a detailed examination and analysis of corrosion by-products were performed. These analysis results are provided in Appendix E. GSFC also assessed whether the “wiping action” of the pins in their sockets was sufficient to remove corrosion and ensure good electrical contact. The NESC T-0 Assessment Team also attempted to demonstrate an intermittent connection. Results of the GSFC work are documented at Appendix F and discussed in Section 7.0.

A quantitative risk assessment was performed, assuming failure of the entire quad-redundant HDP firing circuit. This analysis is provided in Appendix G.

7.0 Data Analysis

The NESC Recurring Anomalies Splinter Team and NESC T-0 Assessment Team both concurred with the findings of the SAIB and the SSP: *that the most likely cause of the STS-112 HDP failure was corrosion-induced intermittent electrical contact at the T-0 umbilical, and it is unlikely a generic or design flaw exists.*

Failure history of the T-0 electrical connections is summarized on page 8 of Appendix C. Eleven incidents were documented over five missions beginning with STS-105. Four were recurrences of the same problem at different times in the Vehicle Assembly Building (VAB) or pad processing flow, so there were seven distinct failures including the STS-112 incident. At least one failure occurred per mission from STS-105 through STS-112 with exception of STS-109. It is important to note that not every connection through the T-0 is continuously monitored, and those that are may not be monitored at a high enough sampling rate to detect a short-duration intermittent failure. Thus, it is possible some intermittent failures occurred and escaped detection. The failures recorded in Appendix C are failures documented in the Problem Reporting and Corrective Action (PRACA) system. Onset of the problems began shortly after a

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processing decision to start re-using MLP T-0 cables rather than replace them after each flow was implemented. The ground-side MLP J71 connector and cable which carry certain Launch Data Bus (LDB) signals (see Appendix C, page 16) were replaced after erratic signals were noted during STS-110 and no failures of those signals were noted after that time. No failures at all have been noted since STS-112 when routine cable replacement was re-instituted. This includes missions processed since the data in Appendix C was collected (STS-114, STS-121, and STS-115).

A review of PRACA documentation revealed that signals could sometimes be restored by de-mating and re-mating connectors. In other instances, signals disappeared and reappeared with no action taken. Failure signatures were not all identical. In some cases, complete loss of signal was reported, but in seven instances degraded signals (distorted waveforms) typical of high-resistance connections were documented. There is no consistent pattern in the timing of the failures, although five occurred during dynamic conditions (SSME start through T-0) and two during tanking or de-tanking. Four incidents were documented with the vehicle under static conditions, at ambient temperature and with no dynamic activity underway. Failed J61 connections were positioned along the outer edges of the connector and those in J71, J60, and J64 were all routed through the connector center.

The involvement of multiple vehicles and subsystems appears to exonerate vehicle-side wiring. Additionally, the successful operation of the umbilical interface from STS-26R to STS-105 points to a process or hardware change, not a design problem. As noted above, the onset of failures after STS-105 is consistent with a change to pad preventive maintenance processes. At the time the first failure occurred, GSE-side cables were not being replaced after each launch, but were cleaned with isopropyl alcohol (IPA), inspected, and re-used. GSFC failure analysis of a MLP cable removed from the pad after STS-112 found non-conductive corrosive compounds consistent with SRB exhaust by-products (Appendices E and F). The corrosive materials were persistent, not readily dislodged from the pins, and were robust enough to survive multiple mate/de-mate cycles. The “wiping action” of the connector socket as it engaged the pin was not sufficient to remove the materials and ensure electrical contact. GSFC was able to duplicate intermittent opens on four of the ten connector pins that were electrically connected.

While the above evidence builds a strong circumstantial case for corrosion as a probable cause of the T-0 failures, the possibility that random vibration at launch could cause intermittent contact remained. If the SSME startup transient is capable of exciting the coupled interface sufficiently, the ground- and flight-side plates might move apart from one another enough to separate the connector halves. Dynamic loads placed on the mated assembly combined with the connector assembly’s internal resonance might also overcome the mating spring force with a similar result.

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Dynamic response of the coupled system was assessed through a combined finite element model that augmented existing plate models to create a single, integrated finite element model suitable for structural dynamic analysis. The integrated model accounted for connector mass, stiffness, and pre-load and was subjected to the loading conditions expected between T-6.6 seconds and T-0, bracketing the period from SSME start to vehicle launch. Combined relative displacements of the ground- and flight-side connector mounting plates were as expected with a worst-case plate displacement of slightly over 0.050 inches predicted (Appendix D). Plate separation of more than 0.25 inches would be required before the connector halves would begin to de-mate. Analysis of the dynamic load at the connector interface also showed that considerable margin exists with a worst-case dynamic load of less than 4 pounds predicted (note these values apply to the J71 connector – the “worst-case force” occurs at the J51 connector, about 8 pounds). This force would have to overcome a worst-case (lowest) spring force of approximately 40 pounds before the connector halves would begin to separate. Given the margin already existing at the interface as suggested by this analysis, re-design of the electrical connections to incorporate additional pin-socket engagement or increase force margin on mated connections is not warranted (Refer to Appendix B, Recommendation 2).

While this analysis indicates a properly-assembled T-0 connection has considerable margin against separation, and thus minimal potential for a vibration-induced intermittent connection, the modeling performed is not anchored with the exception of test data collected through modal tests of the Vandenberg Air Force Base T-0 plate (see Appendix D). Modeling uncertainties exist with regards to the loading environment and the interconnecting elements between the Orbiter and ground-side plate.

Details of the failure probability estimate are provided in Appendix G. Assuming the connector failures experienced are independent and identically distributed across the 113 Space Shuttle missions flown at the time of the analysis, dual redundancy affords 226 independent opportunities to observe a single failure. Given the seven independent events seen, probability of a single connector failure on any launch can be estimated at $7/(2 \times 113) = 0.03$. For the quad-redundant SRB HDP firing circuit, the corresponding loss of fire function is 9.20×10^{-7} .

8.0 Findings, Observations and Recommendations

8.1 Findings

- F-1.** Corrosion of electrical pins in ground-side interface connectors is the most probable proximate cause of the T-0 failures observed from STS-105 through STS-112.

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- F-2. The T-0 interface is a robust design with considerable margin against vibration-induced intermittent electrical connection.
- F-3. Given the margin already existing at the interface, re-design of the electrical connections to incorporate additional pin-socket engagement or increase force margin on mated connections is not warranted.

8.2 Observations

- O-1. Interface failures began shortly after a decision was implemented to stop replacing T-0 interface cables. This hardware is exposed to a corrosive environment at launch, and this change in the cable reuse increased the likelihood that corrosion would damage the interface with subsequent failure of electrical connections.

8.3 Recommendations

- R-1. The SSP should fully implement hardware and process control changes to minimize the potential for future failures at the T-0 interface. *(F-1, F-2, F-3)*
- R-2. The SSP should collect data suitable for anchoring finite element models by instrumenting the ground-side T-0 umbilical plate through at least one launch. *(F-1, F-2, F-3)*

9.0 Alternate Viewpoints

There were no alternative or dissenting opinions identified within the NESC T-0 Assessment Team in the submission of this report.

10.0 Other Deliverables

Finite element models, analyses, and results produced by this effort will be delivered to the SSP.

11.0 Lessons Learned

During the course of this consultation, the following lesson was learned:

- LL-1. Electrical interfaces should be protected against the deposition of nonconductive corrosive environments. Presence of gold plating on connector pins and sockets is insufficient, in and of itself, to ensure corrosion will not occur with subsequent loss of circuit function.

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12.0 Definition of Terms

Corrective Actions	Changes to design processes, work instructions, workmanship practices, training, inspections, tests, procedures, specifications, drawings, tools, equipment, facilities, resources, or material that result in preventing, minimizing, or limiting the potential for recurrence of a problem.
Finding	A conclusion based on facts established during the assessment/inspection by the investigating authority.
Lessons Learned	Knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. A lesson must be significant in that it has real or assumed impact on operations; valid in that it is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or limits the potential for failures and mishaps, or reinforces a positive result.
Observation	A factor, event, or circumstance identified during the assessment/inspection that did not contribute to the problem, but if left uncorrected has the potential to cause a mishap, injury, or increase the severity should a mishap occur.
Problem	The subject of the technical assessment/inspection.
Requirement	An action developed by the assessment/inspection team to correct the cause or a deficiency identified during the investigation. The requirements will be used in the preparation of the corrective action plan.
Root Cause	Along a chain of events leading to a mishap or close call, the first causal action or failure to act that could have been controlled systemically either by policy/practice/procedure or individual adherence to policy/practice/procedure.

13.0 Acronym List

ETVAS	External Tank Vent Arm System
GPC	General Purpose Computers
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center

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HDP	Hold-Down Post
IAT	Independent Assessment Team
IPA	Isopropyl Alcohol
KSC	Kennedy Space Center
LaRC	Langley Research Center
LDB	Launch Data Bus
LH ₂	Liquid Hydrogen
LO ₂	Liquid Oxygen
LPS	Launch Processing System
LVDT	Linear Voltage Displacement Transducers
MEC	Master Events Controller
MLP	Mobile Launch Platform
NASA	National Aeronautics and Space Administration
NDE	NESC Discipline Expert
NESC	NASA Engineering and Safety Center
PASS	Primary Application Software Set
PIC	Pyro Initiated Charge
PRACA	Problem Reporting and Corrective Action
PRCB	Program Requirements Change Board
SAIB	Standing Accident Investigation Board
SE&I	Systems Engineering and Integration
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
STS	Space Transportation System
TSM	Tail Service Mast
VAB	Vehicle Assembly Building

14.0 References

1. PRACA Report P-V6-391545, *During the Launch Sequence, a Signal from the PIC Rack was not Received at the SRB Bolts*, 17 Oct 02
2. *Hold Down Post System A Pyrotechnics Failure, SAIB Team E Report*, 23 Jan 03
3. Final Report KMJ-3011, *Independent Assessment of KSC GSE Directly Interfacing with SSP Flight Elements*, 30 Jul 04
4. NESC Report RP-05-10, *SSP-ISS Recurring Anomalies Review, Part I: Space Shuttle Program*, 19 Jan 05

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5. PRCB Action S062323, *Separation Interfaces Tiger Team Review Summary to PRCB*, March 04
6. KMJ-3011, *Independent Assessment of KSC GSE Interfaces with SSP Flight Elements, IAT Dissenting Opinion*, 16 Mar 05
7. Separation System Tiger Team Website,
http://sspweb.jsc.nasa.gov/ntdata/ssp/webdata/mksio/srb_hdp/Separation%20System%20Tiger%20Team%20Data.htm
8. *Space Shuttle T-0 Umbilical Dynamic Displacement*, Miller, Tsai, Pilkey, and Davis, Rocketdyne, 18 Mar 05
9. KSC-MSL-0608-2002, *Analysis of T-0 Connector and Hardware Associated with the SRB Hold Down Post Pyrotechnics*, 7 Feb 03.
10. *Independent Assessment of KSC GSE Interfaces with SSP Flight Elements, IAT Dissenting Opinion*, revision 2, update 3, 16 Mar 05.

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- A. ITA/I Request Form (NESC-PR-003-FM-01)
- B. NESC White Paper, *Review of the Space Shuttle T-0 Interface Anomaly Resolution*, 23 Mar 05
- C. NESC Presentation to Shuttle Program Requirements Change Board, *GSE T-0 Umbilical to SSP Flight Elements Assessment*, 31 Mar 05
- D. *Space Shuttle T-0 Umbilical Dynamic Displacements and Forces*, Rocketdyne, 22 Aug 05
- E. Report Q50299FA, *Connector Failure Analysis*, Goddard Space Flight Center Parts Analysis Laboratory
- F. *GSE T-0 Umbilical to SSP Flight Elements Assessment Project Status*, 13 Oct 06
- G. Quad-redundant Failure Analysis

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Appendix A. ITA/I Request Form (NESC-PR-003-FM-01)



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NASA Engineering and Safety Center Request Form

Submit this ITA/I Request, with associated artifacts attached, to: nrbexecsec@nasa.gov, or to
NRB Executive Secretary, M/S 105, NASA Langley Research Center, Hampton, VA 23681

Section 1: NESC Review Board (NRB) Executive Secretary Record of Receipt

Received (mm/dd/yyyy h:mm am/pm) 3/17/2005 12:00 AM	Status: New	Reference #: 05-012-E
--	-------------	-----------------------

Initiator Name: Bryan O'Connor	E-mail: bryan.oconnor@nasa.gov	Center: NASA HQ
--------------------------------	-----------------------------------	-----------------

Phone: (202)-358-2699, Ext _____	Mail Stop:
----------------------------------	------------

Short Title: GSE T-0 Umbilical to SSP Flight Element Assessment

Description: This is to provide an assessment precipitated by a dissenting opinion from the Independent Assessment Team (IAT) review, Independent Assessment of KSC GSE Interfaces with SSP Flight Elements. After reviewing the Shuttle Program's final SE&I Tiger team actions and responses to the IAT's risk mitigation recommendations, the IAT has concluded that there still remains a level of uncertainty due to the undetermined root cause by the Tiger Team/Standing Accident Investigation Board (SAIB) and lack of controls for the GSE T-0 umbilical to SSP flight element interfaces posing high risk to future Shuttle flights. IAT is providing this dissenting opinion as a constraint to flight.

Source (e.g. email, phone call, posted on web): email
e-mail request which included presentation: "IAT Dissenting Opinion" (KMJ-3011_16 March 05r2update3.ppt)

Type of Request: Assessment

Proposed Need Date: 3/23/2005

Date forwarded to Systems Engineering Office (SEO): (mm/dd/yyyy h:mm am/pm):

Section 2: Systems Engineering Office Screening

Section 2.1 Potential ITA/I Identification

Received by SEO: (mm/dd/yyyy h:mm am/pm): 3/17/2005 12:00 AM

Potential ITA/I candidate? Yes No

Assigned Initial Evaluator (IE):

Date assigned (mm/dd/yyyy): 3/22/2005

Due date for ITA/I Screening (mm/dd/yyyy):

Section 2.2 Non-ITA/I Action

Requires additional NESC action (non-ITA/I)? Yes No

If yes:

Description of action: There is no initial evaluation required this was approved Out-of-Board to proceed with Tim Wilson leading. This is fast turn-around, high priority with a Special NRB on 3/23/05 for Tim Wilson to present the NESC position

Actionee: Tim Wilson

Is follow-up required? Yes No If yes: Due Date: 3/23/2005

Follow-up status/date:

If no:

NESC Director Concurrence (signature):

Request closure date: .



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Section 3: Initial Evaluation		
Received by IE: (mm/dd/yyyy h:mm am/pm):		
Screening complete date:		
Valid ITA/I candidate? <input type="checkbox"/> Yes <input type="checkbox"/> No		
Initial Evaluation Report #: NESC-PN-		
Target NRB Review Date:		
Section 4: NRB Review and Disposition of NCE Response Report		
ITA/I Approved: <input type="checkbox"/> Yes <input type="checkbox"/> No		Date Approved:
ITA/I Lead: , Phone () - , x		Priority: - Select -
Section 5: ITA/I Lead Planning, Conduct, and Reporting		
Plan Development Start Date:		
ITA/I Plan # NESC-PL-		
Plan Approval Date:		
ITA/I Start Date	Planned:	Actual:
ITA/I Completed Date:		
ITA/I Final Report #: NESC-PN-		
ITA/I Briefing Package #: NESC-PN-		
Follow-up Required? <input type="checkbox"/> Yes <input type="checkbox"/> No		
Section 6: Follow-up		
Date Findings Briefed to Customer:		
Follow-up Accepted: <input type="checkbox"/> Yes <input type="checkbox"/> No		
Follow-up Completed Date:		
Follow-up Report #: NESC-RP-		
Section 7: Disposition and Notification		
Notification type: - Select -		Details:
Date of Notification:		
Final Disposition: - Select -		
Rationale for Disposition:		
Close Out Review Date:		

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Form Approval and Document Revision History

Approved: _____ <small>NESC Director</small>	_____ <small>Date</small>
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Version	Description of Revision	Office of Primary Responsibility	Effective Date
1.0	Initial Release	Principal Engineers Office	29 Jan 04

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Appendix B. NESC White Paper, Review of the Space Shuttle T-0 Interface Anomaly Resolution, 23 March 05

NASA Engineering and Safety Center

Background

Standing Accident Investigation Board (SAIB) Team E was convened at KSC in October, 2002 to determine the root cause of failure of System A pyrotechnics to fire frangible nuts and release the Solid Rocket Booster Hold-Down Post (HDP) studs and External Tank Vent Arm System (ETVAS) during the STS-112 launch. The problem was closed as an unexplained anomaly and attributed to an intermittent failure at the T-0 interface (references 1 and 2).

An Independent Assessment Team (IAT) was formed to review the SAIB report and provide recommendations (reference 3). The Program Requirements Change Board (PRCB) subsequently directed Systems Engineering and Integration (SE&I) to form and lead a Tiger Team to address all findings related to ground support equipment interfaces with Space Shuttle flight elements. The Tiger Team's charter included identifying common failure causes, understanding the multiple environments, and developing corrective actions.

A NESC Recurring Anomalies Splinter Team was formed to participate in a review of the Program response to the IAT findings held at KSC on 28 October and 3 November 2004. At that time, the NESC T-0 Assessment Team concurred with actions the Program was taking to resolve the issue pending completion of forward work (reference 4, appendix 8). NESC was again asked to render an opinion on the issue in response to an IAT dissenting opinion which had been forwarded to the HQ Director of Safety and Mission Assurance in March 05. The NESC splinter team was reformed to review work accomplished since the November meeting. The team was joined by the NESC Discipline Expert (NDE) for mechanisms, John McManamen, NDE for electrical power and avionics, Bob Kichak, NDE for mechanical analysis, Julie Kramer-White, and NDE for structures, Ivatury Raju. Team members reviewed the work accomplished by the Program and the dissenting opinion submitted by the IAT (references 5 - 6), some of the Program Tiger Team data summarized at the team's website (reference 7), and the Rocketdyne dynamic analysis (reference 8). No NESC-chartered tests or independent technical analyses were performed. This follow-on review was hampered by the short time permitted for the work and lack of visibility by some team members into the actual hardware configuration.

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Hardware and Processing Changes

The Program has made significant changes to hardware and processes since the STS-112 incident, mostly to address the most probable causes of the failure cited in the unexplained anomaly and SAIB reports. These changes include:

- (1) Redesign of Orbiter-side wiring to provide for redundant HDP fire signals routed through two separate connectors on both the Liquid Hydrogen (LH2) and Liquid Oxygen (LO2) T-0 plates. This provides for dual redundant channel A and B signal paths (quad redundancy against loss of function) from the Orbiter MEC to the ground PIC racks. While the system has been so-modified, it is important to note the redundant copper paths cannot be verified by test and redundancy could be susceptible to common cause effects if any exist.
- (2) Replacement of ground-side interface cables and connectors each flight. Cables were previously re-used and were thus subject to a buildup of corrosion and contamination. Corrosion of the interface connectors was singled out as a contributor to the STS-112 incident (reference 2). The intermittent and random nature of the failures is considered to be consistent with the presence of corrosion by-products on electrical hardware. KSC Malfunction Lab tests (reference 9) showed that the contamination provided insulation sufficient to register as an open circuit on a multi-meter.
- (3) Improvements to the connector mating process including Videoscope inspection of the interface after mating, specification and measurement of driving nut engagement, verification of connector spring force, verification of connector saver bayonet pin engagement, and improved configuration control of tolerances to minimize the potential for stack-up. Weaknesses in the connector mating process were thought to contribute to the STS-112 incident (reference 2).
- (4) Redesign of interface cables to incorporate Teflon instead of polyimide insulation to minimize the potential for wiring damage or short circuit.

The NESC review team concurs with these actions.

Testing

The Program conducted vibration testing with an instrumented connector mounted in a test fixture intended to represent the GSE-Orbiter T-0 configuration. IAT concerns that this test setup did not fully model the interface because it did not permit relative motion between the two umbilical plates are not without merit, and confidence in the integrity of the connection could be improved by unrestrained multi-axis testing. Such testing might highlight response coupling

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between the plates and connector assembly, if any exists, especially at the low frequencies characteristic of SSME startup. Presence of this coupling would reduce the pin engagement margin.

While initial dynamic response could be better simulated, the NESC T-0 Assessment Team notes that the most critical operating time from the perspective of commands crossing the T-0 interface is not at SSME start-up, but in the few seconds just prior to T-0 when the engines are operating at steady-state. It is at this time that HDP arm and fire commands are sent. The configuration tested does provide visibility into performance of the connector interface independent of the plates. Assuming that the frequency response of the spring connector is significantly higher than the frequency response of the plates, then this is a reasonable simulation of the interface during the critical operating phase. The fact the tests were conducted with a worst-case (minimal) load on the connector provides some confidence that the mated connector will operate properly during the period before T-0. The Program subjected the entire assembly to forcing inputs several orders of magnitude above those seen by the flight vehicle in the low frequency region of the engine steady-state spectrum in an attempt to create a worst-case environment. However the Program has indicated that the frequency response of the spring connector is somewhere between 300 -500 Hz and this specific test used the 16C zone environment which ramps down to low levels well before 300 Hz, suggesting this test was not as conservative as the Program maintains. A more conservative test would have used a composite spectrum that bounds both the zone 16C and 21 environments. Since the whole pin engagement margin hinges on the response of the connector (currently assumed to be above 300 or 500 Hz) under this dynamic loading environment this test should be conducted and a more definitive assessment of connector frequency response obtained. This will improve confidence in the integrity of the mated assembly during the period before T-0.

Modeling

The NESC T-0 Assessment Team reviewed the Finite Element Model (FEM) prepared by the Program to analyze the relative motion between the Orbiter and GSE umbilical plates. The team found the plate model to be well-formulated and concurs with the analysis performed, but notes the analysis is based on the fundamental assumption that low-frequency system response (that below 20 Hz) is not critical. This is not a crucial flaw if one assumes, as above, that the critical operating period for the interface is not during the dynamic startup transient but during steady state operation just prior to T-0 and that system modeling accurately represents any low-frequency coupling with the vehicle which may occur. The NESC T-0 Assessment Team did not see evidence the integrated system models have been anchored to real-world data. Such data should be collected and the models appropriately anchored for improved confidence.

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Safety Margin

While significant pin-to-socket margin does appear to exist, at least under steady-state conditions, the extent of that margin is difficult to quantify. Values quoted by the Program are somewhat misleading since they assume a minimum contact area of 0.001" between a pin and socket is adequate. While this is true from the perspective of current transfer, it is probably not sufficient to ensure a reliable connection and there is no existing rule-of-thumb for de-rating under these circumstances. The manufacturer's connector current ratings are based on pin diameter rather than depth of engagement and assume proper mating of the connector halves. Boeing analysis indicates nominal pin engagement for a connector-to-connector pair with locking ring is 0.096" with a minimum of 0.035", measured beyond the radius of the tip of the pin. This is the minimum pin engagement for which the connector is certified and a more reasonable lower bound on the engagement margin than the 0.001" analytical value quoted by the Program. Vibration testing with pins of varying lengths would help establish the actual design margin.

Attempts to improve the contact margin by lengthening the connector pins are ill-advised without detailed analysis and re-certification of the hardware. This proposed change, while simple on the surface, may well have unintended consequences. The NESC T-0 Assessment Team notes additional margin could probably be gained by increasing the minimum gap proposed for the connector nut from 0.25 inches to 0.38 to 0.5 inches, thus increasing pre-load on the spring and connector assembly and reducing potential for the pins and sockets to separate, without changing the physical characteristics of the interface.

Conclusion

The Program has implemented a number of corrective actions in response to the STS-112 failure. These include increasing redundancy for critical signals across the T-0 interface, significantly improving process controls, and replacing interface cables to minimize the potential for corrosion. NESC concurs these actions are suitable to address the most probable causes of that failure and is satisfied with flight rationale based upon them. Since critical commands do not cross the interface during the SSME startup transient, and those that cross the interface shortly before T-0 have significant redundancy, NESC concurs the interface as-designed can be operated with low probability for catastrophic loss of function.

While it appears the Program has done an adequate job modeling the interface under steady-state conditions, modeling of the integrated system under dynamic conditions is not validated and only covers frequencies above 20 Hz. It could be improved by a better understanding of the system sensitivity to low frequency forcing functions of the kind seen during SSME startup. Models

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should be anchored to real-world data. Vibration testing done to demonstrate pin engagement margin is reasonable for the connector, but is not representative of integrated system performance. Characterization of the connector could be improved with a conservative vibration test conducted using a composite spectrum that bounds both the zone 16C and 21 environments. Additional work to address these issues and better understand the actual design margin should be conducted per the recommendations below, though with exception of the first NESC does not consider these constraints to flight.

Recommendations

1. Program fully implement planned hardware and process control changes.
2. Program revisit the 0.25 inch connector nut gap requirement and consider increasing to 0.38 to 0.5 inches in order to increase force margin on the mated connector assembly.
3. Program collect data suitable for anchoring system level finite element models, optimally by instrumenting the ground side of the T-0 interface through launch.
4. Program verify connector frequency response is in the 300-500 Hz range and conduct a conservative vibration test of the assembled connector using a composite spectrum that bounds both the 16C and 21 environments. Use of instrumented nominal and undersized pins of varying lengths across the full spectrum will help establish design margin.

Review Team Members

Tim Wilson, NESC Chief Engineer, KSC (Team Lead)
 John McManamen, NESC Discipline Expert for Mechanisms
 Julie Kramer White, NESC Discipline Expert for Mechanical Analysis
 Ivatury Raju, NESC Discipline Expert for Structures
 Robert Kichak, NESC Discipline Expert for Power and Avionics
 Robert Beil, NASA KSC
 Robert Cherney, Orbital Sciences
 John Weeks, NASA KSC
 Dave McCann, Boeing

References

1. PRACA Report P-V6-391545, *During the Launch Sequence, a Signal from the PIC Rack was not Received at the SRB Bolts*, 17 Oct 02

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2. *Hold Down Post System A Pyrotechnics Failure, SAIB Team E Report, 23 Jan 03*
3. *Final Report KMJ-3011, Independent Assessment of KSC GSE Directly Interfacing with SSP Flight Elements, 30 Jul 04*
4. *NESC Report RP-05-10, SSP-ISS Recurring Anomalies Review, Part I: Space Shuttle Program, 19 Jan 05*
5. *PRCB Action S062323, Separation Interfaces Tiger Team Review Summary to PRCB, March 04*
6. *KMJ-3011, Independent Assessment of KSC GSE Interfaces with SSP Flight Elements, IAT Dissenting Opinion, 16 Mar 05*
7. *Separation System Tiger Team Website,*
http://sspweb.jsc.nasa.gov/ntdata/ssp/webdata/mksio/srb_hdp/Separation%20System%20Tiger%20Team%20Data.htm
8. *Space Shuttle T-0 Umbilical Dynamic Displacement, Miller, Tsai, Pilkey, and Davis, Rocketdyne, 18 Mar 05*
9. *KSC-MSL-0608-2002, Analysis of T-0 Connector and Hardware Associated with the SRB Hold Down Post Pyrotechnics, 7 Feb 03.*

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Appendix C. NESC Presentation to Shuttle Program Requirements Change Board, *GSE T-0 Umbilical to SSP Flight Elements Assessment*, 31 Mar 05

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NASA Engineering and Safety Center (NESC)

GSE T-0 Umbilical to SSP Flight Elements Assessment

05-012-E

Tim Wilson
NESC Chief Engineer, KSC
31 March 05

This briefing is for status only and does not represent complete engineering data analysis

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T-0 Anomaly Review	Wilson 31 Mar 05
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- NESC assessment team assembled at the request of HQ S&MA
 - Recurring anomalies team members who participated in November and February T-0 anomaly reviews
 - NESC Discipline Experts for mechanisms, mechanical analysis, power and avionics, and structures
- Team reviewed the Program position and IAT opinion
 - PRCB presentation summarizing work performed
 - Modeling
 - Vibration Testing
 - IAT concerns package
 - Finite element model documented as Rocketdyne dynamic analysis
 - Other materials published at Tiger Team website
- NESC team did not conduct independent test or analysis other than a review of the above material

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Conclusions	Wilson 31 Mar 05
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- Program has implemented a number of corrective actions in response to the STS-112 failure
 - Increased redundancy for critical signals across the T-0 interface
 - Significant improvement to process controls
 - Replacement of interface cables to minimize potential for corrosion
- NESC concurs with these corrective actions and with flight rationale based upon them
- Since critical commands do not cross the interface during the SSME startup transient, and those that cross the interface shortly before T-0 have significant redundancy, NESC concurs the interface as-designed can be operated with low probability for catastrophic loss of function. Additional work should be undertaken to better understand margins.

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Conclusions	Wilson 31 Mar 05
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- Additional work should be conducted to address weaknesses in the model and vibration tests and ensure actual design margins are fully understood
 - Finite element modeling should be anchored to real-world data
 - Connector characterization should be improved with a conservative vibration test that bounds the zone 16C and 21 environments
 - Minimum value quoted for pin-socket contact (0.001”) should be increased to 0.035” to ensure connector cert is not invalidated
 - Potential for increasing margin by increasing spring pre-load should be fully explored
- NESC does not consider this follow-on work a constraint to flight

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Recommendations	Wilson 31 Mar 05
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- Program fully implement planned hardware and process control changes before return to flight
- Program revisit the 0.25 inch connector nut gap requirement and consider increasing to 0.38 to 0.5 inches to increase force margin on the mated connector assembly.
- Program collect data suitable for anchoring system level finite element models, optimally by instrumenting the ground side of the T-0 interface through launch.
- Program verify connector frequency response is in the 300-500 hz range and conduct a conservative vibration test of the assembled connector using a composite spectrum that bounds both the 16C and 21 environments. Use of instrumented nominal and undersized pins of varying lengths across the full spectrum will help establish design margin.



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Risk Assessment

Wilson

31 Mar 05

NESC RISK MATRIX						
L I K E L I T H C C D	5	Green	Yellow	Red	Red	Red
	4	Green	Yellow	Yellow	Red	Red
	3	Green A	Yellow	Yellow	Yellow	Red
	2	Green	Green	Green	Yellow	Yellow
	1	Green	Green	Green	Green	Yellow B
		1	2	3	4	5
CONSEQUENCE						

HAZARDOUS EVENTS

A – Loss of a single circuit at the T-0 interface

B – Loss of all critical circuits at the T-0 interface leading to LOCV

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	Wilson
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Backup Charts



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Combined Failure / Flight History

Wilson

31 Mar 05

Flight	Orbiter	MLP	Umbilical	Connector	Signature
STS-105	OV-103	3	LH2	J71 / J71 /	Distorted PCMMU signal during S0009 power-up LDB-1 lost during SSME start – Water in TD connector
STS-108	OV-105	1	LH2	J61 /	SRB LH Bus A erratic after SSME start
STS-109	OV-102	2			None
STS-110	OV-104	3	LH2	J71 /	LDB I/O errors during S0008 power-up LDB I/O errors during S0009 power-up LDB-1 to LDB-2 switch during scrub de-tanking SRB RH Bus A erratic after SSME start
			LO2	J60 /	
STS-111	OV-105	1	LO2	J64 /	SSME-3 EIU parity errors during ambient testing SSME-3 EIU signal recovered during cryo operations SSME-3 EIU signal erratic at SSME start
STS-112	OV-104	3	LH2	J61 /	HDP System A fire 1 command failed at T-0
STS-113	OV-105	2			None
STS-107	OV-102	1			None

Items in red: Troubleshooting revealed a corrupted or distorted waveform

This briefing does not represent complete engineering data analysis

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Failure History Observations	Wilson 31 Mar 05
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- Eleven failures over five missions beginning with STS-105
 - Four are recurrences of the same problem at different times in the VAB or pad processing flow leaving seven distinct failures
 - At least one failure per mission from STS-105 through STS-112 with exception of STS-109
 - No failure of MLP J71 connection since STS-110 cable replacement
 - No failures of any connections since STS-112 cable replacements
- Failure signatures
 - Degraded signals typical of high-resistance connections noted
 - Loss of signal (open circuit) noted in some cases
 - Signals could sometimes be restored by de-mating and re-mating connectors

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Failure History Observations	Wilson 31 Mar 05
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- Failures occurred at various times during the processing flows
 - Four during static conditions: ambient temperatures, no dynamic activity
 - Two during tanking / de-tanking (one was a signal recovery)
 - Four at SSME start
 - One at T-0
 - Signals sometimes disappeared or reappeared with no action taken
- Discrepant connector pin configuration
 - J71 : LH2 Plate – Failed signals in connector center
 - J61 : LH2 Plate – Failed signals along connector edge
 - J60 : LO2 Plate – Failed signals in connector center
 - J64 : LO2 Plate – Failed signals in connector center

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Corrosion / Mate as Likely Cause	Wilson 31 Mar 05
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- Involvement of multiple vehicles and subsystems appears to exonerate vehicle-side wiring
- Successful operation of the interface from STS-26R to STS-105 points to a process or hardware change, not a design problem
 - PRACA research extended to STS-26R
 - Low probability of an undetected or unreported failure prior to STS-105
 - First failure (distorted PCMMU signal resulting in loss of OI data) was highly problematic and drove extensive troubleshooting
 - Identical problem detection and resolution processes have been in place since STS-26R
- Loss of individual circuits / pins instead of whole connectors or groups of pins points to a failure mechanism other than vibration or marginal pin-socket contact

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Corrosion / Mate as Likely Cause	Wilson
	31 Mar 05

- Failures observed are consistent with corrosion and/or improper mating
 - Would expect corroded or contaminated connections to cause random failures
 - High resistance connections would lead to signal degradation of the type noted
 - Corroded connections would have marginal contact area resulting in connections sensitive to vibration, minor thermal transients, etc.
 - Most failures were to low-voltage signals, the ones most susceptible to high-resistance degradation
 - Several of the failures cleared when connectors were de-mated and re-mated
 - Pins associated with STS-112 fail-to-fire are near periphery of connector and thus most likely affected by a cocked or poorly mated connection

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Corrosion / Mate as Likely Cause	Wilson 31 Mar 05
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- Process and hardware discrepancies are known to have existed at the time of the first failure
 - GSE cables were not replaced but cleaned and re-used post-flight
 - Interface connectors were exposed to highly-corrosive environments
 - Cleaning not effective in removing corrosion products
 - Interface connectors had corrosion on pins and connector shells as confirmed by failure analysis of the J71 and J61 cables
 - Corrosion products were non-conductive in nature
 - Corrosion had breached, and caused damage to, gold plating
 - Mating process was not well-controlled until after STS-112
 - Blind mate not confirmed by visual inspection
 - Spring force not controlled
 - Parts tolerance stack-up not controlled

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Corrosion / Mate as Likely Cause	Wilson 31 Mar 05
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- Problems have not recurred since likely causes were addressed
 - MLP3 J71 connection was especially problematic
 - Failures observed on both STS-105 and the following MLP3 mission, STS-110
 - No J71 failures have been observed since the cable and interface connector were replaced (one mission, STS-112)
 - No MLP1 failures were observed in the single mission processed since all interface cables on that MLP were replaced



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LO2 Umbilical Connectors

Wilson

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Connector	Wired Pins	Active at T-0	Circuits
50J52	4	0	Main Bus B Feed
50J54	4	0	Main Bus C Feed
50J56	50	20	ICOM, C Monitors, LO2/LH2 Press, PRSD Vlv Ccmds, MEC 2 HDP Arm/Fire
50J58	59 Max	Varies	Payload - Mission Specific
50J60	51	10	V Monitors, MEC 2 SRB Arm/Fire, SRB ATVC Deadface Relay, TD Umb Arm/Fire, MDM Mon, Bus Pwr Ccmds, RSS SRB Inhib/Reset, GSE Bus Rmt Sense
50J62	9	4	Dump Line HR2, Pre-Flt Test Bus
50J64	45	9	LDB2, EIU2/3, MMU, PCMMU2, P/L Signal Processor
50J66	0	0	Spare
50J68	28	0	FCMS, MADS Recorder
50J70	46	18	FDM FMM2, PMM1, MADS Recorder
50J72	6	Varies: Min 1	MTU, S-Band FM Signal Processor, Payload - Mission Specific
50J74	12	Varies	Payload - Mission Specific

Minimum Number Active at T-0: 62

Pins active at T-0 are those carrying > 100 uA
Connectors in red are those with a failure history



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LH2 Umbilical Connectors

Wilson

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Connector	Wired Pins	Active at T-0	Circuits
50J51	4	0	Main Bus A Feed
50J53	53	26	Mid Dcdr LM1 Pwr, Drag Chute Sensor, MEC 1 HDP Arm/Fire, PRSD Vlv Ccmds, ICOM, LH2 Press, C Monitors
50J55	50	Varies	Payload - Mission Specific
50J57	10	4	SSME 1-3 Htr Pwr, Pre-Flt Test Bus
50J59	50	Varies	Payload - Mission Specific
50J61	45	19	V Monitors, Drag Chute Door Sensor Pwr, RSS SRB Inhib/Reset, GSE Bus Rmt Sense, Bus Pwr Ccmds, HDP A Arm/Fire, T0 Umb Arm/Fire, SrB ATVC Deadface Relay, LH2 Press, MDM Mon
50J63	0	0	Spare
50J65	12	0	Recirc Pump Power
50J67	45	Varies	Payload - Mission Specific
50J69	45	Varies	Payload - Mission Specific
50J71	44	10	NSP, P/L Recorder, MMU, PCMMU1, EIU1, LDB1
Minimum Number Active at T-0:		59	

Pins active at T-0 are those carrying > 100 uA
Connectors in red are those with a failure history

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**Appendix D. Space Shuttle T-0 Umbilical Dynamic Displacements and Forces,
Rocketdyne, 22 Aug 05**



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Space Shuttle T-0 Umbilical
Dynamic Displacements and Forces



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Approved by: John E. Larson

Rocketdyne

August 22, 2005



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1.0 Introduction

A port and starboard umbilical system is used to provide fluid and electrical lines to the Space Shuttle prior to launch at T-0. Each umbilical system is composed of Ground Support Equipment (GSE) which includes an aluminum Carrier Plate that mates to an Orbiter interface panel. The orbiter interface panel is integral to the Orbiter. The port and starboard GSE including the carrier plates retract at T-0 into their own Tail Service Mast (TSM) which is equipped with a blast shield that drops to protect the GSE from launch pad environments.

On STS-112 an electrical signal did not get through the umbilical system and although a backup system did work, a question was raised as to whether dynamic loads prior to liftoff could create a displacement (gap) between the GSE and the orbiter panel that was big enough to contribute to the loss of electrical signal. This report presents the predicted dynamic displacements and dynamic forces between the GSE and the Orbiter panel in the last 6 seconds prior to liftoff.

2.0 Executive Summary

An integrated finite element model (FEM) was created incorporating both the GSE LH₂ T-0 Umbilical Carrier Plate and the LH₂ T-0 Umbilical Orbiter Panel. Modal testing of both the port and starboard GSE, including the Carrier Plates, helped validate the FEMs. Sensitivity studies showed that the models were insensitive to key modeling assumptions. The dynamic relative displacement between the GSE side (Carrier Plate) and the Orbiter side (Orbiter Panel) and the dynamic spring force for each electrical connector on the LH₂ side are shown in Figure 1. Analysis indicates that similar results would be expected for the LO₂ side.

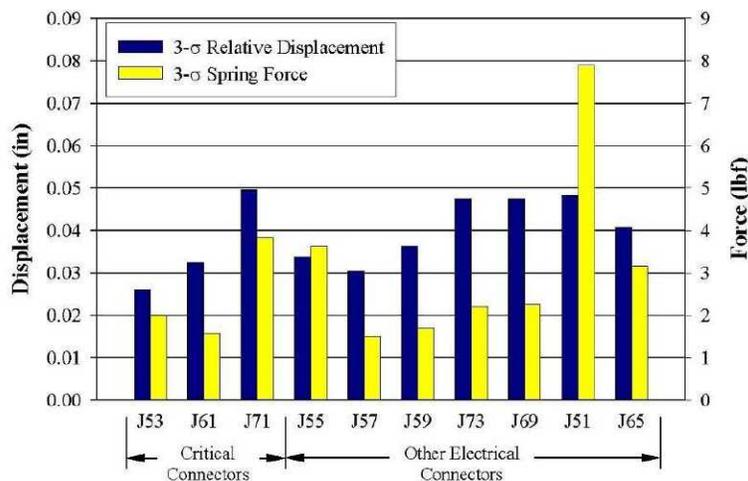


Figure 1. Electrical Connectors Dynamic Relative Displacement and Force



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3.0 T-0 Umbilical LH₂ Carrier Plate Finite Element Model

The LH₂ T-0 Umbilical Carrier Plate is one component in the ground support equipment (GSE) that supports the Space Shuttle program. The T-0 Umbilical Carrier Plate is part of the Tail Service Mast (TSM) which is part of the Mobile Launch Platform (MLP). The MLP has two TSMs with each TSM having a T-0 Umbilical Carrier Plate. One of the T-0 Umbilical Carrier Plates is used to supply the Orbiter and Tank with LH₂ and the other T-0 Umbilical Carrier Plate is used to supply the Orbiter and Tank with LOX. T-0 Umbilical Carrier Plate is mated to the Orbiter and is used to supply the Orbiter and Tank with all the electrical and fluid lines for the GSE equipment. Milliseconds after launch (T-0) the mated T-0 Umbilical Carrier Plate is automatically detached from the Orbiter and is retracted into the TSM. A blast shield on the TSM is then closed to protect the T-0 Umbilical Carrier Plate from the flame of the Space Shuttle Main Engines as the Orbiter lifts off. Figure 2 shows a view of the T-0 Umbilical Carrier Plate, the yellow rectangular shape plate, mated to the Orbiter. A view of the Orbiter side of the T-0 Umbilical Carrier Plate in a partially retracted state is shown in Figure 3. In this view, the fluid and electrical connectors that mate with matching connectors on the Orbiter can be seen. The largest fluid connector, located on the middle of the plate, is the connector for the LH₂ fill-and-drain line. There are a total of twelve electrical connectors. The electrical connectors are located to the left and right of the LH₂ fill-and-drain line.

To aid in the identification of the connectors, the connector numbering scheme from the Space Shuttle Operation and Maintenance Document VULML001-01 [1] is used in this report (see Figure 4). The locations of the critical electrical connectors J53, J61, and J71 are also identified in Figure 4. A picture viewing the GSE plate from the orbiter side of the plate with fluid connector labeled is shown in Figure 5. Table 6 contains a list of the connectors and their functions.



Figure 2. LH₂ T-0 Umbilical Plate Mated To Orbiter



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Figure 3. View Looking at the LH₂ T-0 Umbilical Carrier Plate from the Orbiter

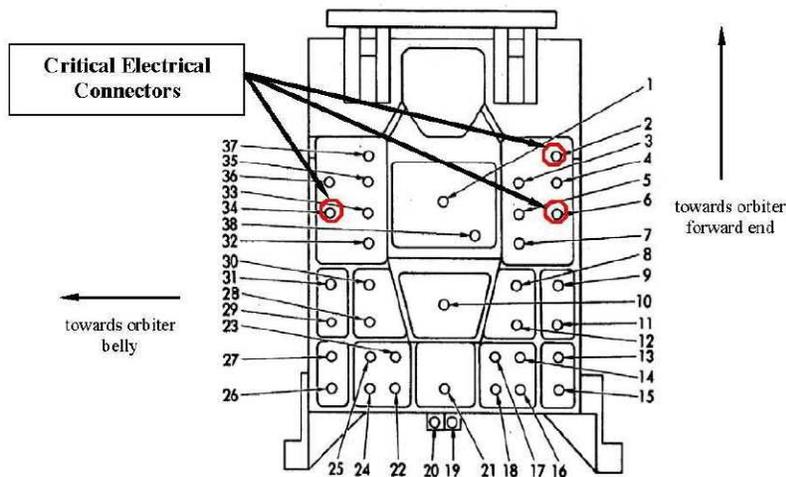


Figure 4. View Looking At GSE Side of Plate

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Figure 5. View Looking At Orbiter Side of GSE Plate

3.1 T-0 Umbilical LH2 Carrier Plate Finite Elements

The LH₂ T-0 Umbilical Carrier Plate was modeled using ANSYS 8.1. The plate was meshed from an IGES file produced by Pro/E. Rocketdyne's design group constructed the Pro/E model from the T-0 Umbilical Carrier Plate drawings out of the SDS system. The model was meshed with 3-D tetrahedral elements with mid-side nodes. These elements have been found to be very good in bending. A fine mesh (145,000 nodes) was used for the solid geometry as can be seen in Figure 6.

The two collets near the top of the T-0 Umbilical Carrier Plate are used to mate the plate to the Orbiter before launch. The collets were modeled as beam elements. Each collet contains two different regions (Figure 7). Each region represents a different component of the collet. One region represents the non-moving outer structure of the collet and the other region represents the finger of the collet that expands to lock into the Orbiter. Each zone has different material properties and different real properties. The real properties are used to define the beam dimensions such as diameter and thickness. The collet beam elements were connected to the solid elements on the GSE side of the plate by constraint equations and couples. The constraint equations are used to transfer load along the beam axis. The couples are used to restrain the beam elements in the in-plane direction of the plate. Also for each collet, one beam node was restrained against rotation about the beam axis (again see Figure 7).



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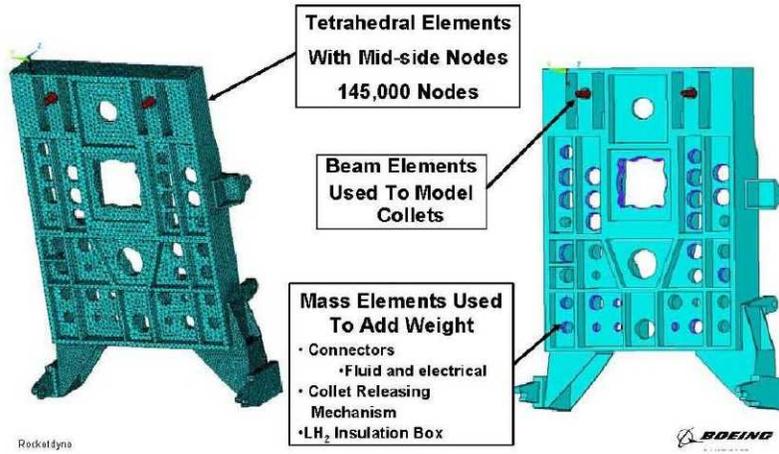


Figure 6. T-0 Umbilical Carrier Plate FE Model

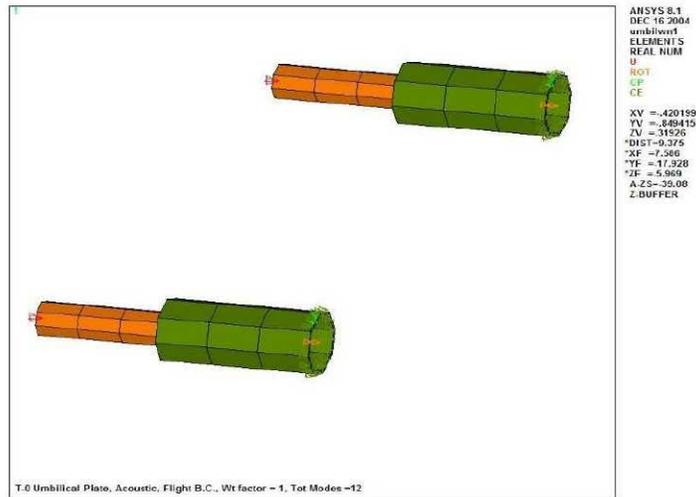


Figure 7. T-0 Umbilical Carrier Plate FEM Collet



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3.2 T-0 Umbilical Carrier Plate Mass Elements

Mass elements were used to represent the weight of the fluid and electrical connectors and a portion of the line weight. Mass elements were also used to represent the weight of the collet releasing mechanism and the LH₂ insulation box. The mass elements are shown in purple in Figure 8. The weight of the electrical connector, collet releasing mechanism and the LH₂ insulation box were estimated based on SDS drawings. The weight estimate of the collet releasing mechanism and the LH₂ insulation box did not include all the miscellaneous parts so a 1.2 scale factor was applied to the weight estimate. The weight of the mass elements is shown on the right side of Figure 8. In this figure, "WtF" is a parameter that can be used to scale the weights and was only used in sensitivity study #2. For the baseline case, "WtF" was set to one. The weight parameter number corresponds to VULML001-01 [1] or Figure 4.

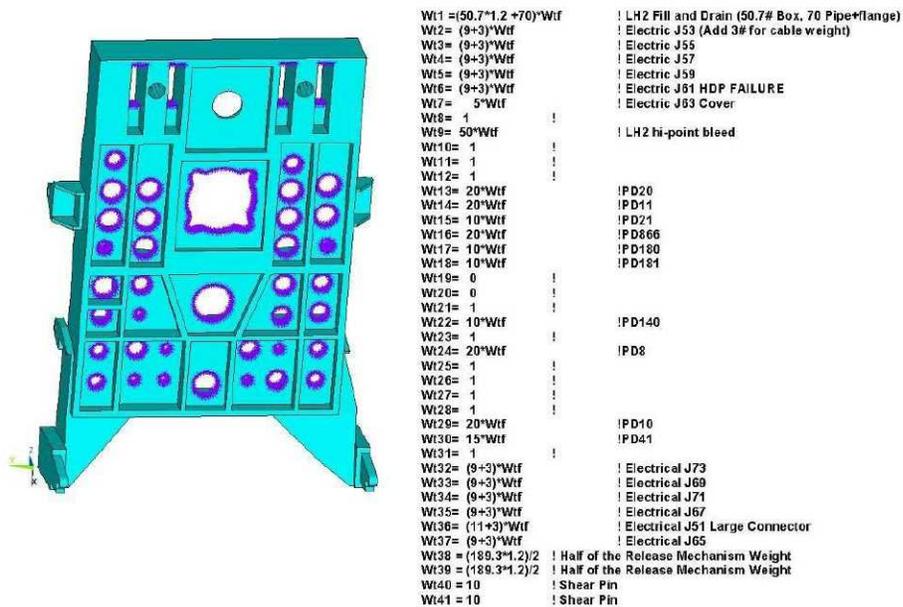


Figure 8. T-0 Umbilical Carrier Plate FEM Mass Elements



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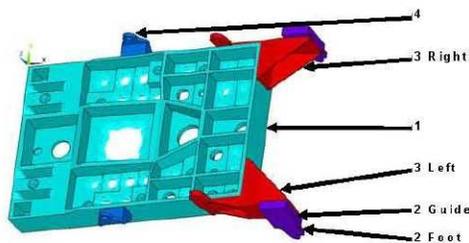
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3.3 T-0 Umbilical Carrier Plate Material Properties and Temperature

LH₂ T-0 Umbilical Carrier Plate is machined out of a solid plate of 2219 aluminum. The LH₂ T-0 Umbilical Carrier Plate foot is made out of A-286 and 17-4 PH stainless steel (see Figure 9). The collet housing is made out of A-286 and the collet fingers that mate with the Orbiter are made out of Beryllium Copper. Detailed material properties are shown in Appendix A.

The temperature of the LH₂ T-0 Umbilical Carrier Plate at T-0 is below room temperature. Thermal couple data show that at T-0 the plate temperature ranges between 0 °F and 45 °F. To be conservative, 70 °F material properties were used in the FE model. The 70 °F temperature is conservative because the elastic modulus is lower than at a colder temperature however the difference is a small amount. At 90 °F the elastic modulus is 10.16 msi and at 20 °F the elastic modulus is 10.22 msi which is less than 0.4 % difference.



Material Number	Material Description	Part Number
1	Alumimin 2219 (MB0170-092 Heat Treat T852)	G070-582301
2 Foot	A-286 (AMS5525 Heat treat MA0111-307)	G070-582510
2 Guide	A-286 (AMS5525)	G070-582507
2 Collet	A-286 (AMS 5737)	G070-582429
3 Right	17-4 PH (Mil-S-81506 or AMS 5604)	G070-582511
3 Left	(Heat Treat 1150 MA0111-307)	G070-582506
4	Alum 2124 (QQA-250/29 Heat Treat T851)	G070-582515
5 Collet (Fingers)	Beryllium Copper (QQ-C-530 Comp 172)	G070-582423

Figure 9. T-0 Umbilical Carrier Plate FEM Materials and Drawing Numbers

3.4 Vandenberg T-0 Umbilical Carrier Plate

The Space Shuttle Program has a spare LH₂ T-0 Umbilical Carrier Plate. This plate was originally to be used at the Vandenberg launch site. The Vandenberg launch site was never completed and the LH₂ T-0 Umbilical Carrier Plate for that site became known as the spare Vandenberg LH₂ T-0 Umbilical Carrier Plate.

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3.4.1 T-0 Umbilical Carrier Plate Density Adjustment (Vandenberg Plate)

The Vandenberg spare plate was weighted as shown in Figure 10. The weight of the Vandenberg spare plate was 1,350 pounds. The Vandenberg spare plate does not contain any of the fluid and electrical lines. Also, as can be seen in Figure 10, the Vandenberg spare plate was missing one electrical connector socket and two fluid line connectors. The baseline FE model was copied and then modified to match the configuration of the Vandenberg plate. A comparison of Figure 8 (added mass for baseline) and Table 1 (added mass for Vandenberg spare plate) shows the modifications done to represent the Vandenberg plate. The weight calculated from the modified FE model, Vandenberg FE model, was 1,225 pounds. Comparing the weight of the actual Vandenberg plate to the Vandenberg FE model shows the FE model was approximately 10% too light. Therefore the FE model material density and mass elements were scaled up by 10% to match the Vandenberg plate weight. This was done for all three FE models, baseline with launch boundary conditions, baseline with partially retracted boundary conditions and Vandenberg configuration. All analyses were then performed with the adjusted weight.



Figure 10. Vandenberg Spare T-0 Umbilical Carrier Plate



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Table 1. Added Mass For Vandenberg Spare Carrier Plate

WN1 = (50.7*1.2)*WNf	! LH2 Fill and Drain (50.7# Box, 70 Pipe+flange)
WN2 = (2)*WNf	! Electric J53 (Add 3# for cable weight)
WN3 = (2)*WNf	! Electric J55
WN4 = (2)*WNf	! Electric J57
WN5 = (2)*WNf	! Electric J59
WN6 = (0)*WNf	! Electric J61 HDP FAILURE
WN7 = (2)*WNf	! Electric J63 Cover
WN8 = 1	!
WN9 = 0*WNf	! LH2 hi-point bleed
WN10 = 1	!
WN11 = 1	!
WN12 = 1	!
WN13 = 20*WNf/2	! PD20
WN14 = 20*WNf/2	! PD11
WN15 = 10*WNf/2	! PD21
WN16 = 20*WNf/2	! PD866
WN17 = 10*WNf/2	! PD180
WN18 = 10*WNf/2	! PD181
WN19 = 0	!
WN20 = 0	!
WN21 = 1	!
WN22 = 10*WNf/2	! PD140
WN23 = 1	!
WN24 = 20*WNf/2	! PD8
WN25 = 1	!
WN26 = 1	!
WN27 = 1	!
WN28 = 1	!
WN29 = 20*WNf/2	! PD10
WN30 = 0*WNf	! PD41
WN31 = 1	!
WN32 = (2)*WNf	! Electrical J73
WN33 = (2)*WNf	! Electrical J69
WN34 = (2)*WNf	! Electrical J71
WN35 = (2)*WNf	! Electrical J67
WN36 = (2)*WNf	! Electrical J51 Large Connector
WN37 = (2)*WNf	! Electrical J65
WN38 = (189.3*1.2)/2	! Half of the Release Mechanism Weight
WN39 = (189.3*1.2)/2	! Half of the Release Mechanism Weight
WN40 = 10	! Shear Pin
WN41 = 10	! Shear Pin

3.4.2 Verification of FEM using Spare Vandenberg LH₂ Carrier Plate

The spare Vandenberg LH₂ T-0 Umbilical Carrier Plate was modal tested using portable modal test equipment. The portable modal test equipment consisted of an instrumented hammer (see Figure 11), accelerometers, and modal processor. The Vandenberg plate was modal tested in the free-free state by suspending the plate from the rafters (see Appendix A for more modal testing information). The accelerometer data from the modal test was then process with the X-Modal modal software. This software does a best fit to derive the modal frequencies and mode shapes. The first two significant mode shapes from the modal test data are shown in Figure 12. The X-Modal software contains only geometry information, x, y, z location of the accelerometers, therefore the plots and animations are stick figures such as that shown in Figure 12.

The Vandenberg FE model was run for modal frequency and shape. The first two significant mode shapes from the FE model are shown in Figure 13. The first mode was a torsion mode and the mode shape from the FE model (Figure 13) compares well with the mode shape from the modal test data (Figure 12). The second mode was bending in the long direction of the plate. Again, the mode shape from the FE model compares well with the modal test data. A frequency comparison for the first three modes is shown in Table 2. From this table it can be seen that the modal frequencies from the FE model closely match the modal test data therefore, the FE model has been verified by the modal test data.

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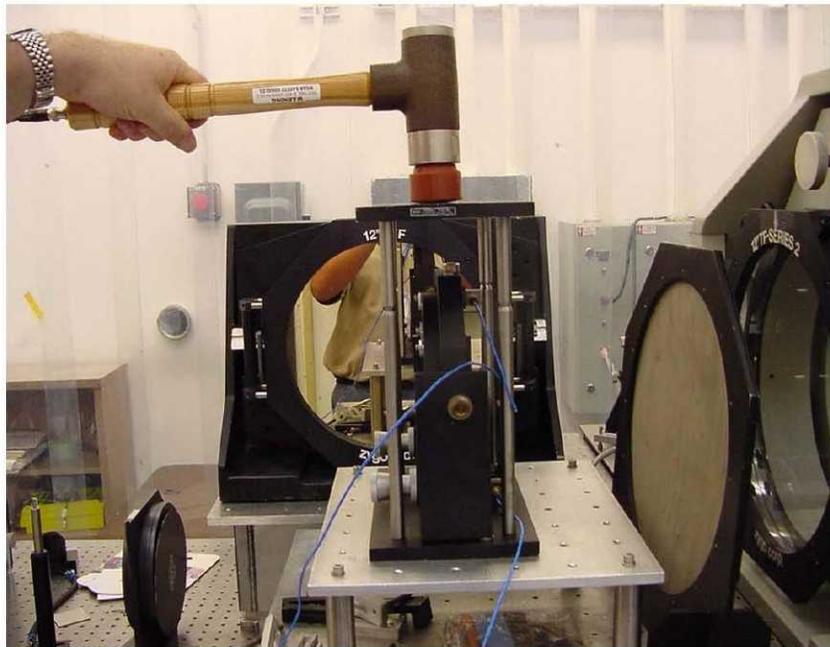


Figure 11. Instrument Modal Test Hammer



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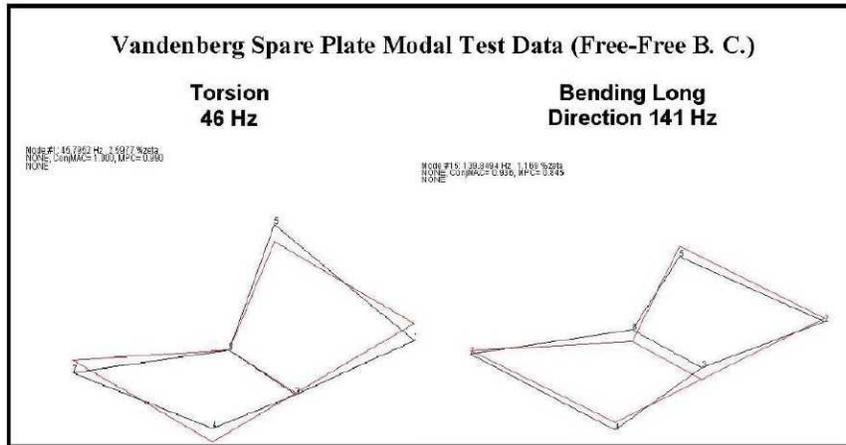


Figure 12. Vandenberg Plate Modal Test Data (Free-Free B.C.)

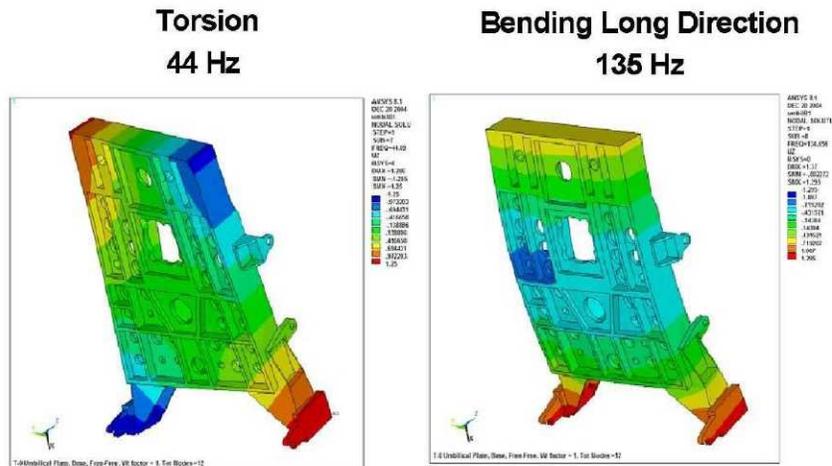


Figure 13. Vandenberg FE Model Modal Frequency and Shape

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Table 2. Frequency Comparison of Vandenberg Modal Test Data against FE Model

Mode Shape	Frequency Vandenburg (Hz)	Frequency FE Model (Hz)
Torsion	46	44
Bending	141	135
2 nd Torsion	178	179



3.5 Verification of FE Model Weight Estimate for Fluid and Electrical Line Weights

The difference between the Vandenberg FE model (free-free B.C.) and the Baseline FE model (Launch B.C.) besides boundary conditions is that the Baseline FE model contains added mass for the fluid and electrical line weight. The effective fluid and electrical line weight supported by the LH₂ T-0 Umbilical Carrier Plate was estimated and applied to the model with mass elements. This increased the total weight of the Vandenberg FE model from 1,350 pounds to the Baseline FE model weight of 1,700 pounds. To verify the estimated fluid and electrical line weight the LH₂ T-0 Umbilical Carrier Plate in the partially retracted state was modal tested (see Figure 14). The plate in the partially retracted state was supported by a pair of links on both sides. The Baseline FE model was copied and then the boundary conditions were modified to match the carrier plate in the partially retracted state. The two modes, where the stiffness of the supporting links does not affect the modal frequency, are torsion of the plate top and bending in the long direction (see Figure 15 for the FE model mode shapes). Table 3 contains a frequency summary comparison between the modal test data and the FE modal in the partially retracted state. The table shows a good comparison between the modal test data and the frequencies calculated from the FE model. This indicates that the estimated added mass for the fluid and electrical line weight was a good estimate. Also Sensitivity Study #2 shows that the estimate fluid and electrical line weight is not a strong driver in the dynamic out-of-plane displacement (see 3.11.2).



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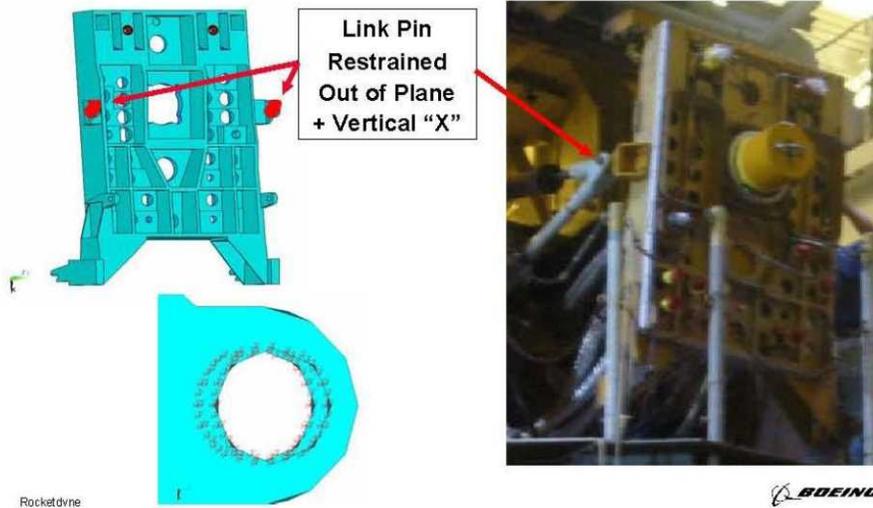


Figure 14. T-0 Umbilical Carrier Plate Partially Retracted

Mode VII (115 Hz)
Torsion Of Top

Mode VIII (133 Hz)
Bending Long Direction

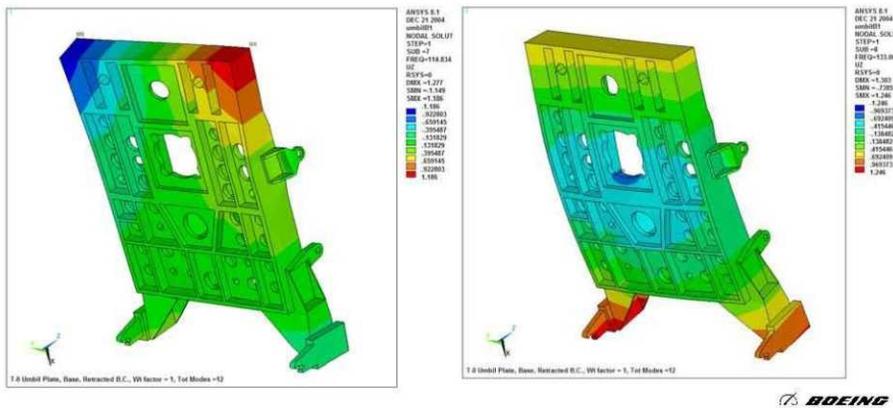


Figure 15. T-0 Umbilical Carrier Plate Partially Retracted FE Mode Shapes

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Table 3. Frequency Comparison (Partially Retracted) Modal Test Data against FE Model

Mode Shape	Frequency LH ₂ Retracted (Hz)	Frequency FE Model (Hz)
Torsion	116	115
Bending	133	133

3.6 T-0 Umbilical Carrier Plate Launch Boundary Conditions

T-0 Umbilical Carrier Plate has six points of contact when the plate is mated to the Orbiter. Launch boundary conditions are the boundary conditions when the plate is mated to the Orbiter. At the top of the plate are the two collets. A rod is pushed down the center of the collet, causing the fingers of the collet to expand and make contact with the Orbiter. The collet fingers are individual thin walled small width fingers. These small fingers transfer very little shear load therefore, the FE model boundary condition at the end of the collet consist of restrained out of plane of the plate only. Located in the middle of the plane are two shear pins. At the shear pin locations, the FE model is restrained in the in-plane directions. At the bottom of the plate are the feet. The feet are restrained in the out of plane direction of the plate and in the vertical direction, long dimension of the plate (see Figure 16).



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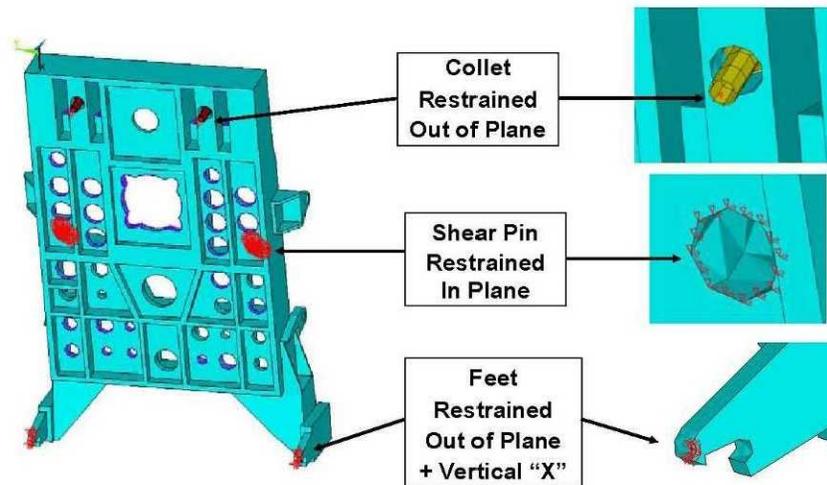


Figure 16. T-0 Umbilical Carrier Plate FEM Launch Boundary Conditions

3.7 T-0 Umbilical Carrier Plate Damping

The damping ratio used in the LH₂ T-0 Umbilical Carrier Plate FE model was 3.3 %. Most of the fluid lines connecting to the plate are external wire braced lines which produce a great deal of damping (see Figure 17). Damping is a function of the magnitude of the displacement. The magnitude of damping ratio will decrease if displacement is decreased. The damping value of 3.3 % was based on modal testing of the LH₂ T-0 Umbilical Carrier Plate in the partially retracted state. In the modal test of the LH₂ T-0 Umbilical Carrier Plate, the plate is stung with a rubber tipped hammer. Since the plate is only stung once the vibration of the plate decays with time. Therefore the damping ratio from the modal test should decay with time. The actual damping ratio for the plate bending mode from the modal testing is shown in Figure 18 as the black line. The “x” axis of this plot is “data window size”. The larger the data window size the larger the time span that is used to calculate damping. This figure shows the modal test damping ratio decaying with time as expected. The damping of the LH₂ T-0 Umbilical Carrier Plate is over 4.2 % based on the modal test when the magnitude of the vibration during the modal test is taken into account. The vibration amplitude from the SSME acoustic noise is much larger than the modal test input from a rubber tipped hammer therefore, the actual damping during launch is higher than the modal test results. The 3.3% damping used in the FE model is conservative compared to the 4.2% modal test damping. The 3.3 % damping for the FE model was selected because it was conservative and because it is also the same damping ratio used on all the fluid duct line on the Space Shuttles Main Engines.



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Figure 17. T-0 Umbilical Carrier Plate Wire Braided Hoses

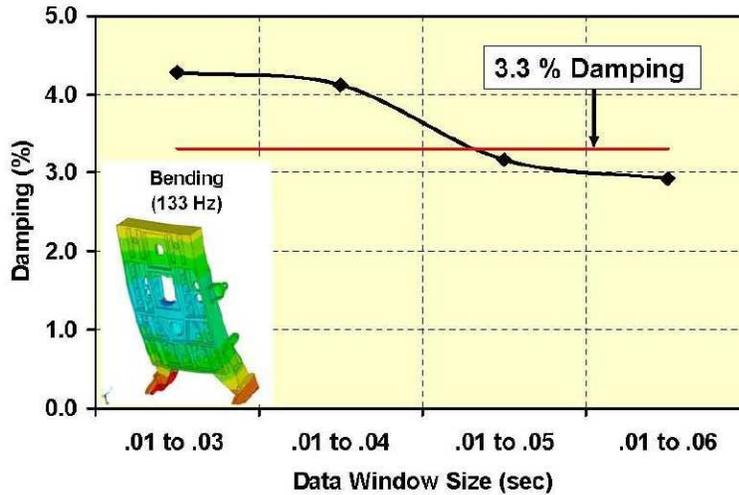


Figure 18. T-0 Umbilical Damping Ratio vs. Data Window SizeT-0 Umbilical Carrier Plate



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3.8 Dynamic Load

The dynamic load used in the analysis is random base excitation in the plate out-of-plane direction. The low frequency transient loads (less than 10 Hz) are not included in this analysis. The excitation is applied, fully correlated, in the out-of-plane direction at the collets and at the feet (see Figure 16). The power spectral density (PSD) function of the excitation is obtained from Boeing Company NASA System MF 0004-014 Table 3.2.2.2d-1 [4], and a plot of that PSD function is shown in Figure 19. Two power spectral density curves are shown in this figure. The Zone 21A PSD as listed in MF0004-014 is for "aft fuselage umbilical plate (mated)" therefore, this PSD could have been used for the GSE plate. However to be conservative, the PSD for the Orbiter, Zone 16C, was used for T-0 Umbilical Carrier Plate. For T-0 Umbilical Carrier Plate the bending mode with launch boundary conditions occurs at 75 Hz. Figure 19 shows the Zone 16C curve to be a little larger in magnitude than the Zone 21A curve at the 75 Hz frequency. Also the loads people out of Houston have stated Figure 19 includes accelerations due to acoustic excitations. Consequently, no acoustic excitation is applied to the FEM.

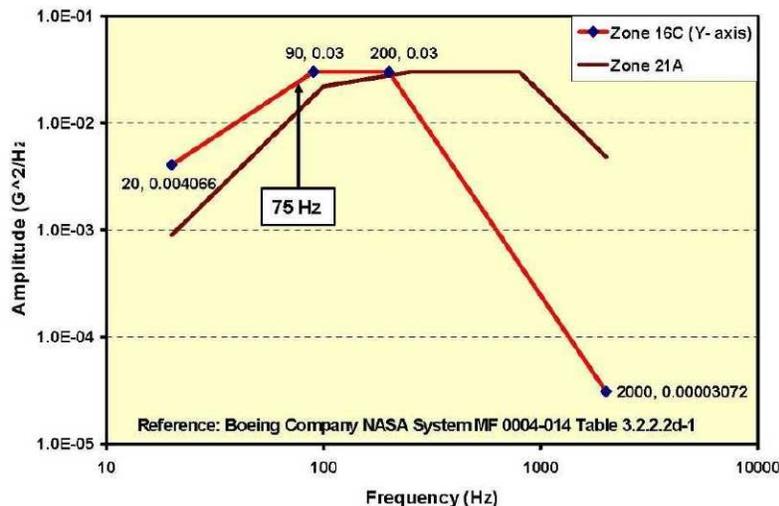


Figure 19. T-0 Umbilical Carrier Plate Base Excitation Spectrum

3.9 T-0 Umbilical Carrier Plate Frequency & Mode Shape (Launch Boundary Conditions)

Plots of the first four mode shapes for the baseline case are shown in Figure 20 through Figure 21. The contour colors in these plots indicate the relative out-of-plane displacements of the modes. The first mode (75 Hz) is plate bending in the long direction of the plate. This is the mode that produces all of the out-of-plane displacements at the electrical connector locations. The second mode is a torsion mode at 103 Hz. This mode is hard to excite since it does both positive and negative work. The third mode is an in-plane shear mode. This mode is hard to



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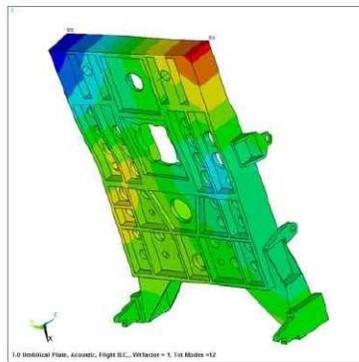
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**In-plane Shear
156 Hz**



**Complex Mode
169 Hz**

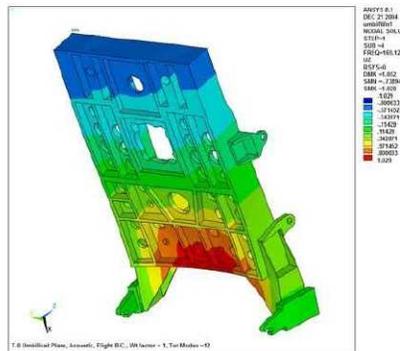


Figure 21. T-0 Umbilical Carrier Plate Mode Shapes (3rd and 4th Mode)

Table 4. T-0 Umbilical Carrier Plate Modal Frequencies

Filename	umbilWn1
SET	FREQ (Hz)
1	75
2	103
3	156
4	169
5	208
6	212
7	223
8	277
9	318
10	361
11	362
12	415

3.10 T-0 Umbilical Carrier Plate Displacement (Launch Boundary Conditions)

The LH₂ T-0 Umbilical Carrier Plate 3-sigma out-of-plane displacements were calculated using the first twelve modes. The deflection shape is shown in Figure 22. This figure shows that the maximum deflections occur at the electrical connector locations. A bar graph showing the 3-sigma out-of-plane maximum displacement at electrical connector plus the shear pin locations is



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shown in Figure 23. The maximum 3-sigma out-of-plane displacement for all the electrical connectors is 0.045 inches and occurs at connector J61, which is one of the three critical connectors. The out-of-plane displacement at the shear pins is approximately the same value as the electrical connectors.

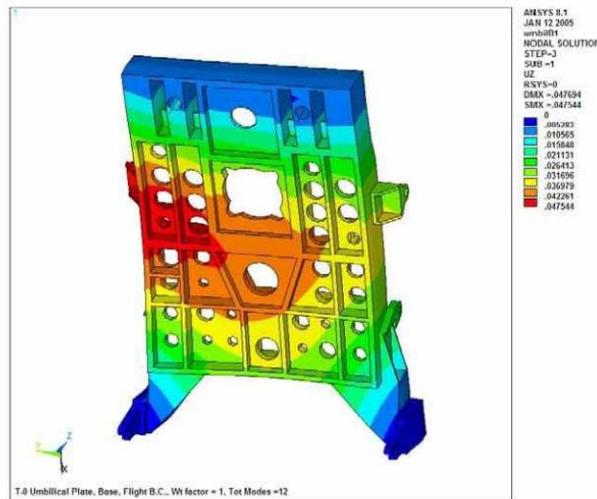


Figure 22. T-0 Umbilical Carrier Plate 3σ Displacement Shape

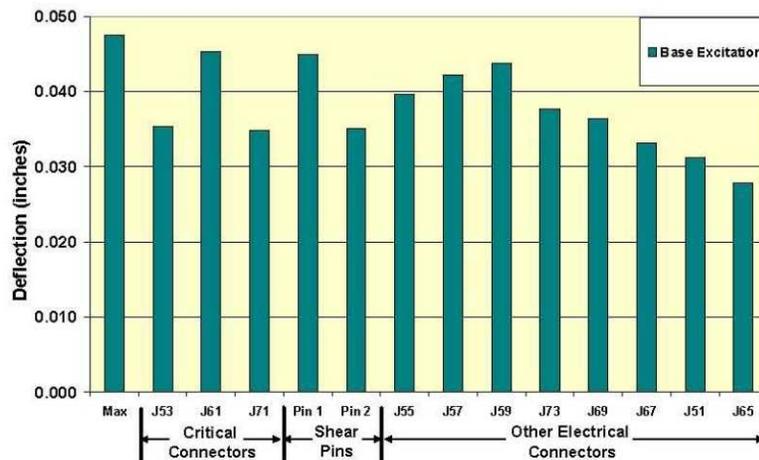


Figure 23. T-0 Umbilical Carrier Plate 3σ Connector Displacement

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3.11 Sensitivity Studies

Three dynamic sensitivity studies were performed on the T-0 Umbilical Carrier Plate. The first sensitive case was to study the effect of the number of modes included in the FE model dynamic deflection calculation. The second sensitivity case was to study the effect of different fluid and electrically line weights. The last sensitivity case was to study the effect of the fluid line stiffness.

3.11.1 Number of Modes Sensitivity (Sensitivity Study #1)

The LH₂ T-0 Umbilical Carrier Plate 3-sigma out-of-plane displacements for the baseline case were calculated using the first twelve modes (green bars shown in Figure 24). Note that the displacement magnitudes of the green bars in Figure 23 are the same as those of the green bars in Figure 24. The red bar in Figure 24 is the 3-sigma out-of-plane displacement with only the first mode (bending in the long direction at 75 Hz) included in the FE model calculation. From this figure it can be seen that all of the out-of-plane deflections are produced by the first mode.

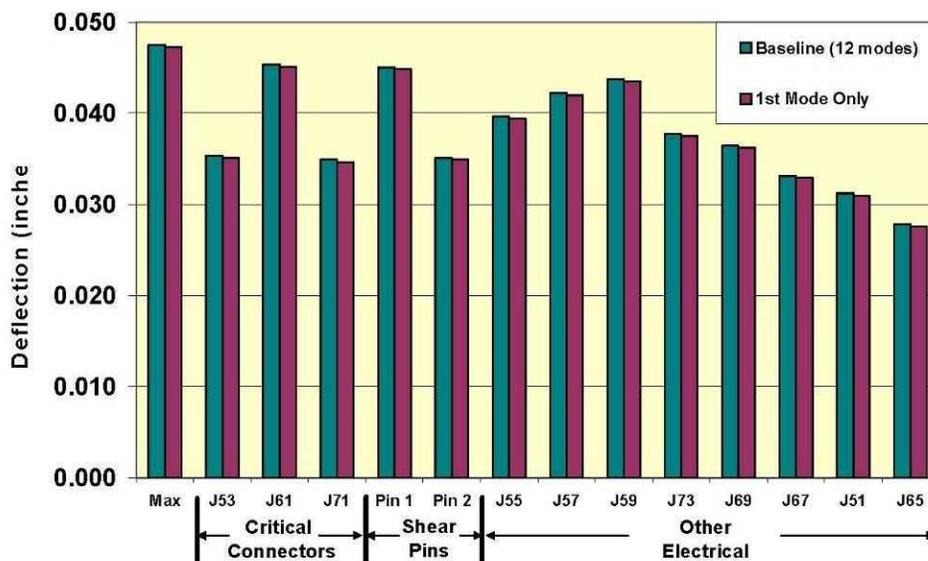


Figure 24. T-0 Umbilical Carrier Plate Sensitivity Study #1

3.11.2 Fluid and Line Weight Sensitivity (Sensitivity Study #2)

The portion of the fluid and electrical line weight that would be effectively supported by the LH₂ T-0 Umbilical Carrier Plate was estimated therefore, a sensitivity study of this estimated effective line weight was performed. Again, the LH₂ T-0 Umbilical Carrier Plate 3-sigma out-of-plane displacements for the baseline case are shown as green bars in Figure 25. For the baseline



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case, the total weight of the plate, connectors, and the estimated portion of the line weights was 1,700 pounds. For this sensitivity study, an extra 500 pounds of weight was added to the line weights to give a total weight of 2,230 pounds. The 3-sigma out-of-plane displacements with the modified weight of 2,230 pounds are shown as red bars in Figure 25. The difference in displacement between the two weight cases is only 0.005 inches. On top of the fact that the 0.005 inches is a small amount out of the .250 inches allowable, the modal testing of the LH₂ T-0 Umbilical Carrier Plate in the partially retracted state indicates that the baseline line weight estimate was good since the frequencies between modal test and FE model match.

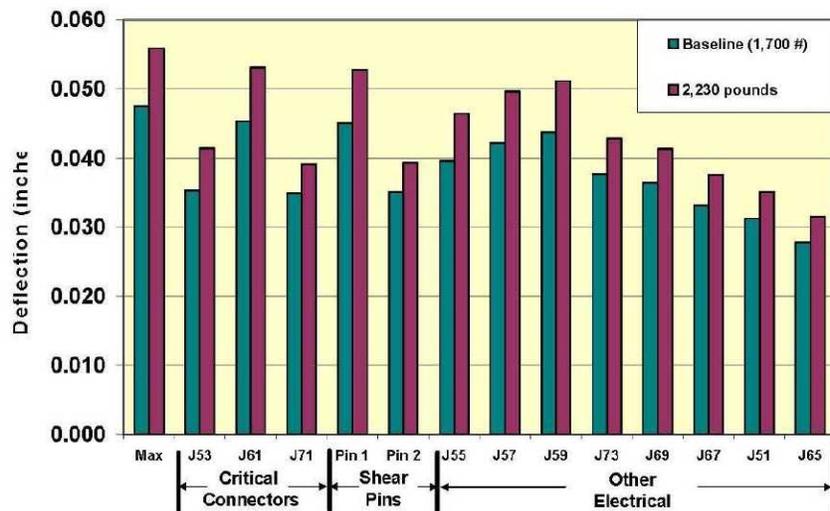


Figure 25. T-0 Umbilical Carrier Plate Sensitivity Study #2

3.11.3 Effect of Fluid Line Stiffness and Spring Stiffness (Sensitivity Study #3)

The LH₂ fluid fill line stiffness and the electrical connector spring stiffness are not included in the FE model based on an engineering decision to be conservative. Again the weights of fluid and connector springs are included in the model. The stiffness of the LH₂ fluid fill line is low due to the fact that at T-0 the fill line has no pressure and the fill line is made of a hose type construction. The LH₂ fluid fill line without pressure has intermittent supports since it does not have enough stiffness to support its own weight.

The reason that not including the LH₂ fluid fill line and connector spring stiffness in the FE model is conservative is because as the plate deflects, the fluid line and connector spring stiffness will resist the motion. The LH₂ fluid fill line will be dragging across the intermediate supports resisting the motion. The electrical connector spring force will also act in such a way as to reduce the relative deflection between the GSE plate and the Orbiter panel. The springs would produce



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an increase in resisting force over the static force as the GSE plate and Orbiter panel came together. The reverse effect would occur as the GSE plate and Orbiter panel move away from each other. During separation, the spring force decreases compared to the static force. Both of these effects would result in less relative deflection if included in the FE model.

Furthermore the effect of the LH₂ fluid fill line stiffness as it affects the acceleration load from the PSD was also explored. Including the LH₂ fluid fill line stiffness would result in an increase in frequency for the 1st mode. As stated previously, the frequency of the 1st mode with launch boundary conditions was 75 Hz. Reviewing the PSD again, as shown on the left side of Figure 26, an increase in frequency from the 75 Hz would result in an increase in the acceleration. In order to band the effect of frequency change on the out-of-plane displacement of the plate, an artificial PSD was created as shown on the right of Figure 26. This PSD was a flat PSD at the actual PSD maximum magnitude. The FE model was then used to calculate the LH₂ T-0 Umbilical Carrier Plate 3-sigma out-of-plane displacements with this artificially high and flat PSD. The 3-sigma displacement results comparison is contained in Figure 27. The displacement with the artificially high PSD increases the displacement by only .005 inches. This is a small amount out of the allowable .250 inches. Also remember that if the fluid line and spring stiffness were included, the total effect of the increase in resisting force and frequency would be a reduction in the displacement. In conclusion, the connector spring and fluid line stiffness were not included in the FE model so that the FE results would be conservative.

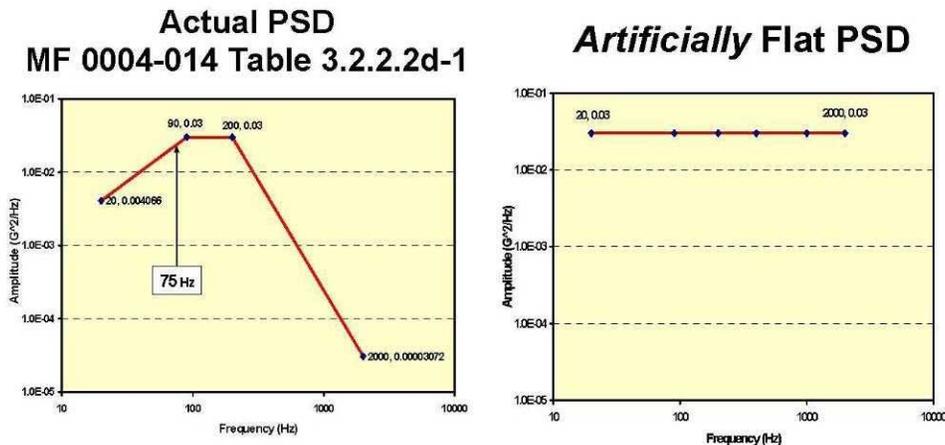


Figure 26. T-0 Umbilical Carrier Plate Sensitivity Study #3 Artificial Flat PSD



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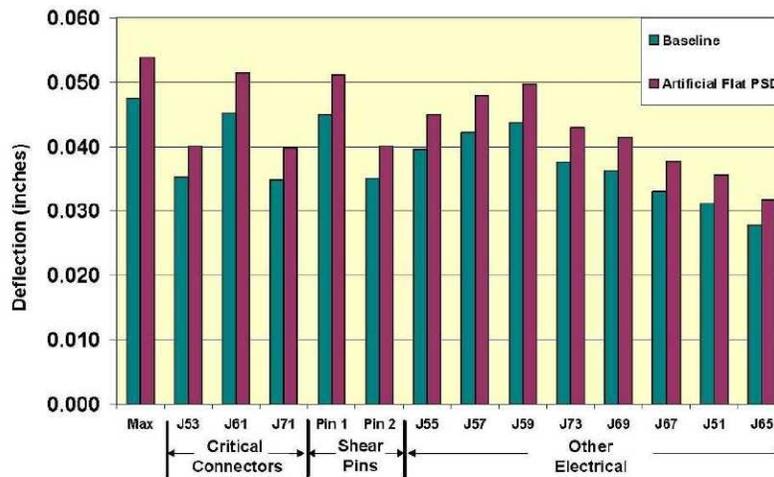


Figure 27. T-0 Umbilical Carrier Plate Sensitivity Study #3 Displacement

4.0 Comparison of LH₂ and LOX T-0 Umbilical Carrier Plates

The LOX T-0 Umbilical Carrier Plate has the same global dimensions as the LH₂ T-0 Umbilical Carrier Plate. Both LOX and LH₂ carrier plates are made out of the same material. The main difference between these two plates is that the LOX plate has three extra medium size fluid hoses located at the bottom of the plate near its feet. Frequency comparison from modal testing the LH₂ T-0 Umbilical Carrier Plate versus the LOX T-0 Umbilical Carrier Plate is shown in Table 5.

Table 5. Modal Test Frequency Comparison LH₂ Plate vs. LOX Plate

Mode Shape	LH ₂ Retracted Frequency (Hz)	LOX Retracted Frequency (Hz)
Torsion	116	109
Bending	113	125

The frequencies from the two plates are similar, with the LOX plate having slightly lower frequencies, most likely due to the weight of the aforementioned three extra fluid lines. Because the extra weight in the LOX plate is located at the bottom of the plate near the feet, its effect on the out-of-plane deflection of the electrical connectors locations should be relatively small. Furthermore, sensitivity study #2 showed only a 0.005 inches increase in deflection due to an extra 500 pounds of weight. The bending stiffness of the plates is governed by the ribbed portions rather than by the webbed portions. Differences between the two plates in their webbed portions due to cut-outs for fluid lines should not cause significant differences in their bending stiffness. For these reasons, the dynamic out-of-plane deflection of the LOX T-0 Umbilical Carrier Plate is expected to be similar to that of the LH₂ T-0 Umbilical Carrier Plate.



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5.0 Orbiter LH₂ T-0 Umbilical Panel Finite Element Model

The Space Shuttle Orbiter LH₂ T-0 Umbilical Panel is a trapezoidal shaped panel located on the port (left) side of the orbiter aft fuselage (see Figure 28). As viewed from the orbiter exterior (see Figure 29), the panel contains connectors for attaching fluid and electrical umbilical lines. The largest connector, located on the forward portion of the panel, is the connector for the LH₂ fill-and-drain line. The electrical connectors are located above and below the LH₂ fill-and-drain line.

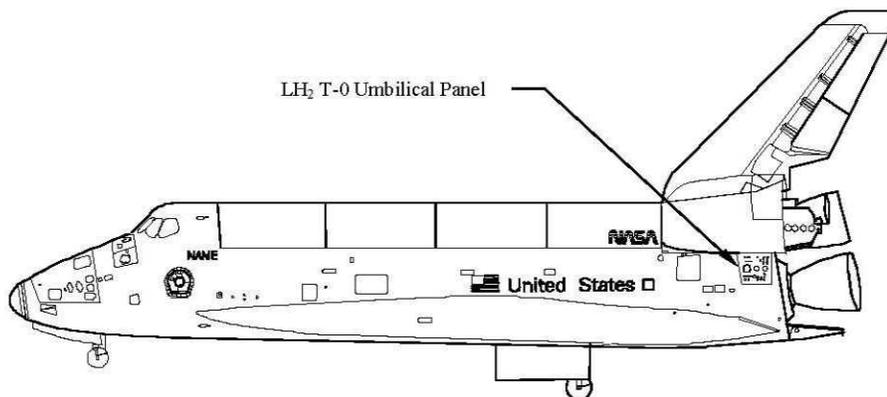


Figure 28. Location of LH₂ T-0 Umbilical Panel on Orbiter



Figure 29. Orbiter LH₂ T-0 Umbilical Panel Exterior



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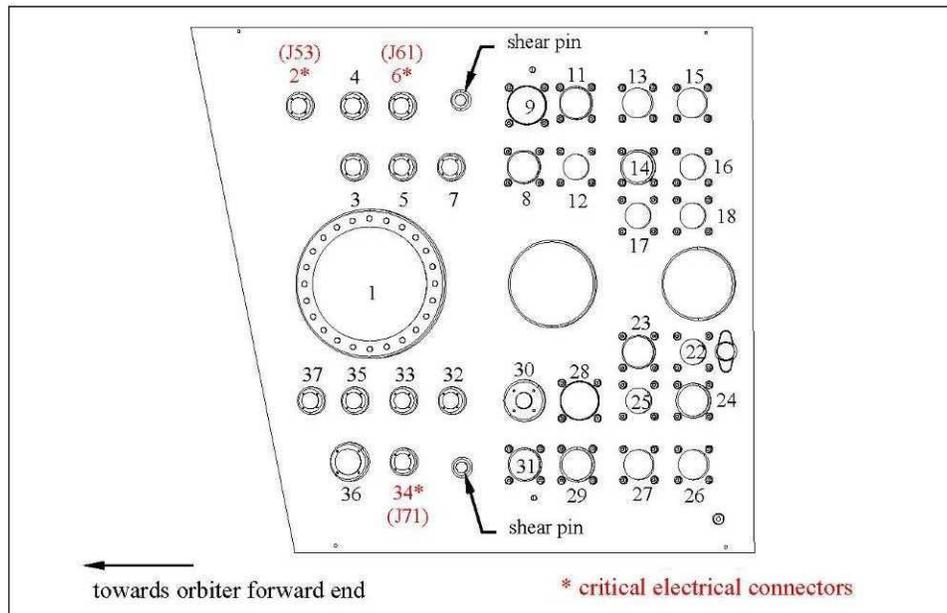


Figure 30. Orbiter LH₂ T-0 Umbilical Panel Connector Numbering Scheme

To aid in the identification of the connectors on the orbiter panel, the connector numbering scheme from the Space Shuttle Operation and Maintenance Document VULML001-01 [1] is used in this report. A picture of the panel with connector number labels is shown in Figure 30. The locations of the critical electrical connectors J53, J61, and J71 are also identified in the Figure 30. Table 6 contains a list of the connectors and their functions.

The stiffening ribs on the LH₂ T-0 Umbilical Panel can be seen from the orbiter interior as shown in Figure 31. The panel is bolted to the orbiter structural frame along its four edges, as well as along a vertical beam located just aft of the LH₂ fill-and-drain line. Fluid lines and electrical wire bundles emanate from the connectors on the panel. Also evident from Figure 31 is that many of the connectors are capped and not used.

In Figure 32, an interior view of the Orbiter LO₂ T-0 Umbilical Panel is shown. The main difference between the LO₂ and LH₂ panels is the existence of three medium sized lines at the aft region of the LO₂ panel. The forward regions of the two panels, where the electrical connectors are located, are very similar. Both panels also have vertical beams located in the panel's middle region. Due to their structural similarities at the forward region, the out-of-plane displacements of the electrical connector location of both panels are expected to be comparable.



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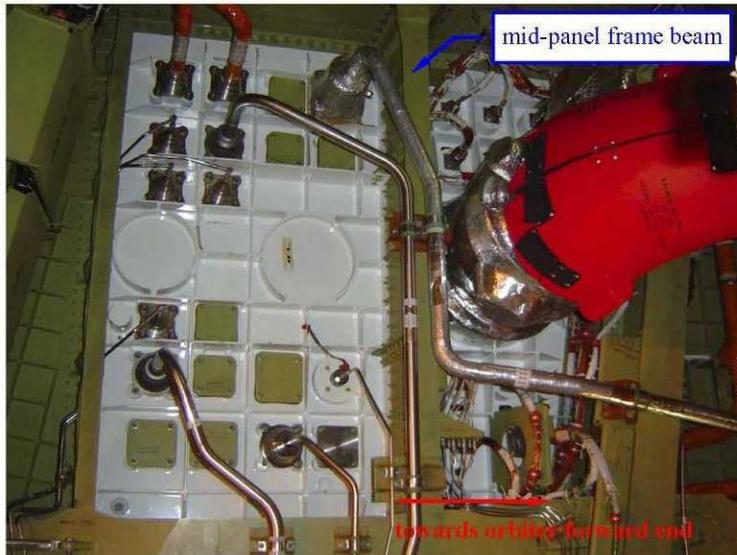


Figure 31. Orbiter LH₂ T-0 Umbilical Panel Interior



Figure 32. Orbiter LO₂ T-0 Umbilical Panel Interior



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Table 6. Connector Description

Index Number*	Type	Reference Designator	Function
1	Fluid	S0517PD7	LH ₂ fill & drain
2	Electric	50V77W85J53	EPDC, C&T systems
3	Electric	50V77W199J55	Payload systems (connector 1)
4	Electric	50V77W88J57	EPDC systems
5	Electric	50V77W197J59	Payload systems (connector 2)
6	Electric	50V77W88J61	EPDC, EC, DP&S systems
7	Electric	50V77W151J63	DFI systems (connector 2)
8	Fluid	S0517PD0998	Spare
9	Fluid	S0517PD887	LH ₂ hi-point bleed (MPS)
11	Fluid	S0517PD0997	Spare
12	Fluid	S0517PD0999	Spare
13	Fluid	S0517PD20	ECLSS primary coolant supply
14	Fluid	S0517PD11	MPS GN ₂ engine purge
15	Fluid	S0517PD21	ECLSS primary coolant return
16	Fluid	S0517PD886	OV/ET LH ₂ disconnect purge
17	Fluid	S0517PD180	Payload bay gas leak detection
18	Fluid	S0517PD181	Mid fuselage gas leak detection
22	Fluid	S0517PD140	Aft fuselage gas leak detection
23	Fluid	S0517PD0996	Spare
24	Fluid	S0517PD8	MPS LH ₂ - He pre-pressure
25	Fluid	S0517PD0998	Spare
26	Fluid	S0517PD23	ECLSS secondary coolant return
27	Fluid	S0517PD22	ECLSS secondary coolant supply
28	Fluid	S0517PD46	Payload cold He fill
29	Fluid	S0517PD10	MPS He fill
30	Fluid	S0517PD41	PRSD H ₂ gas supply
31	Fluid	S0517PD0994	Spare
32	Electric	50V77W100J73	Payload systems (connector 3)
33	Electric	50V77W151J69	DFI systems (connector 1)
34	Electric	50V77W1J71	OI, DP&S, C&T systems
35	Electric	50V77WXXJ67	Spare
36	Electric	50V77W2J51	GSE main power bus
37	Electric	50V77W29J65	MPS systems

* Numbering scheme is obtained from VUML00-001 [1], page 1-6, figure 1-3.
 Refer to Figure 30 in this report for connector locations.



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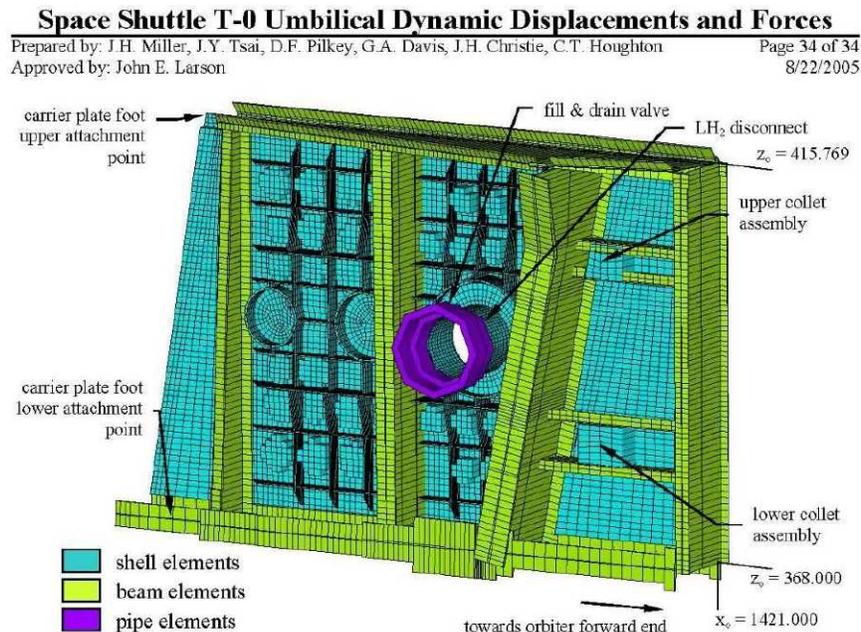


Figure 33. Orbiter LH₂ T-0 Umbilical Panel Finite Element Model

The Orbiter LH₂ T-0 Umbilical Panel finite element model, shown in Figure 33, is a linear elastic ANSYS model. It includes not only the umbilical panel itself but also portions of the surrounding structure. The model extends from the aft heat shield shell structure aft of the panel to the $x_0 = 1421.000$ (refer to MD-V70 [2] for orbiter coordinates) vertical frame beam forward of the panel. Included in the model are portions of the orbiter frame beams, skin panels forward and aft of the umbilical panel, and the LH₂ fill-and-drain disconnect, valve, and line assembly. The attachments for the T-0 Umbilical Carrier Plate, located at the collet assemblies and at aft attachment points, are also included in the model. Various aspects of the model will be discussed in the following sections.

5.1 Element Types

The model uses six different types of elements as listed in Table 7. As shown in Figure 33, the umbilical panel, skin panels, and the LH₂ fill-and-drain disconnect are represented by shell elements. Beam elements are used for the orbiter frame beams, and pipe elements for the LH₂ fill-and-drain valve body.

The masses of the LH₂ fill-and-drain line and those of other lines and connectors are represented by mass elements as shown in Figure 34. A mass element located above the valve body pipe elements represents the mass of the valve actuator. The total mass of the valve assembly is assumed to be evenly distributed between the valve body and the valve actuator. Three spring elements connect the node at the most inboard end of valve body pipe elements to a coincident node. The spring elements represent the relative translational stiffness of the LH₂ fill-and-drain



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line. The estimated stiffness of the line is described in detail in section 5.5.1. Finally, rigid elements are used to connect the umbilical panel to the aft skin panel because the two panels do not share an edge at their mutual boundary.

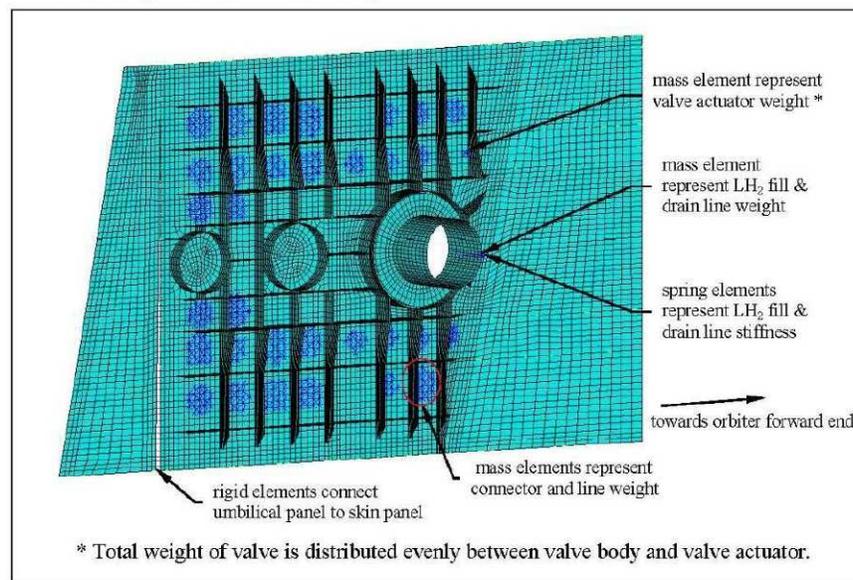


Figure 34. Mass, Spring, and Rigid Elements

The ANSYS SHELL181 element is a 4-node quadrilateral shell element incorporating first-order transverse shear deformation (Mindlin-Reissner) theory. The full integration with incompatible modes option is used for these shell elements in the FEM. These elements allow for layered sections, whose use in the model is described in sections 5.5.2 and 5.5.3.

The ANSYS BEAM188 element is a 2-node beam element. As used in the model, the beam elements include warping degree of freedom. The FEM uses the beam's first-order transverse shear deformation (Timoshenko) theory option. The actual geometric cross-sections of the beams, along with the appropriate nodal offsets, are used in the model.

Table 7. Element Type List

Element Type	ANSYS Name	Description
Shell	SHELL181	4-node Mindlin-Reissner shell element
Beam	BEAM188	2-node Timoshenko beam element with warping degree of freedom
Pipe	PIPE16	2-node Euler-Bernoulli beam element with circular cross-section
Mass	MASS21	1-node concentrated mass element with translational inertia only
Spring	COMBIN14	2-node translational spring element
Rigid	MPC181	2-node rigid beam element



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5.2 Material Properties

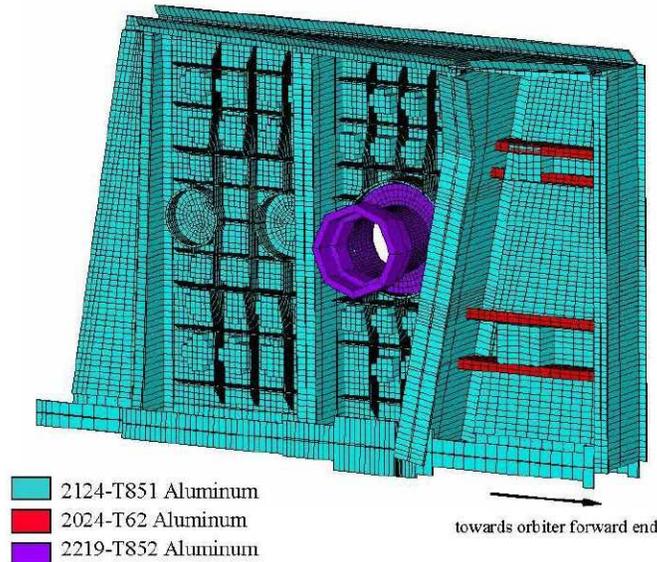


Figure 35. Materials in Finite Element Model

As shown in Figure 35, the major structural components included in the FEM are made of aluminum alloys. The elastic material properties of the aluminum alloys are listed in Table 8. All properties are obtained from Rocketdyne's material properties database accessed through the MVISION computer program. Since the temperature of the panel at the time of Main Engine Ignition is expected to be near room temperature, the values of the material properties are evaluated at 70 °F. MVISION printouts of the material properties are included in Appendix A.

Table 8. Material Properties List

Material Name	Property	Value (70 °F)	Source
2124-T851	Elastic Modulus	10.45×10^9 psi	MPM 3203.01.01.01-02
	Poisson's Ratio	0.33	MPM 3203.01.01.01-02
	Density	0.1 lb/in ³	MPM 3203.01.01.01-02
2024-T62	Elastic Modulus	10.68×10^9 psi	MPM 3202.21.10.01-01B
	Poisson's Ratio	0.33	MPM 3203.01.01.01-02
	Density	0.1 lb/in ³	MPM 3202.01.01.01-02
2219-T852	Elastic Modulus	10.65×10^9 psi	MPM 3215.21.01.01-01
	Poisson's Ratio	0.325	MPM 3215.01.01.01-02
	Density	0.103 lb/in ³	MPM 3215.01.01.01-02
Inconel 718*	Elastic Modulus	29.6×10^6 psi	718,ALL,ALL,EMOD,MPM,JUN77,TYP

* Inconel 718 is used for fill-and-drain line stiffness estimation FEM (see section 5.5.1).



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5.3 Mass Properties

The weight of the Orbiter LH₂ T-0 Umbilical Panel is estimated as 82.5 pounds based on a CAD model supplied by Boeing Huntington Beach. The estimated weights of the connectors and lines, as shown in Table 9, are based on the appropriate disconnect specifications and line drawings. The weights of the electrical connectors and lines, as well as those of the unused fluid lines, are assumed to be 1 pound. The weights are converted into masses for use in the FEM. As discussed later in section 5.8, these baseline mass estimates are used in the FEM baseline case. The masses of the connectors and lines used in the FEM are varied from their baseline estimates for the sensitivity cases.

Table 9. Connector and Line Weight Estimates

Index Number*	Installation Drawing	Disconnect Specification	Line Drawing	Estimated Weight (lbs)
1	V070-415704-008	MC276-0005-0041	MC276-0076-0021	121 (line) 13 (disconnect) 46 (valve)
2	-	-	-	1
3	-	-	-	1
4	-	-	-	1
5	-	-	-	1
6	-	-	-	1
7	-	-	-	1
8	-	-	-	1
9	V070-415610-011	MC276-0004-0003	V070-415612-004	2.1284
11	-	-	-	1
12	-	-	-	1
13	V070-635300-044	MC276-0035-1205	V070-635301-041	2.3249
14	V070-415101-002	MC276-0003-0007	V070-415110-001	3.6679
15	V070-635300-044	MC276-0035-1205	V070-635301-040	2.3249
16	V070-385030-007	MC276-0021-0618	V070-385032-024	1.7671
17	V070-385071-006	MC276-0021-0611	V070-385701-059	1.7841
18	V070-385071-006	MC276-0021-0617	V070-385701-058	1.7671
22	V070-385071-006	MC276-0021-0610	V070-385701-068	1.7739
23	-	-	-	1
24	V070-415413-034	MC276-0003-0007	V070-415410-009	3.7719
25	-	-	-	1
26	-	-	-	1
27	-	-	-	1
28	-	-	-	1
29	V070-415141-083	MC276-0003-0006	V070-415520-059	3.5334
30	V070-455002-004	MC276-0012-1210	V070-455110-149	1.0341
31	-	-	-	1
32	-	-	-	1
33	-	-	-	1
34	-	-	-	1
35	-	-	-	1
36	-	-	-	1
37	-	-	-	1

* Numbering scheme is obtained from VUML00-001 [1], page 1-6, figure 1-3.
Refer to Figure 30 in this report for connector locations.



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5.4 Boundary Conditions

The in-plane boundary conditions used in the FEM are illustrated in Figure 36, while the out-of-plane boundary conditions are shown in Figure 37. Since the orbiter skin panels extend beyond the upper, lower, and forward boundaries of the FEM, the FEM is restrained along these edges in the in-plane translational direction that is normal to the respective edge. No in-plane restraint is applied at the aft edge of the FEM since there is no structure further aft of the edge.

However, the aft edge of the FEM is restrained in the out-of-plane translational direction due to the presence of the aft heat shield shell structure. The shell structure is oriented perpendicular to the aft skin panel along the skin panel's aft edge. The rotations about the local x-axis at the upper aft and lower aft corners are also restrained because of the aft shell structure's presence. A short portion of the upper edge at the FEM's upper aft corner is restrained in the out-of-plane translational direction. A longeron fitting at this location limits out-of-plane motions.

The four corners of the umbilical panel, along the upper and lower ends of the mid-panel frame beam (located just aft of the LH₂ fill-and-drain line), are restrained in the out-of-plane translational direction due to orbiter frame beams that pass through these locations and continue beyond the upper and lower boundaries of the FEM. Orbiter frame beams that continue beyond the upper, lower, and forward boundaries of the FEM at the upper forward and lower forward corners of the FEM limit out-of-plane motions these locations. Consequently, both the out-of-plane translation and the rotation about the local x-axis at these locations are restrained.

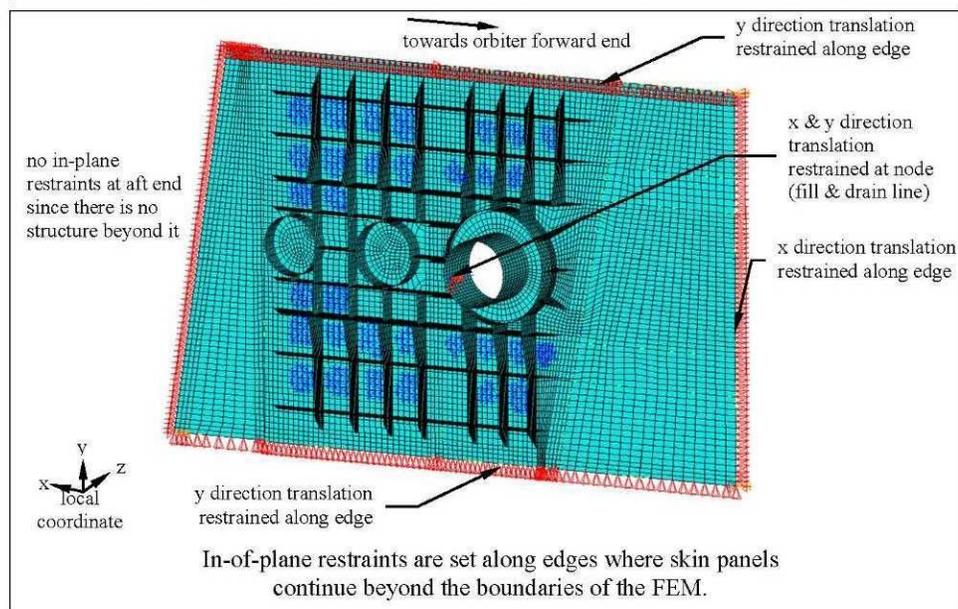


Figure 36. In-Plane Boundary Conditions



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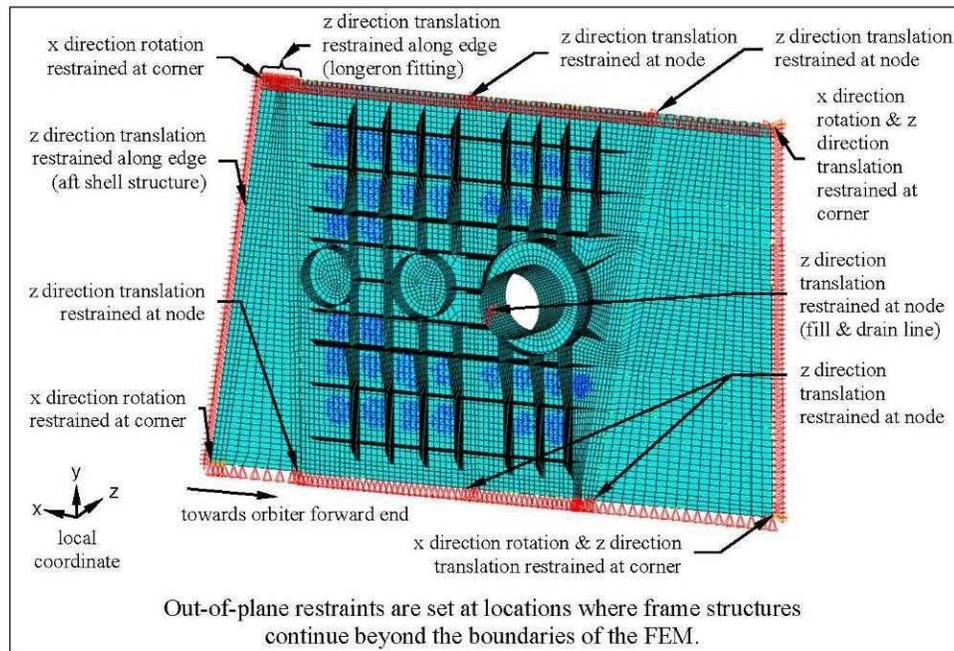


Figure 37. Out-of-Plane Boundary Conditions

5.5 Special Features

The Orbiter LH2 T-0 Umbilical Panel finite element model includes several special features that are discussed in the following sections.

5.5.1 Estimate of LH2 Fill-and-Drain Line Stiffness

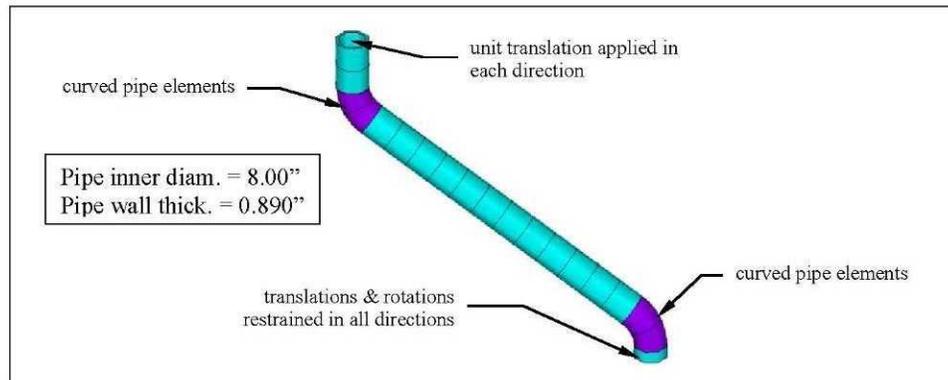


Figure 38. FEM Used in Estimating LH2 Fill-and-Drain Line Stiffness

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The stiffness of the LH₂ fill-and-drain line was estimated using an ANSYS liner elastic finite element model, as shown in Figure 38. The line is modeled using ANSYS PIPE16 elements for the straight sections and PIPE18 elements for the curved sections. Inconel 718 material properties are used for the line in the FEM. The flexibility factors from the ASME NB-3686.2 [3] are used in the curved pipe sections. The inboard end of the fill-and-drain line is restrained in all translational and rotational directions. Unit translations are applied at the outboard end of the line in each direction, in one direction at a time. The resulting reaction forces due to each applied unit translation are used as the baseline stiffness constants of the spring elements in the Orbiter LH₂ T-0 Umbilical Panel FEM (see Figure 34). The spring elements' stiffness constants in the Orbiter Panel FEM are varied from their baseline values for the sensitivity cases, as described in section 5.8.

5.5.2 Orthotropic Shell Elements

The orbiter skin panels that are included in the Orbiter Panel FEM contain stiffening ribs, similar to those on the LH₂ T-0 Umbilical Panel. Shell elements, with the actual geometry of the ribs, are used to represent explicitly the ribs on the T-0 Umbilical Panel. However, since such level of detail is not necessary for the skin panels, equivalent orthotropic shell elements are used to represent the combined rib-and-web structure of the skin panels in order to facilitate model construction. The locations of these orthotropic shell elements are shown in Figure 39.

These orthotropic shell elements contain two layers, with the first layer representing the panel web and the second layer the stiffening ribs. The first layer has isotropic material properties, and its thickness is equal to the panel web's thickness. The thickness of the second layer is equal to the height of the stiffening ribs. The second layer contains orthotropic material properties, in which the reduced elastic modulus value in each direction accounts for the stiffness of the ribs in the corresponding direction. The elastic modulus of the second layer is factored by the ratio of the rib thickness to the rib spacing distance in each of the two principal in-plane directions.

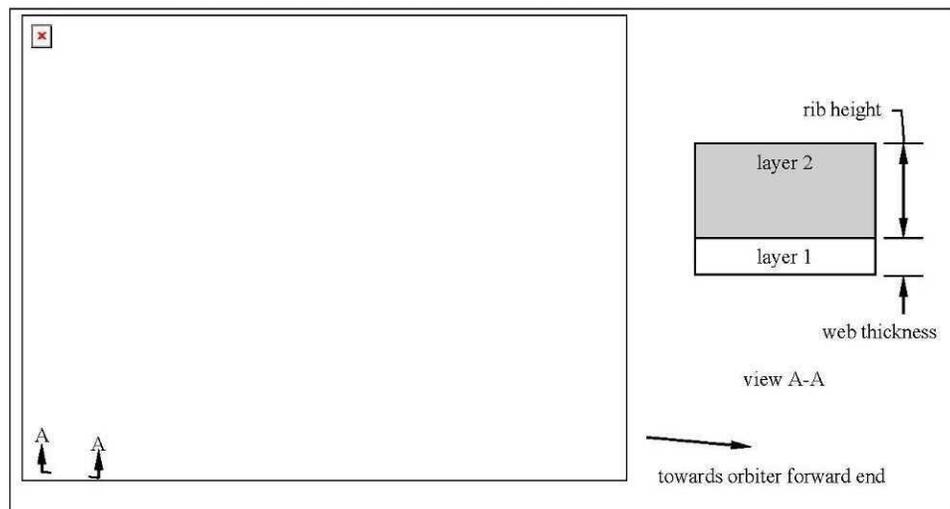


Figure 39. Orthotropic Shell Elements



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5.5.3 Connector Region Reinforcements

At connector locations on the panel, there are extra materials providing reinforcement, as seen in the left portion of Figure 40. These reinforcements are represented by thickened shell elements as seen in the center of Figure 40. These thickened elements have two layers. The first layer, representing the panel web, has its thickness equal to the web thickness. The second layer represents the reinforcement. Its thickness is equal to the reinforcement height, and its elastic modulus value is reduced by the ratio of the actual volume reinforcement material to the volume of the second layer. Because of the mass elements located at the connector regions representing the masses of connectors and lines (see Figure 34), the connector regions in the FEM deform excessively if the reinforcement stiffness are not included (see Figure 41). Including the reinforcement stiffness prevents such excessive deformation at the connector regions.

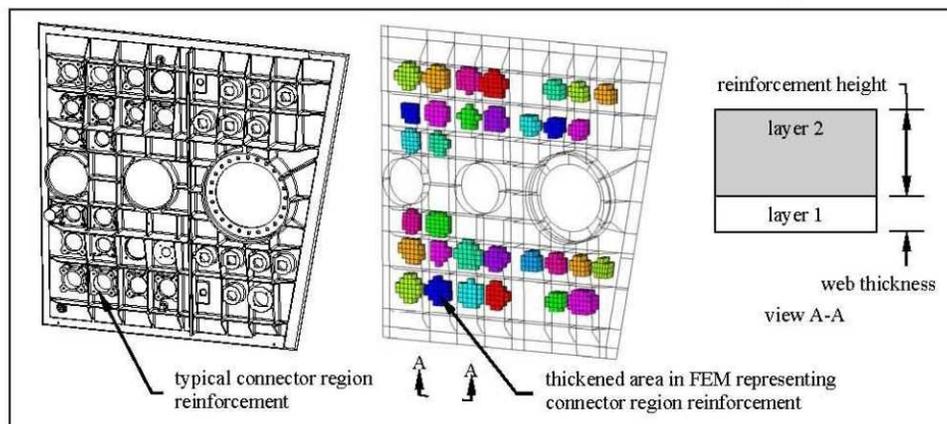


Figure 40. FEM Representation of Connector Reinforcement Regions

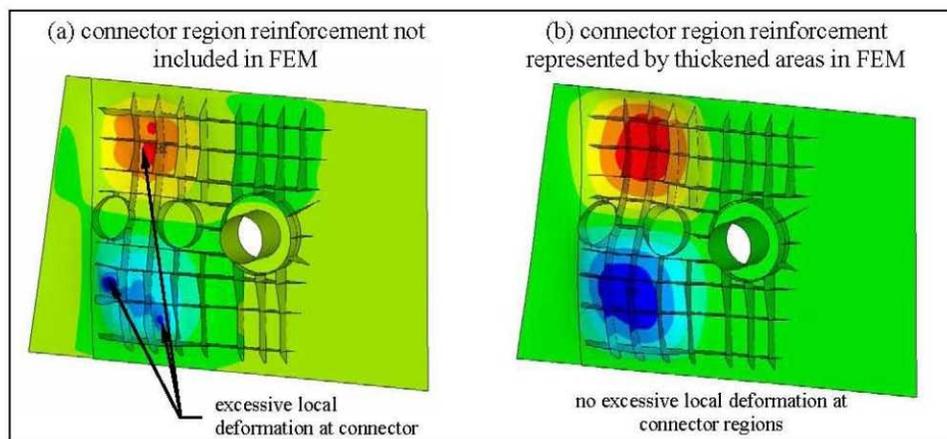


Figure 41. Effect of Including Connector Region Reinforcement in FEM



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5.5.4 Constraint Equations

The Orbiter Panel FEM includes many constraint equations which couple the motions of various nodes. The locations of the constraint equation nodes are shown in Figure 42. There is a set of constraint equations which ties the LH₂ disconnect flange to the corresponding flange on the T-0 Umbilical Panel. Another set of equations ties the LH₂ disconnect shell elements to the LH₂ valve body pipe elements. The mass element representing the LH₂ valve actuator mass (see Figure 34) is also tied to the LH₂ valve body pipe elements using constraint equations. For the above three sets of constraint equations, all translational and rotational degrees-of-freedom (DOF) are coupled.

Since the beam elements used in the FEM include the warping DOF, the warping DOF must be decoupled at nodes where beam elements intersect. Warping, unlike the translations and rotations, is not coupled at beam intersections in which beams connect at sharp angles. In the FEM, two coincident nodes exist at each beam intersection, with one node belonging to each of the intersecting beam elements. The translational and rotational DOF of the two coincident nodes are coupled, while the warping DOF is left uncoupled.

The constraint equations between the orbiter frame beam and the umbilical panel edge, and those between the mid-panel frame beam and umbilical panel ribs, are described in detail in the following sections 5.5.4.1 and 5.5.4.2 respectively.

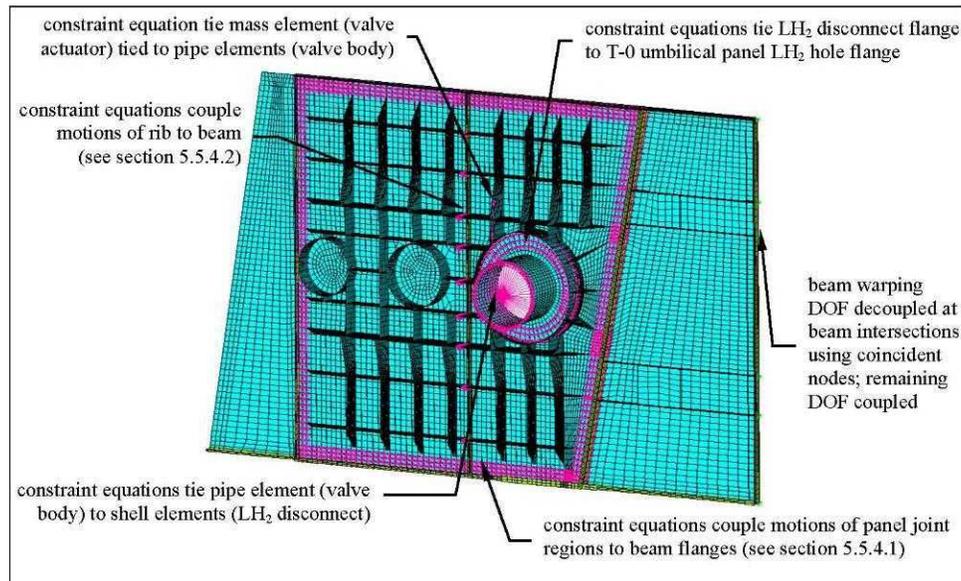


Figure 42. Constraint Equations in FEM



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5.5.4.1 Panel Edge Constraint Equations

The T-0 Umbilical Panel is bolted to the flanges of the orbiter frame beams along strips along the panel's edges. In the FEM, the beam elements representing the orbiter frame beams are one-dimensional elements and therefore do not actually have flanges. Consequently, the panel may separate from the beam flanges at the bolted joints in the FEM, as shown in the top left portion of Figure 43. Constraint equations, shown in the bottom portion shown in the bottom portion of Figure 43, are used to tie the panel web to the beam flange. The constraint equations couple the out-of-plane translation of the slave nodes on the panel shell elements to the out-of-plane translation and beam-axis rotation of the beam elements. In addition, rotation about the beam axis at the panel shell nodes is coupled to that of the beam element. By using the appropriate constraint equations, the panel remains attached to the beam flange at the bolted joint as shown in the top right portion of Figure 43.

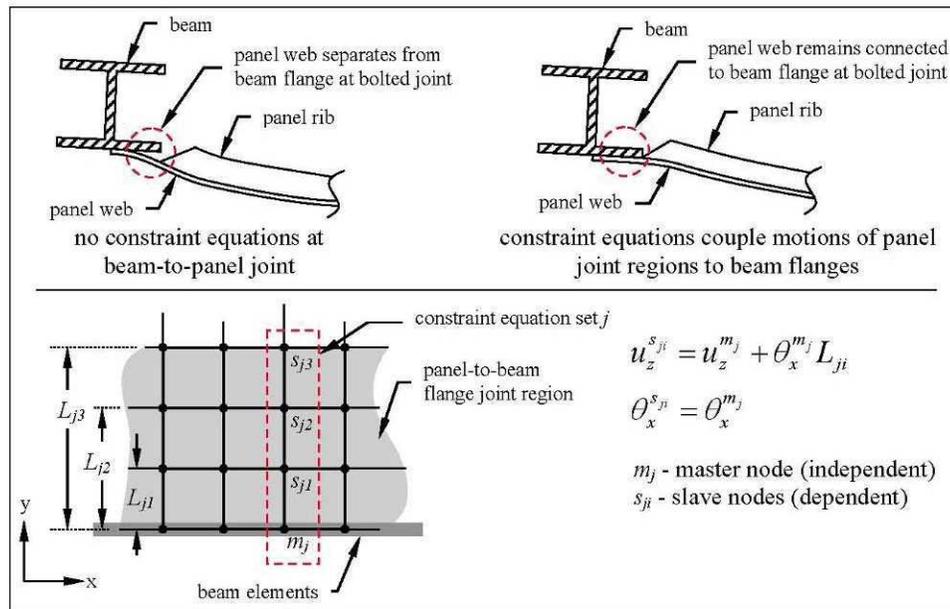


Figure 43. Use of Constraint Equations at Panel Edge

5.5.4.2 Mid-Panel Frame Beam Constraint Equations

The mid-panel frame beam is bolted to a rib on the Umbilical Panel just aft of the LH₂ fill-and-drain line, as shown in the left portion of Figure 44. In the FEM, the beam and the rib to which it is attached are combined into a single entity represented by beam elements (see the right portion of Figure 44). This approach is used in the FEM because the beam and rib, when bolted together, will tend to act as a single beam entity.



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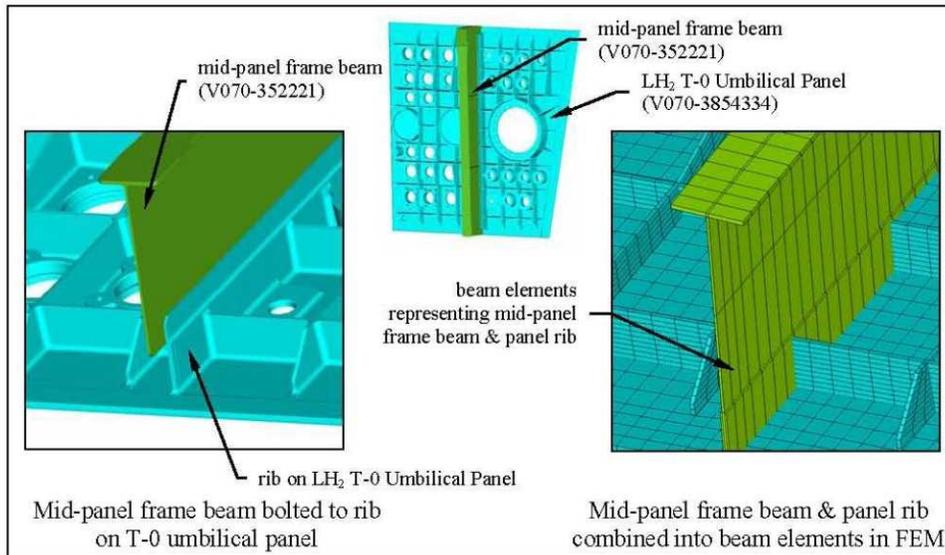


Figure 44. FEM Representation of Mid-Panel Frame Beam

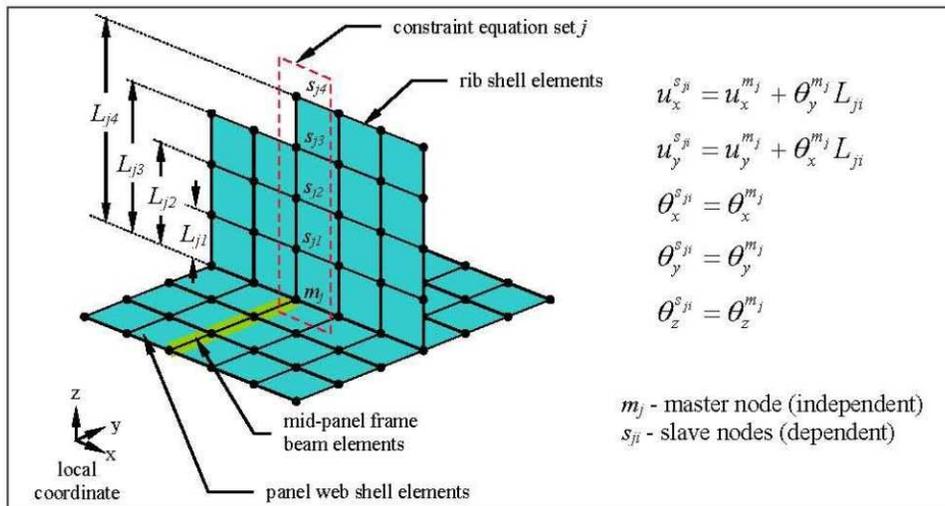


Figure 45. Constraint Equations at Mid-Panel Frame Beam

Since the beam elements do not actually have webs or flanges, constraint equations are used to couple the motions of the beam elements to those of the perpendicular rib shell elements. The appropriate constraint equations for the mid-panel frame beam elements and the rib shell elements are shown in Figure 45. The in-plane translation (in the rib longitudinal direction) of



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the rib shell nodes is coupled to the translation in the same direction and the rotation about the beam-axis of the beam node. The out-of-plane translation (with respect to the rib) of the rib shell nodes is coupled to the translation in the same direction and the rotation about the rib longitudinal axis of the beam node. In addition, all rotations of the rib shell nodes are coupled to those of the beam node. Without the use of the constraint equations, the ribs separate from and slide relative to the beam, as shown in the left portion of Figure 46. However, with the appropriate constraint equations, the ribs remain connected to the beam (see the right portion of Figure 46).

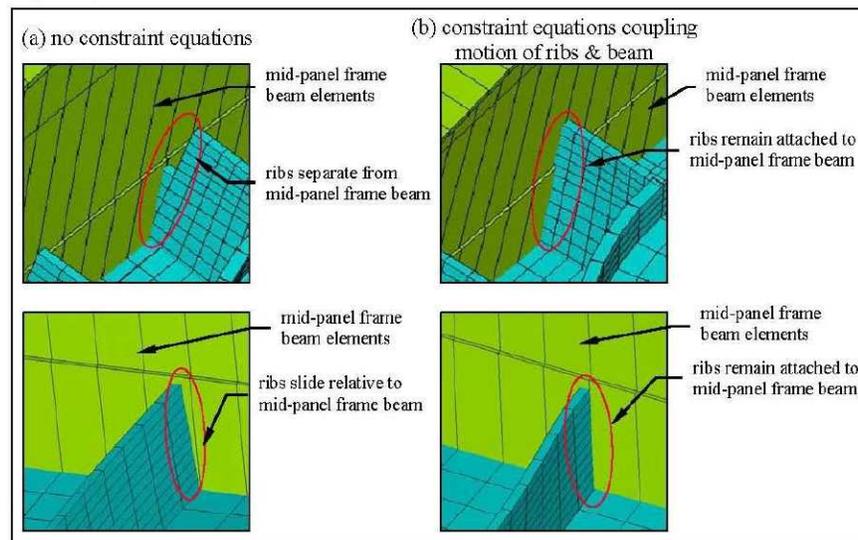


Figure 46. Effect of Constraint Equations at Mid-Panel Frame Beam

5.6 Damping

Based on the results of the T-0 Umbilical Carrier Plate modal test (section 3.7), a damping ratio value of 3.3% is used in the analysis of the Orbiter T-0 Umbilical Panel.

5.7 Applied Dynamic Loads

The load used in the analysis is random base excitation in the out-of-plane direction. The low frequency transient loads are not included in this analysis. The excitation is applied, fully correlated, at all out-of-plane translational restraints shown in Figure 37, including the LH₂ fill-and-drain line and the entire aft edge. The power spectral density (PSD) function of the excitation is obtained from MF0004-014 [4], and a plot of that PSD function is shown in Figure 47. James Lambert, in his presentation to the T-0 Separation Interface Tiger Team on October 26, 2004 [5], identifies this PSD function as the appropriate one to use for the Orbiter T-0 Umbilical Panel. In the same presentation, Mr. Lambert also indicates that this PSD function



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already includes accelerations due to acoustic excitations. Consequently, no acoustic excitation is applied to the FEM.

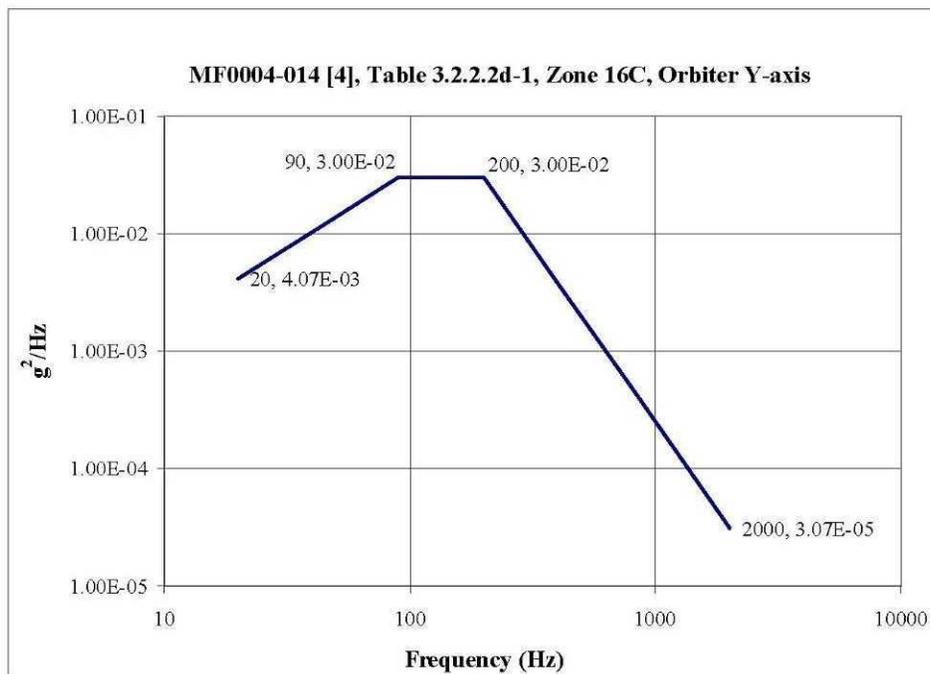


Figure 47. Orbiter T-0 Umbilical Panel Random Base Excitation PSD Function

5.8 Baseline Configuration FEM Frequencies and Mode Shapes

Plots of the first four mode shapes for the baseline case are shown in Figure 48 through Figure 51. The contour colors in these plots indicate the relative out-of-plane displacements of the modes.

The first two modes, which are the rocking modes of the LH₂ fill-and-drain line, do not contribute significantly to the out-of-plane displacement of the electrical connectors. The third mode, shown in Figure 50, is the full panel bending mode and is the primary contributor to the out-of-plane displacement at the electrical connector locations. The frequency of the third mode for the baseline FEM configuration (114 Hz), is located at the peak value of the base excitation PSD in Figure 47. The fourth mode, shown in Figure 51, has significant out-of-plane displacements at the aft region of the panel, but none at the electrical connector locations.

The higher frequency modes, whose mode shape are not shown in this report, have complex out-of-phase deflections, and are difficult to excite. In addition, the input base excitation values decreases rapidly for frequencies above 200 Hz. Consequently, the higher modes do not contribute significantly to the out-of-plane displacement at the electrical connector locations.



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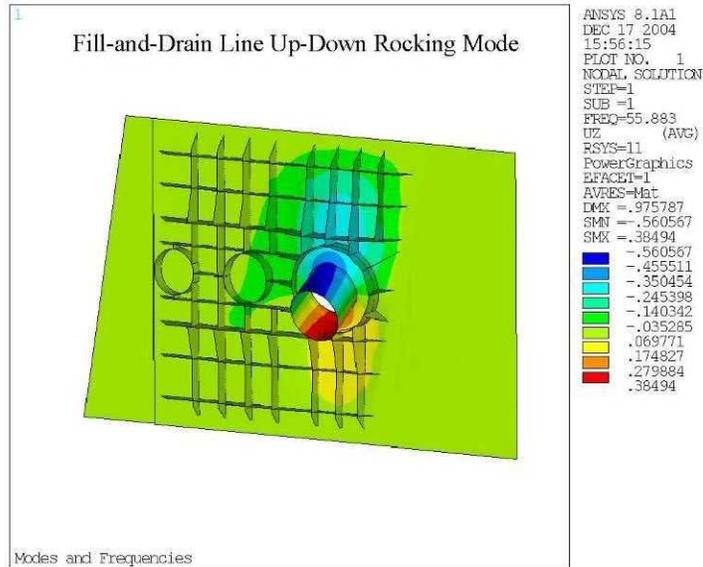


Figure 48. First Mode Shape (56 Hz) - Baseline

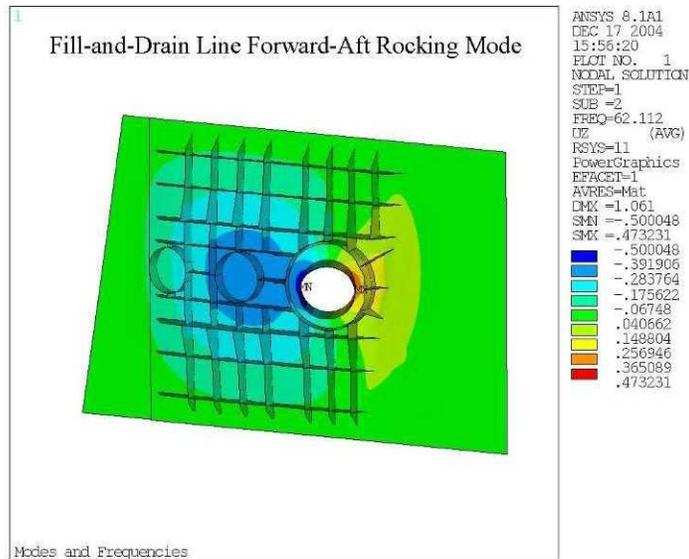


Figure 49. Second Mode Shape (62 Hz) - Baseline



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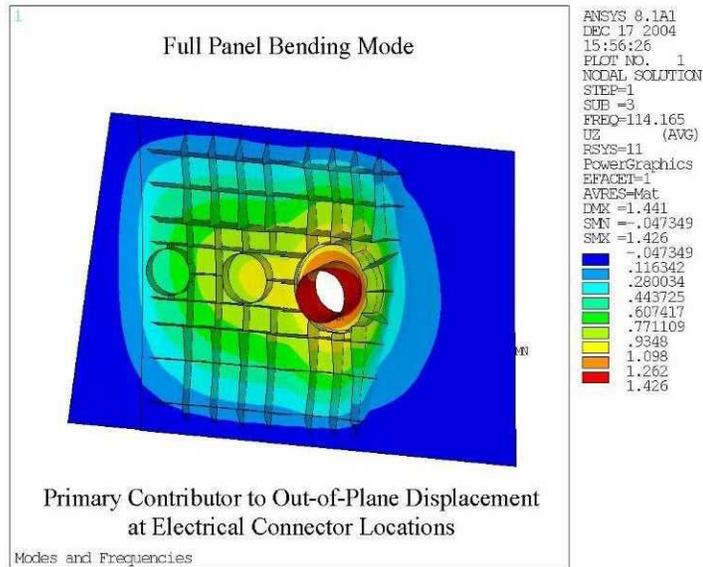


Figure 50. Third Mode Shape (114 Hz) - Baseline

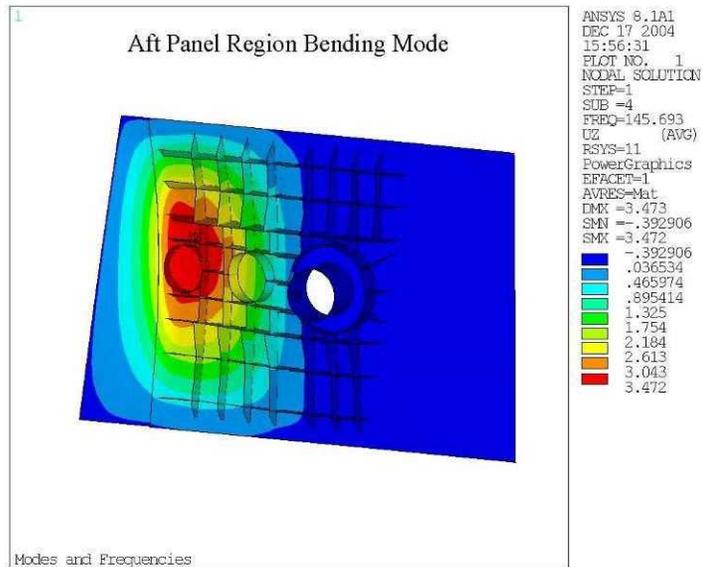


Figure 51. Fourth Mode Shape (147 Hz) - Baseline



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5.9 Baseline Configuration FEM Displacements

Using the first 15 modes along with the base excitation PSD, the orbiter panel 3-sigma out-of-plane displacements are calculated, as shown in Figure 52. A bar graph showing displacements at electrical connector and shear pin locations is shown in Figure 53. For the baseline case, the maximum out-of-plane displacement on the entire panel occurs at the LH₂ fill-and-drain line. The electrical connectors, which are located above and below the LH₂ line, have 3-sigma out-of-plane displacements that range from 0.008" to 0.016". The three critical connectors (J53, J61, and J71), being located on the outer rows of electrical connector, have slightly smaller displacements that range from 0.007" to 0.012".

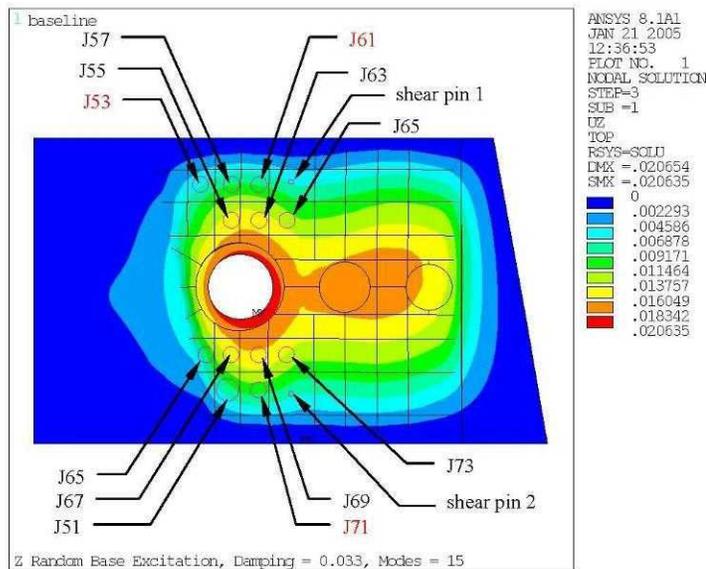


Figure 52. Orbiter Panel 3-σ Out-of-Plane Displacement – Baseline



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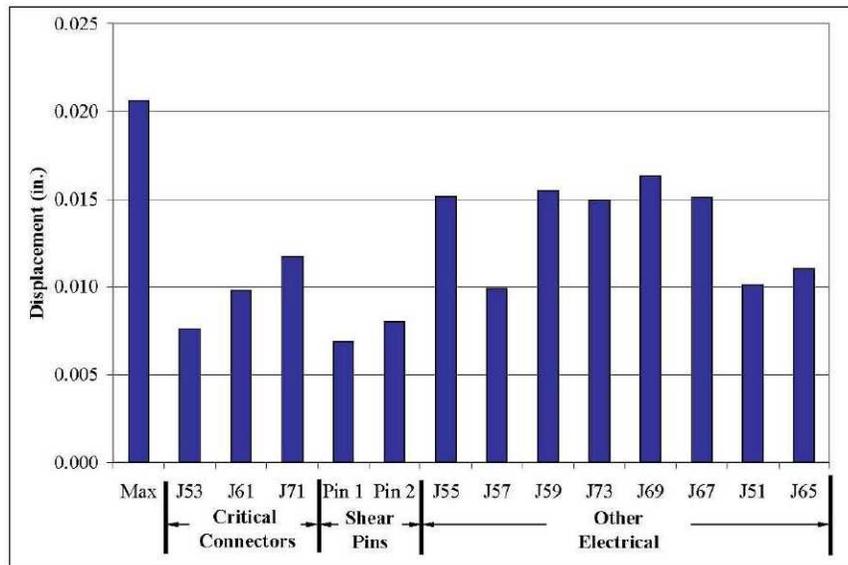


Figure 53. Orbiter Panel Baseline FEM Electrical Connectors & Shear Pins 3-6 Out-of-Plane Displacement

5.10 Sensitivity Studies

Table 10. Orbiter Panel Finite Element Model Configuration List

Configu-ration	Fill & Drain Line Weight Factor ¹	Connectors Weight Factor ²	Connector Region Stiffness ³	Fill & Drain Line Stiffness Factor ⁴	X-rotation Restraints at Panel Corners ⁵	Number of Modes
Baseline	1	1	Yes	1	No	15
Case 1	1	2	Yes	0.5	No	15
Case 2	1	2	Yes	1	No	15
Case 3	0.5	1	Yes	1	No	15
Case 4	1	1	Yes	1	No	1
Case 5	1	1	Yes	1	Yes	15
Case 6	1	1	No	1	No	15

1. The weight factor applies only to the weight of the LH₂ fill-and-drain line assembly (121 lbs) in Table 9.
2. The weight factor applies to the all connector weights in Table 9 except for the LH₂ fill-and-drain disconnect, valve, and line assembly.
3. See section 5.5.3 for the discussion on the incorporation of connector region stiffness in the FEM.
4. See section 5.5.1 for the discussion on the use of spring elements for fill-and-drain line stiffness.
5. See Figure 37 for the locations and the direction of the boundary conditions.

The analysis includes sensitivity studies in which the model's weight, boundary conditions, and the number of modes are varied. A list of the FEM configurations and the parameters used in the sensitivity study are shown in Table 10. Damping ratio of 3.3% is used for all cases.

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5.10.1 Natural Frequencies

The natural frequencies of the first 15 modes for each of the FEM configurations are listed in Table 11. The natural frequencies of the third mode, which is primary contributor to out-of-plane displacements at the electrical connector locations, range from 109 Hz to 134 Hz. This frequency range resides within the maximum value region of the input base excitation PSD (Figure 47).

Table 11. Orbiter Panel Finite Element Model Natural Frequencies

Mode No.	Baseline	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
1	55.88	53.90	55.86	69.12	55.88	55.99	55.79
2	62.11	58.33	62.01	79.68	62.11	63.52	62.05
3	114.17	109.27	110.53	134.23	114.17	124.27	113.65
4	145.69	124.30	124.75	150.87	145.69	164.97	142.49
5	231.79	188.97	188.97	231.81	231.79	236.17	218.49
6	299.51	275.61	275.62	299.52	299.51	301.32	289.72
7	319.93	293.56	293.57	321.87	319.93	342.72	298.18
8	359.27	333.95	333.95	359.55	359.27	367.96	336.85
9	368.19	346.91	346.91	368.29	368.19	375.56	341.77
10	388.86	350.42	350.42	388.94	388.86	401.26	359.85
11	406.94	372.86	372.86	407.35	406.94	419.65	379.41
12	421.35	388.25	388.26	423.64	421.35	427.22	390.07
13	430.87	410.18	410.18	432.64	430.87	454.87	399.13
14	459.59	418.44	418.46	461.13	459.59	469.18	404.60
15	474.55	428.21	428.21	479.72	474.55	492.20	411.27

Modes in shaded cells are not used in subsequent displacement calculations.

5.10.2 Displacement Results

The 3-sigma out-of-plane displacement values at the electrical connectors and shear pins as calculated by the FEM are presented in Figure 54. Color contour plots of the 3-sigma out-of-plane displacements across the entire Orbiter T-0 Umbilical Panel for each of the FEM sensitivity study configurations are shown in Figure 55 through Figure 60.



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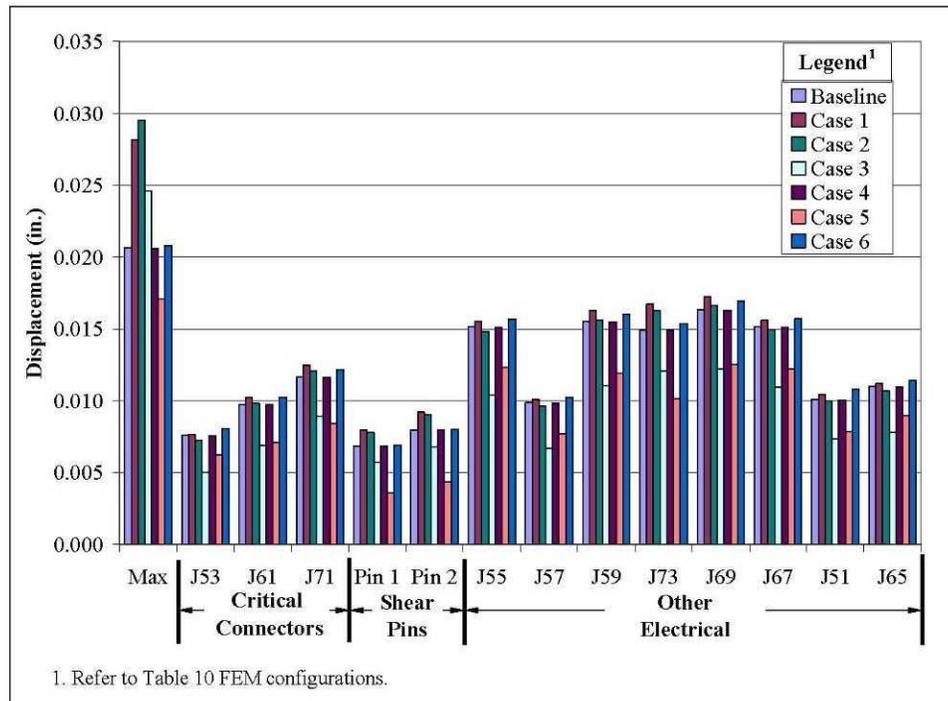


Figure 54. Orbiter Panel Sensitivity Studies Electrical Connectors & Shear Pins 3-σ Out-of-Plane Displacement

For case 1, the weight of the connectors (except for the LH₂ fill-and-drain line) is doubled and the LH₂ fill-and-drain line stiffness is halved from their baseline values. These changes caused a minor increase to the displacement of the electrical connectors with respect to the baseline case displacements. However, the maximum displacement on the panel is significantly greater than that of the baseline case. As seen in Figure 55, the location of the maximum displacement on the panel has shifted from the LH₂ line in the baseline case towards the aft panel region. The shift is a result of increased weight of the connectors located in the aft panel region. Since the weight of the LH₂ line, the most massive component located in the forward panel region, did not change from its baseline value, the displacements of the electrical connectors did not change significantly from their baseline values.

Similar to case 1, the weight of the connectors not including the LH₂ line in case 2 is doubled. However, unlike case 1, the LH₂ line stiffness values in case 2 remain at their baseline values. The displacements at the electrical connectors change slightly from the baseline case displacements. The location of the maximum displacement also shifts from the LH₂ in the baseline case to the aft panel region (see Figure 56).

In case 3, the effective weight of the LH₂ fill-and-drain line is set to half of its total weight. All other parameters are set equal to the baseline values. For this case, there is a decrease for the

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electrical connector displacements, but an increase for the maximum panel displacement, as compared with the baseline displacements. The reduction in the effective weight of the LH₂ line also shifts the location of the maximum displacement from the LH₂ line to the aft panel region (see Figure 57).

The weights and boundary conditions for case 4 are the same as those of the baseline case. However, only the third mode, the full panel bending mode (see Figure 50), is used in calculating the out-of-plane displacements. The displacements calculated for case 4 (see Figure 58), which only used one mode, are very similar to those calculated for the baseline case, which used the first 15 modes. This result indicates that the full panel bending mode is the only mode which contributes significantly to the out-of-plane displacements of the panel.

For case 5, the rotations about the orbiter longitudinal axis at the four panel corners are restrained. These rotational restraints are in addition to the in-plane and out-of-plane translational restraints that are present in the baseline case (see Figure 36 and Figure 37). In the actual orbiter, the frame beams that continue beyond the upper and lower boundaries of the FEM limit the rotation at the panel corners. With the panel corners' rotations restrained, the out-of-plane displacements for case 6 (see Figure 59) are smaller than those for the baseline case. As expected, the boundary conditions for the baseline case allow for greater out-of-plane displacements than those for case 6.

In case 6, the stiffness provided connector region reinforcements (see section 5.5.3) is not included in the FEM. All other parameters in this case are the same as those in the baseline case. The out-of-plane displacements across the whole panel for case 6 are only slightly greater than those for the baseline case. The excessive local deformations shown in Figure 41, when the stiffness connector region reinforcement is not included in the model, occur only at the higher modes. Since the higher modes do not contribute significantly to the panel's out-of-plane displacements under the applied loading, the calculated displacements are insensitive to the stiffness of connector region reinforcements (see Figure 60).

As seen in Figure 54, if considering only the out-of-plane displacements at the electrical connector and shear pin locations, the values for the baseline case are close to the maximum values for the sensitivity study cases. The values for certain sensitivity study cases are only slightly higher than those of the baseline case. Consequently, the baseline case's out-of-plane displacements at the electrical connector and shear pin location are used in the final calculation of the total relative displacement between the Orbiter T-0 Umbilical Panel and the T-0 Umbilical Carrier Plate.



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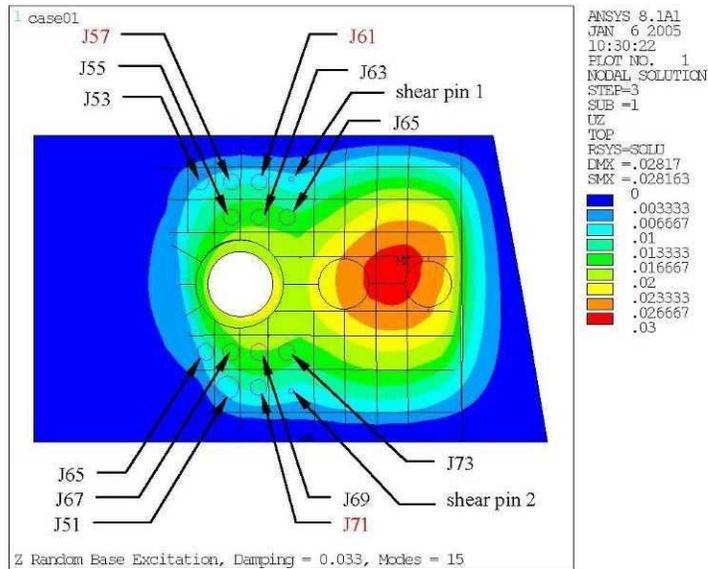


Figure 55. Orbiter Panel 3-σ Out-of-Plane Displacement – Case 1

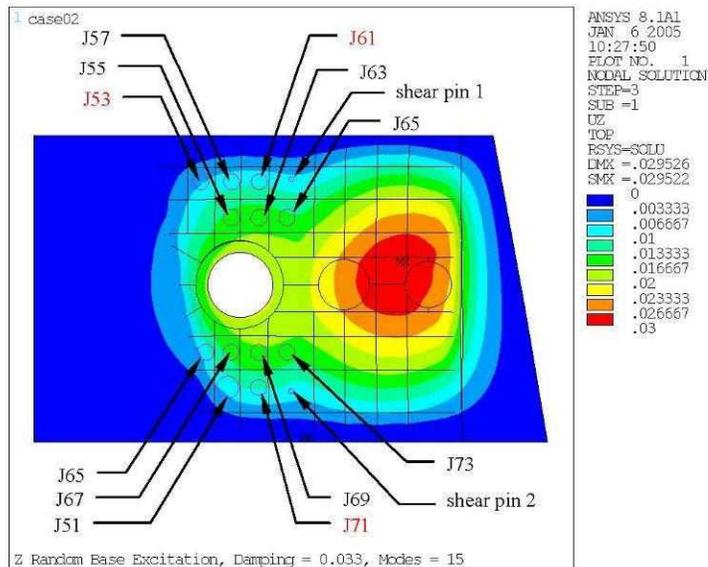


Figure 56. Orbiter Panel 3-σ Out-of-Plane Displacement – Case 2



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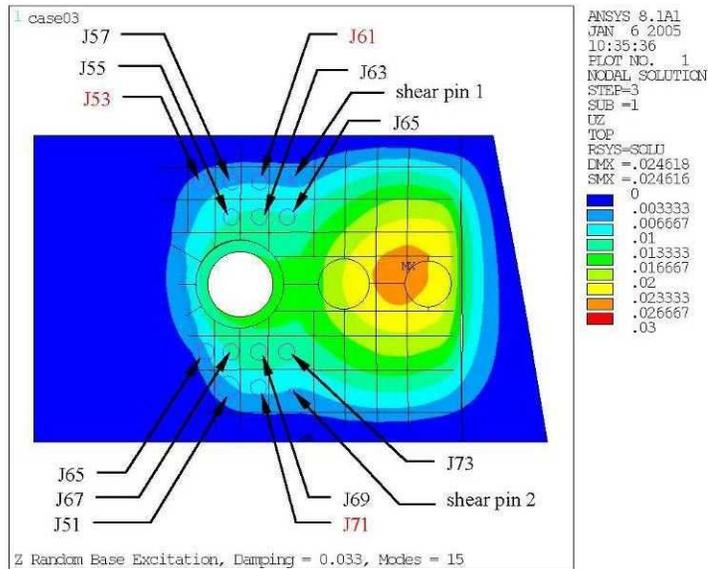


Figure 57. Orbiter Panel 3-σ Out-of-Plane Displacement – Case 3

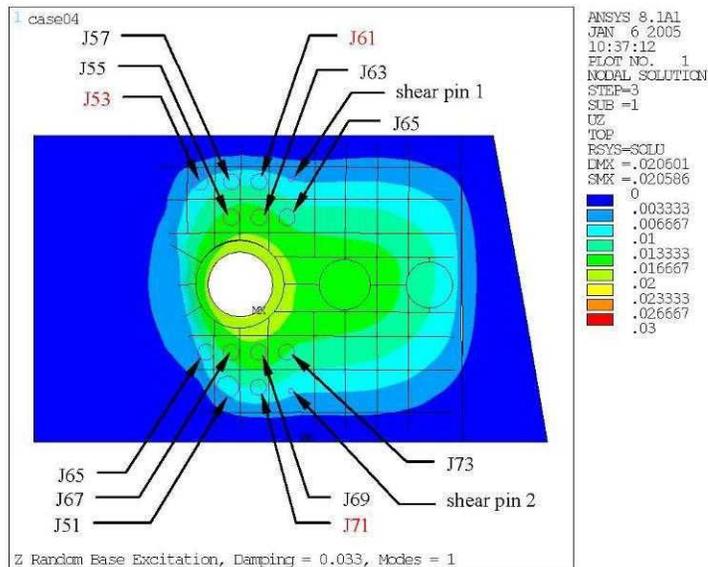


Figure 58. Orbiter Panel 3-σ Out-of-Plane Displacement – Case 4



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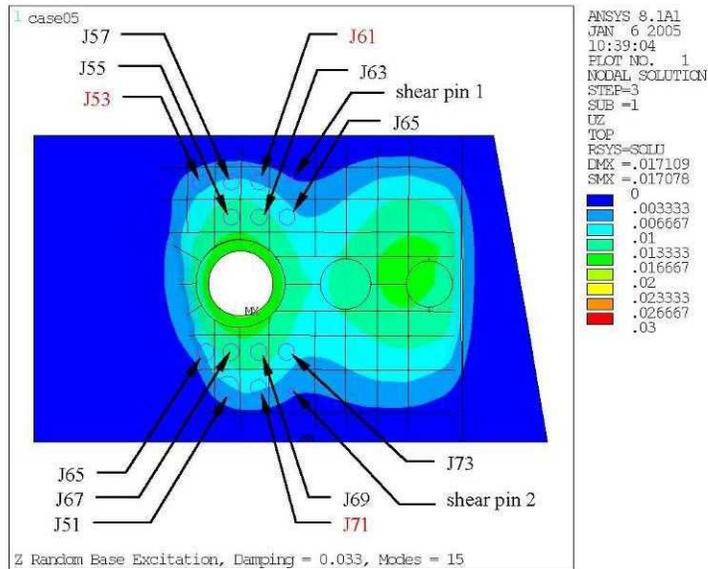


Figure 59. Orbiter Panel 3- σ Out-of-Plane Displacement – Case 5

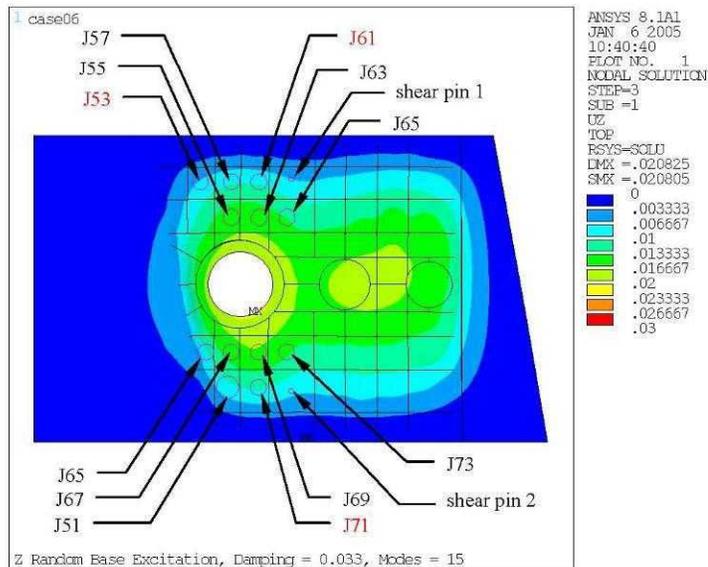


Figure 60. Orbiter Panel 3- σ Out-of-Plane Displacement – Case 6



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6.0 Integrated LH₂ T-0 Umbilical FEM

The stand-alone LH₂ T-0 Umbilical Carrier Plate FEM and the stand-alone Orbiter LH₂ T-0 Umbilical Panel FEM are combined to form an integrated LH₂ T-0 Umbilical FEM, as shown in Figure 61. The Carrier Plate FEM is transformed from its local coordinate system to the global orbiter coordinate system so that it is in the correct position and orientation relative to the Orbiter Panel FEM. As seen in Figure 62, the planes of the Carrier Plate and the Orbiter Panel are parallel to each other. However, the fluid disconnects and electrical connectors that span the Carrier Plate and the Orbiter Panel are not oriented perpendicular to either the Carrier Plate or the Orbiter Panel. As also shown in Figure 62, the attachments for the Carrier Plate feet on the orbiter are located inboard of the Orbiter T-0 Umbilical Panel.

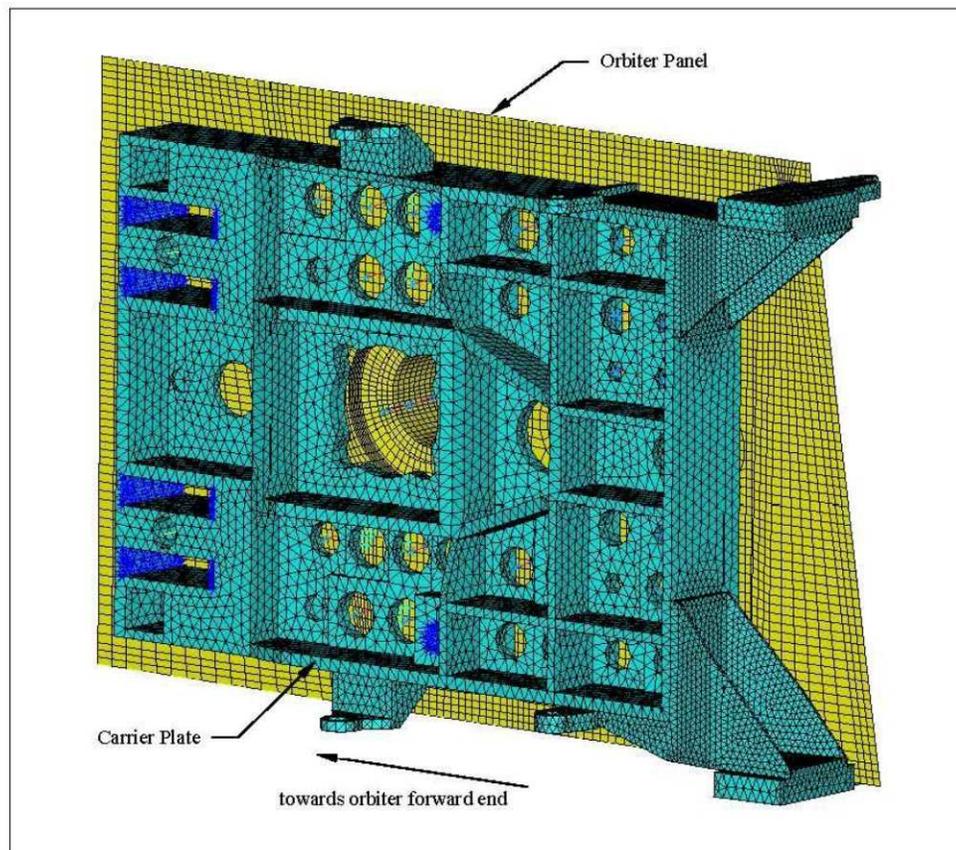


Figure 61. Integrated T-0 Umbilical FEM



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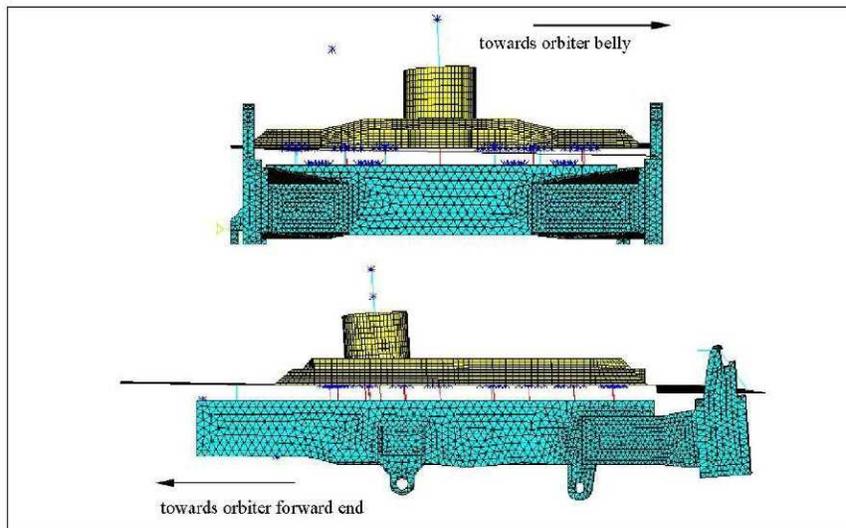


Figure 62. Side Views of Integrated T-0 Umbilical FEM

The original boundary conditions of the stand-alone Orbiter Panel FEM, as described in section 5.4, are retained in the Integrated T-0 Umbilical FEM. However, since the carrier plate is attached to the orbiter panel in the integrated FEM, the original boundary conditions of the stand-alone Carrier Plate FEM (see section 3.6) are removed from the integrated FEM. In place of these boundary conditions at the collets, shear pins, and feet, constraint equations are used to tie the Carrier Plate FEM to the Orbiter Panel FEM at the aforementioned locations.

6.1 Collet Connections

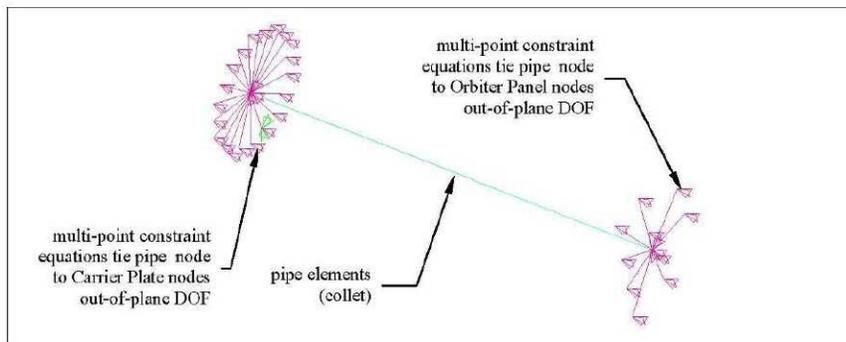


Figure 63. Collet Connection

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The collets are restrained in the out-of-plane direction in the stand-alone Carrier Plate FEM, as seen in Figure 16. In the integrated FEM, the collets on the carrier plate are tied to their respective receptacles on the orbiter panel using multi-point constraint equations in the out-of-plane direction, as seen in Figure 63. A single node at the end of each collet is tied to multiple nodes on the orbiter panel that are located within the collet receptacle region.

6.2 Shear Pin Connections

In the stand-alone Carrier Plate FEM, the nodes at the shear pins locations are restrained in the in-plane directions as shown in Figure 16. In the Integrated T-0 Umbilical FEM, the in-plane degrees-of-freedom of these nodes are coupled to those of the corresponding nodes on the Orbiter Panel FEM, as shown in Figure 64.

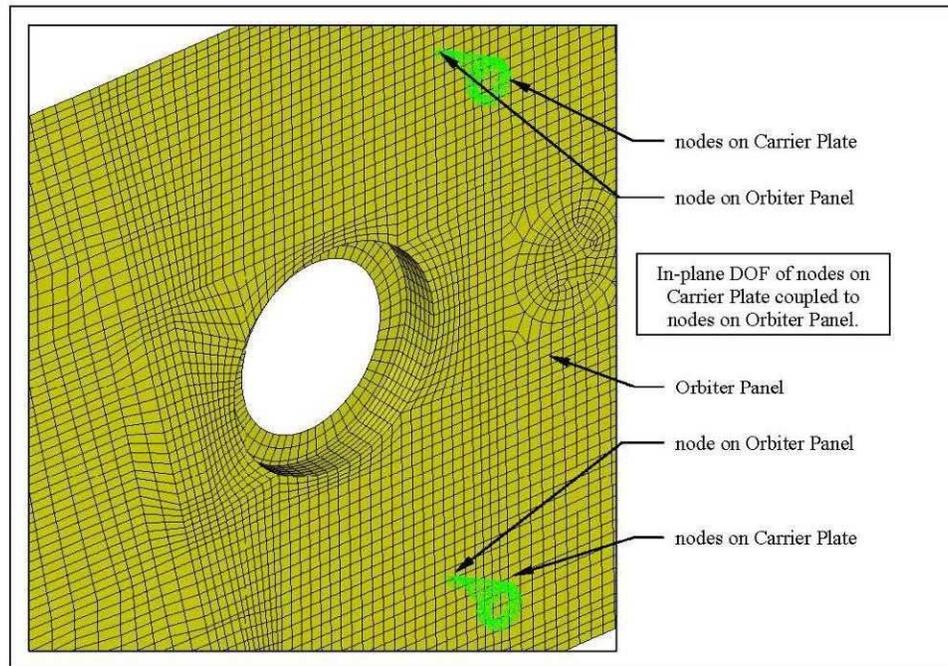


Figure 64. Shear Pin Connections

6.3 Feet Connections

The feet on the Carrier Plate latch onto the orbiter panel at two locations shown in Figure 65. The upper foot attaches to a clevis that is bolted onto the aft end of the orbiter aft fuselage frame. The lower foot attaches a horizontal frame beam that runs along the lower edge of the orbiter T-0 umbilical panel. Consequently, both feet attachment locations on orbiter are relatively stiff. In the stand-alone Carrier Plate FEM, the feet are restrained in the out-of-plane and orbiter longitudinal directions (see Figure 16).



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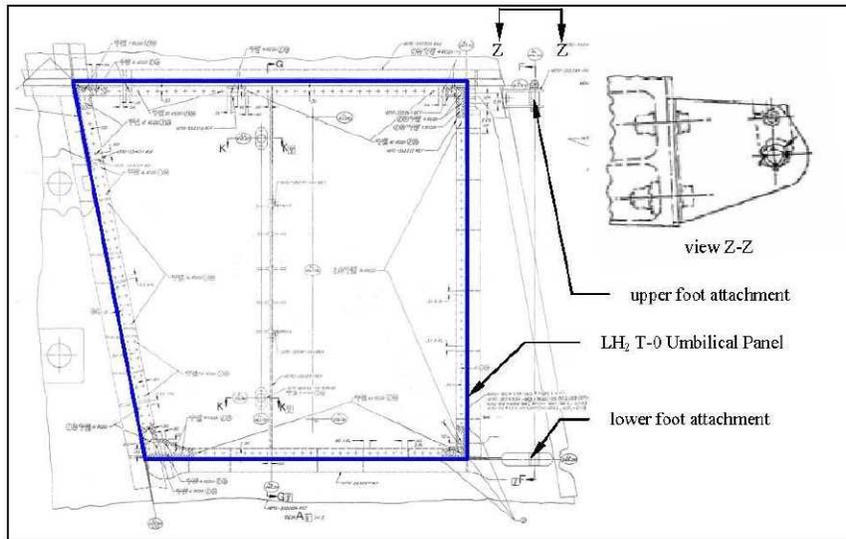


Figure 65. Carrier Plate Foot Attachment Locations on Orbiter

In the Integrated T-0 Umbilical FEM, a beam element (BEAM4) is used to represent the upper foot attachment clevis. A detailed shell-element FEM of the clevis (see Figure 66) is used to determine the appropriate stiffness for the clevis beam element in the Integrated T-0 Umbilical FEM. As shown in Figure 67, the clevis beam element is attached to the Orbiter Panel FEM by coupling its forward end node to the upper aft corner node the Orbiter Panel FEM. The aft end node of the clevis beam element is coupled to the corresponding Carrier Plate foot nodes in the out-of-plane and the orbiter longitudinal degrees-of-freedom.

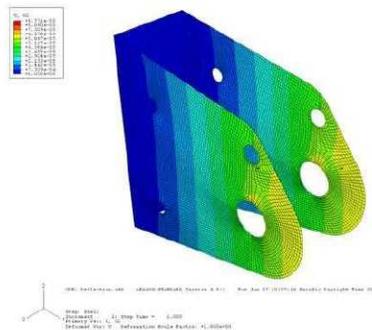


Figure 66. Upper Foot Attachment Clevis FEM



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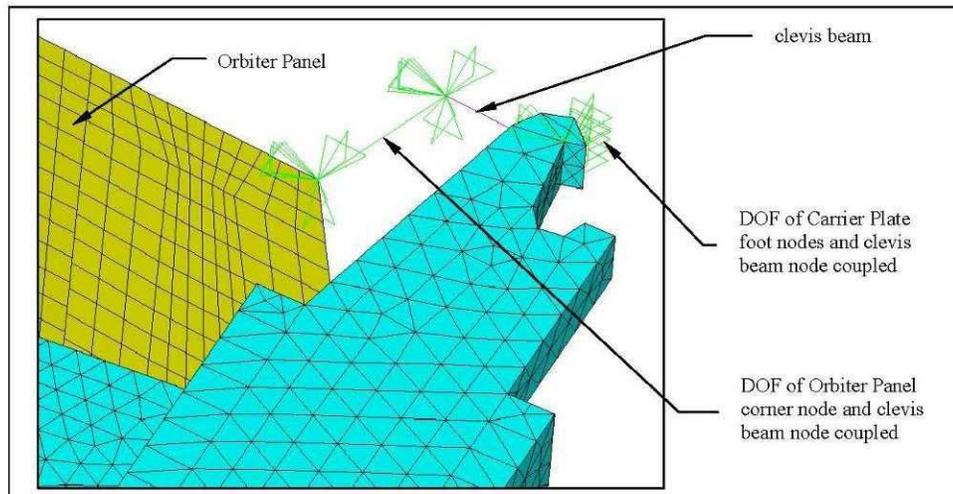


Figure 67. Upper Foot Attachment

The lower foot of the Carrier Plate attaches to a horizontal frame beam of the orbiter aft fuselage. Since the attachment on the orbiter is integral to the beam frame, stiff beam elements (BEAM4) are used to connect the lower foot with the orbiter frame beam in the Integrated T-0 Umbilical FEM (see Figure 68). The out-of-plane and orbiter longitudinal degrees-of-freedom of the of these connection beam element inboard nodes are coupled to those of the Carrier Plate lower foot nodes.

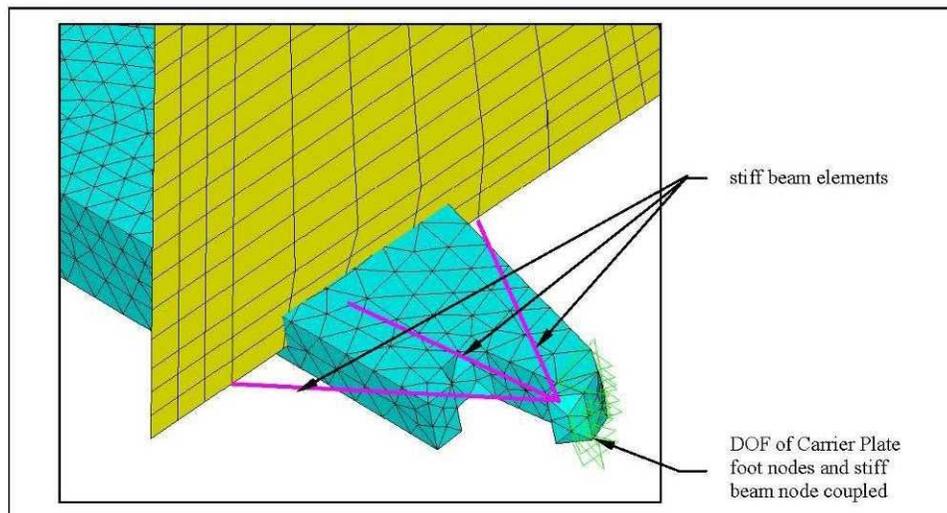


Figure 68. Lower Foot Attachment



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6.4 Fluid and Electrical Connections

In the stand-alone Carrier Plate FEM and the stand-alone Orbiter Panel FEM, the weights of the connectors (the components which span between the Carrier Plate and Orbiter Panel) are all concentrated on the Carrier Plate. For the Integrated T-0 Umbilical FEM, the weights of these connector components are distributed between the Carrier Plate and Orbiter Panel as shown in Table 12. The stiffness and preload for each line are also listed in Table 12.

Table 12. Integrated FEM Connector Parameters

Index Number ¹	Connector / Disconnect Specification	Weight (lbs) on Carrier Plate	Weight (lbs) on Orbiter Panel ²	Elect. Conn. Spring Weight (lbs) ³	Stiffness (lb/in)	Preload (lb _r)
1	MC276-0005-0063	211.25	16.01	-	40	700
2 (J53)	80K61565 (small)	8.28	4.97	0.20	35	60
3 (J55)	80K61565 (small)	8.28	4.97	0.20	35	60
4 (J57)	80K61565 (small)	8.28	4.97	0.20	35	60
5 (J59)	80K61565 (small)	8.28	4.97	0.20	35	60
6 (J61)	80K61565 (small)	8.28	4.97	0.20	35	60
7	-	2.76	2.76	-	-	-
8	-	-	-	-	-	-
9	MC276-0004-0002	1.99	1.99	-	40	200
11	-	-	-	-	-	-
12	-	-	-	-	-	-
13	MC276-0035-1206	2.21	2.21	-	40	75
14	MC276-0003-0008	3.15	3.15	-	40	40
15	MC276-0035-1206	2.21	2.21	-	40	40
16	MC276-0021-0612	2.21	2.21	-	40	40
17	MC276-0021-0612	2.21	2.21	-	40	40
18	MC276-0021-0612	2.21	2.21	-	40	40
22	MC276-0021-0612	2.21	2.21	-	40	40
23	-	-	-	-	-	-
24	MC276-0003-0008	3.15	3.15	-	40	75
25	-	-	-	-	-	-
26	-	-	-	-	-	-
27	-	-	-	-	-	-
28	-	-	-	-	-	-
29	MC276-0003-0008	3.15	3.15	-	40	75
30	MC276-0012-4221	6.62	6.62	-	40	130
31	-	-	-	-	-	-
32 (J73)	80K61565 (small)	8.28	4.97	0.20	35	60
33 (J69)	80K61565 (small)	8.28	4.97	0.20	35	60
34 (J71)	80K61565 (small)	8.28	4.97	0.20	35	60
35	-	-	-	-	-	-
36 (J51)	80K61565 (large)	6.07	11.62	0.28	35	60
37 (J65)	80K61565 (small)	8.28	4.97	0.20	35	60

1. Numbering scheme is obtained from VUML00-001 [1], page 1-6, figure 1-3. Refer to Figure 30 in this report for connector locations.
2. For electrical connectors, weights include 4-foot section of cable.
3. Spring weights represent only the active coils.



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6.4.1 Fluid Line Connections

In the Integrated T-0 Umbilical FEM, each fluid connection is represented two mass elements and a single truss (LINK8) element as seen in Figure 69. The two mass elements represent the weights of a fluid connection placed onto the Carrier Plate and Orbiter Panel respectively. For the LH₂ fill-and-drain line, 90% of the disconnect weight and a portion of the line weight are placed on the Carrier Plate. The remaining 10% of the disconnect weight is placed on the Orbiter Panel. The weights of the other fluid lines are evenly distributed between the Carrier Plate and the Orbiter Panel. The zero-mass truss element represents the stiffness of the fluid disconnect. The nodes at each ends of the truss element are connected to nodes on either the Carrier Plate or the Orbiter Panel with constraint equations.

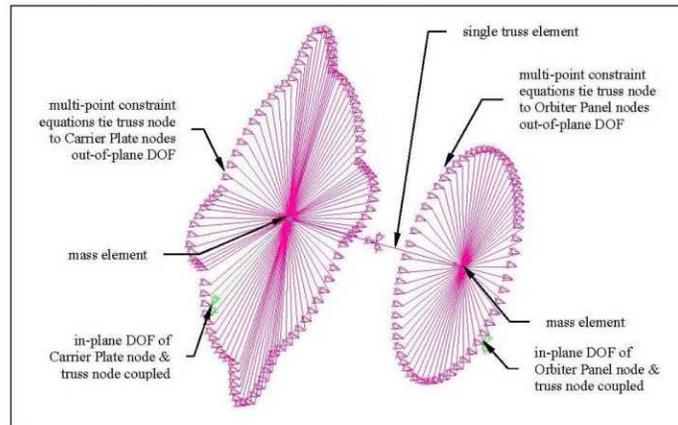


Figure 69. Fluid Disconnect FEM Representation

6.4.2 Electrical Line Connections

For the electrical connectors, the weight of the connector sleeve (see Figure 70) and a 4-foot portion of the electrical cable are placed on the Orbiter Panel. The weights of the remaining components, other than the spring, are placed on the Carrier Plate. The weight of the active coils (coils that actually flex) of the spring are placed on elements that span the Carrier Plate and Orbiter Panel.



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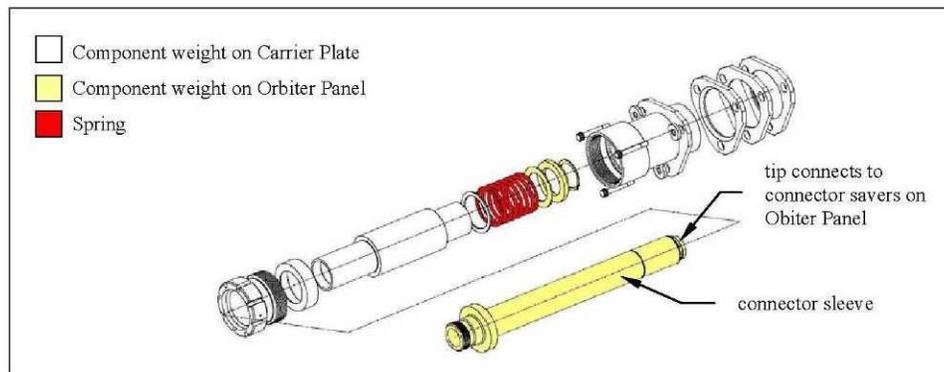


Figure 70. Electrical Connector Assembly

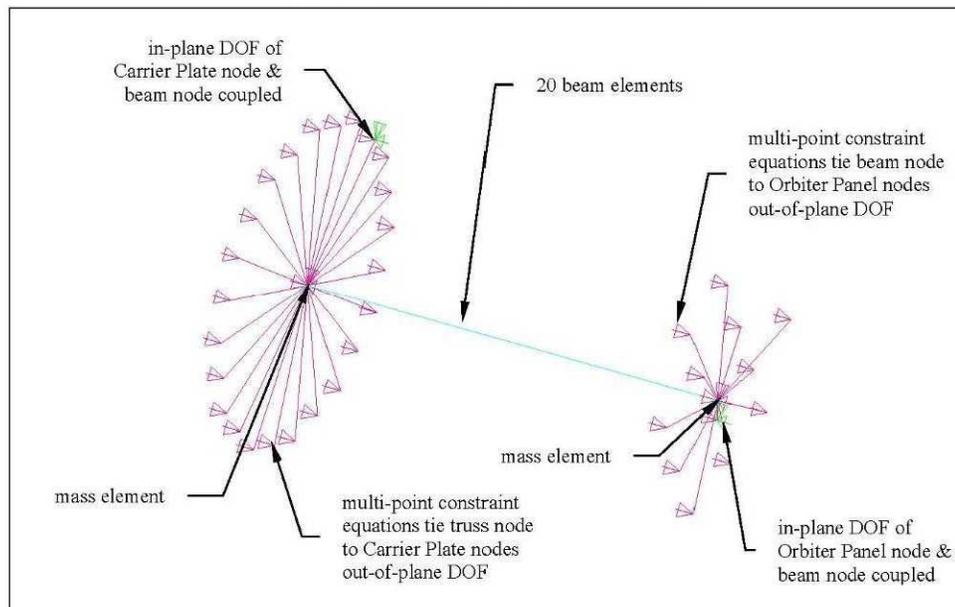


Figure 71. Electrical Connector FEM Representation

Since the focus of this analysis is on the electrical connectors, the electrical connections have more detailed representations in the Integrated T-0 Umbilical FEM than those of the fluid connections. Each electrical connector in the Integrated T-0 Umbilical FEM is represented by two mass elements and 20 beam elements (see Figure 71). The two mass elements represent the weights of an electrical connection placed onto the Carrier Plate and Orbiter Panel respectively. The stiffness of the spring and weight of the active spring coils are represented by the 20 beam elements (BEAM44). The axial stiffness of these beam elements is set to a value such that their



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combined axial stiffness is equal to that of the spring. Because the connector sleeve can only slide but not rotate relative to the outer sleeve, the bending stiffness of the electrical connector is much greater than its axial stiffness. In the FEM, the bending stiffness of the electrical connector beam elements is set to a value lower than that of the physical connector, but the value is high enough so that the beam bending mode frequencies are above the frequency range of interest. As with the fluid disconnects, the nodes at the ends of the spring beam elements are tied to nodes on either the Carrier Plate or the Orbiter Panel with constraint equations.

6.5 Damping

Based on the results of the T-0 Umbilical Carrier Plate modal test (section 3.7), a damping ratio value of 3.3% is used in the analysis of the Integrated T-0 Umbilical FEM. A sensitivity study of the effect of the local damping value for the electrical connector springs on the dynamic spring forces is presented in Appendix C.

6.6 Applied Dynamic Load

The load used in the analysis is random base excitation in the out-of-plane direction. The excitation is applied to the Orbiter Panel, fully correlated, at all out-of-plane translational restraints shown in Figure 37, including the LH₂ fill-and-drain line and the entire aft edge. The power spectral density (PSD) function of the excitation, shown in Figure 72, is obtained from MF0004-014 [4], but with an update that includes values from 1 Hz to 20 Hz. Details of this update is contained in Brent Mann and Dan Paul's presentation [6] to the Space Shuttle Program Loads Panel on May 11, 2005.

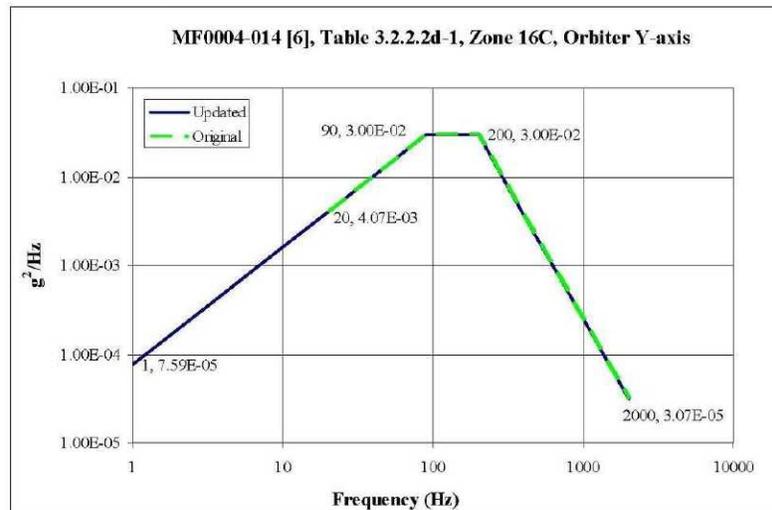


Figure 72. Updated Orbiter T-0 Umbilical Random Base Excitation PSD Function



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6.7 Baseline Configuration FEM Frequencies and Mode Shapes

The first 15 modes of the Integrated T-0 Umbilical FEM are shown in Figure 73 through Figure 87. The contour colors in these plots indicate the relative out-of-plane relative displacements of the modes.

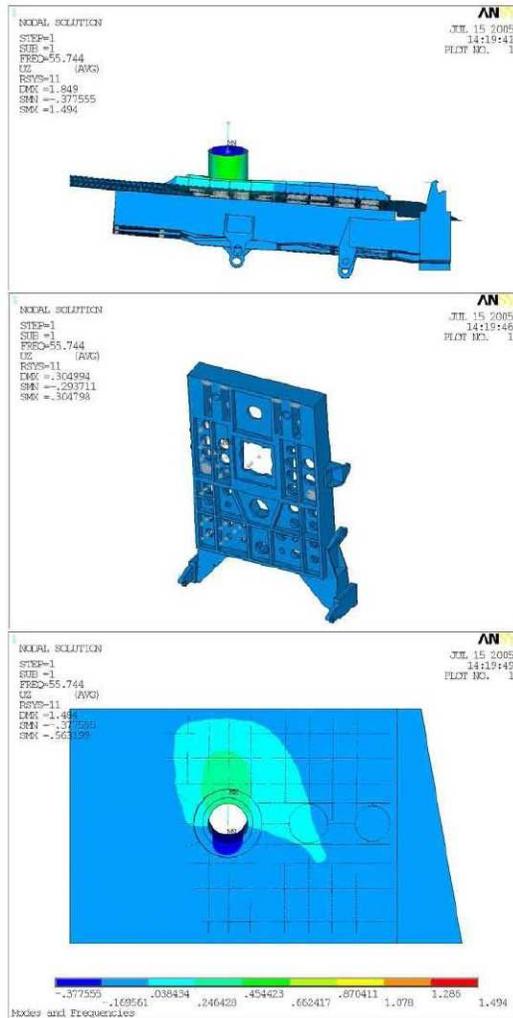


Figure 73. Integrated FEM 1st Mode Shape (56 Hz)



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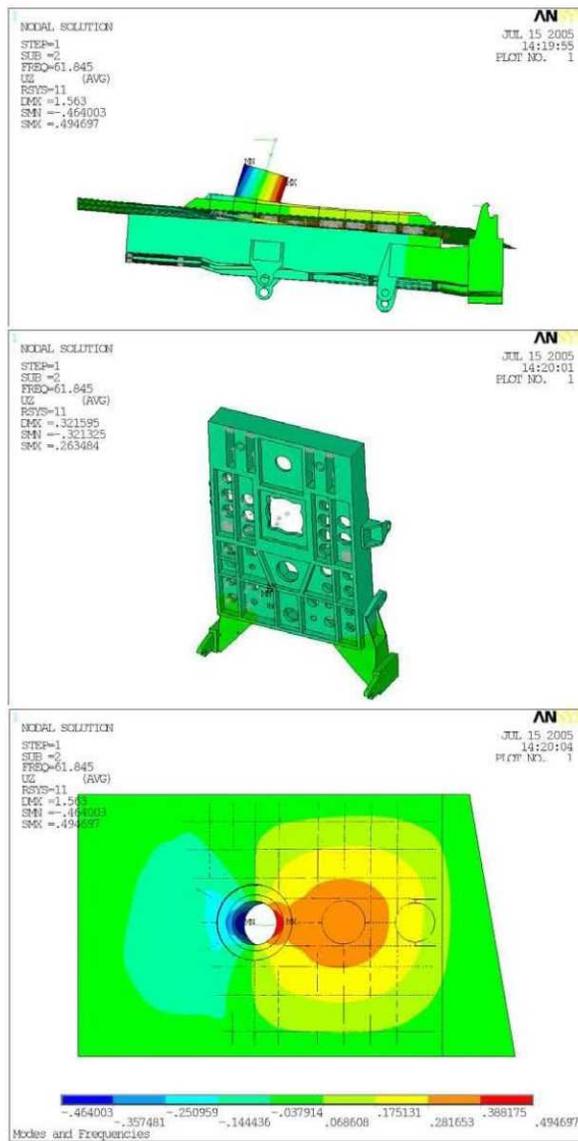


Figure 74. Integrated FEM 2nd Mode Shape (62 Hz)



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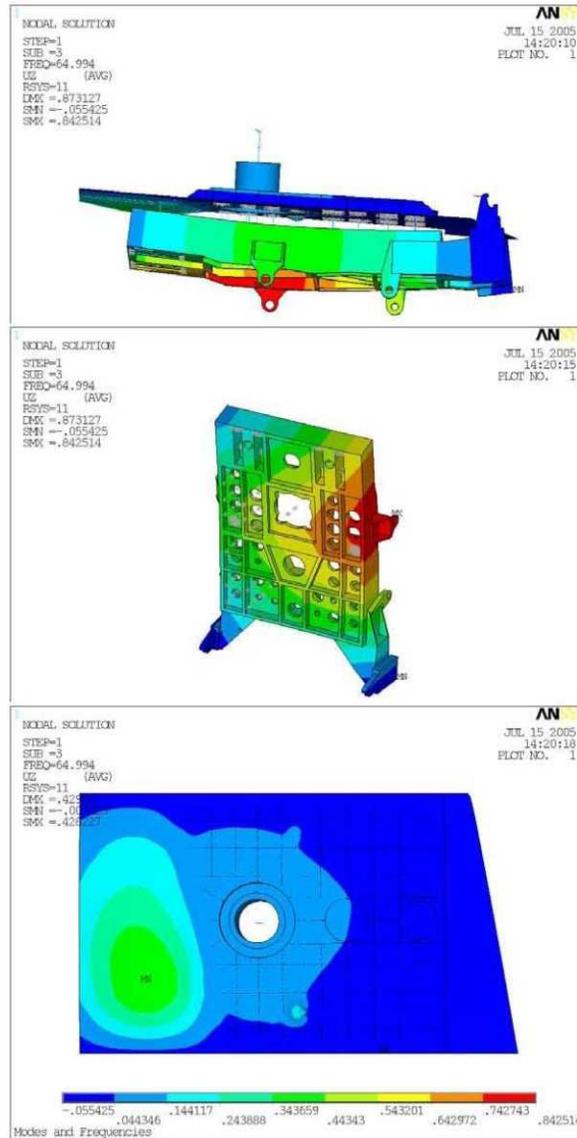


Figure 75. Integrated FEM 3rd Mode Shape (65 Hz)



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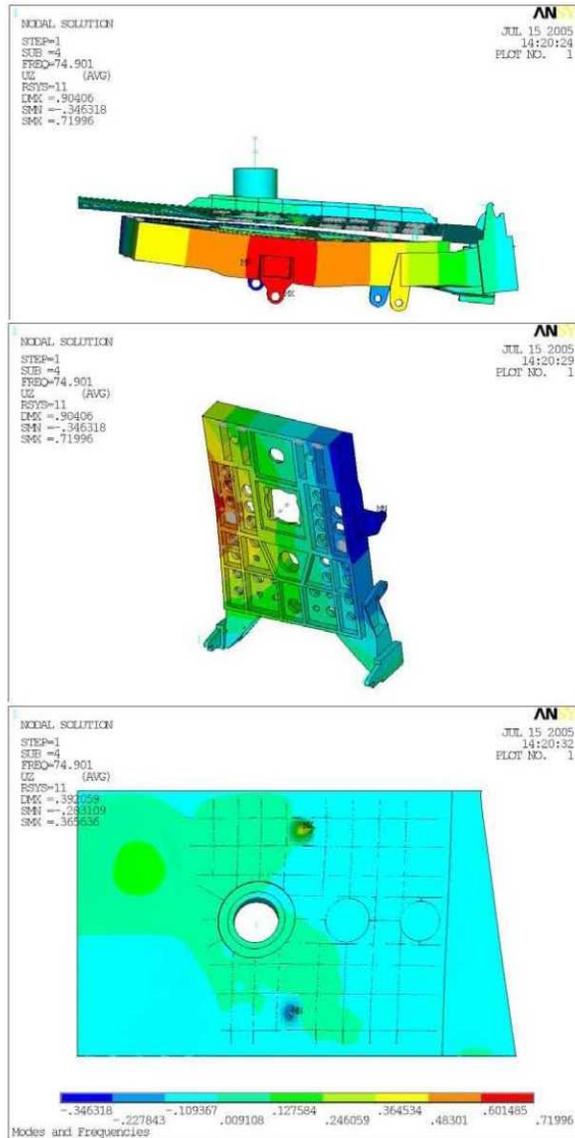


Figure 76. Integrated FEM 4th Mode Shape (75 Hz)



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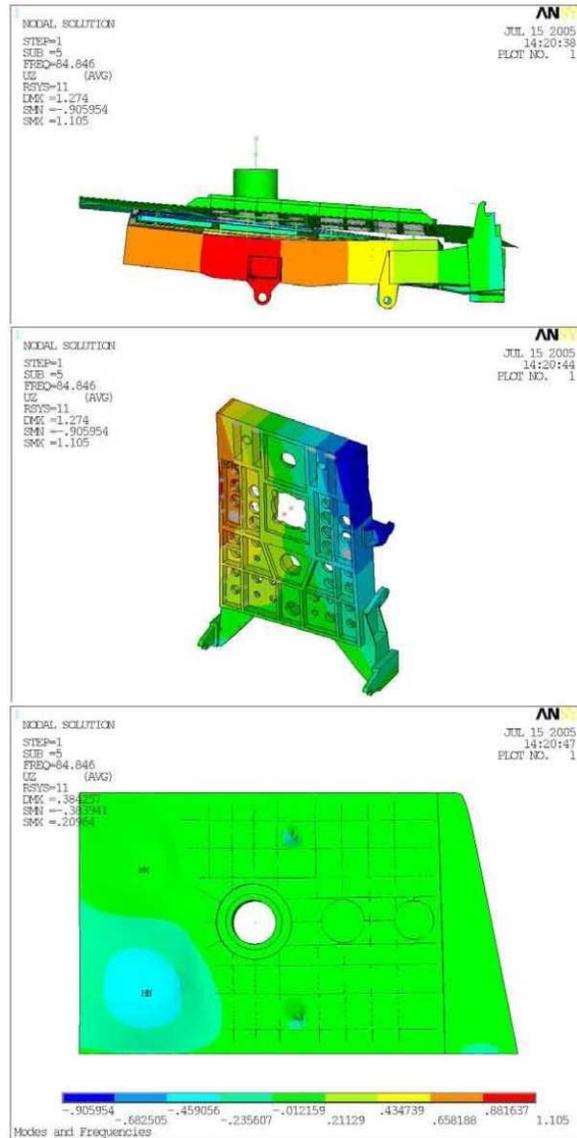


Figure 77. Integrated FEM 5th Mode Shape (85 Hz)



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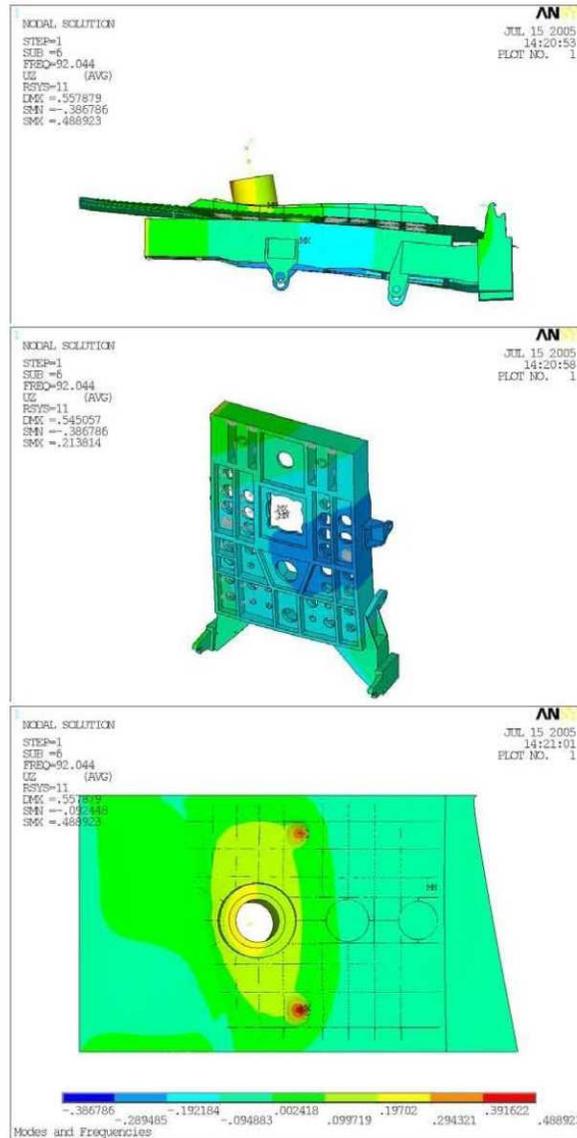


Figure 78. Integrated FEM 6th Mode Shape (92 Hz)



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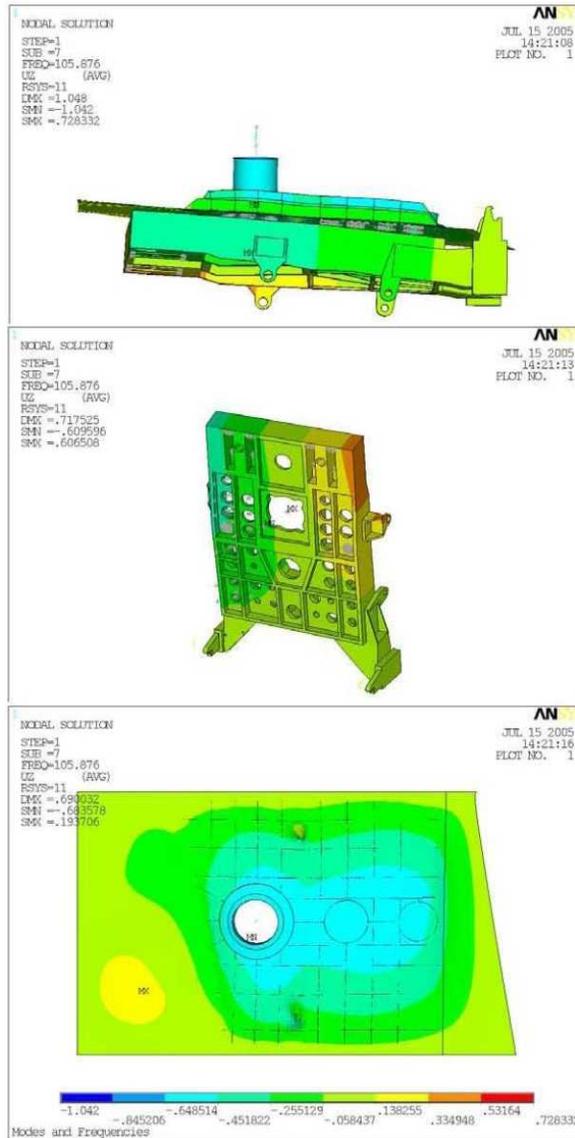


Figure 79. Integrated FEM 7th Mode Shape (106 Hz)



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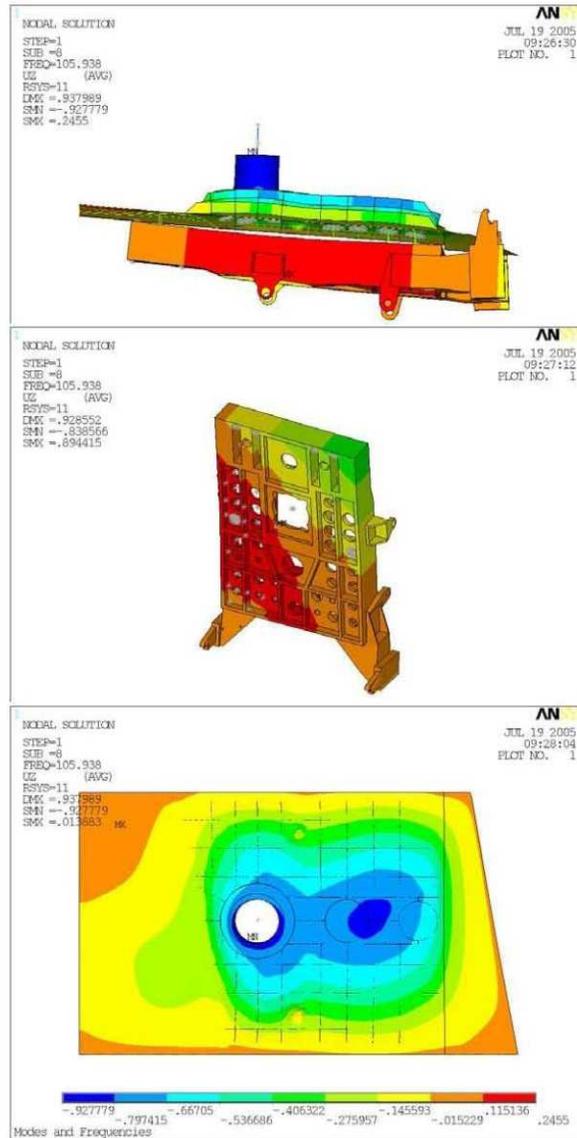


Figure 80. Integrated FEM 8th Mode Shape (106 Hz)



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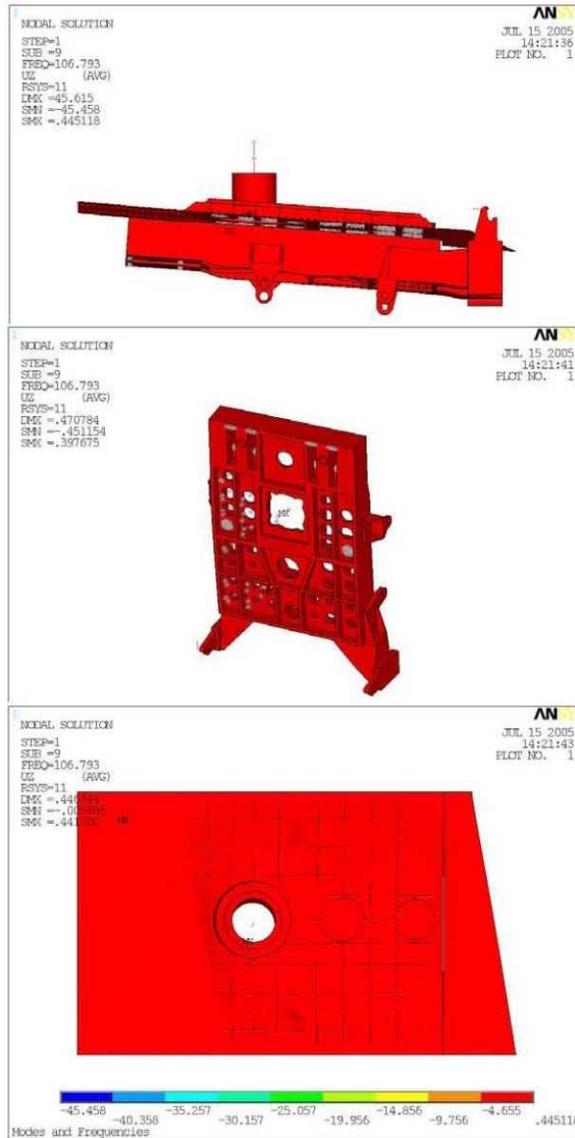


Figure 81. Integrated FEM 9th Mode Shape (107 Hz)



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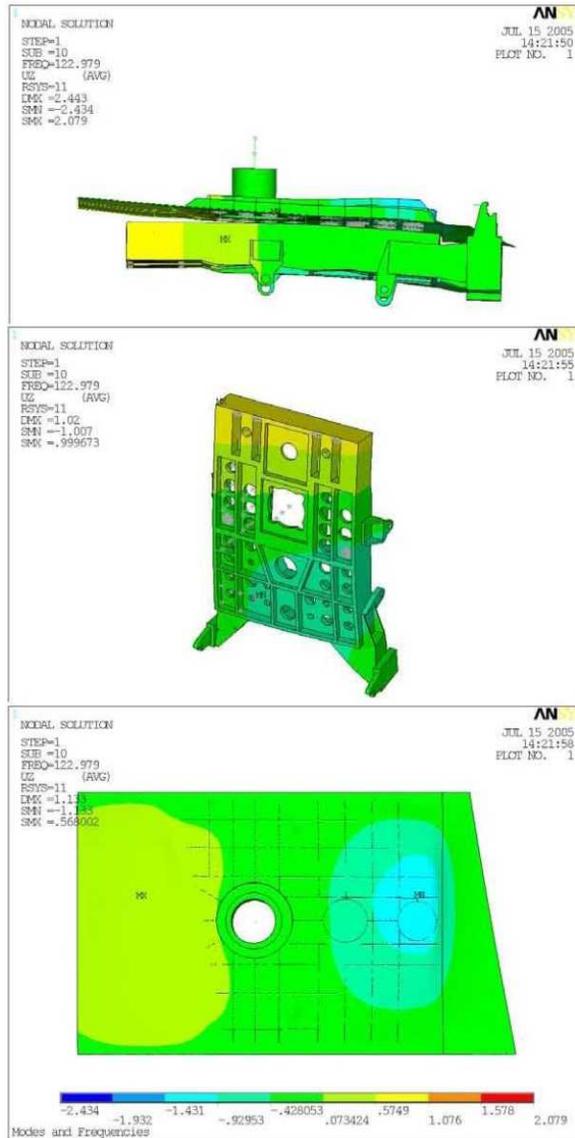


Figure 82. Integrated FEM 10th Mode Shape (123 Hz)



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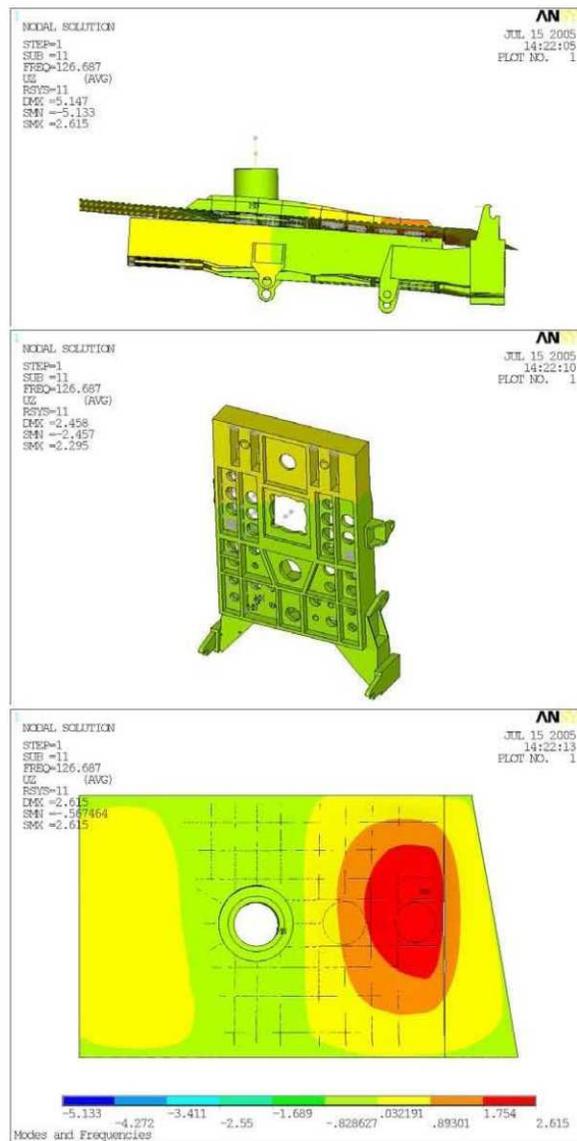


Figure 83. Integrated FEM 11th Mode Shape (127 Hz)



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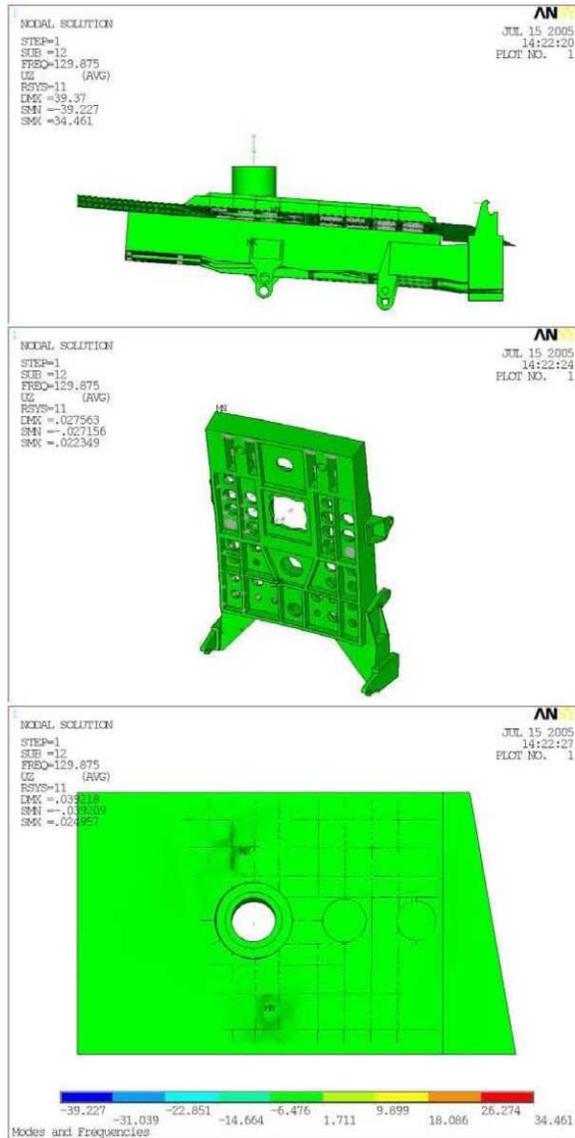


Figure 84. Integrated FEM 12th Mode Shape (130 Hz)



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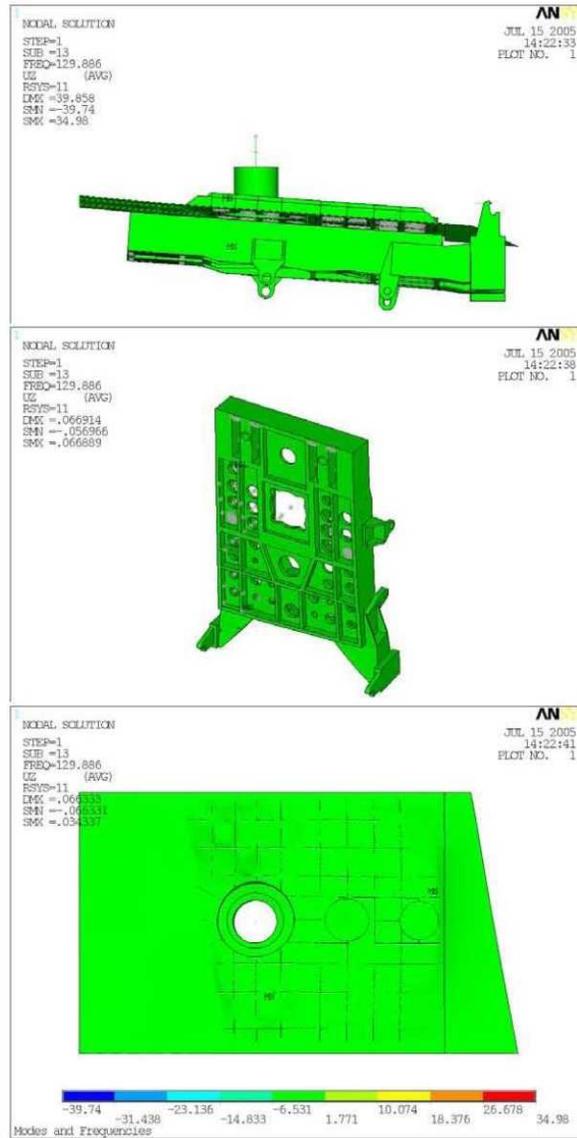


Figure 85. Integrated FEM 13th Mode Shape (130 Hz)



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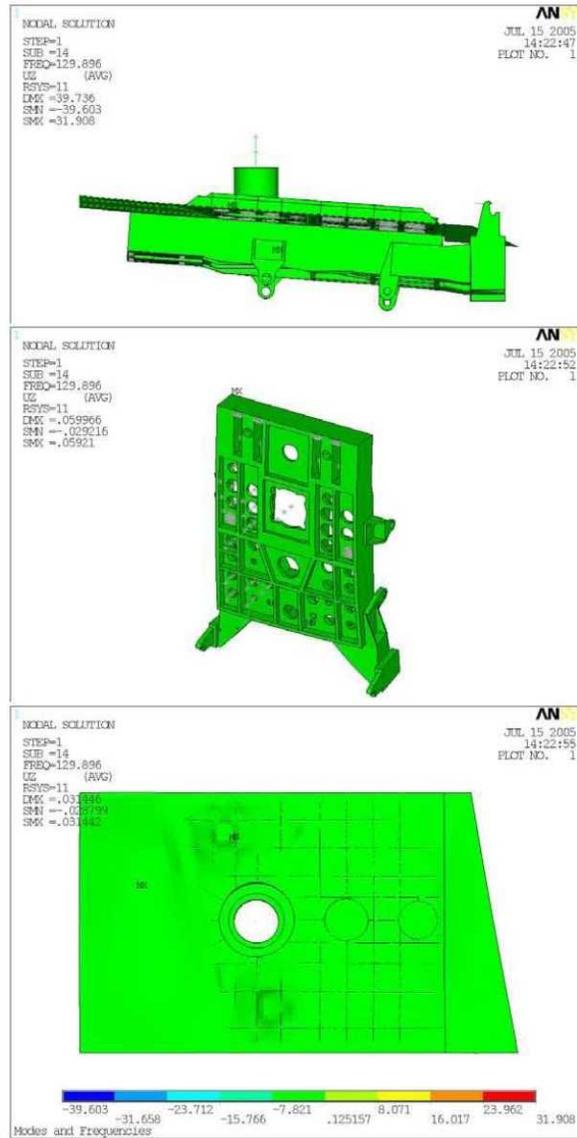


Figure 86. Integrated FEM 14th Mode Shape (130 Hz)



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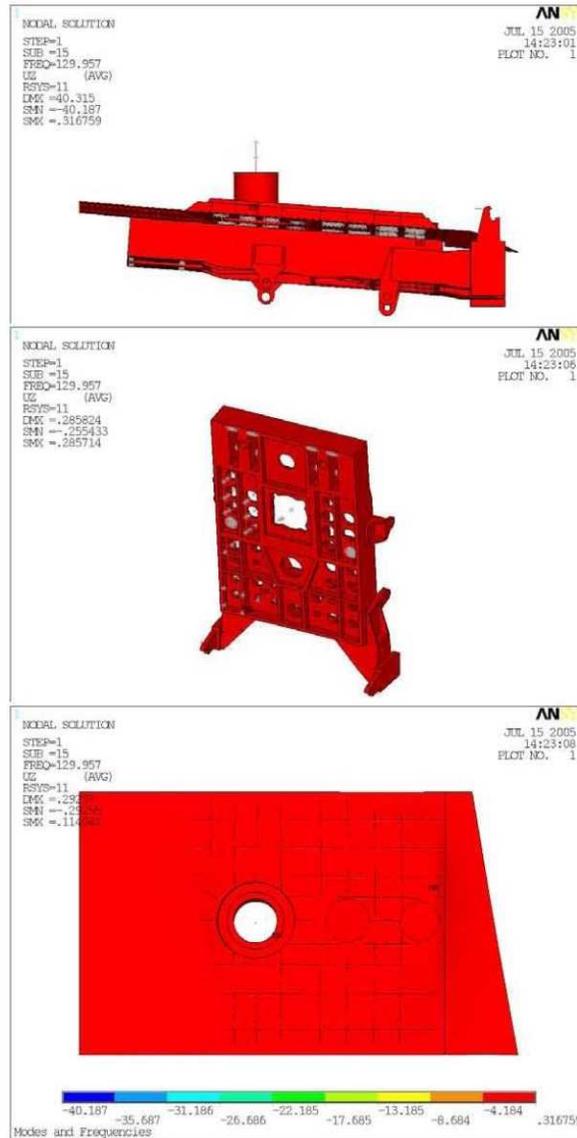


Figure 87. Integrated FEM 15th Mode Shape (130 Hz)

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6.7.1 Modes 1 and 2

The first two modes (Figure 73 and Figure 74) are the rocking modes of the LH₂ fill-and-drain line on the Orbiter Panel. They correspond to the first two modes of the stand-alone Orbiter Panel FEM (see Figure 48 and Figure 49). These two modes do not contribute significantly to the out-of-plane relative displacement of the electrical connectors.

6.7.2 Mode 3

The third mode (Figure 75) of the integrated FEM is the primary bending mode the Carrier Plate. This mode corresponds to the first mode of the stand-alone Carrier Plate FEM (see Figure 20), and is a significant contributor to the out-of-plane relative displacements at the electrical connectors. While the maximum deflection for the Carrier Plate on the stand-alone FEM is located on the upper (near the orbiter tail fin) side, the maximum deflection on the integrated FEM is located on the lower (near the orbiter belly) side.

In the stand-alone FEM, both collets are restrained in the out-of-plane direction. However, the upper (near the orbiter tail fin) side of the Carrier Plate is heavier than the other side, due to the presence of heavier fluid lines. Consequently, the heavier side has a slighter larger deflection in the stand-alone FEM. In the integrated FEM, the collets are attached to the Orbiter Panel. The lower collect attachment point on the Orbiter Panel is more flexible than the upper attachment, as the lower attachment is located in the middle of the skin panel while the upper attachment is located near an orbiter frame beam. Consequently, the maximum deflection of the integrated FEM is located on the upper (near orbiter tail fin) side of the Carrier Plate. Another effect of the more flexible attachments for the Carrier Plate is that the frequency of the Carrier Plate primary bending mode is reduced from 75 Hz in the stand-alone FEM to 65 Hz in the integrated FEM.

6.7.3 Mode 4

In mode 4 (Figure 76), the Carrier Plate exhibits in-plane twisting relative to the Orbiter Panel. Because of most of the motion in this mode is in the in-plane directions, this mode does not contribute significantly to the out-of-plane relative displacement of the electrical connectors.

6.7.4 Mode 5

Mode 5 (Figure 77) is the primary torsion mode of the Carrier Plate. It corresponds to the second mode of the stand-alone Carrier Plate FEM (see Figure 20). Due to its out-of-phase displaced shape, this mode is not easily excited and therefore does not contribute significantly to the out-of-plane relative displacement at the electrical connectors.

6.7.5 Mode 6

In mode 6 (Figure 78), the Carrier Plate slides in the longitudinal in-plane direction relative to the Orbiter Panel. Since the primary motion of this mode is in the in-plane directions, this mode does not contribute significantly to the out-of-plane relative displacement of the electrical connectors.

6.7.6 Mode 7

Mode 7 (Figure 79) exhibits in-plane transverse sliding of the Carrier Plate feet along with a twisting of the Carrier Plate collet region. The Orbiter Panel also exhibits bending in this mode.

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However, due to its out-of-phase displaced shape, mode 7 is difficult to excite and does not contribute significantly to the out-of-plane relative displacement at the electrical connectors.

6.7.7 Mode 8

This mode (Figure 80) is the Orbiter Panel primary bending mode. It corresponds to the third mode of the stand-alone Orbiter Panel FEM (see Figure 50), and is also a significant contributor to out-of-plane relative displacements at the electrical connectors. Its frequency of 106 Hz is lower than that of the corresponding stand-alone FEM mode of 114 Hz. The drop in frequency is mainly due to the weight redistribution of the connectors (the components which span between the Carrier Plate and Orbiter Panel), which had previously been placed entirely on the Carrier Plate in the stand-alone FEM, but are distributed between the Carrier Plate and the Orbiter Panel in the integrated FEM.

6.7.8 Mode 9

Mode 9 (Figure 81) is the primary spring mode of the large electrical connector, connector number 36 (see Figure 30 for location). While this mode is not a significant contributor to the out-of-plane relative displacement of connector 36, it has a significant effect on the connector 36's spring forces, due to closeness of its frequency to the Orbiter Panel primary bending mode frequency.

6.7.9 Mode 10

This mode (Figure 82) is coupled bending mode of the Carrier Plate and the Orbiter Panel about the short transverse axis through the LH₂ fill-and-drain line. This mode is difficult to excite due to its out-of-phase displaced shape.

6.7.10 Mode 11

Mode 11 (Figure 83) is the bending of the aft region of the Orbiter Panel. It corresponds to the fourth mode of the stand-alone Orbiter Panel FEM (see Figure 51). Since this mode has very little motion at the locations of the electrical connectors, it is not a significant contributor to their out-of-plane relative displacement.

6.7.11 Mode 12 to 15

These modes (Figure 84 through Figure 87) are the primary spring modes of the small electrical connectors. They do not have a significant effect on either the out-of-plane relative displacement or the spring forces of the electrical connectors.

6.7.12 Modes 16 to 30

A total of 30 modes are used in the analysis of the baseline configuration. These higher modes have complex out-of-phase displaced shapes, and are therefore difficult to excite. Consequently, these modes do not contribute significantly to either the out-of-plane relative displacements or the spring forces of the electrical connectors.



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6.8 Sensitivity Study Configurations

The analysis included sensitivity studies in which the weight, fluid and electrical connection properties, preload value, and the input PSD are varied. A list of the FEM configurations and the parameters used in the sensitivity studies are shown in Table 13. Damping ratio of 3.3% is used for all cases.

Table 13. Integrated FEM Sensitivity Study Configuration List

Case No.	Loading Environment (PSD) ⁽⁵⁾	Conn. Weight Distribution ⁽⁶⁾	Fluid Discon. Weight (lbs)	Elect. Conn. Stiff. (lb _f /in)	Fluid Discon. Stiff. (lb _f /in)	Elect. Conn. Preload (lb _f)	Fluid Discon. Preload (lb _f)	Elect. Conn. Spring Element
1	Orig. 16C	100 / 0	(2)	Stand-alone Carrier Plate and Orbiter Panel FEM				
2	Orig. 16C	100 / 0	(2)	-	-	-	-	-
3	Updt. 16C	100 / 0	(2)	-	-	-	-	-
4	Updt. 16C	50 / 50	(3)	-	-	-	-	-
5	Updt. 16C	50 / 50	(3)	35	40	60	-	-
6	Updt. 16C	50 / 50	(2)	35	40	60	(1)	1 Elem.
7	Updt. 16C	50 / 50	(3)	35	40	60	(3)	1 Elem.
8	Updt. 16C	(4)	(3)	35	40	60	(3)	1 Elem.
9 ⁽⁷⁾	Updt. 16C	(4)	(3)	35	40	60	(3)	20 Elem.
10	Updt. 16C + 1.5 dB	100 / 0	(2)	-	-	-	-	-
11	Updt. 16C + 1.5 dB	50 / 50	(3)	35	40	60	(1)	1 Elem.
12	Updt. 16C + 1.5 dB	(4)	(3)	35	40	60	(3)	20 Elem.

1. All fluid disconnect preload are set to 60 lbs except for disconnect # 29, which has 100 lbs preload.
2. Electrical connector weights are as listed in Figure 8.
3. Fluid disconnect weights and preloads are as listed in Table 12.
4. Connector weight distributions are as described in Table 12.
5. See Figure 72 for the applied PSD.
6. Distribution nomenclature: (% of weight on Carrier Plate) / (% of weight on Orbiter Panel).
7. Case 9 is the baseline configuration.

In addition to the sensitivity studies of the configurations shown in Table 13, the contribution of each mode to the overall electrical connector dynamic relative displacement and spring forces is also investigated. The effect of the connector preload on the static relative displacement is also included in the sensitivity studies. Both the mode contribution and preload studies used the baseline (case 9) FEM configuration.

6.9 Dynamic Relative Displacement and Spring Forces

A color contour plot of the 3-sigma out-of-plane displacement of the baseline (case 9) Integrated FEM is shown in Figure 88. The 3-sigma out-of-plane relative displacement values between the Carrier Plate and the Orbiter Panel at the electrical connector locations as calculated by the Integrated T-0 Umbilical FEM are shown in Figure 89. The 3-sigma electrical connector spring dynamic forces are shown in Figure 90.



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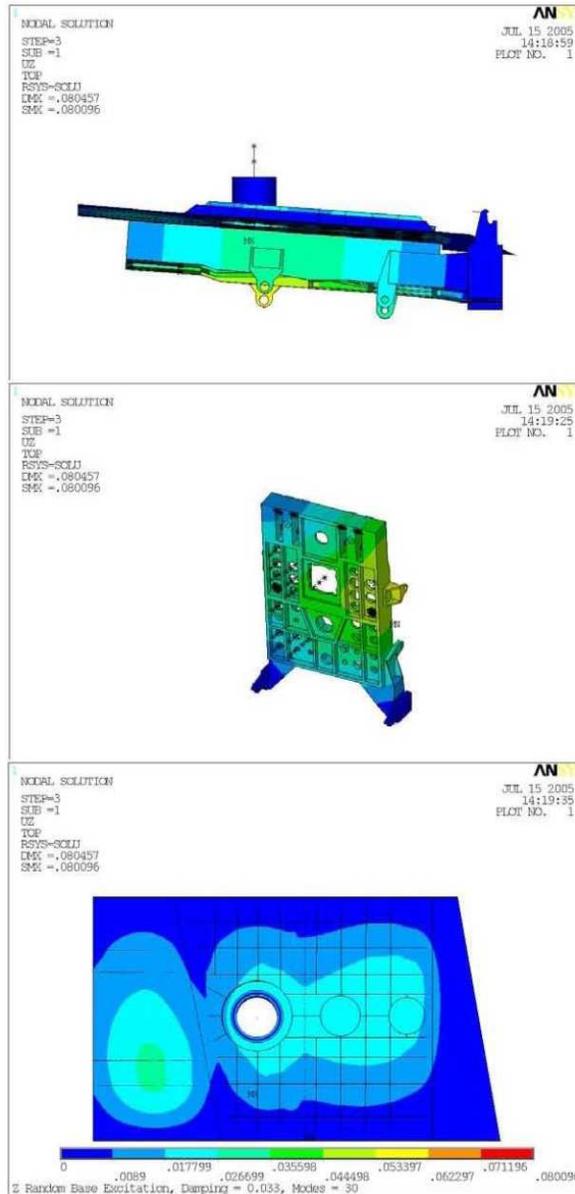


Figure 88. Integrated FEM 3- σ Out-of-Plane Displacement - Baseline Configuration



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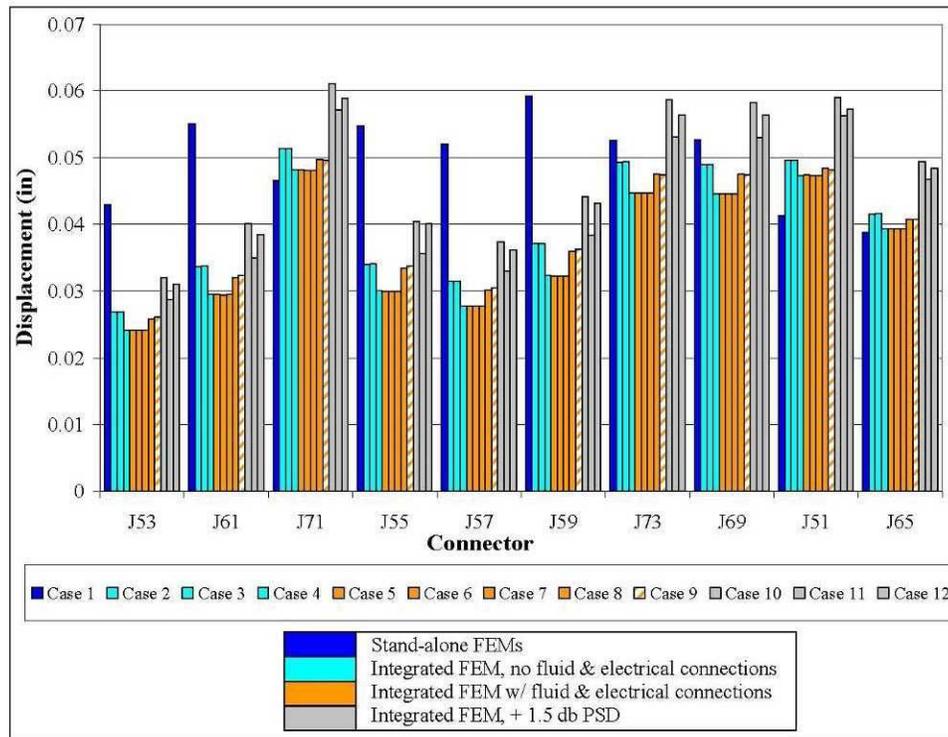


Figure 89. Integrated FEM Electrical Connector 3-σ Out-of-Plane Relative Displacement

As seen in Figure 89, the maximum electrical connector relative displacement value of the Integrated T-0 Umbilical FEM baseline configuration (case 9) is lower than that of the stand-alone Carrier Plate and Orbiter Panel FEM. Based on the results of the sensitivity analysis, the dynamic relative displacement values are insensitive to weight, fluid and electrical connection properties, and preload. As expected, the displacement results for the higher (+1.5 db) PSD input are greater than those for the nominal PSD input.

The connector spring force results are only calculated for the cases which included electrical connections. The frequencies of the connector springs' primary mode (107 Hz for the large connector, 130 Hz for the small connectors) are within maximum PSD excitation level frequency range, and are near several modes of the primary structure. Consequently, multiple elements are required to adequately capture the local motion of the connector springs. As seen in Figure 90, the two cases with detailed spring representation, case 9 and case 12, have significantly higher spring forces than cases with simple spring representation. The large connector, number 36 (J51), has much greater dynamic spring forces than the small connectors due to it being heavier and its primary spring mode frequency being very close the primary Orbiter Panel bending mode frequency. However, connector 36 (large connector) is powered off prior to SSME start, and the 3-sigma spring forces are all well below the minimum connector spring preload of 40 pounds.



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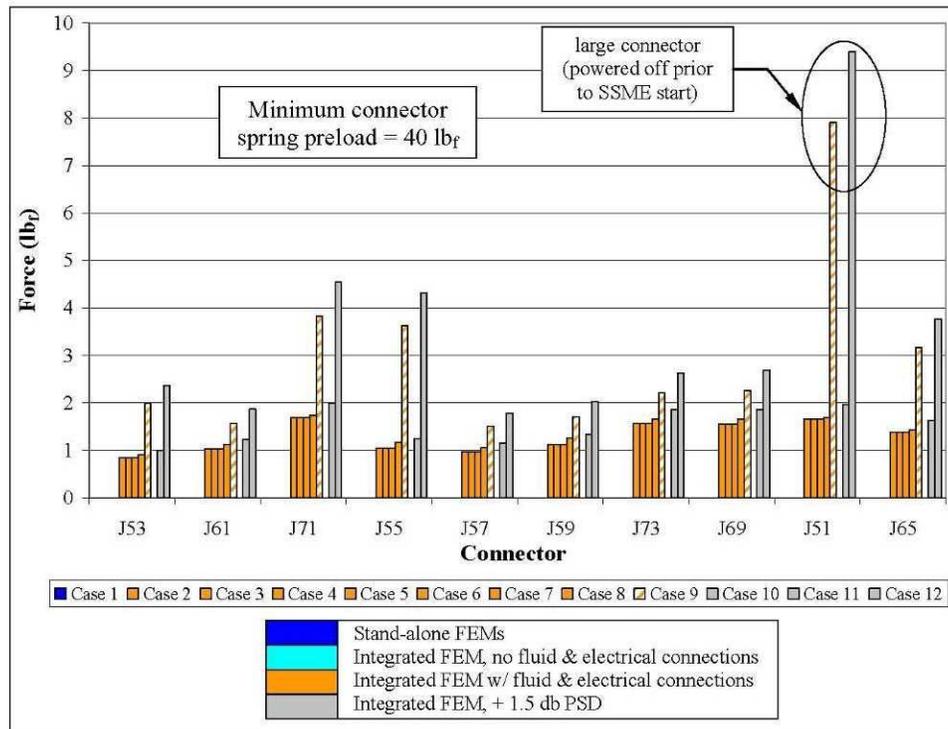


Figure 90. Integrated FEM Electrical Connector 3-σ Dynamic Spring Force

The contribution of each mode to the overall dynamic relative displacement and spring force responses is investigated in the study. As shown in Figure 91, mode 3 (Carrier Plate primary bending mode) and mode 8 (Orbiter Panel primary bending mode) are the main contributors to the dynamic out-of-plane relative displacements of the electrical connectors. This result is consistent with the findings of the sensitivity studies for the stand-alone Carrier Plate FEM (see section 3.11.1) and the stand-alone Orbiter Panel FEM (see section 5.10).

Mode 3 and mode 8 are also the main contributors to the connector spring force responses. However, for connector number 3 (J55) and number 36 (J51), other modes also contribute significantly. As mention previously in section 6.7.8, the primary spring mode of the large connector (mode 9) is a significant contributor to its dynamic spring force response due to its frequency being very near to that of mode 8. Consequently, both modes 8 and 9 are included when calculating the “mode 8” spring forces response for the large connector as shown in Figure 92. Connector 3 (J55) spring force response also has significant contributions from modes other than mode 3 and 8, but its overall response is less than 4 pounds.

The static relative displacements of the electrical connectors due to connector preload are shown in Figure 93. The preload values of the fluid and electrical connectors are shown in Table 12. The static relative displacements due to connector preload are small, less than 0.010 inches.



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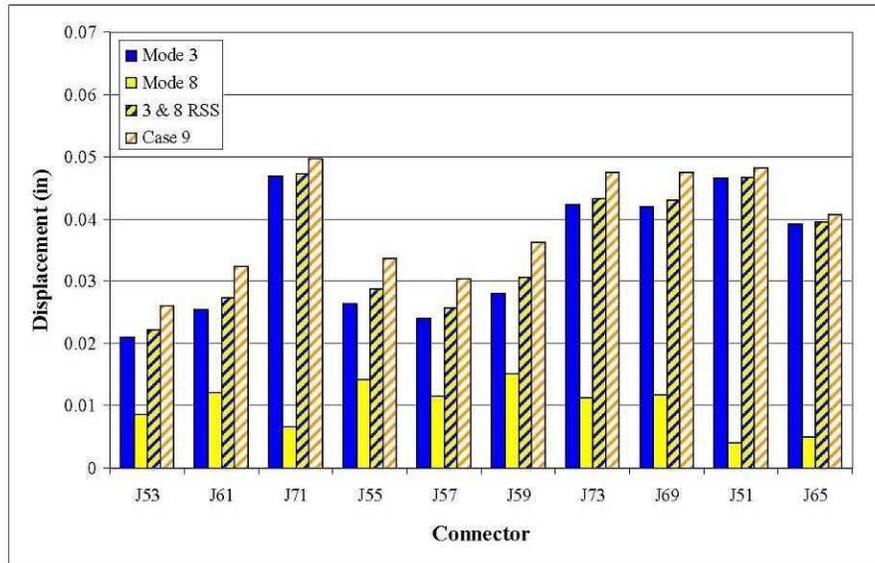


Figure 91. Mode Contribution to Connector 3-σ Relative Displacement Response

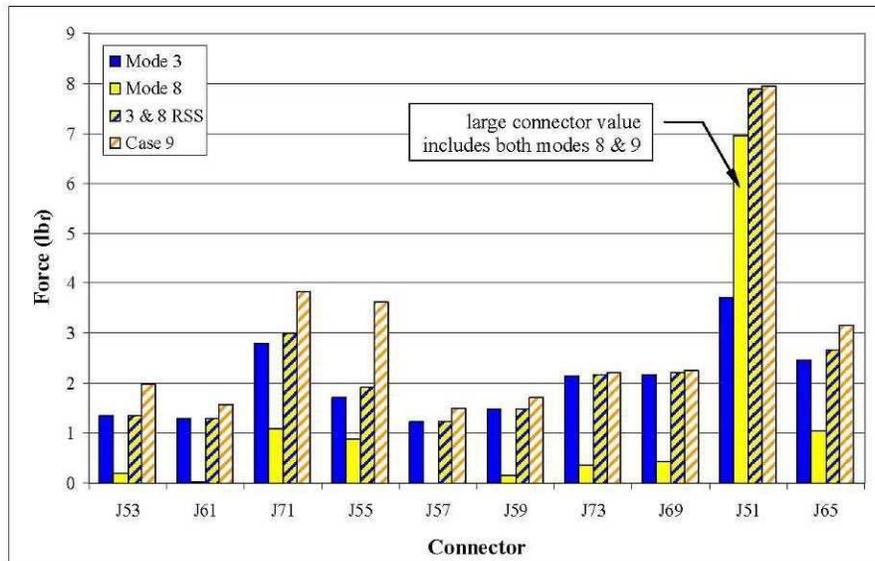


Figure 92. Mode Contribution to Connector 3-σ Spring Force Response



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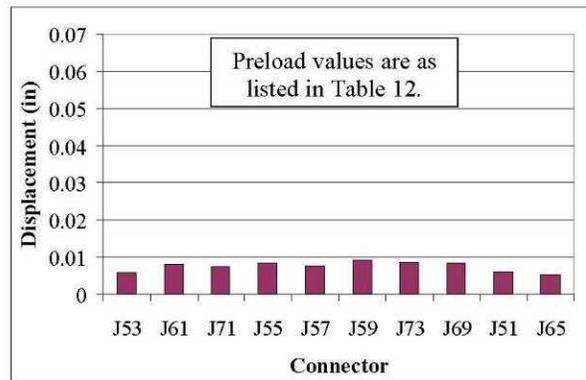


Figure 93. Static Relative Displacement due to Connector Preload

7.0 Conclusion

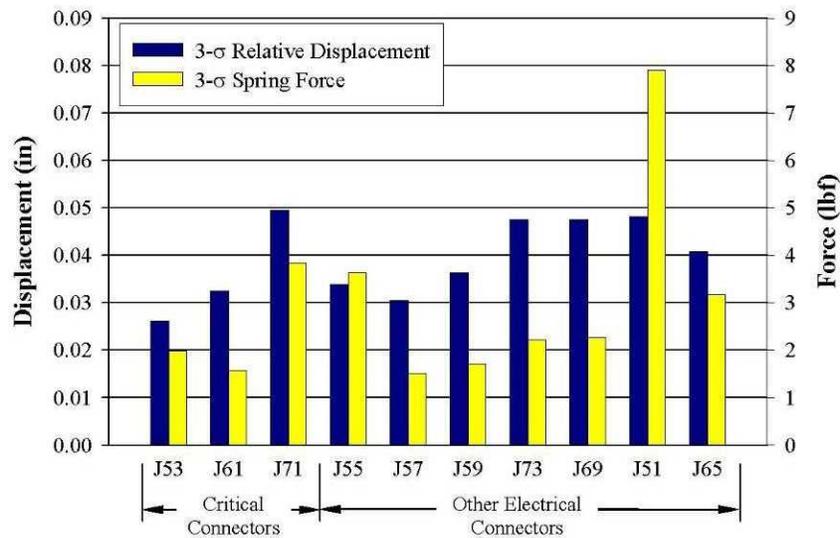


Figure 94. Integrated FEM Electrical Connector Dynamic Relative Displacement & Force

An integrated finite element model (FEM) was created incorporating both the GSE LH₂ T-0 Umbilical Carrier Plate and the LH₂ T-0 Umbilical Orbiter Panel. Modal testing of both the port and starboard GSE, including the Carrier Plates, helped validate the FEMs. Sensitivity studies showed that the models were insensitive to key modeling assumptions. The dynamic relative displacement between the GSE side (Carrier Plate) and the Orbiter side (Orbiter Panel) and the dynamic spring force for each electrical connector on the LH₂ side are shown in Figure 94. Analysis indicates that similar results would be expected for the LO₂ side.

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8.0 References

- [1] VULML001-01, "LH2 Launch (T-0) Umbilical Carrier Plate, Model S70-0517, P/N GW70-580517," Space Shuttle Operation and Maintenance Document, Sept. 15, 1981.
- [2] MD-V70, "Space Shuttle Master Dimensions," Rockwell International Space Division Specification.
- [3] "Curved Pipe and Welding Elbow," ASME Boiler and Pressure Vessel Code, Section III, Division 1, NB-3686.2, Jan. 7, 2004.
- [4] MF0004-014, Rev. F, "Environmental Requirements and Test Criteria for the Orbiter Vehicle," Boeing NASA Systems Specification, Sept. 30, 2003.
- [5] Lambert, James C, "TSM/MLP Launch Acoustic Environments," Presentation to T-0 Separation Interface Tiger Team Mid-Term Meeting, Oct. 26, 2004.
- [6] Mann, Brent and Dan Paul, "TSM Y-PSD Low-Frequency Environment," Presentation to Space Shuttle Program Loads Panel, May 11, 2005.

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Appendix A. Modal Test Report

A.1 Objectives and Purpose

The objective of the modal testing conducted on the T-0 umbilical plates was to measure the natural frequencies, mode shapes, and damping of the primary vibration modes.

The purpose for conducting the tests was to validate and update existing finite element models of the plates. The frequency data was used to correct for added mass not included in the model such as lines connectors, and non-structural items. The damping values obtained from the tests were used in the dynamic response analysis.



Figure A-1. Modal test setup for Vandenberg Plate in free-free state

A.2 Results Summary

Modal tests were performed on three different umbilical plates on Dec. 8, 2004. The test hardware consisted of the spare “Vandenberg” plate, an LH₂ plate, and a LOX plate. The Vandenberg plate was tested in a simulated free condition hanging from an overhead beam, while the LH₂ and LOX plates were tested as mounted in their respective tail service masts (TSM). All test objectives were met and excellent quality data was obtained.

The primary natural frequencies of the Vandenberg plate ranged from 46 Hz to 192 Hz and involved bending and torsion of the plate. Damping calculated from the data was found to range from 0.89% to 2.74%.

The primary natural frequencies of the LH₂ plate ranged from 42 Hz to 203 Hz and also involve bending and torsion of the plate. Damping was calculated ranging from 1.3% to 13.4%.

Natural frequencies were also obtained for plate rigid body motion on flexible supports. Three of these modes were found ranging from 1.75 Hz to 12.5 Hz.

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A.3 Instrumentation & Excitation Method

Test equipment consists of a rubber-tipped excitation hammer, accelerometers, signal conditioning electronics, assorted cables, and a portable PC. The rubber-tipped hammer is used to input and measure the force pulse that causes structural response. The hammer, shown in Figure A-3 and Figure A-4, is equipped with 4 different rubber tips and a load cell that senses the instantaneous force applied to the structure being tested. Accelerometers are used to measure structural response and are attached to the test article with a small amount of wax or, in some instances, hot glue. The hammer force and accelerometer time histories pass through signal conditioning equipment prior to being recorded on the portable PC. The PC and signal conditioning equipment are shown in Figure A-2. All equipment is powered by standard 110 volt, AC current, but can be operated for short periods on battery power alone.

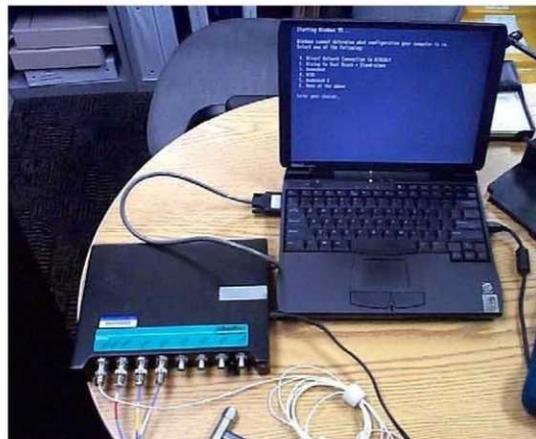


Figure A-2. Test setup - Portable PC and Signal Conditioning Equipment

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Figure A-3. Excitation Hammer with Rubber Tips



Figure A-4. Excitation Hammer on Back of Plate, Accelerometers on Front



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Space Shuttle T-0 Umbilical Dynamic Displacements and Forces

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Approved by: John E. Larson

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A.4 Test Descriptions - LH₂ Plate

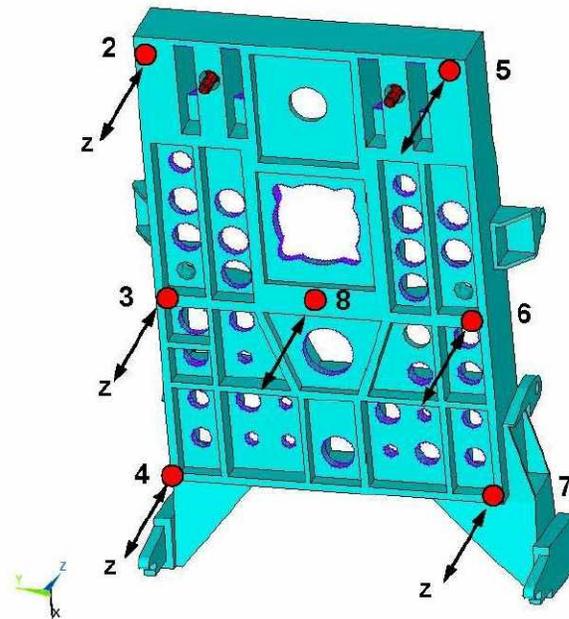


Figure A-5. Accelerometer Locations & Measurement Directions for Tests 1-5 (LH₂ Plate)

A.4.1 LH₂ Plate-Test 1

The test article was the LH₂ plate in a partially deployed condition as mounted on the tail service mast (TSM). Cables were not attached to the top of plate. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-5. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input to the plate in the z-direction directly opposite from accelerometer 7 on the side of the plate that faces away from the orbiter. Ten hammer pulses were used for the test. Data was recorded for 0.8 seconds during each pulse with 2048 pts, 0-1000 Hz, with a frequency resolution of 1.25 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 6 Hz, 55 Hz, 126 Hz, and 190 Hz.

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A.4.2 LH₂ Plate-Test 2

The test article was the LH₂ plate in a partially deployed condition identical to the configuration of Test 1. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-5. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input to the plate in the z-direction directly opposite from accelerometer 5 on the side of the plate that faces away from the orbiter. Ten hammer pulses were used for the test. Data was recorded for 1.6 seconds during each pulse with 2048 pts, 0-500 Hz, with a frequency resolution of 0.625 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 6.25, 55, 78, 116, 193 Hz.

A.4.3 LH₂ Plate-Test 3

The test article was the LH₂ plate in a partially deployed condition identical to the configuration of Test 1. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-5. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input to the plate in the z-direction on the orbiter side of the plate in the location of the missing accelerometer 6. This is the side of the plate that faces towards the orbiter. Ten hammer pulses were used for the test. Data was recorded for 1.6 seconds with 2048 pts, 0-500 Hz, with a frequency resolution of 0.625 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 6.25, 55, 78, 126, 193, and 206 Hz.

A.4.4 LH₂ Plate-Test 4

The test article was the LH₂ plate in a partially deployed condition identical to the configuration of Test 1. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-5. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input to the plate in the z-direction directly opposite from accelerometer position 2 on the side of the plate that faces away from the orbiter. Ten hammer pulses were used for all tests. Data was recorded for 1.6 seconds with 2048 pts, 0-500 Hz, with a frequency resolution of 0.625 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 5.6, 55, 72, 117, 126, 193, and 206 Hz.

A.4.5 LH₂ Plate-Test 5

The test article was the LH₂ plate in a partially deployed condition identical to the configuration of Test 1. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-5. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

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The hammer pulse was input to the orbiter side of the plate in the z-direction directly between accelerometers 2 and 5. Ten hammer pulses were used for all tests. Data was recorded for 1.6 seconds with 2048 pts, 0-500 Hz, with a frequency resolution of 0.625 Hz. The green hammer tip was used for this test.

Accelerometer 3 was discovered loose at the end of the test.

Predominate response frequencies found during this test were 5.6, 6.25, 71, and 126 Hz.

A.4.6 LH₂ Plate-Test 6

The test article was the LH₂ plate in a partially deployed condition identical to the configuration of Test 1. Accelerometers were wax mounted on the plate at the locations shown in Figure A-6. Accelerometers 2, 3, & 4 were oriented to measure in the y-direction, accelerometer 8 measured x-direction motion and accelerometers 5 & 7 measured z-direction. Accelerometers 2, 3, 4, & 8 were mounted on the edge of the plate. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input at the edge of the plate in the y-direction near accelerometer 5. Ten hammer pulses were used for all tests. Data was recorded for 4.00 seconds with 2048 pts, 0-200 Hz, with a frequency resolution of 0.25 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 1.75, 6.5, 13.5, 18.8, 55, 78, 94, 117, and 125 Hz.

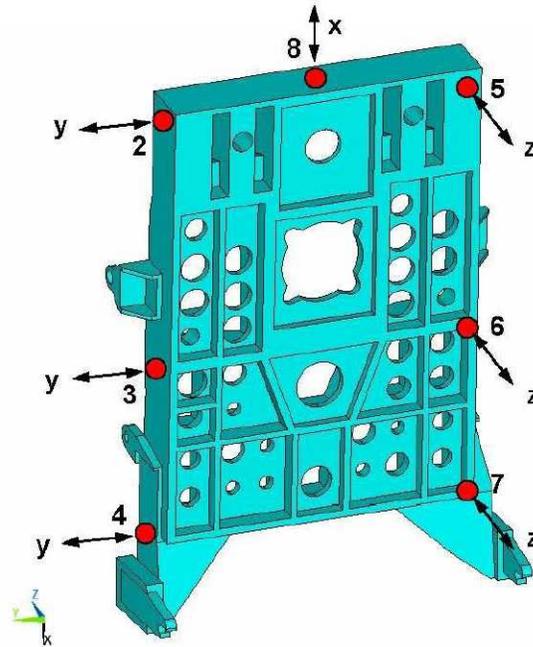


Figure A-6. Accelerometer Locations & Measurement Directions for Tests 6-7 (LH₂ Plate)



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A.4.7 LH₂ Plate-Test 7

This test was identical to test 6 with the exception that the rubber hammer tip was changed from green to brown for a lower frequency input pulse. The test article was the LH₂ plate in a partially deployed condition identical to the configuration of Test 1. Accelerometers were wax mounted on the plate at the locations shown in **Error! Reference source not found.** Accelerometers 2, 3, & 4 were oriented to measure in the y-direction, accelerometer 8 measured x-direction and accelerometers 5 & 7 measured z-direction. Accelerometers 2, 3, 4, & 8 were mounted on the edge of the plate. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input at the edge of the plate in the y-direction near accelerometer 5. Ten hammer pulses were used for all tests. Data was recorded for 4.0 seconds with 2048 pts, 0-200 Hz, with a frequency resolution of 0.25 Hz. The brown hammer tip was used for this test.

Predominate response frequencies found during this test were 1.75, 6.5, 12, 34.5, 47, 55, 117, and 125 Hz.

A.4.8 LH₂ Plate-Test 8

This test used the brown hammer tip for a lower frequency input pulse. The test article was the LH₂ plate in a partially deployed condition identical to the configuration of Test 1. Accelerometers were wax mounted on the plate at the locations shown in Figure A-7. Accelerometers 2 & 4 were oriented to measure in the y-direction, accelerometer 8 measured x-direction and accelerometers 3, 5, & 7 measured z-direction. Accelerometers 2, 4, & 8 were mounted on the edge of the plate. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input at the bottom edge of the plate in the x-direction between accelerometers 4 & 7. Ten hammer pulses were used for all tests. Data was recorded for 4.0 seconds with 2048 pts, 0-200 Hz, with a frequency resolution of 0.25 Hz.

Predominate response frequencies found during this test were 1.75, 11.5, 18.5, 30, 34.5, 45, 67 and 126 Hz.

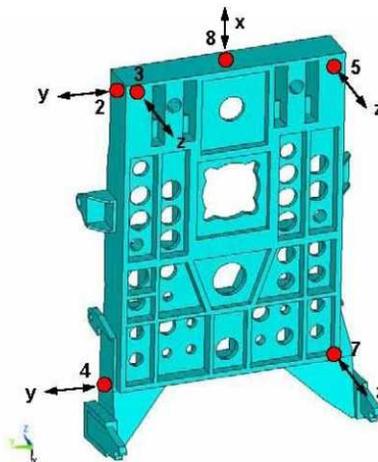


Figure A-7. Accelerometer Locations & Measurement Directions for Test 8 (LH₂ Plate)



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A.5 Test Descriptions - Vandenberg Plate

A.5.1 Vandenberg Plate - Test 1

The test article was the Vandenberg plate in a free-free state. The plate was hanging from cables attached to top of plate as shown in Figure A-4. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-8. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

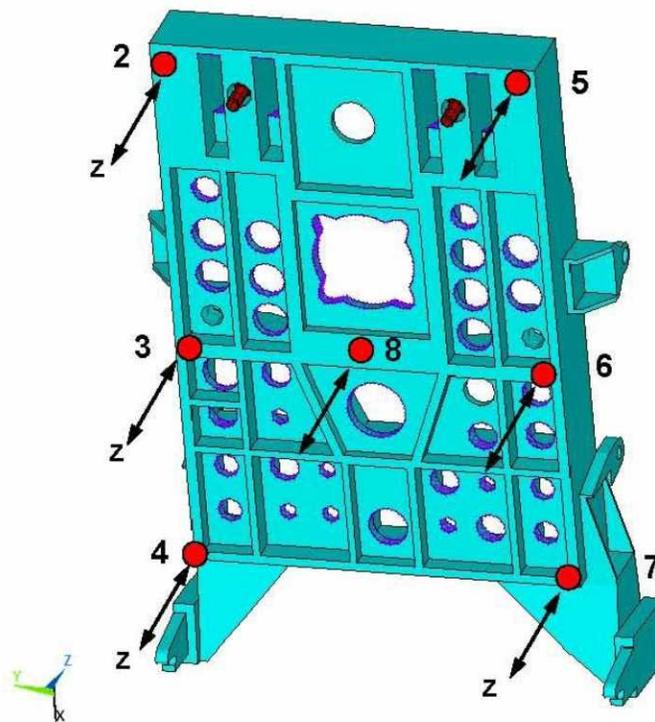


Figure A-8. Accelerometer Locations & Measurement Directions for Tests 1-4
(Vandenberg Plate)

The hammer pulse was input to the plate in the z-direction directly opposite from accelerometer 4 on the side of the plate that would face away from the orbiter. Ten hammer pulses were used for the test. Data was recorded for 0.8 seconds during each pulse with 2048 pts, 0-1000 Hz, with a frequency resolution of 1.25 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 46.3 Hz, and 141 Hz.

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A.5.2 Vandenberg Plate - Test 2

The test article was the Vandenberg plate in a free-free state. The plate was hanging from cables attached to top of plate as shown in Figure A-4. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-8. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input to the plate in the z-direction directly opposite from accelerometer 6 on the side of the plate would face away from the orbiter. Ten hammer pulses were used for the test. Data was recorded for 0.8 seconds during each pulse with 2048 pts, 0-1000 Hz, with a frequency resolution of 1.25 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 46, 143, and 179 Hz.

A.5.3 Vandenberg Plate - Test 3

The test article was the Vandenberg plate in a free-free state. The plate was hanging from cables attached to top of plate as shown in Figure A-4. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-8. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input to the plate in the z-direction directly opposite from accelerometer position 2 on the side of the plate that would face away from the orbiter. Ten hammer pulses were used for all tests. Data was recorded for 1.6 seconds with 2048 pts, 0-500 Hz, with a frequency resolution of 0.625 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 23 and 183 Hz.

A.5.4 Vandenberg Plate - Test 4

The test article was the Vandenberg plate in a free-free state. The plate was hanging from cables attached to top of plate as shown in Figure A-4. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-8. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input to the plate in the z-direction directly opposite from accelerometer position 2 on the side of the plate that would face away from the orbiter. Ten hammer pulses were used for all tests. Data was recorded for 1.6 seconds with 2048 pts, 0-500 Hz, with a frequency resolution of 0.625 Hz. The green hammer tip was used for this test.

Predominate response frequency found during this test was 46.3 Hz.

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A.6 Test Descriptions - LOX Plate

A.6.1 LOX Plate - Test 1

The test article was the LOX plate in a partially deployed condition as mounted on the tail service mast (TSM). Cables were not attached to top of plate. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-9. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

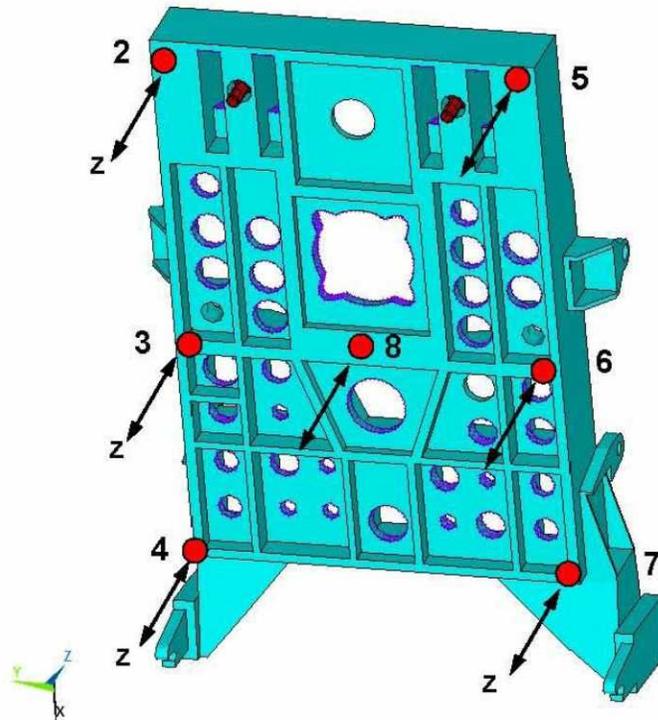


Figure A-9. Accelerometer Locations & Measurement Directions for Tests 1-4 (LOX Plate)

The hammer pulse was input to the plate in the z-direction directly opposite from accelerometer 4 on the side of the plate that faces away from the orbiter. Ten hammer pulses were used for the test. Data was recorded for 1.6 seconds during each pulse with 2048 pts, 0-500 Hz, with a frequency resolution of 0.625 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 5 Hz, 54 Hz, 121 Hz, and 191 Hz.

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A.6.2 LOX Plate - Test 2

The test article was the LOX plate in a partially deployed condition identical to the configuration of Test 1. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-9. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input to the plate in the z-direction directly opposite from accelerometer 2 on the side of the plate that faces away from the orbiter. Ten hammer pulses were used for the test. Data was recorded for 1.6 seconds during each pulse with 2048 pts, 0-500 Hz, with a frequency resolution of 0.625 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 5, 54, 77, 109, and 189 Hz.

A.6.3 LOX Plate - Test 3

The test article was the LOX plate in a partially deployed condition identical to the configuration of Test 1. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-9. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

The hammer pulse was input to the plate in the z-direction on the orbiter side of the plate near the location of accelerometer 8. This is the side of the plate that faces towards the orbiter. Ten hammer pulses were used for the test. Data was recorded for 1.6 seconds with 2048 pts, 0-500 Hz, with a frequency resolution of 0.625 Hz. The green hammer tip was used for this test.

Predominate response frequencies found during this test were 5, 44, 69, 122, and 189 Hz.

A.6.4 LOX Plate - Test 4

The test article was the LOX plate in a partially deployed condition identical to the configuration of Test 1. Accelerometers were wax mounted on the orbiter side of the plate at the locations shown in Figure A-9. All of the accelerometers were oriented to measure in the z-direction. Accelerometer 6 shown in the figure was not installed.

The excitation was supplied by hand pushing on the plate in the z-direction directly opposite from accelerometer position 7 on the side of the plate that faces away from the orbiter. Pushing was done to excite the rigid body modes of the plate. Data was recorded for 16 seconds with 2048 pts, 0-50 Hz, with a frequency resolution of 0.0625 Hz. The hammer was not used for this test.

Predominate response frequencies found during this test were 1.75 and 4.25 Hz.



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A.7 Comparing test data with numerical results

The modal assurance criterion (MAC) was used as a measure of correlation between the analytical and measured mode shape vectors. The MAC makes use of the measured mode shapes ϕ_{mj} and the analytical mode shapes ϕ_{aj} .

$$MAC_{jk} = \frac{|\phi_{mj}^T \phi_{ak}|^2}{(\phi_{ak}^T \phi_{ak}) (\phi_{mj}^T \phi_{mj})}$$

There are two measured mode shapes that are being matched with the analytical shapes. X-Modal software was used to identify the measured mode shapes, which occur at 45 and 149.9 Hz

$$\phi_{m(45\text{ Hz})} = \begin{bmatrix} 1.9159\text{E} + 02 \\ 1.5449\text{E} + 01 \\ -1.4632\text{E} + 02 \\ -1.8996\text{E} + 02 \\ 1.3987\text{E} + 02 \\ -1.7208\text{E} + 00 \end{bmatrix}, \text{ and } \phi_{m(149.9\text{ Hz})} = \begin{bmatrix} 6.5339\text{E} + 00 \\ -8.3175\text{E} + 00 \\ 3.6573\text{E} + 00 \\ -2.2586\text{E} + 00 \\ 1.4363\text{E} + 00 \\ -7.3868\text{E} + 00 \end{bmatrix}$$

Displacements were taken from the finite element model to determine the mode shapes of interest at 44 and 144 Hz.

$$\phi_{m(44\text{ Hz})} = \begin{bmatrix} -0.65043 \\ 0.17526 \\ 1.0155 \\ 0.60913 \\ 0.60913 \\ 0.38780\text{E} - 02 \end{bmatrix}, \text{ and } \phi_{m(144\text{ Hz})} = \begin{bmatrix} 0.32295 \\ -0.70997 \\ 0.62753 \\ 0.22015 \\ 0.50992 \\ -0.69071 \end{bmatrix}$$

Using the equation above for the modes listed, the MAC is:

$$MAC = \begin{bmatrix} 0.8511 & 0.0005 \\ 0.0438 & 0.7325 \end{bmatrix}$$

A good correlation between analytical and measured mode shapes would show values near 1 on the diagonal of the MAC matrix and near zero on the off diagonals. The analytical and measured mode shapes are thus adequately correlated.

A.8 References

- [A1] Friswell, M.I., and Mottershead, J.E., *Finite Element Model Updating in Structural Dynamics*, Kluwer Academic Publishers, 1995.
- [A2] X-Modal II Release 2.6, University of Cincinnati, Structural Dynamics Research Lab, 2004.



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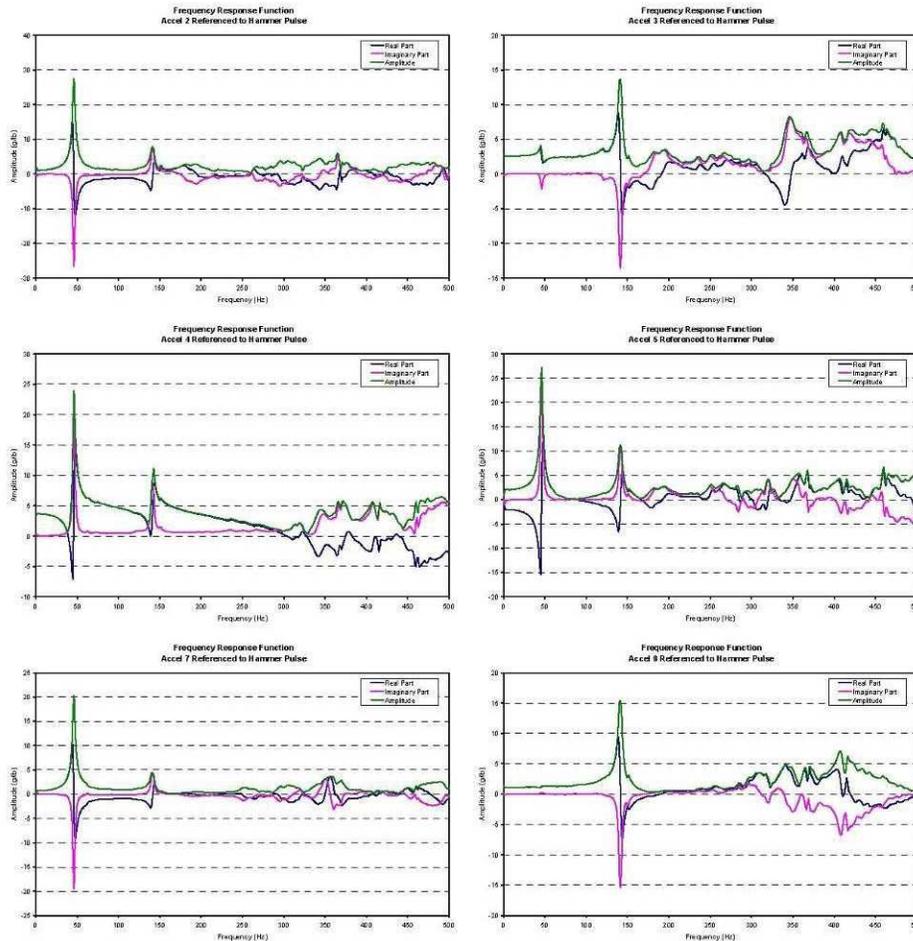
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A.9 Modal Test Results – Vandenberg Plate

A.9.1 Vandenberg Plate, Test 1 – Frequency Response Function





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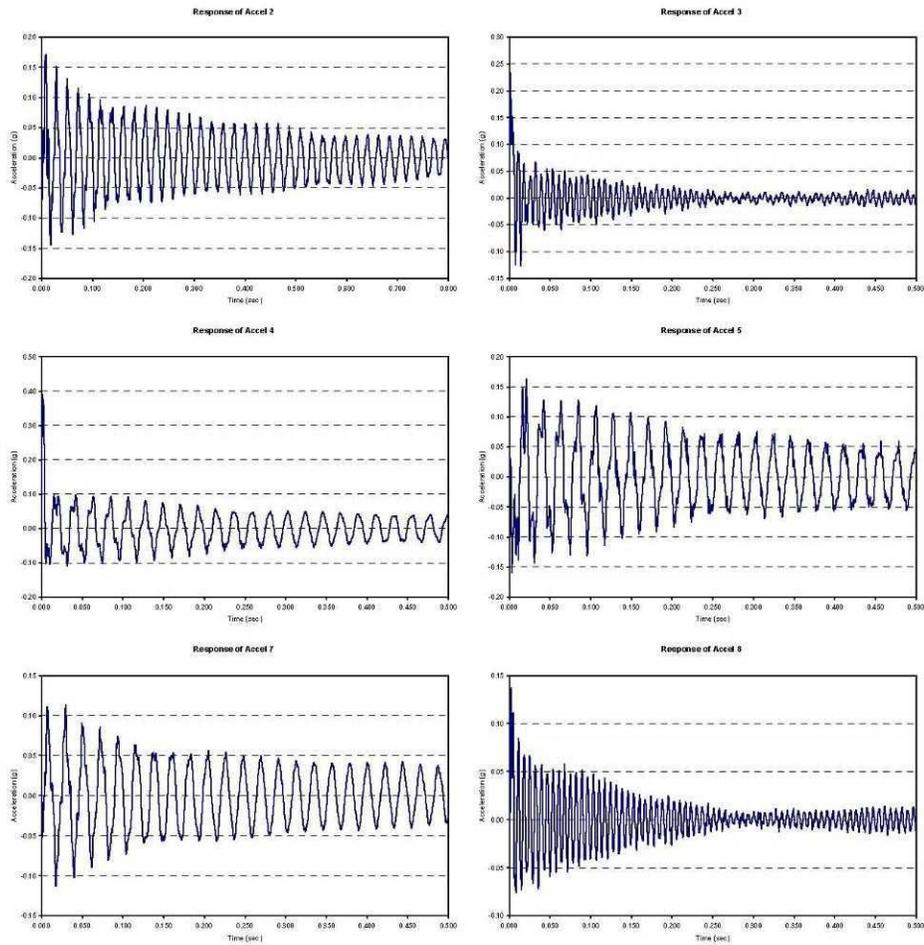
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A.9.2 Vandenberg Plate, Test 1 – Time History Plots





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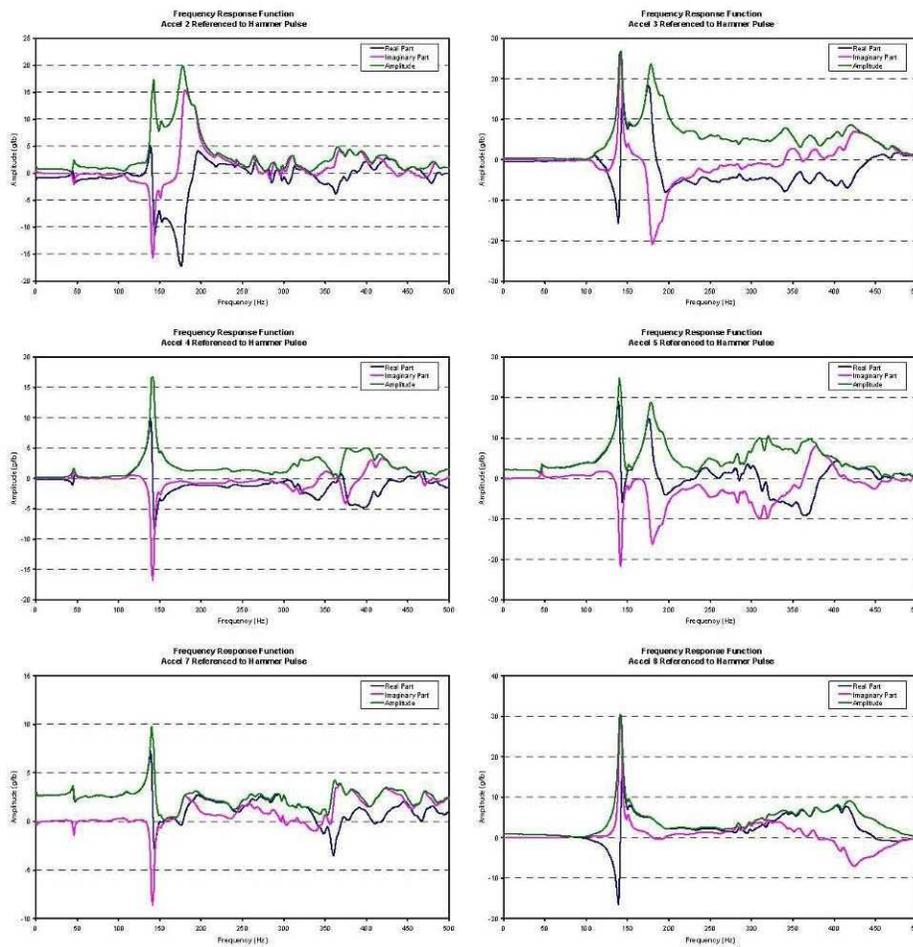
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A.9.3 Vandenberg Plate, Test 2 – Frequency Response Function





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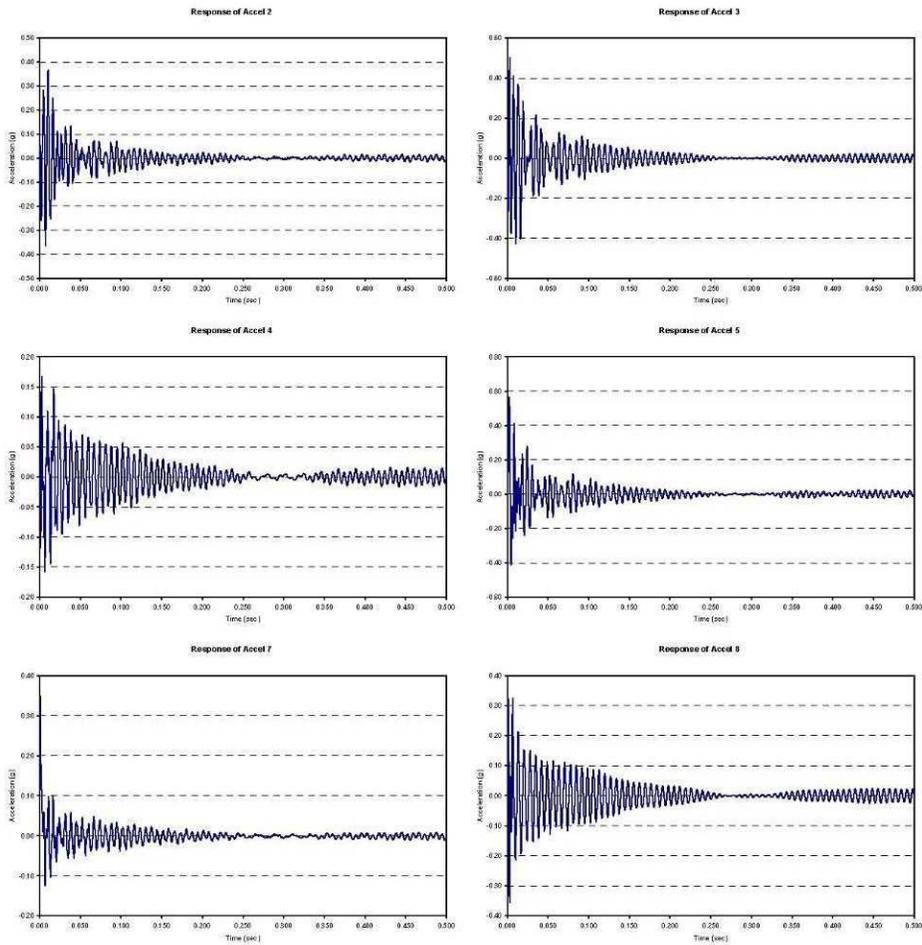
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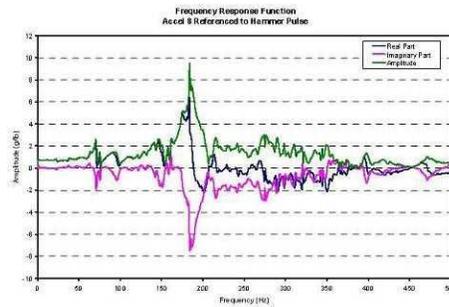
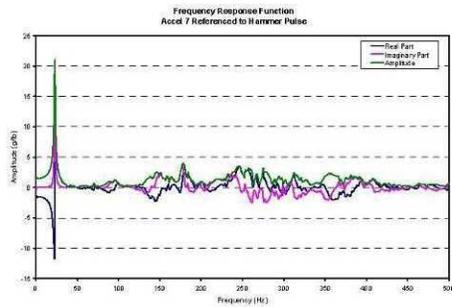
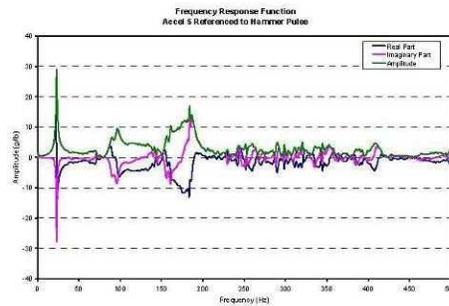
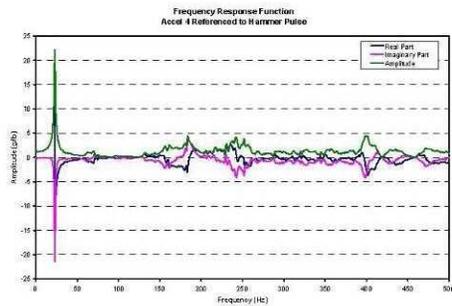
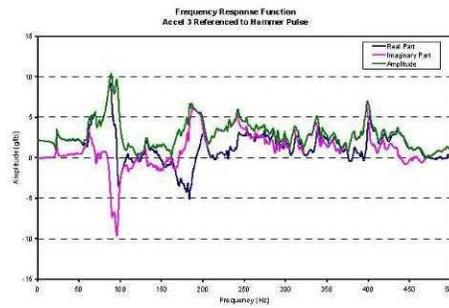
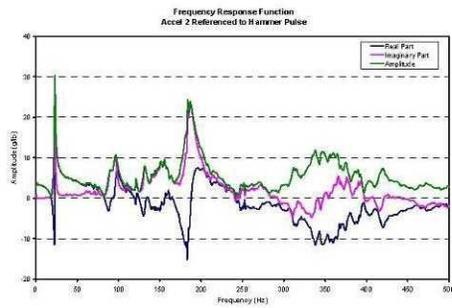
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A.9.5 Vandenberg Plate, Test 3 – Frequency Response Function





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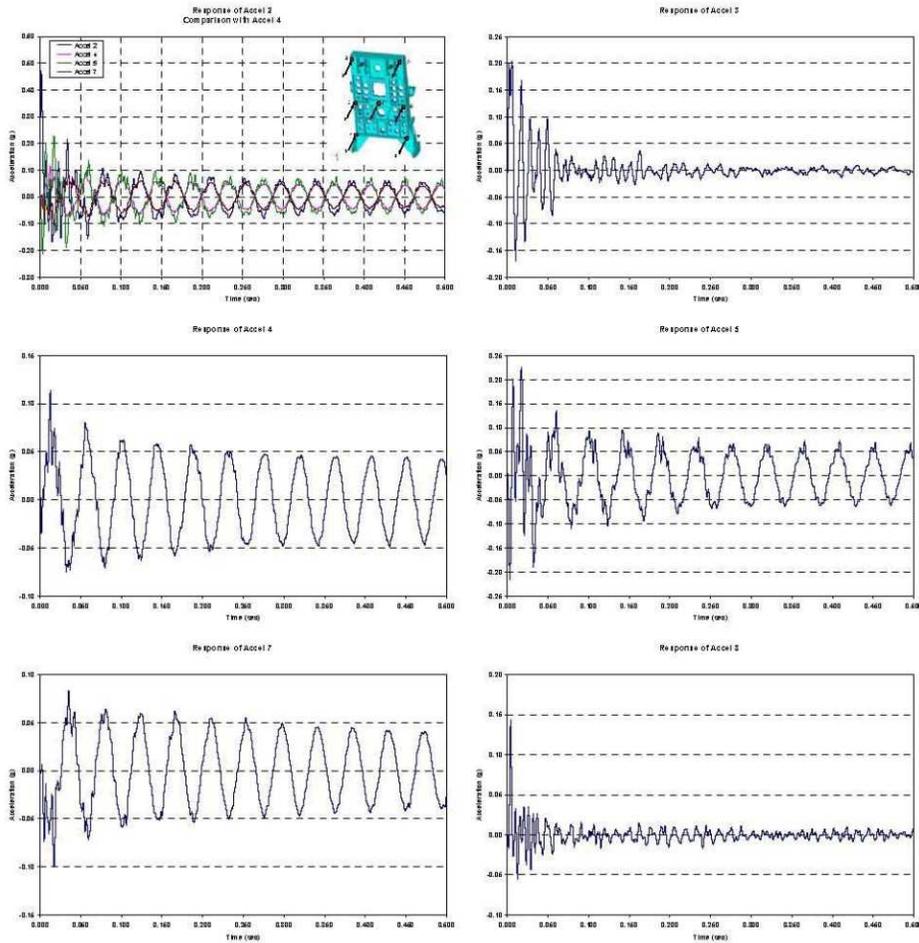
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A.9.6 Vandenberg Plate, Test 3 – Time History Plots





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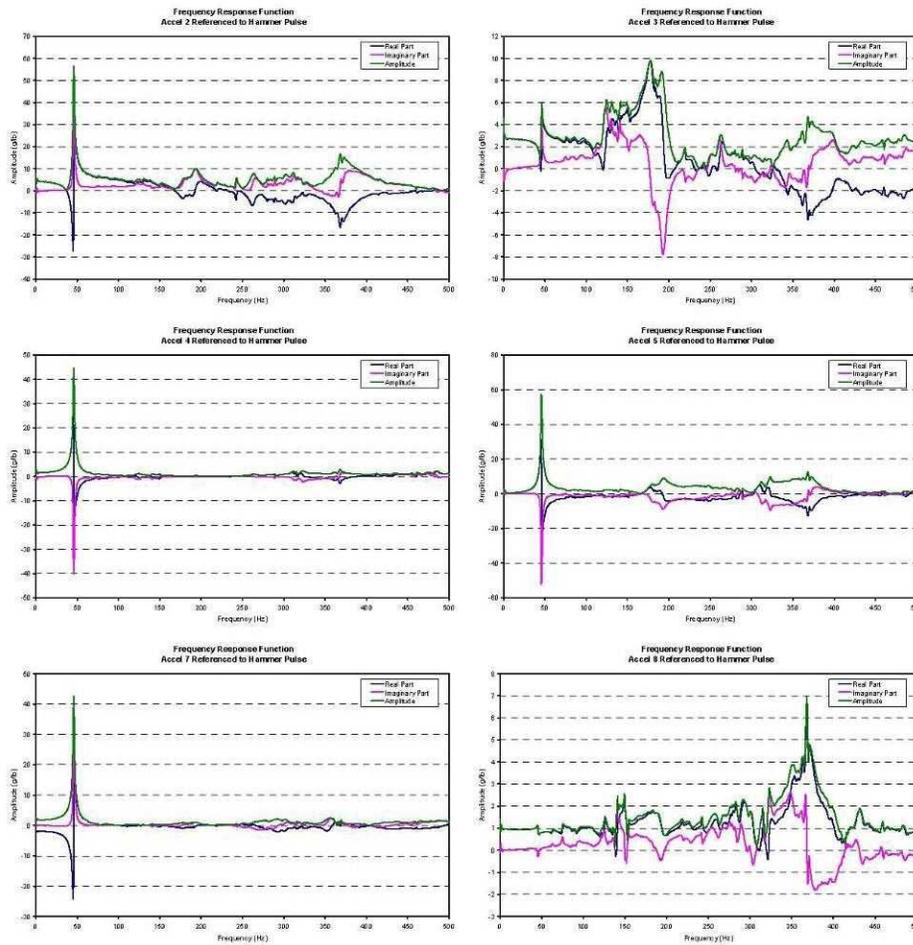
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A.9.7 Vandenberg Plate, Test 4 – Frequency Response Function





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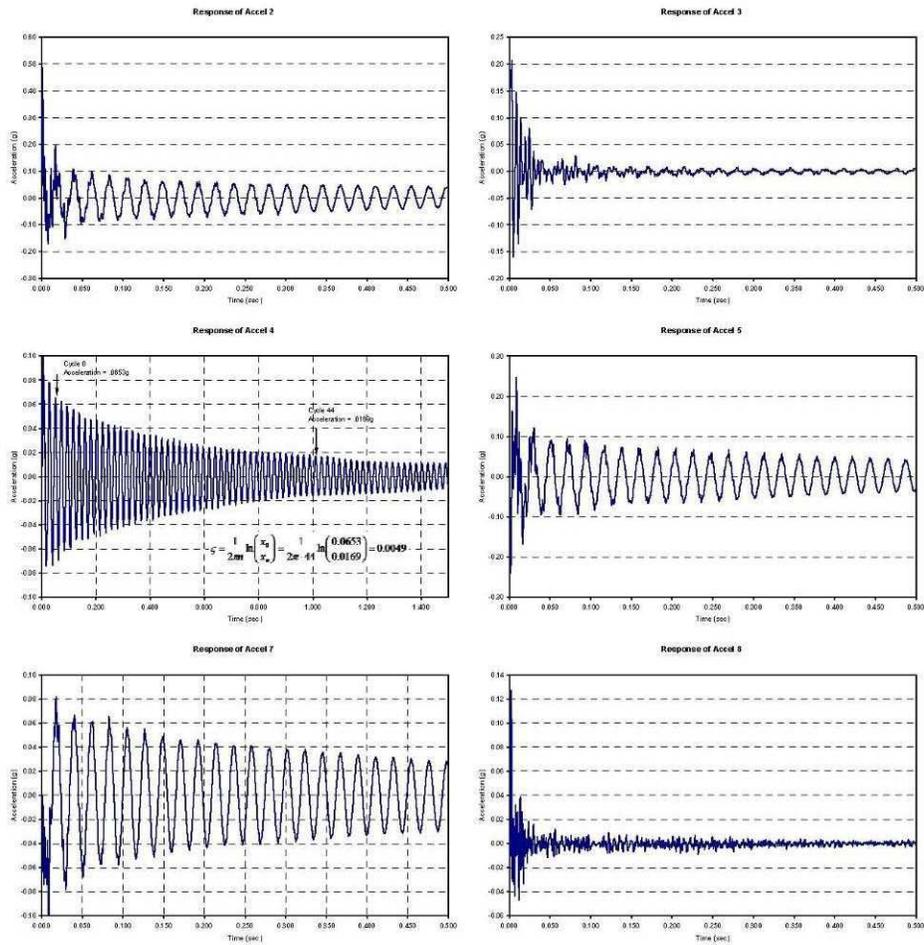
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Prepared by: J.H. Miller, J.Y. Tsai, D.F. Pilkey, G.A. Davis, J.H. Christie, C.T. Houghton
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A.9.8 Vandenberg Plate, Test 4 – Time History Plots





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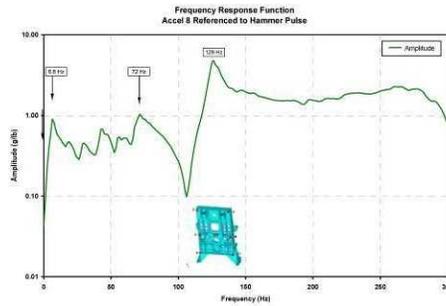
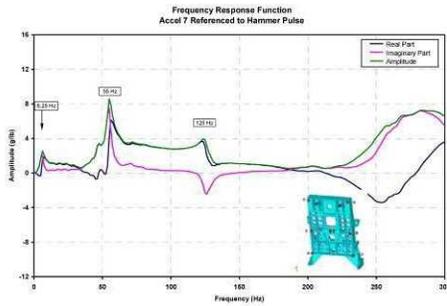
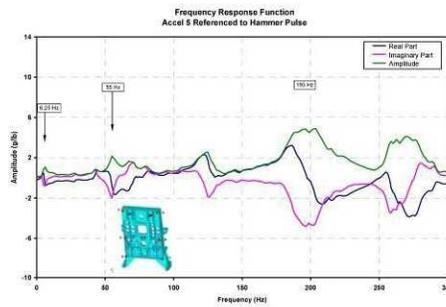
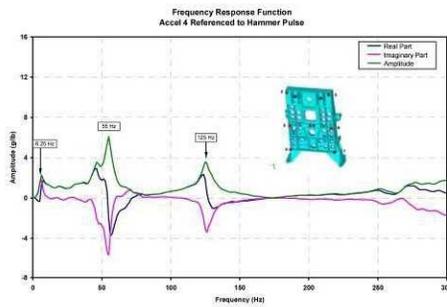
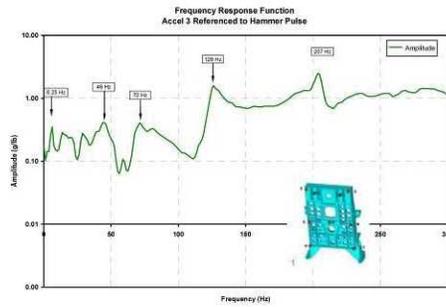
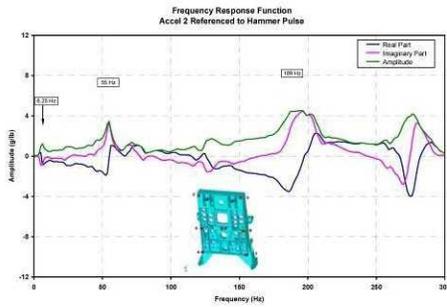
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A.10 Modal Test Results – LH₂ Plate

A.10.1 LH₂ Plate, Test 1 – Frequency Response Function





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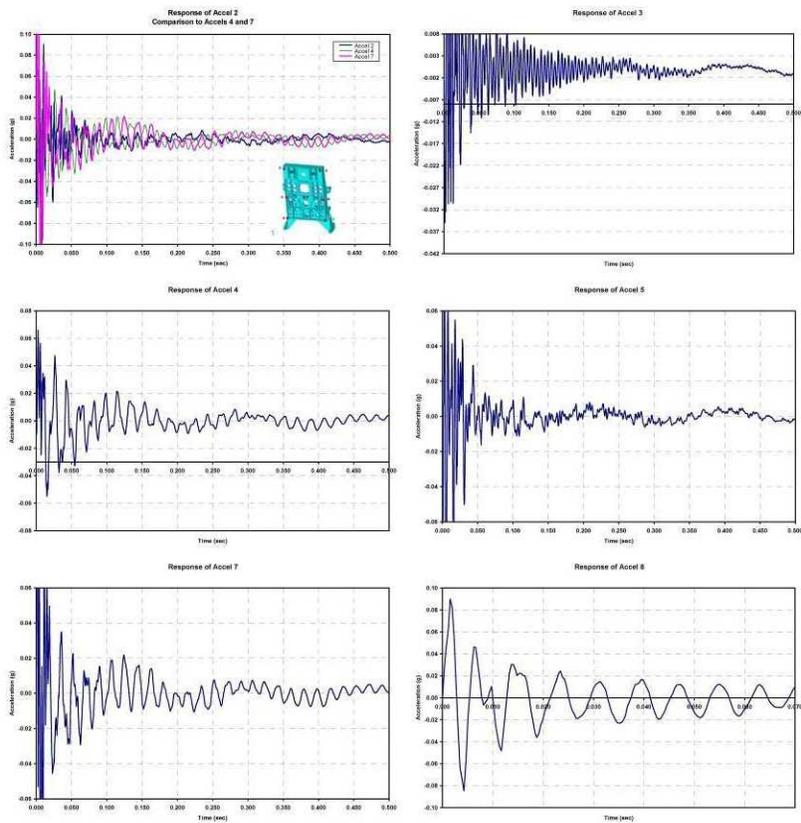
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A.10.2 LH₂ Plate, Test 1 – Time History Plots





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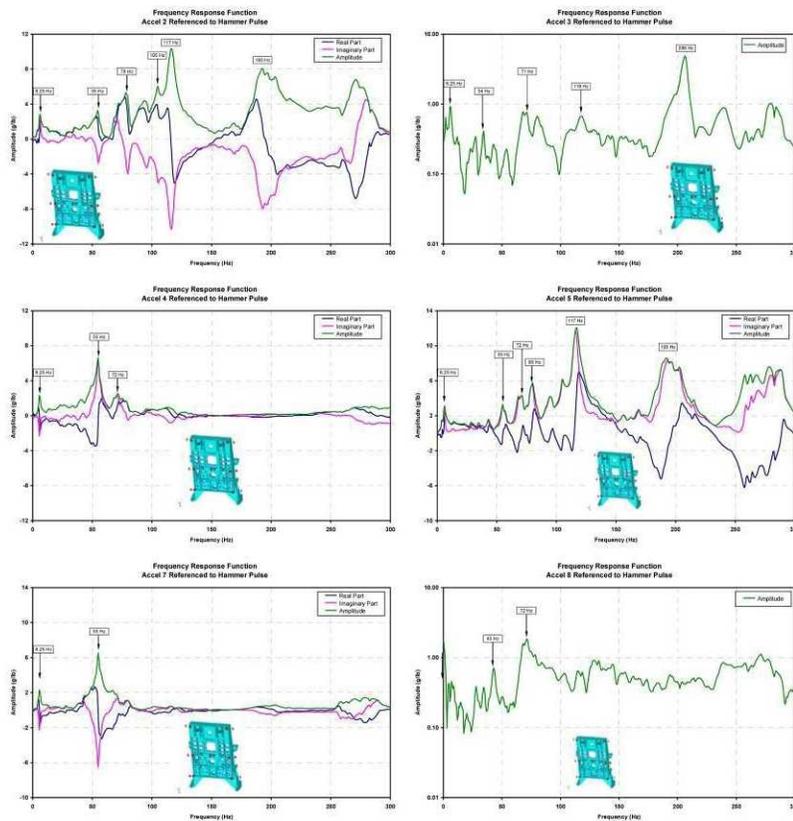
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A.10.3 LH₂ Plate, Test 2 – Frequency Response Function





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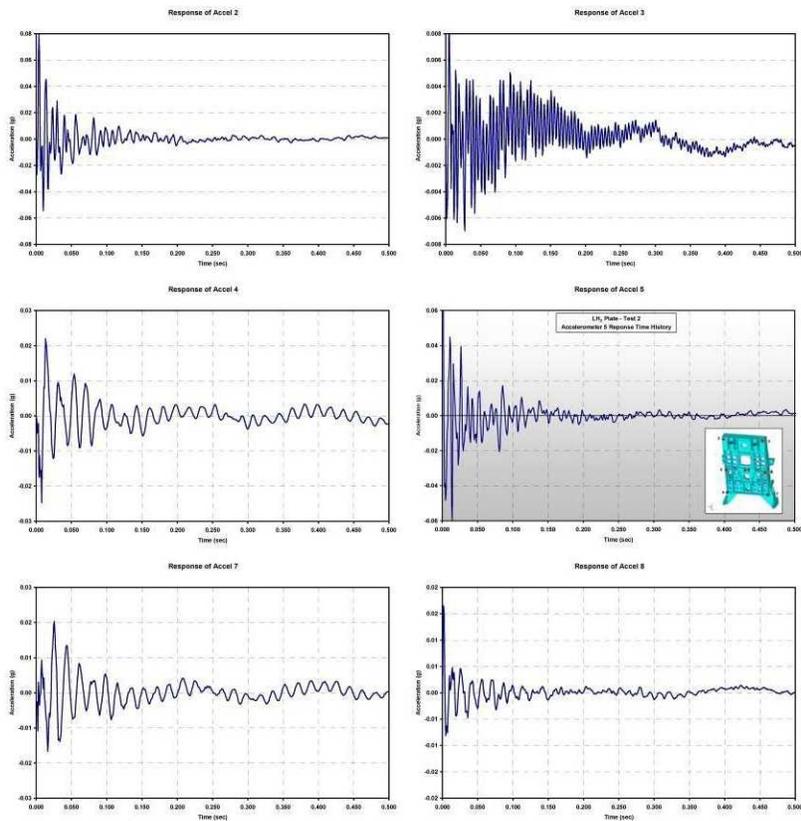
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A.10.4 LH₂ Plate, Test 2 – Time History Plots





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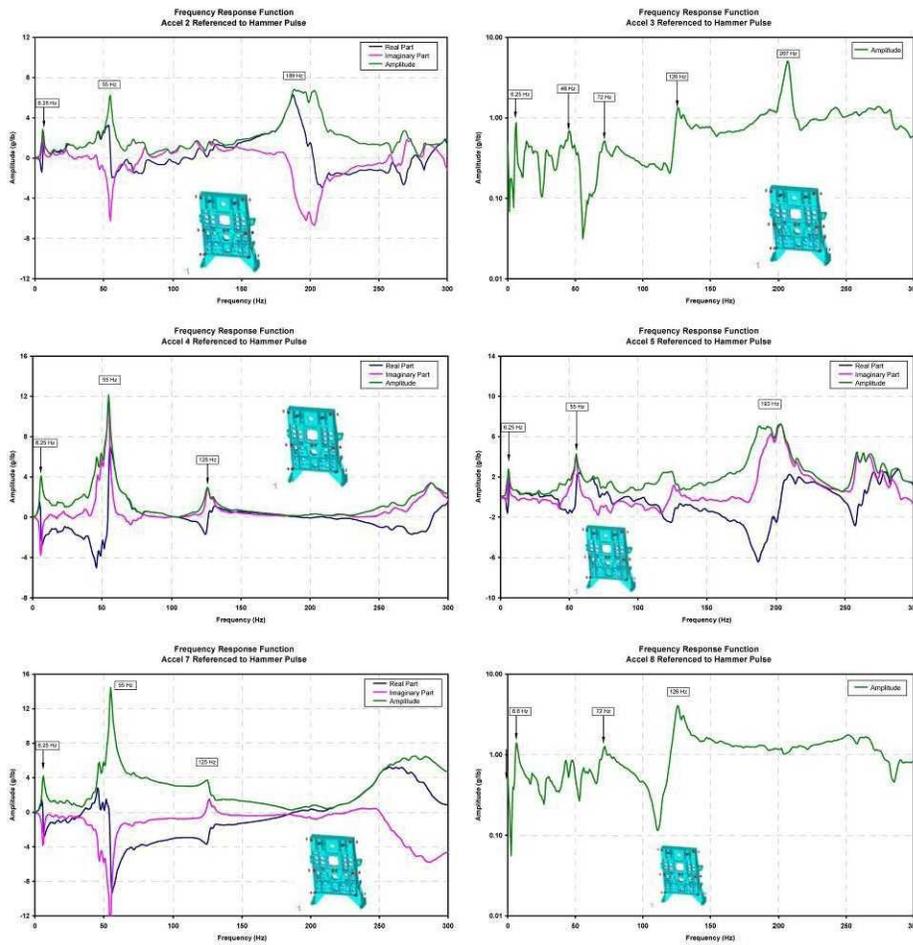
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A.10.5 LH₂ Plate, Test 3 – Frequency Response Function





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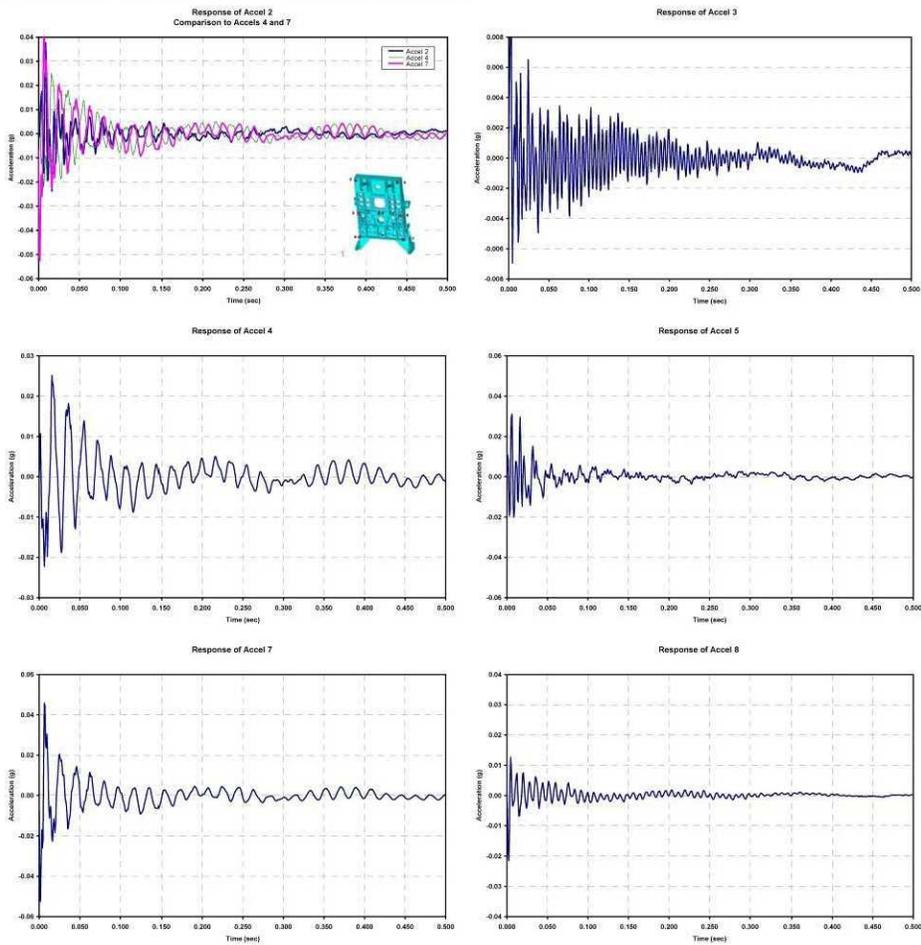
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A.10.6 LH₂ Plate, Test 3 – Time History Plots





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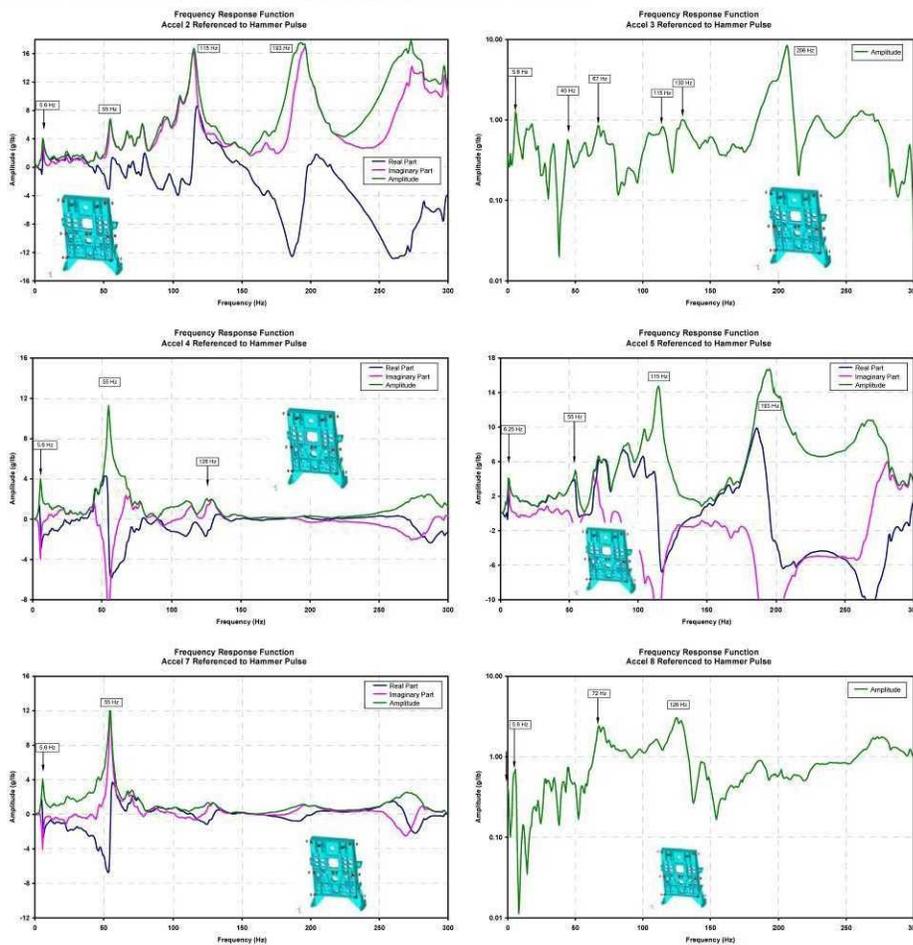
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A.10.7 LH₂ Plate, Test 4 – Frequency Response Function





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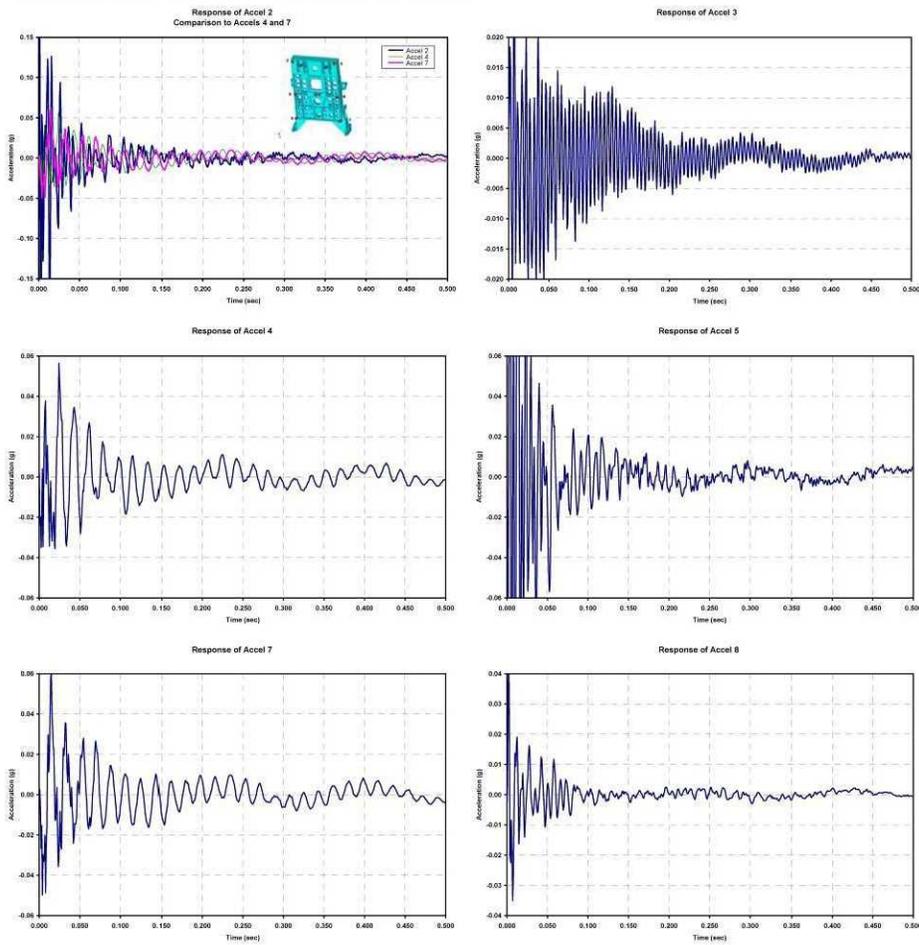
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A.10.8 LH₂ Plate, Test 4 – Time History Plots





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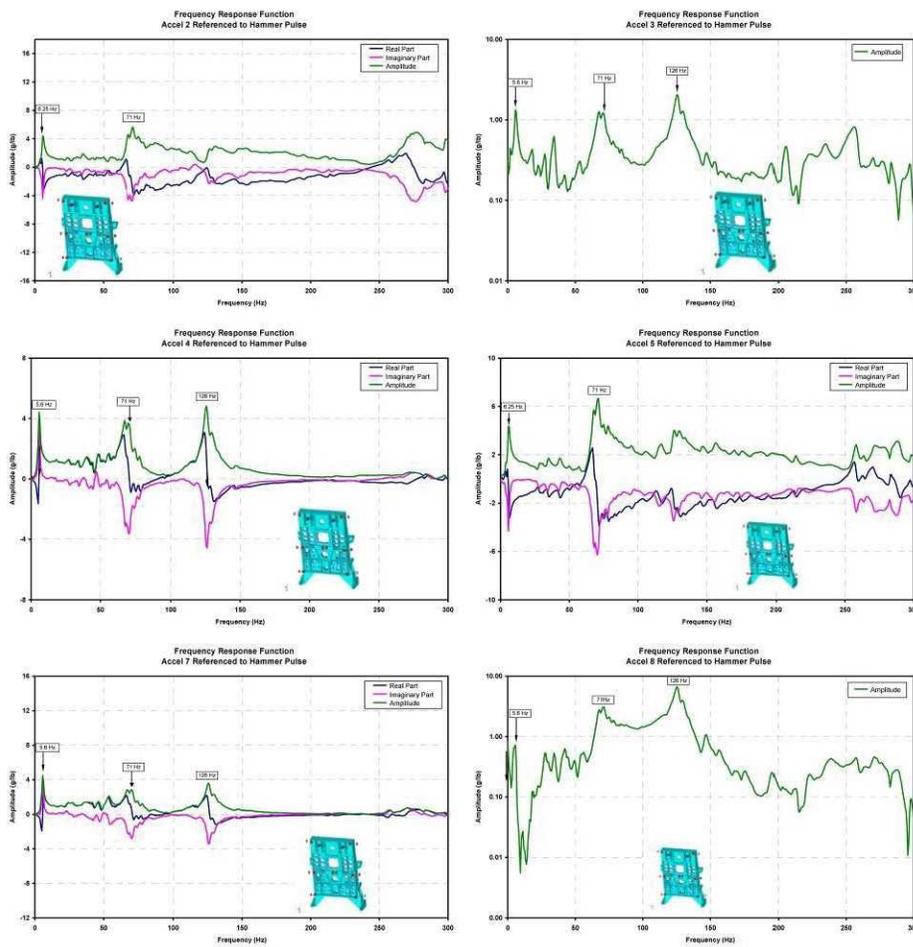
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A.10.9 LH₂ Plate, Test 5 – Frequency Response Function





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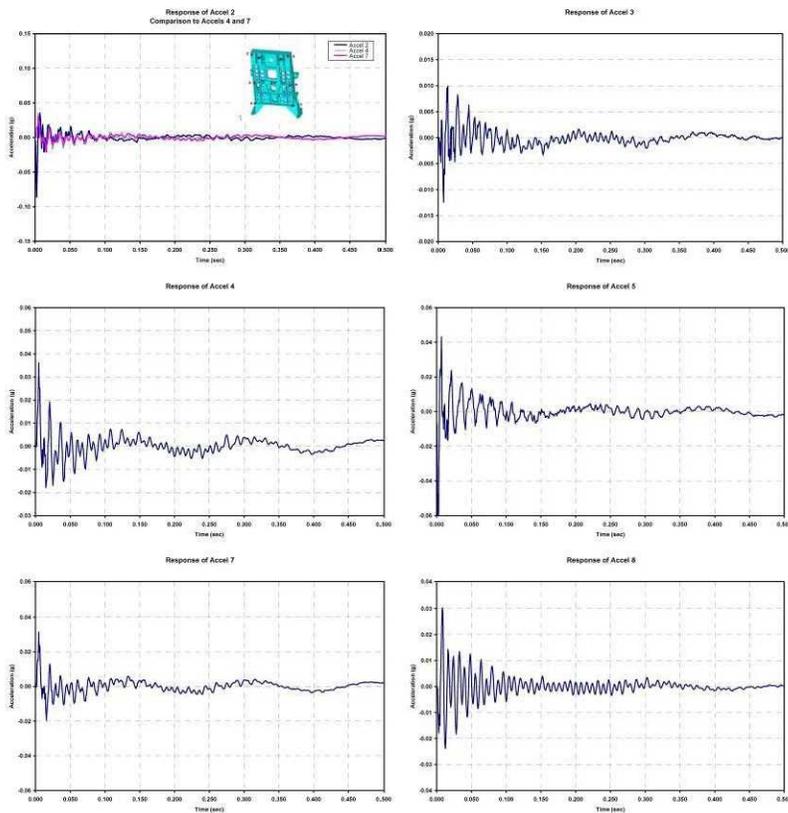
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A.10.10 LH₂ Plate, Test 5 – Time History Plots





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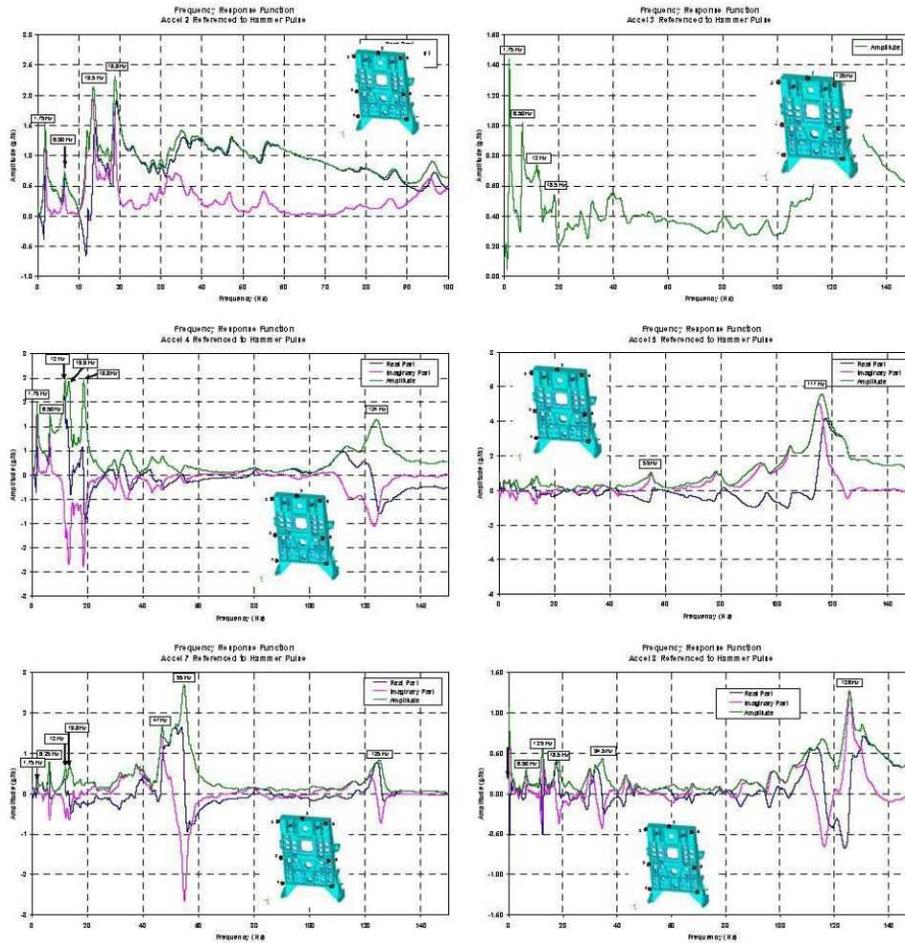
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A.10.11 LH₂ Plate, Test 6 – Frequency Response Function





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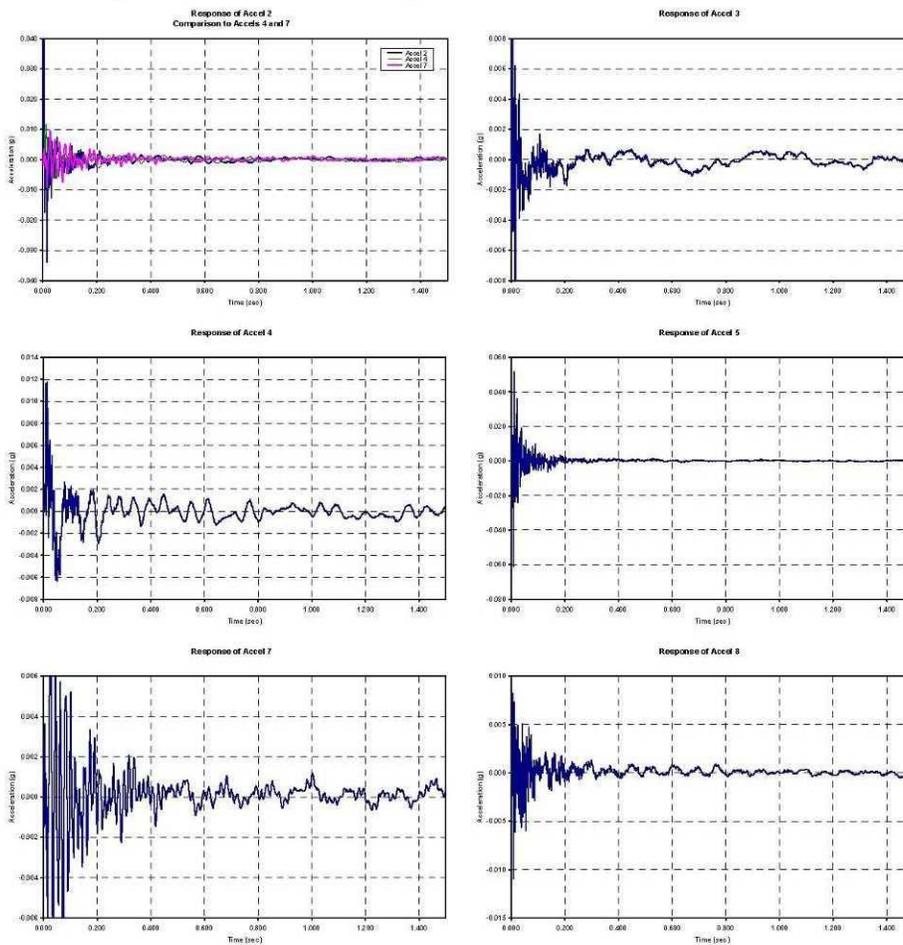
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A.10.12 LH₂ Plate, Test 6 – Time History Plots





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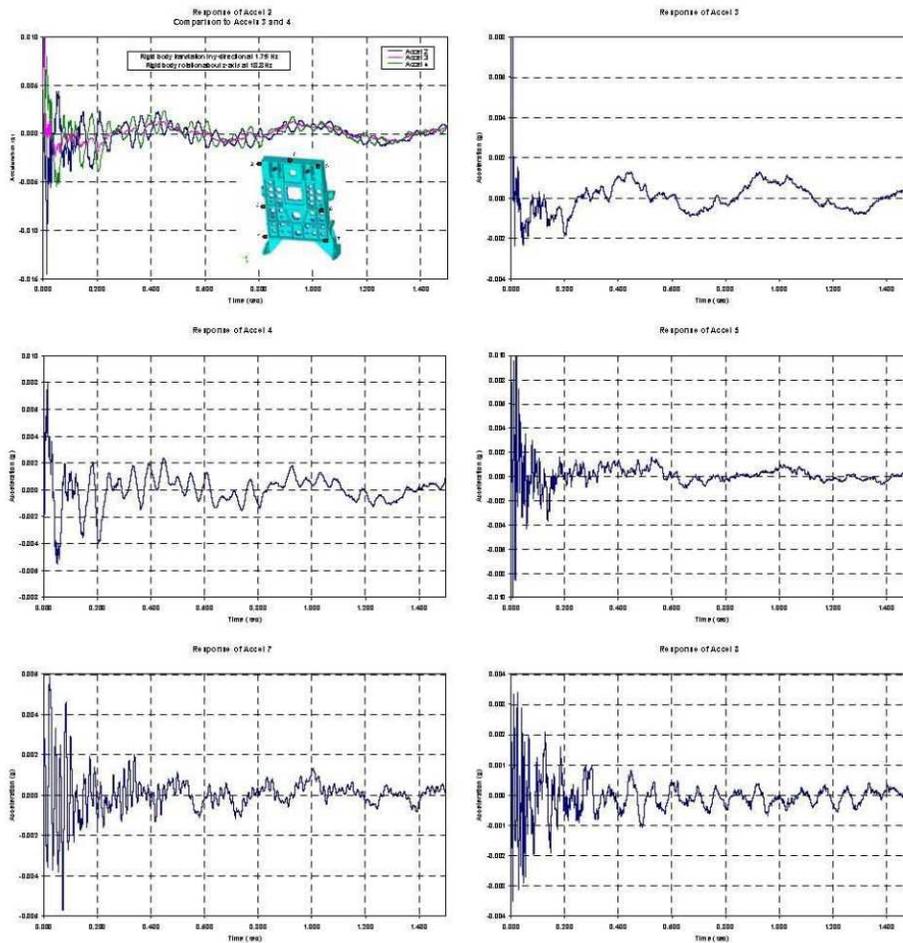
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A.10.14 LH₂ Plate, Test 7 – Time History Plots





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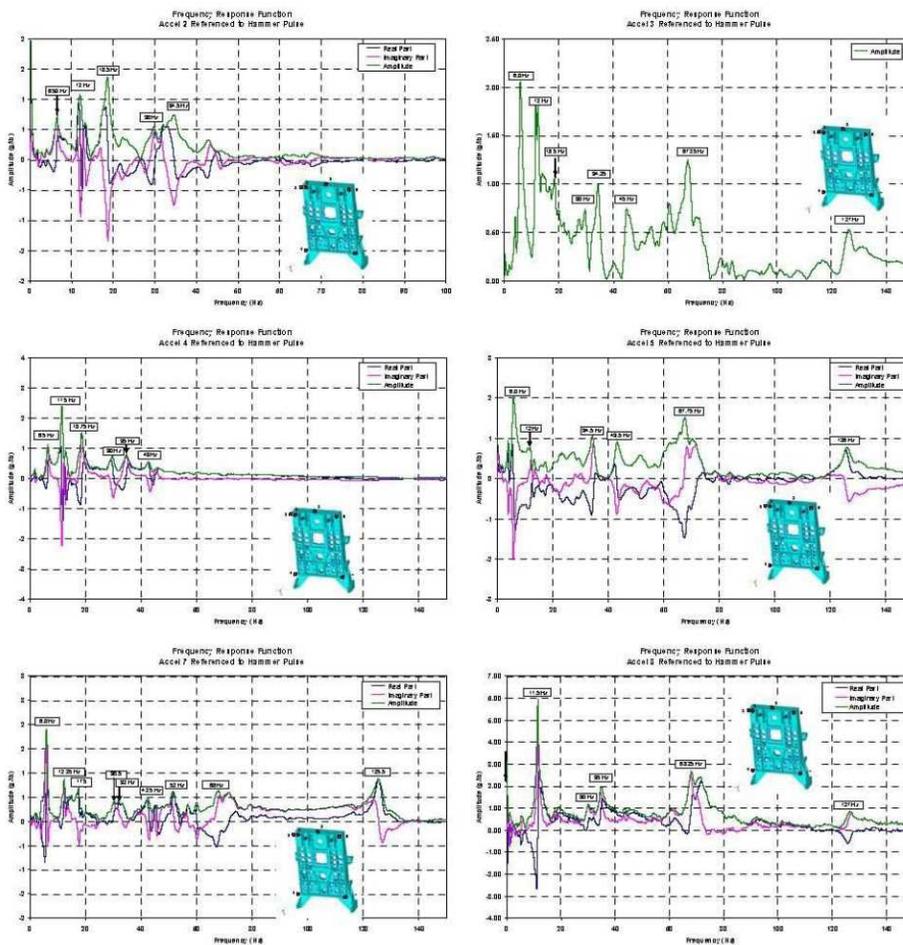
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A.10.15 LH₂ Plate, Test 8 – Frequency Response Function





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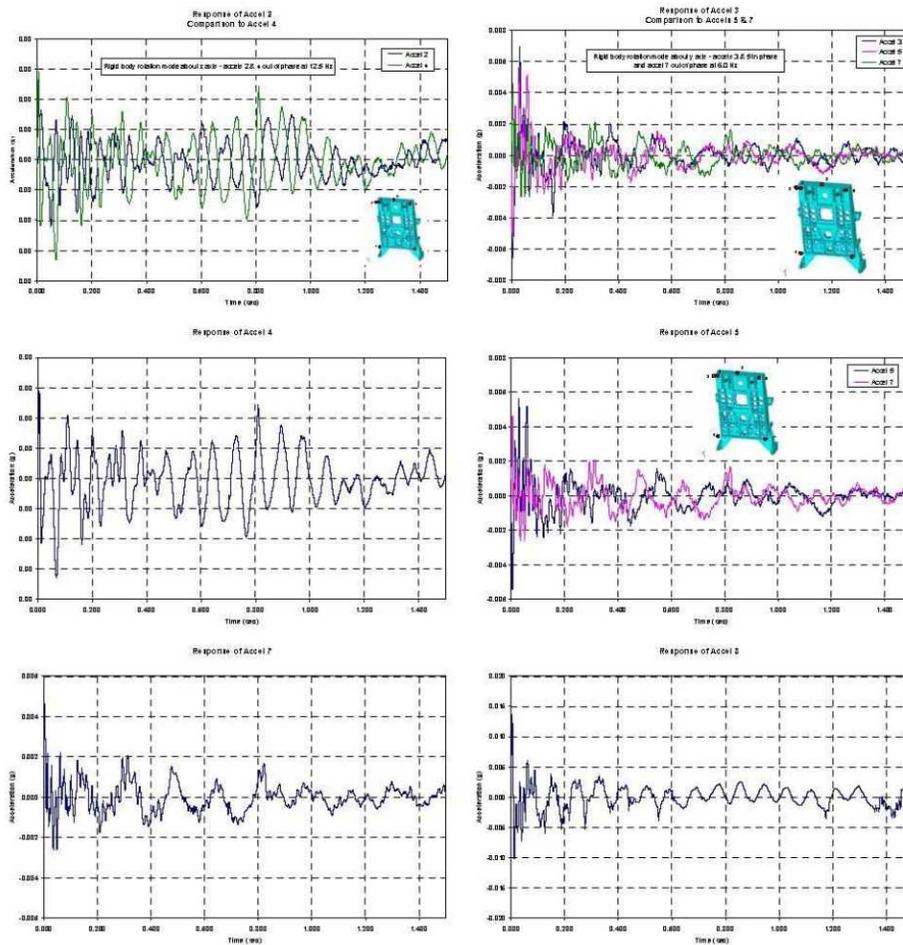
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A.10.16 LH₂ Plate, Test 8 – Time History Plots





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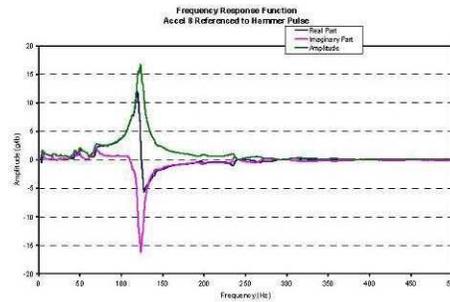
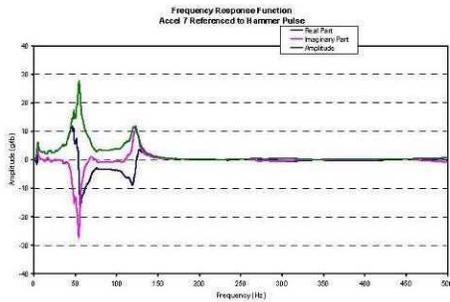
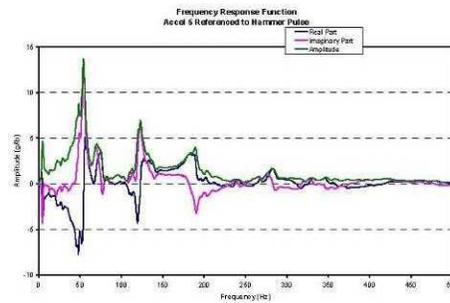
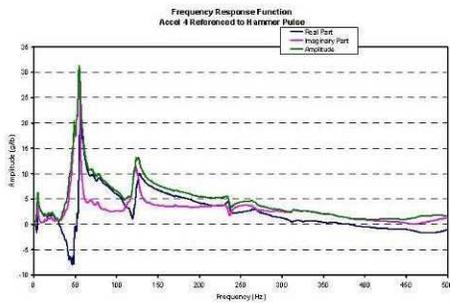
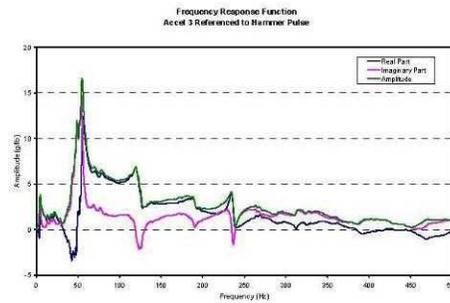
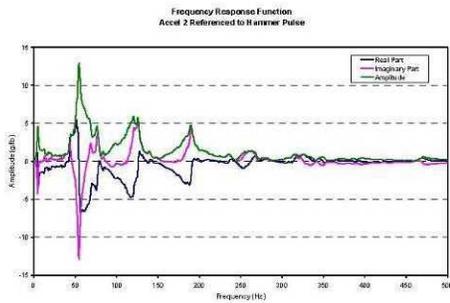
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A.11 Modal Test Results – LOX Plate

A.11.1 LOX Plate, Test 1 – Frequency Response Function





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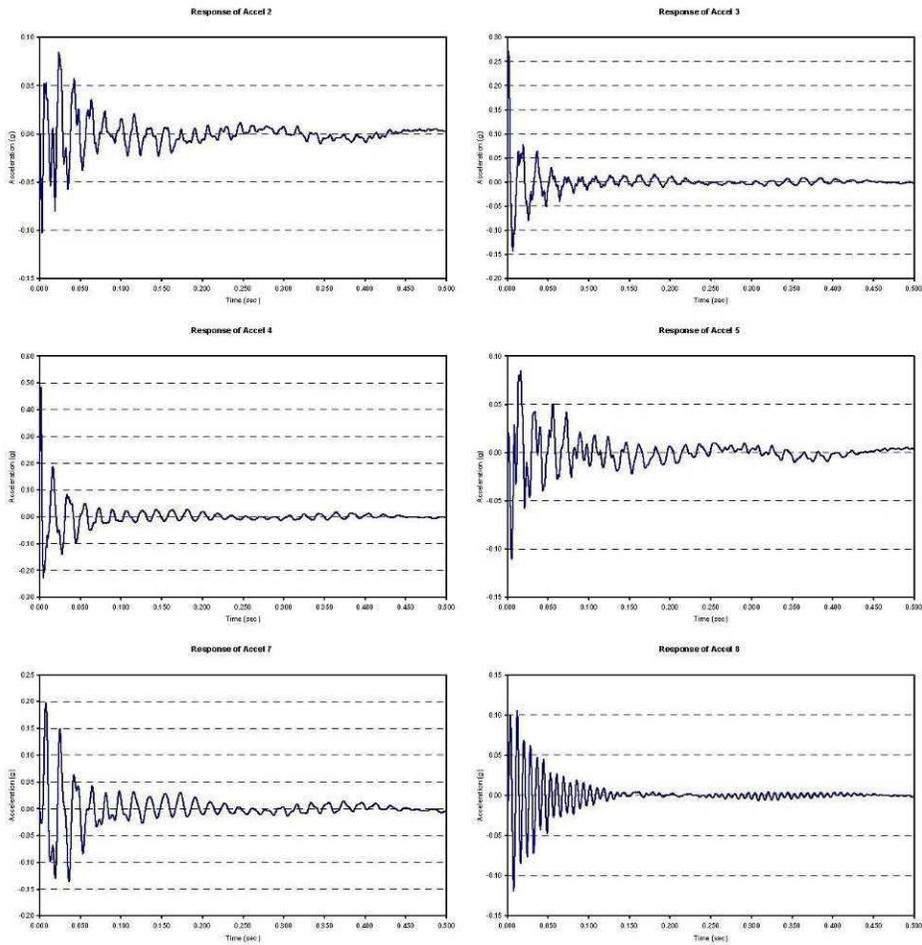
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A.11.2 LO2 Plate, Test 1 – Time History Plots





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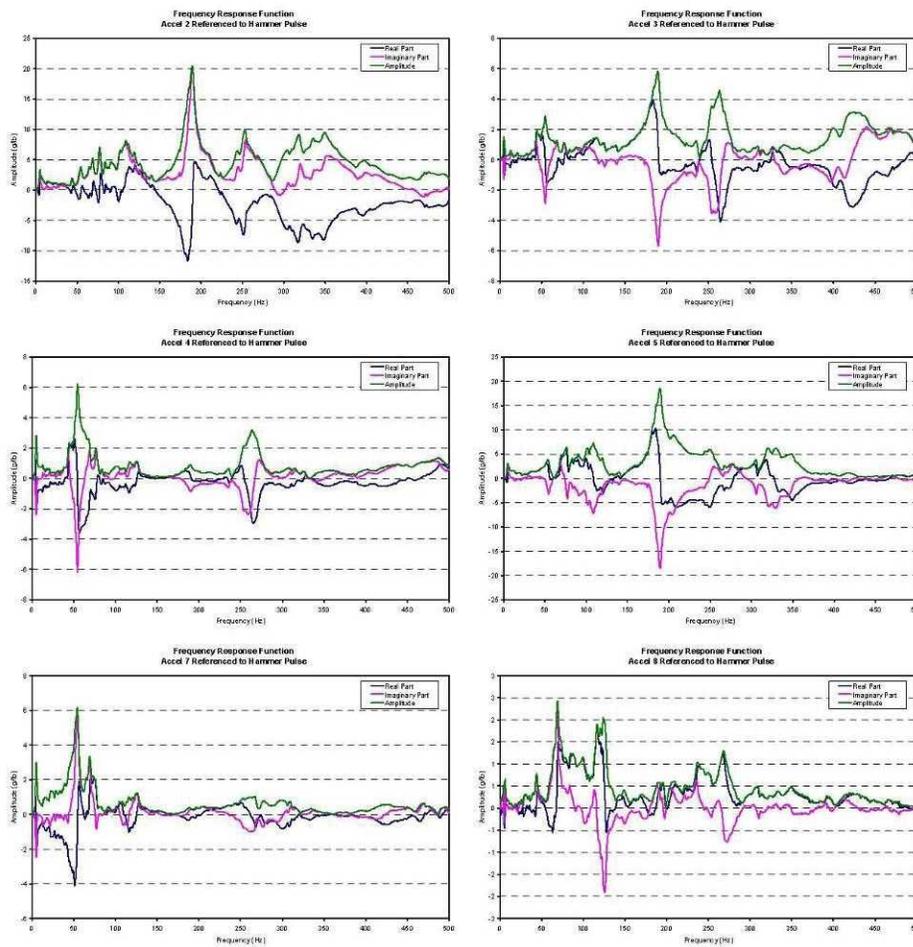
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A.11.3 LOX Plate, Test 2 – Frequency Response Function





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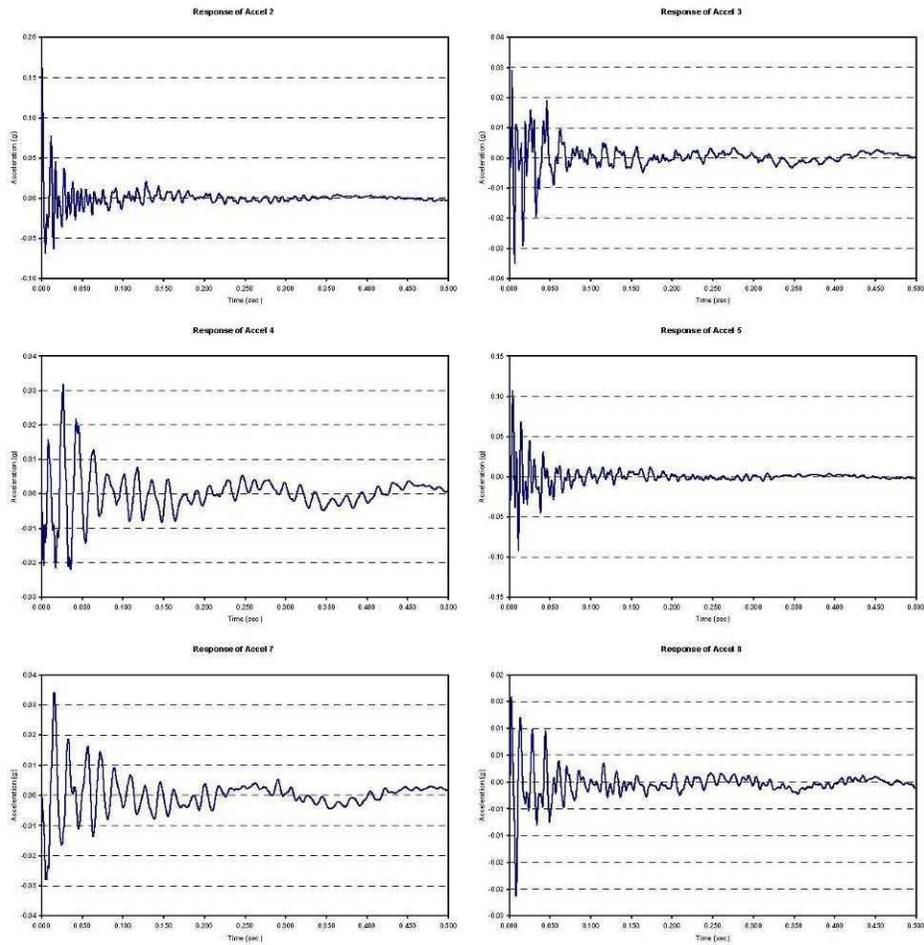
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A.11.4 LOX Plate, Test 2 – Time History Plots





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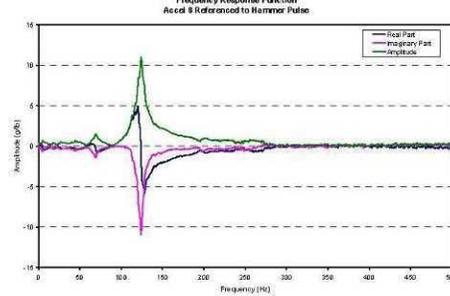
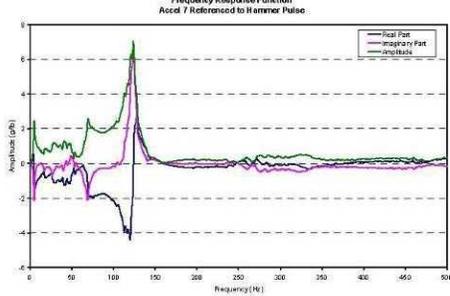
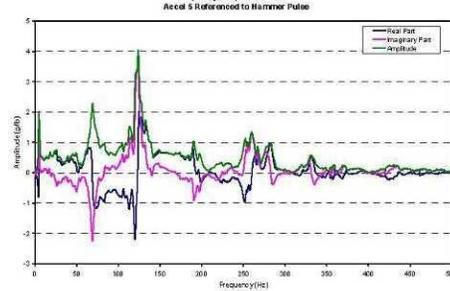
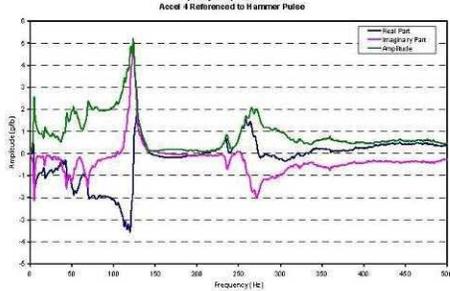
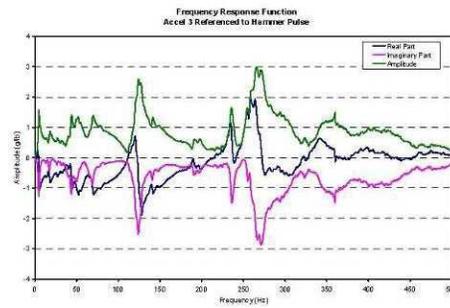
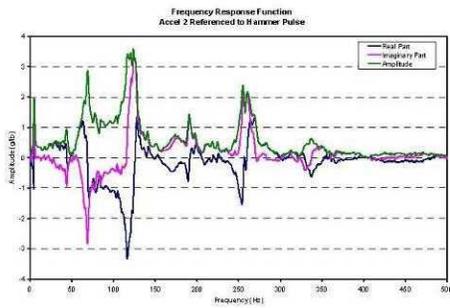
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A.11.5 LOX Plate, Test 3 – Frequency Response Function





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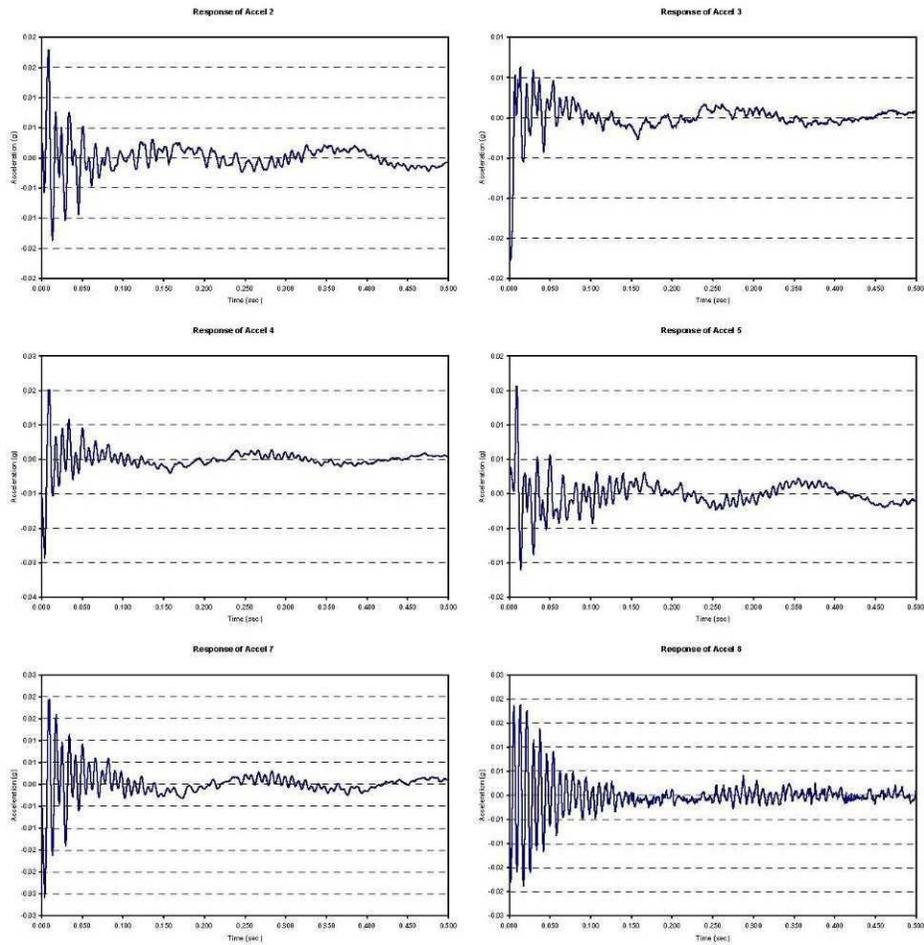
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A.11.6 LOX Plate, Test 3 – Time History Plots





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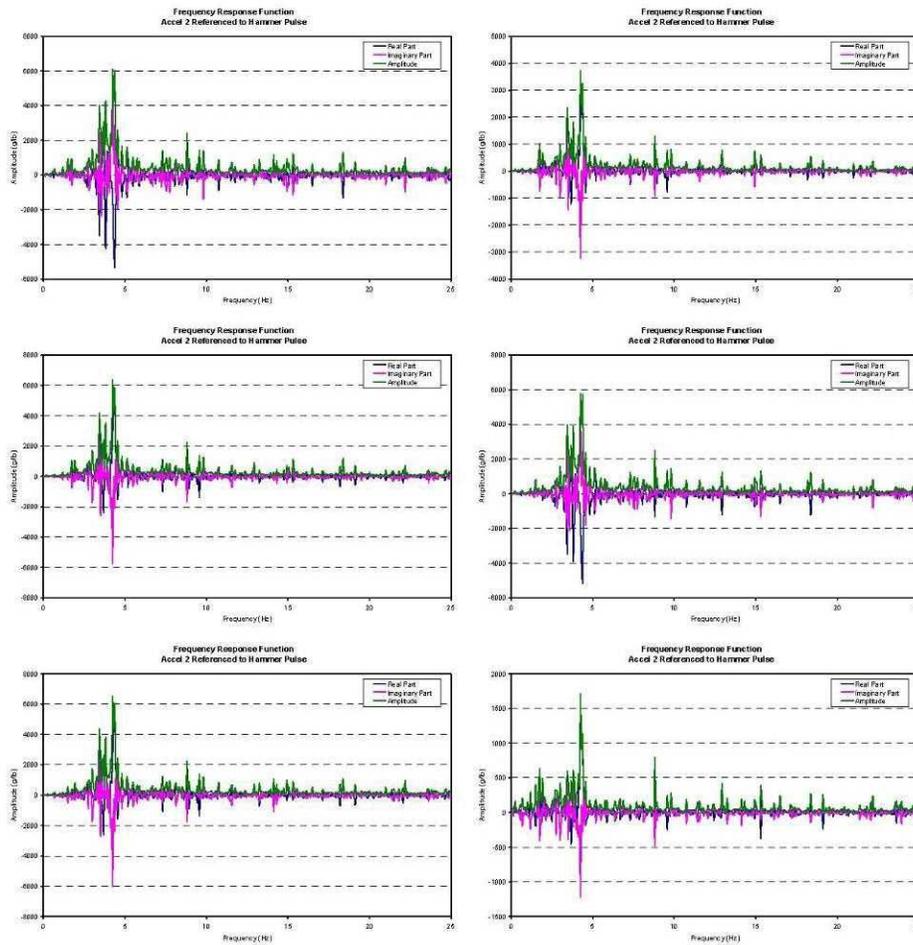
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A.11.7 LOX Plate, Test 4 – Frequency Response Function





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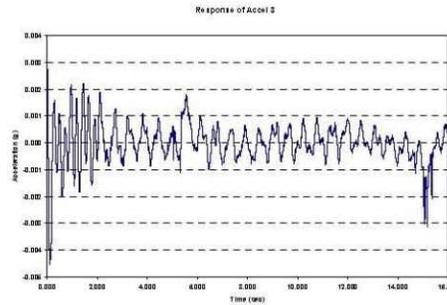
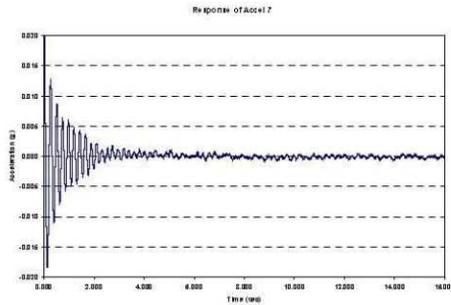
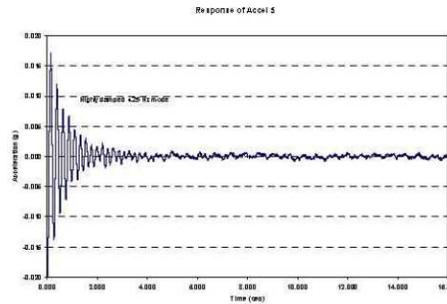
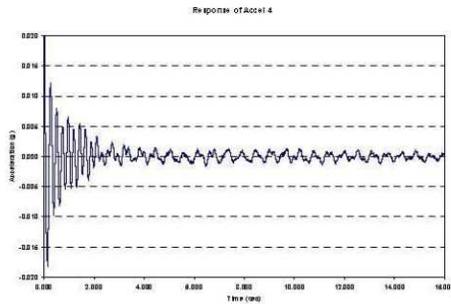
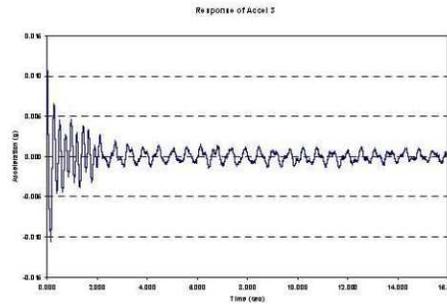
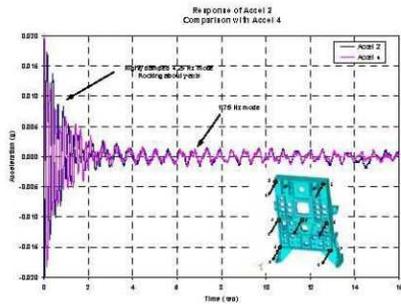
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A.11.8 LOX Plate, Test 4 – Time History Plots





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Appendix B. Material Properties Data

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UNS_NUMBER UNS Number	A92124
<u>FORM_HIREAT</u>	
MATERIAL_FORM Material form	All
HEAT_TREAT Heat treat condition, final	All
<u>PHYSICAL_PROP</u>	
BASIS Basis for data confidence level	Typical
MPM_PAGE Curve name or MPM Page Number	3203.01.01.01-02
TEST_TYPE Type of test	GENERAL
TEST_DATE Test date	10-30-87
PROGRAM Program for which curve was generated	Historical
DISTRIBUTION Database distribution	User
BOEING_SECURITY Boeing security category	BOEING PROPRIETARY
DENSITY Material density at room temperature	0.1 lbs/in ³
SPECIFIC_HEAT Specific heat at room temperature	0.21 btu/lb-F
THERMAL_CONDUCTIVITY_1 Thermal Conductivity at room temperature	87.5 btu-ft/hr-ft ² -F
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Space Shuttle T-0 Umbilical Dynamic Displacements and Forces

Prepared by: J.H. Miller, J.Y. Tsai, D.F. Pilkey, G.A. Davis, J.H. Christie, C.T. Houghton
Approved by: John E. Larson

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THERMAL_EXPANSION_1 Thermal Coefficient of Expansion for temperatures from 70 to 200F	1.29e-05 in/in/F
MELTING_TEMP_MIN Melting Temperature range lower bound	935 deg F
MELTING_TEMP_MAX Melting Temperature range upper bound	1190 deg F
E_MODULUS Elastic Modulus at room temperature	10.45 msi
SHEAR_MODULUS Shear Modulus at room temperature	3.93 msi
POISSONS_RATIO Poisson's Ratio at room temperature	0.33



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EMODULUSvsTEMP COMMON DATA

MATERIAL_NAME Commercial or common name	2024 Aluminum
MATERIAL_CLASS Major material class	Aluminum Alloys
MPM_TEXT TEXT: Material description from hardcopy MPM	/data/mvission/MPMtext/2024-aluminum.html
UNS_NUMBER UNS Number	A92024
MATERIAL_FORM Material form	All
HEAT_TREAT Heat treat condition, final	All
BASIS Basis for data confidence level	Typical
REFERENCE Reference (MPR, MCP files, etc.)	3202-04
REPLACES Curve replaced by the current version	3202.21.10.10-01A
TEST_ENGINEER Responsible engineer	Aryeh P. Meisels
MPM_PAGE Curve name or MPM Page Number	3202.21.10.01-01B
TEST_TYPE Type of test	ELASTIC MODULUS
TEST_DATE Test date	07-07-87
PROGRAM Program for which curve was generated	Historical
MATERIAL_SPECIFICATION Material specification number	QQ-A-268
DISTRIBUTION Database distribution	User
BOEING_SECURITY Boeing security category	BOEING PROPRIETARY

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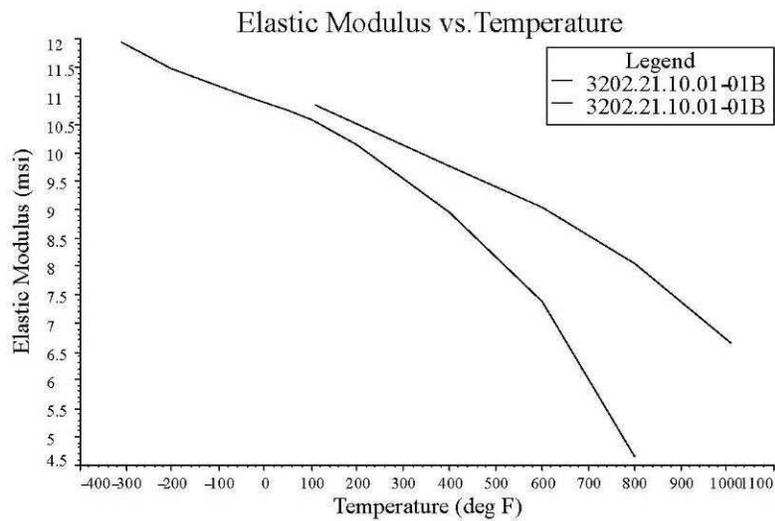
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EMODULUSvsTEMP DIFFERENCE DATA

CURVE_COM
Comments on curves

EMOD= STATIC

EMOD= DYNAMIC



PLOT SET 1

3202.21.10.01-01B

CURVE SEGMENT 1

-310	11.95
-200	11.48
-40	11
50	10.75
100	10.57
200	10.13
400	8.95



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600	7.38
800	4.65

3202.21.10.01-01B

CURVE SEGMENT 1

110	10.85
400	9.75
600	9.05
800	8.05
1010	6.65



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DATABANK

/data/mvision_databank/dblk_eval/MPMuser.des

PHYSICAL_PROP PEDIGREE DATA

PHYSICAL_PROP

BASIS Basis for data confidence level	Typical
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TEST_TYPE Type of test	GENERAL
TEST_DATE Test date	10-30-87
PROGRAM Program for which curve was generated	Historical
MATERIAL_SPECIFICATION Material specification number	QQ-A-268
DISTRIBUTION Database distribution	User
BOEING_SECURITY Boeing security category	BOEING PROPRIETARY
DENSITY Material density at room temperature	0.1 lbs/in ³
THERMAL_CONDUCTIVITY_1 Thermal Conductivity at room temperature	134 btu-ft/hr-ft ² -F
THERMAL_EXPANSION_1 Thermal Coefficient of Expansion for temperatures from 70 to 200F	1.29e-05 in/in/F
MELTING_TEMP_MIN Melting Temperature range lower bound	935 deg F
MELTING_TEMP_MAX Melting Temperature range upper bound	1180 deg F
RESISTIVITY Electric Resistance at room temperature	30000 ohm-circ_mil/ft
E_MODULUS Elastic Modulus at room temperature	10.6 msi
SHEAR_MODULUS Shear Modulus at room temperature	4 msi
EMISSIVITY Emissivity at room temperature	0.035



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THERMAL_CONDUCTIVITY_2

Thermal Conductivity $\text{btu}\cdot\text{ft}/\text{hr}\cdot\text{ft}^2\cdot\text{F}$ at different temperatures

PHYS_PROP_COM

Comments on the physical properties listed above

134 (BTU-ft/hr-ft²-F) for 0 TEMPER AT ROOM TEMPERATURE, 84 (BTU-ft/hr-ft²-F) for T3, T4, AND T361 TEMPER

EMISSIVITY has range values of 0.035 to 0.07



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EMODULUSvsTEMP PEDIGREE DATA

MATERIAL_NAME Commercial or common name	2219 Aluminum
MATERIAL_CLASS Major material class	Aluminum Alloys
MPM_TEXT TEXT: Material description from hardcopy MPM	/data/mvision/MPMtext/2219-aluminum.html
UNS_NUMBER UNS Number	A92219
MATERIAL_FORM Material form	All
HEAT_TREAT Heat treat condition, final	All
BASIS Basis for data confidence level	Typical
REFERENCE Reference (MPR, MCP files, etc.)	3215-05
REPLACES Curve replaced by the current version	3215.21.10.10-01
MPM_PAGE Curve name or MPM Page Number	3215.21.01.01-01
TEST_TYPE Type of test	ELASTIC MODULUS
TEST_DATE Test date	OCT-4 980
PROGRAM Program for which curve was generated	Historical
MATERIAL_SPECIFICATION Material specification number	ASTM-B-209-64
DISTRIBUTION Database distribution	User
BOEING_SECURITY Boeing security category	BOEING PROPRIETARY



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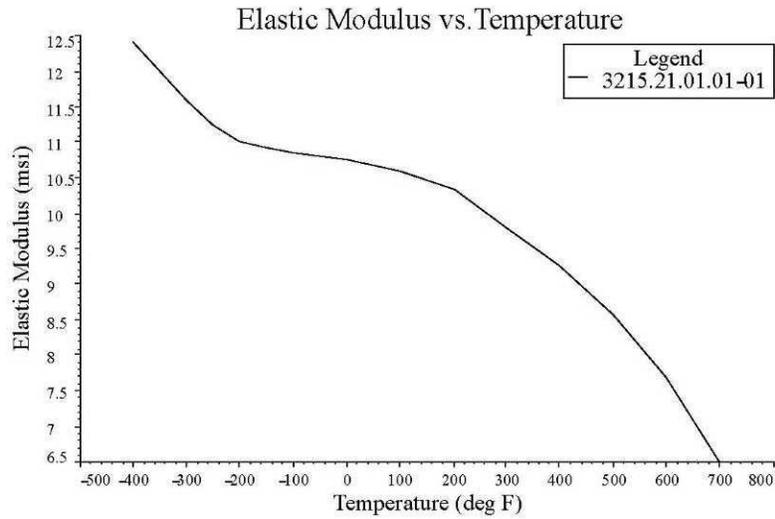
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PLOT SET 1

3215.21.01.01-01

CURVE SEGMENT 1

-400	12.4
-300	11.6
-250	11.25
-200	11
-150	10.92
-100	10.86
-50	10.8
0	10.75
100	10.6
200	10.34
300	9.8
400	9.27



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500	8.57
600	7.68
700	6.5



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DATABANK

/data/mvision_databank/dblk_eval/MPMuser.des

PHYSICAL_PROP PEDIGREE DATA

PHYSICAL_PROP

BASIS Basis for data confidence level	Typical
MPM_PAGE Curve name or MPM Page Number	3215.01.01.01-02
TEST_TYPE Type of test	GENERAL
TEST_DATE Test date	10-30-87
PROGRAM Program for which curve was generated	Historical
MATERIAL_SPECIFICATION Material specification number	ASTM-B-209-64
DISTRIBUTION Database distribution	User
BOEING_SECURITY Boeing security category	BOEING PROPRIETARY
DENSITY Material density at room temperature	0.103 lbs/in ³
SPECIFIC_HEAT Specific heat at room temperature	0.23 btu/lb-F
THERMAL_CONDUCTIVITY_1 Thermal Conductivity at room temperature	99 btu-ft/hr-ft ² -F
MELTING_TEMP_MIN Melting Temperature range lower bound	1010 deg F
MELTING_TEMP_MAX Melting Temperature range upper bound	1190 deg F
E_MODULUS Elastic Modulus at room temperature	10.6 msi
SHEAR_MODULUS Shear Modulus at room temperature	4 msi
POISSONS_RATIO Poisson's Ratio at room temperature	0.325



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THERMAL_CONDUCTIVITY_2

Thermal Conductivity $\text{btu}\cdot\text{ft}/\text{hr}\cdot\text{ft}^2\cdot\text{F}$ at different temperatures

THERMAL_EXPANSION_2

Thermal Coefficient of Expansion $\text{in}/\text{in}/\text{F}$ for other temperature ranges

99 (BTU-ft/hr-ft²-F) for 0 TEMPER AT ROOM TEMPERATURE, 72 (BTU-ft/hr-ft²-F) for T6, T62, T81, and T87 TEMPER

12.5E-06 (in/in/F) for TEMPF= 212, 13.0E-06 (in/in/F) for TEMPF= 392



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EMODULUSvsTEMP PEDIGREE DATA

MATERIAL_NAME Commercial or common name	Inconel 718
MATERIAL_CLASS Major material class	Nickel Alloys
MPM_TEXT TEXT: Material description from hardcopy MPM	/data/mvision/MPMtext/alloy-718.html
UNS_NUMBER UNS Number	N07718
MATERIAL_FORM Material form	All
HEAT_TREAT Heat treat condition, final	All
MATERIAL_SIZE Pre-fabrication dimensions	All
BASIS Basis for data confidence level	Typical
REFERENCE Reference (MPR, MCP files, etc.)	6105.21.10.01-01; 6105-03,04,05
REPLACES Curve replaced by the current version	6105.21.10.10-01
MPM_PAGE Curve name or MPM Page Number	718,ALL,ALL,EMOD,MPM,JUN77,TYP
TEST_TYPE Type of test	ELASTIC MODULUS
TEST_DATE Test date	JUN-1977
PROGRAM Program for which curve was generated	Historical
MATERIAL_SPECIFICATION Material specification number	RB0170-153, RB0170-154
DISTRIBUTION Database distribution	User
BOEING_SECURITY Boeing security category	BOEING PROPRIETARY



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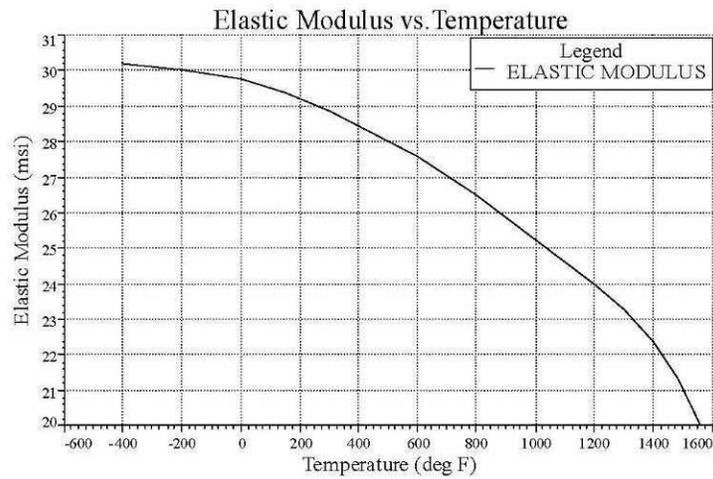
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PLOT SET 1

ELASTICMODULUS

CURVE SEGMENT 1

-400	30.2
-200	30.05
0	29.75
150	29.4
300	28.9
600	27.6
800	26.5
1200	24
1300	23.26
1400	22.35
1480	21.35
1560	20

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/COM  FORM= All
mat_num = 5
MPTEMP
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MPTEMP, 7, 7.00000E+02, 8.00000E+02, 9.00000E+02
MPTEMP, 10, 1.00000E+03
MPDATA, EX, mat_num, 1, 1.90000E+07, 1.83000E+07, 1.77000E+07
MPDATA, EX, mat_num, 4, 1.70500E+07, 1.62500E+07, 1.53000E+07
MPDATA, EX, mat_num, 7, 1.42000E+07, 1.23000E+07, 8.10000E+06
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MPTEMP
MPTEMP, 1, 7.00000E+01, 1.00000E+03
MPDATA, NUXY, mat_num, 1, 2.66000E-01, 2.66000E-01
MP, DENS, mat_num, 0.316/386.4
MP, ALPX, mat_num, 9.3e-06
  
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A-286 AMS5731, AMS5734, AMS5737, RB0160-014, RB0160-047					
DENSITY: 0.287 #/in ³					
TEMP Deg F	E psi	TEMP Deg F	Nu	TEMP Deg F	ALPHA in/in F
-423	30.80E+06			-450	5.40E-06
-200	30.15E+06			-400	5.90E-06
0	29.35E+06	-320	0.298	-300	6.50E-06
70	29.00E+06	70	0.306	-200	7.00E-06
400	27.30E+06	600	0.318	-100	7.50E-06
800	24.85E+06	1060	0.33	0	7.90E-06
1200	21.90E+06	1500	0.344	70	8.20E-06
1600	19.00E+06			200	8.50E-06
				400	8.80E-06
				600	9.05E-06
				1000	9.55E-06
				1300	9.92E-06
				1600	1.03E-05
				2000	1.08E-05



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17-4 PH AMS5643 (Updated on 9/29/2004) DENSITY = 0.284 #/in ³						
Form, Heat Treat Environment						
TEMP Deg F	E psi	TEMP Deg F	Nu	TEMP Deg F	ALPHA in/in	ALPHA in/in F
70	28.500E+06	70	0.272	70		6.10E-06
300	26.900E+06			200		6.60E-06
500	25.500E+06			300		6.80E-06
700	24.100E+06			500		7.05E-06
900	22.800E+06			700		7.20E-06
				900		7.30E-06

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Appendix C. Connector Spring Damping Ratio Sensitivity Study

The 3.3% damping ratio used in the stand-alone and integrated T-0 Umbilical FEMs is determined from the modal test of the T-0 Carrier Plate (see section 3.7). This damping value is appropriate for global modes, in which there are motions of the primary structures and/or large fluid lines. Because of the concern that this global damping value may be too high for the local electrical connector spring modes, the effect of the local damping ratio of the electrical connector springs on the dynamic spring forces is examined.

C.1 Local Electrical Connector Spring FEM

Local electrical connector spring FEMs are used in the damping ratio sensitivity study. A picture of the FEM is shown in **Error! Reference source not found.**. The local FEM consists of 50 LINK8 truss elements. All nodes are restrained in the transverse directions to allow for axial motion only. The two end nodes are also restrained in the axial direction.

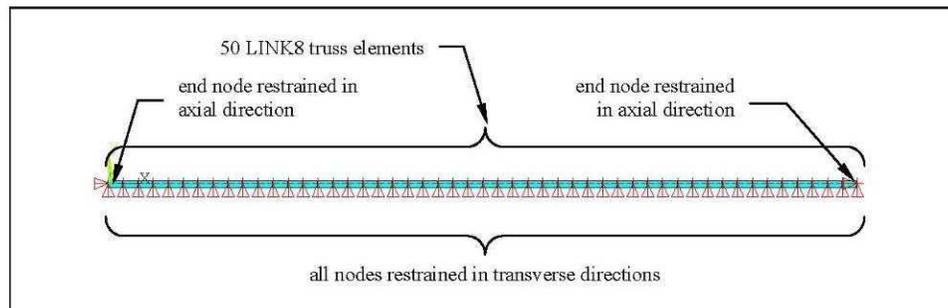


Figure C-1. Electrical Connector Spring Local FEM

The elastic modulus, cross-sectional area, and density of the truss elements are set to values so that the overall stiffness and weight of the local spring FEM match those values shown below in Table C-1.

Table C-1. Electrical Connector Spring Properties

Connector Type ¹	Weight (lbs) ²	Stiffness (lb/in)
Small (No. 2-6, 23-34, 37)	0.20	35
Large (No. 36)	0.28	35

1. Numbering scheme is obtained from VUML00-001 [1], page 1-6, figure 1-3
 2. Spring weights represent only the active coils.

C.2 Applied Dynamic Loads

The random base excitation loads are applied to the two end nodes of the local spring FEM. The PSD functions are obtained from the response acceleration PSD from the Integrated T-0 Umbilical FEM at the appropriate electrical connector locations. The response PSD of two small connectors with the highest dynamic loads as predicted by the integrated FEM (J55 and J71), along with the large connector (J55), are examined in the study. Enveloping PSD, as shown in Figure C-2 through Figure C-10, are developed from the response PSD and used as excitation. The analysis uses the first five modes of the connector spring and a damping ratio of 1%.



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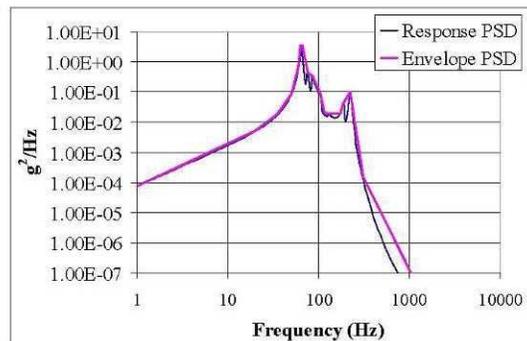


Figure C-2. Small Electrical Connector 3 (J55) Carrier Plate Side Response PSD

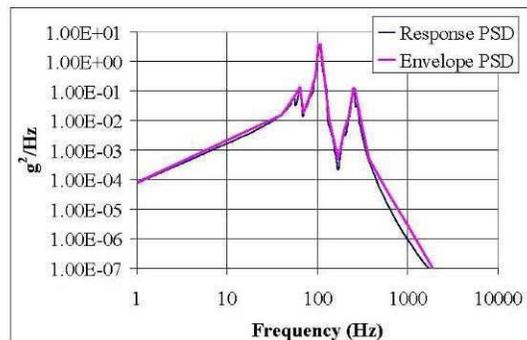


Figure C-3. Small Electrical Connector 3 (J55) Orbiter Panel Side Response PSD

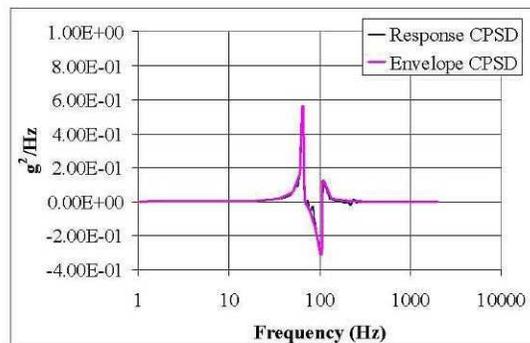


Figure C-4. Small Electrical Connector 3 (J55) Response Cross-PSD



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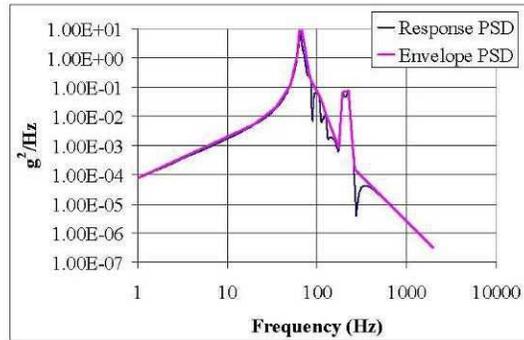


Figure C-5. Small Electrical Connector 34 (J71) Carrier Plate Side Response PSD

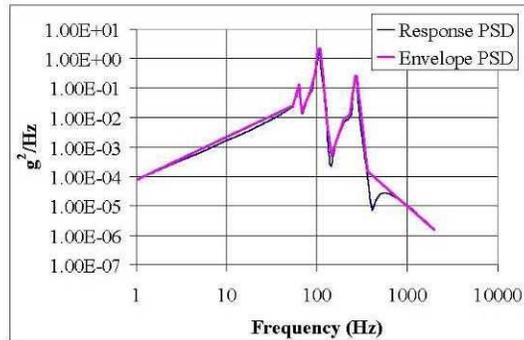


Figure C-6. Small Electrical Connector 34 (J71) Orbiter Panel Side Response PSD

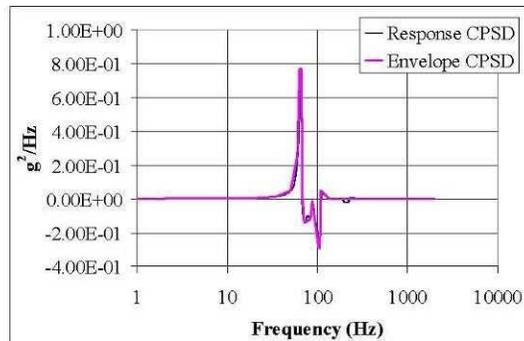


Figure C-7. Small Electrical Connector 34 (J71) Response Cross-PSD



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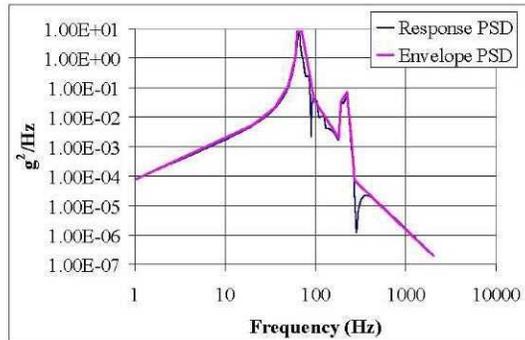


Figure C-8. Large Electrical Connector 36 (J51) Carrier Plate Side Response PSD

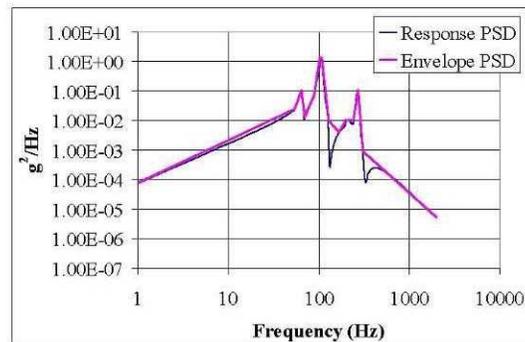


Figure C-9. Large Electrical Connector 36 (J51) Orbiter Panel Side Response PSD

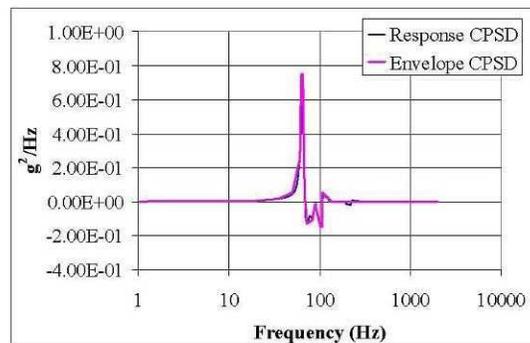


Figure C-10. Large Electrical Connector 36 (J51) Response Cross-PSD

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Space Shuttle T-0 Umbilical Dynamic Displacements and Forces

Prepared by: J.H. Miller, J.Y. Tsai, D.F. Pilkey, G.A. Davis, J.H. Christie, C.T. Houghton Page C-5 of 5
 Approved by: John E. Larson 8/22/2005

C.3 Connector Spring Dynamic Forces

The 3-sigma dynamic forces of the electrical connector spring as predicted by the local spring FEM are shown in Table C-2. The maximum dynamic force for the small connector springs with 1% damping is slightly higher as compared to those predicted by the integrated FEM with 3.3% damping. The large increase in the dynamic force on the large connector from the reduction in damping ratio of 3.3% to 1% is mainly due to the fundamental frequency of the large connector spring being very close to the frequency of the Orbiter Panel primary bending mode. Nevertheless, these dynamic forces are still well below the minimum spring preload of 40 pounds, and the large connector is powered off prior to SSME start.

Table C-2. Electrical Connector Dynamic Spring Forces

Connector	Damping Ratio	3- σ Force (lb) No Cross-PSD	3- σ Force (lb) with Cross-PSD	3- σ Force (lb) Integrated FEM (3.3% damping)
No. 3 Small (J55)	1%	4.72	5.39	3.62
No. 34 Small (J71)	1%	3.78	3.82	3.82
No. 36 Large (J51)	1%	18.57	17.06	7.90

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**Appendix E. Report Q50299FA, *Connector Failure Analysis*, Goddard Space
Flight Center Parts Analysis Laboratory**



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GODDARD SPACE FLIGHT CENTER

Parts Analysis Laboratory

Connector Failure Analysis

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Project:	SHUTTLE	Part Type:	Connector
Subsystem:	UMBILICAL	Manufacturer:	Unkwn
Requestor:	N. Helmsold	Part Number:	Unkwn
Investigator:	F. Felt	Date Code:	Unkwn
Date:	Rdate	Serial Number:	SNA, SNB, SNC

Background

Intermittent signal loss was detected on a Shuttle umbilical connector. Corrosion was suspected as the root cause. Tape lifts of connector material were taken from pins at both ends of the umbilical and from a control sample. The samples were labeled 'A', 'B', and 'C', and submitted to the NASA GSFC Failure Analysis Laboratory for morphology and elemental analysis.

Part Description

The umbilical mates to the Shuttle transportation system and disconnects at time of launch. The de-mated connector then faces upward and is exposed to propulsion blast during vehicle lift-off. Sample A consists of material taken from the blast-exposed end of the connector. Sample C is the protected connector on the other end of the umbilical. Sample B is material taken from a control connector.

Analysis and Results

The three samples, A, B, and C—consisting of material on carbon tape, were inspected in the scanning electron microscope

(SEM) and photo-documented. Samples A and C consisted largely of crushed material. Sample B consisted of many small fibers and particles, roughly similar in size but dissimilar in appearance. In general, the particles were nonconductive, making high-resolution imaging difficult. Nevertheless, gold sputtering was delayed until after initial EDS analysis had been performed.

Comparative EDS spectra were performed on groups of particles on each sample. The EDS results from sample B indicated particles of varied composition. EDS mapping found that copper, chlorine, and oxygen tracked well in Sample A, and that nickel, chlorine, and oxygen tracked in Sample C. There was also appeared to be some tracking of minor elements, such as calcium and sulfur. Iron was found in small quantities.

Quantitative analysis was performed on samples C and A. The results for C are not given her. It was found that the ratio of copper to chlorine to oxygen in Sample A material was approximately 2.3 : 1.0 : 4.0.

It is noted that the composition of the solid rocket propellant used in the Shuttle SRBs consists of aluminum powder with ammonium perchlorate and a polymer binder. Iron is used as a catalyst in approximately the same amount as detected here.



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GODDARD SPACE FLIGHT CENTER

Part Type Connector
Manufacturer Unkwn

Part Number Unkwn
Lot Code Unkwn

Appended Photographs:

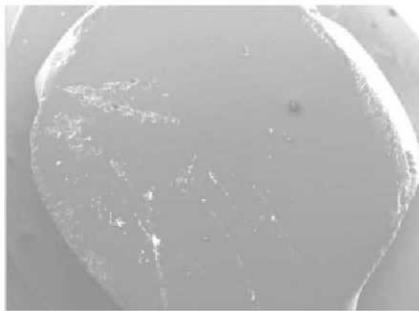


Figure 1. Sample A zoom-out, showing material on carbon tape.

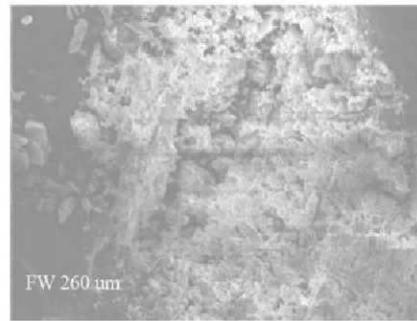


Figure 2. Sample A close-up of material. This image is taken at location 1 of Figure 3.

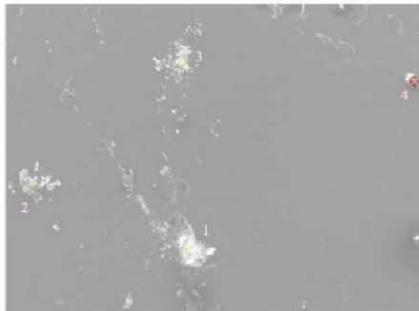


Figure 3. Sample A material. Yellow letters identify the four sites probed. Spectrum is found in Figure 4.

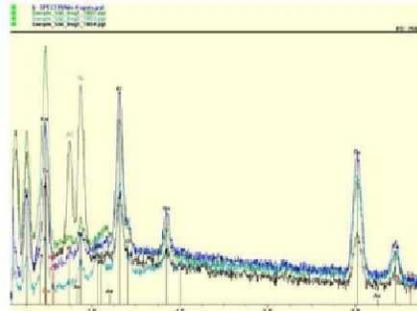


Figure 4. Sample A. Refer to the locations identified in Figure 3. One probed location seems to be an oddball with dominant aluminum and silicon. The other three locations track together both in appearance and spectra, showing copper, chlorine, oxygen, and calcium.



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GODDARD SPACE FLIGHT CENTER

Part Type Connector
Manufacturer Unkwn

Part Number Unkwn
Lot Code Unkwn

Appended Photographs:

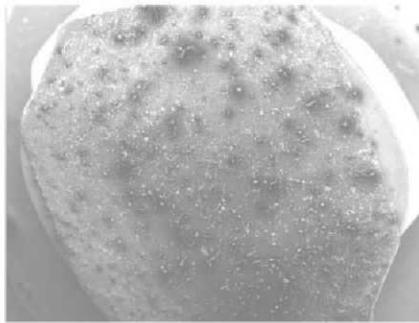


Figure 5. Sample B zoom-out, showing material on carbon tape.

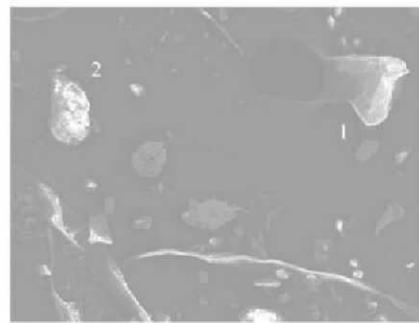


Figure 6. A close-up SEM view of Sample B shows fibers and particles, some bright and some faint.

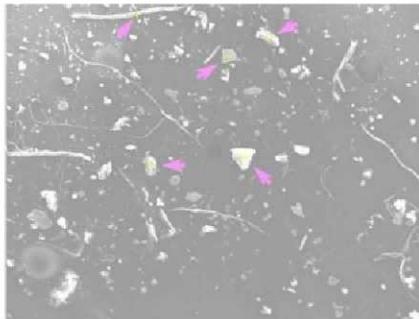


Figure 7. Arrows identify locations probed by EDS on Sample B. Yellow tags identify numbering. Site 1 is at lower right, site 5 is at upper left, and numbering follows a 'z' pattern. Note the diversity of particle types and fibers.

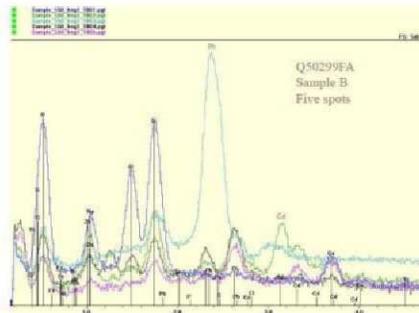


Figure 8. EDS spectra of the sites shown in Figure 7 indicates a diversity of composition.



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GODDARD SPACE FLIGHT CENTER

Part Type Connector
Manufacturer Unkwn

Part Number Unkwn
Lot Code Unkwn

Appended Photographs:

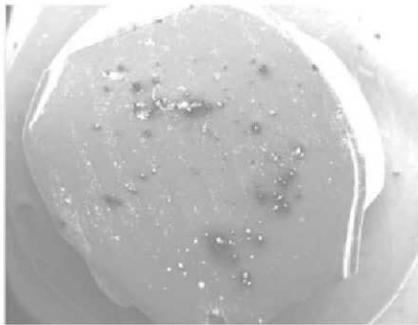


Figure 9. Sample C zoom-out SEM image.

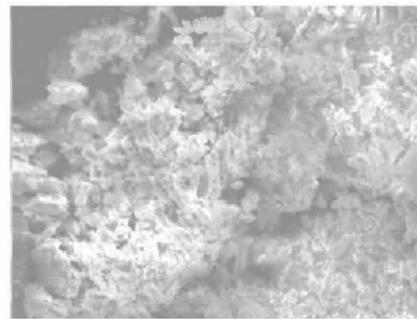


Figure 10. A close-up view of material on Sample C.

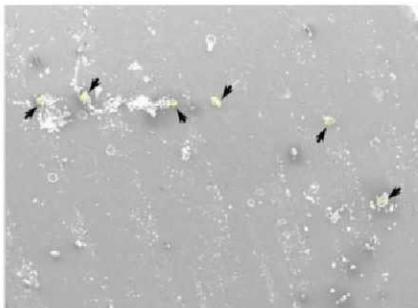


Figure 11. This SEM image shows five sites probed with EDS. The matching spectra are found in Figure 12.

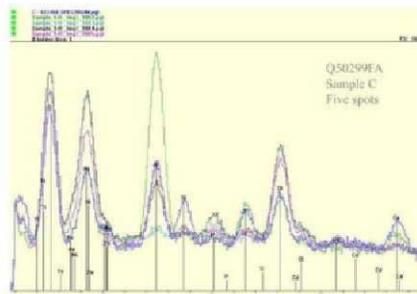


Figure 12. Three of five spectra track together, indicating oxygen, nickel, aluminum, and chlorine. Sulfur and



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GODDARD SPACE FLIGHT CENTER

Part Type Connector
Manufacturer Unkwn

Part Number Unkwn
Lot Code Unkwn

Appended Photographs:

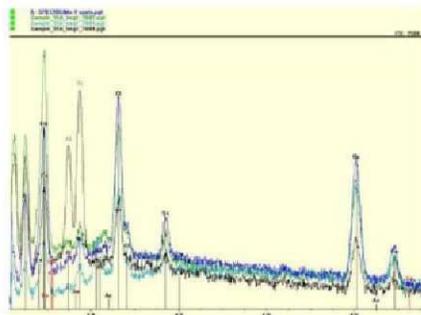


Figure 13. Sample A spectra repeated here for comparison with Figure 14. Caution: keV scale difference.

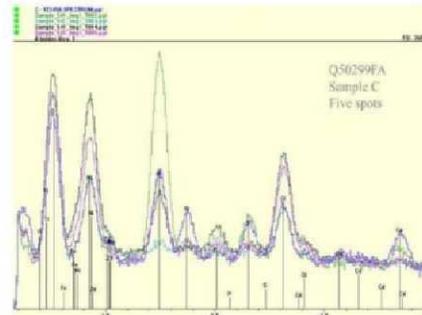


Figure 14. Sample C spectra, repeated here for comparison to Figure 13. Caution: keV scale difference.



Figure 15. SEM image of Sample A material at 3000X. Gold was sputtered in sample preparation but the irregular surface made coating difficult. Some charging is seen.

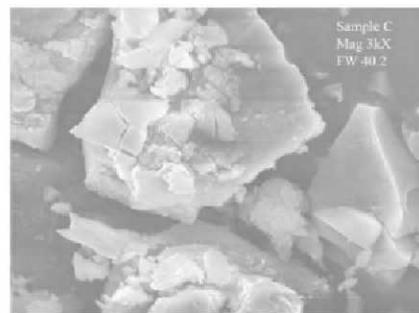


Figure 16. SEM image of Sample C material at 3000X.



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GODDARD SPACE FLIGHT CENTER

Part Type Connector

Part Number Unkwn

Manufacturer Unkwn

Lot Code Unkwn

Appended Photographs:

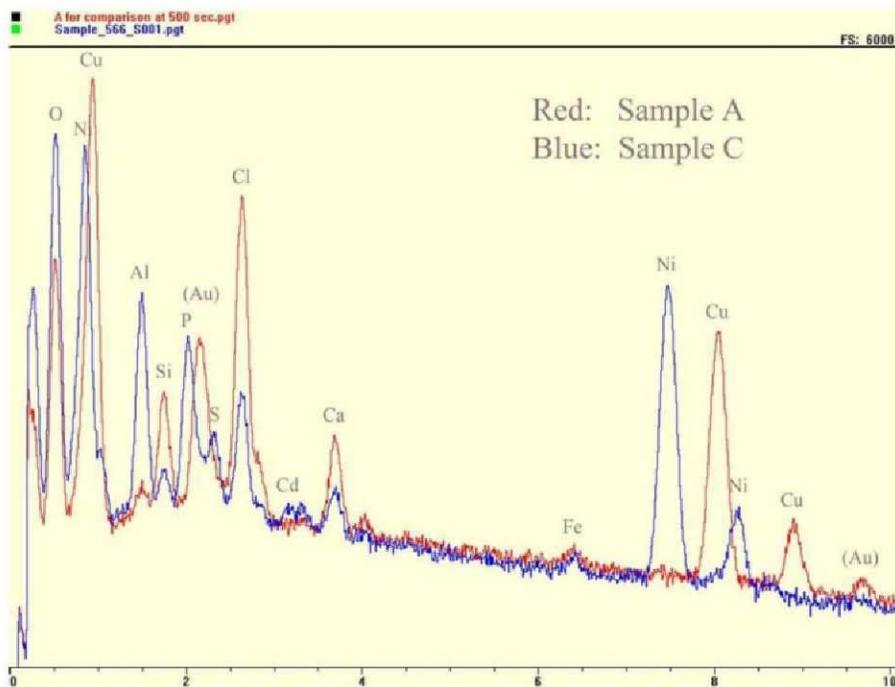


Figure 17. Representative spectra of samples A and C are overlaid in this plate, where red shows

material from sample A and blue indicates sample C material. Compare to Figures 13 and 14.



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GODDARD SPACE FLIGHT CENTER

Part Type Connector
Manufacturer Unkwn

Part Number Unkwn
Lot Code Unkwn

Appended Photographs:

Figures 18. Elemental dot maps for **Sample C** show that most of the detected elements track together.

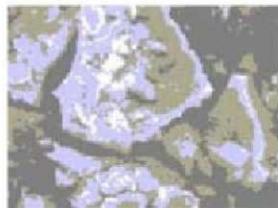
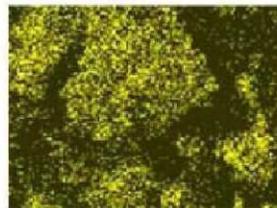
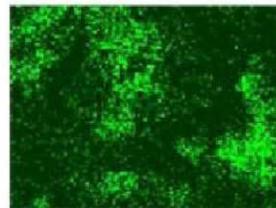


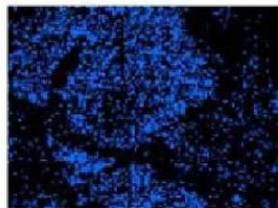
Image at 3000X



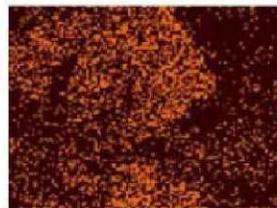
Oxygen



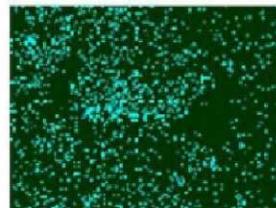
Aluminum



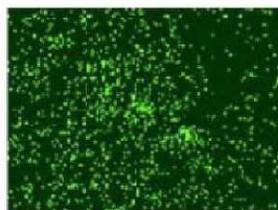
Nickel



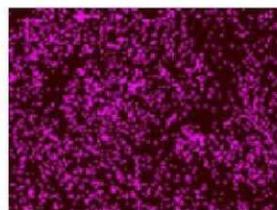
Chlorine



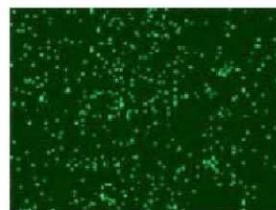
Silicon



Calcium



Sulfur



Iron



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Part Type Connector
Manufacturer Unkwn

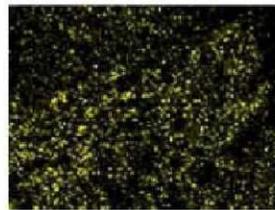
Part Number Unkwn
Lot Code Unkwn

Appended Photographs:

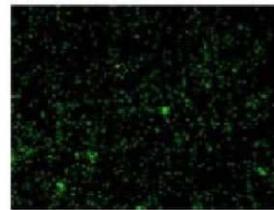
Figures 19. Elemental dot maps for Sample A show that chlorine, copper, and oxygen track together, with possible tracking of silicon, calcium, and sulfur.



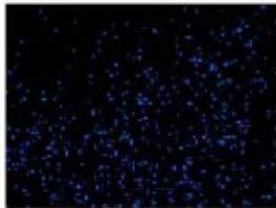
Image at 586X



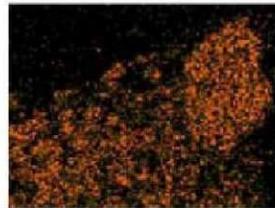
Oxygen



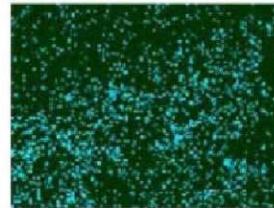
Aluminum



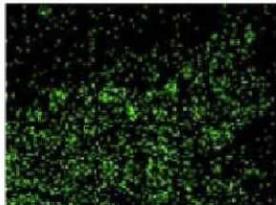
Nickel



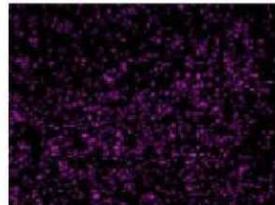
Chlorine



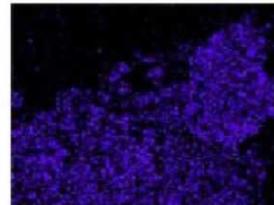
Silicon



Calcium



Sulfur



Copper



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Part Type	Connector	Part Number	Unkwn
Manufacturer	Unkwn	Lot Code	Unkwn

Quantitative Analysis:

Sample A (sample from blast exposed end)

Element	----- Atomic Percent Composition -----			----- Average -----	
	Location 1	Location 2	Location 3	All	L2+L3
Copper	24.69	29.86	30.82	28.46	30.34
Chlorine	10.21	13.03	13.15	12.13	13.09
Silicon	2.69	2.13	1.66	2.16	1.90
Calcium	1.70	2.25	1.55	1.83	1.90
Iron	0.46	0.19	0.25	0.30	0.22
Oxygen	59.42	51.93	52.04	54.46	51.99
Aluminum	0.74	0.61	0.53	0.63	0.57

However, the results at Location 1 are noted to not agree well with Locations 2 and 3. And because aluminum would not be found in a pure form, it is assumed that an aluminum oxide exists. Likewise, iron and silicon oxides also probably use some of the oxygen found in the quantitative analysis. It is also noted that the iron exists roughly in the magnitude of the iron used in the propellant as a catalyst.

Thus, the ratio of chlorine to copper to oxygen at Locations 2 and 3 is approximately 2.3 : 1 : 4.

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GODDARD SPACE FLIGHT CENTER
 Part Type Connector Part Number Unkwn
 Manufacturer Unkwn Lot Code Unkwn

Appended Photographs:



The screenshot shows the NASA ShuttlePower website. It features a navigation menu on the left with links like 'Return to Flight', 'Future Missions', 'NASA News', 'Marshall Space Flight Center', and 'Shuttle Reference Manual'. The main content area is titled 'Solid Rocket Booster Specifications' and contains two tables. The first table lists specifications such as Height (360.2), Diameter (12.2), Weight (empty) (100,430), and Weight (full) (5,300,000). The second table, titled 'Solid Rocket Booster Propellant Mixture', lists the components and their ratios: Carbon-Ammonium Perchlorate (89.6%), Fuel-Aluminum Powder (9.0%), Burn Rate Catalyst-Iron Oxide (0.4%), and Other-Polymer Binder, Coating Agent (1.0%).

Specifications	Value
Height (ft)	360.2
Diameter, Casings (ft)	12.2
Weight (lb - empty)	100,430
Weight (lb - full)	5,300,000

Mixture Element	Ratio
Carbon - Ammonium Perchlorate (NH ₄ ClO ₄)	89.6%
Fuel - Aluminum Powder (Al)	9.0%
Burn Rate Catalyst - Iron Oxide (Fe ₂ O ₃)	0.4%
Other - Polymer Binder, Coating Agent	1.0%

Figure 20. A copy of the NASA website with Shuttle SRB propellant information. The oxidizer is ammonium perchlorate (NH₄ClO₄). The fuel is aluminum powder. Iron is used as a catalyst. A polymer binder makes up the remaining composition.

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**Appendix F. GSE T-0 Umbilical to SSP Flight Elements Assessment Project
Status, 13 Oct 06**

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GSE T-0 Umbilical to SSP Flight Elements Assessment

Project Status

13 Oct 06

1

N. Helmold
Code 562, GSFC

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T-0 Anomaly Review Actions

- The NESC T-0 anomaly assessment results presented to Shuttle Program PRCB and SMARR resulted in several additional actions.
- The NESC assessment team has three activities underway.
 - Integrated plate / connector modeling
 - > Improve understanding of T-0 interface
 - > Assess potential for connector pin-to-socket motion
 - Connector examination and analysis
 - > Examine corrosive products on a used connector assembly
 - > Attempt to demonstrate corrosion-induced intermittent contact under controlled conditions
 - Determine probability of quad-redundant circuit failure

13 Oct 06

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N. Helmold
Code 562, GSFC

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Connector Examination and Analysis

- A pre-STS-112 connector and cable assembly was located at KSC and forwarded to GSFC for detailed analysis.
 - Pins were examined for corrosion product.
 - Pin-to-socket wiping action was assessed.
 - Intermittent connections were demonstrated.
 - A corrosion-induced failure mechanism was determined.
- Results of the connector analysis are consistent with earlier failure analyses.

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Corrosion Product

- Two regions of corrosion were seen on 19 of the 55 pins.
 - A narrow ring of corrosion, more or less continuous around the pin, averaging 0.5 mm from first point of electrical contact
 - Corrosion patches roughly, but not exactly, 180 degrees apart about half way down the exposed length of the pin
- The corrosion product is electrically insulative and persistent – it is not dislodged when probed.
- Analysis of corrosion product by Scanning Electron Microscope and Energy Dispersive X-Ray Spectroscopy (SEM / EDS) showed copper chlorate and trace amounts of aluminum and iron believed to be from chemical reactions with SRB combustion products.

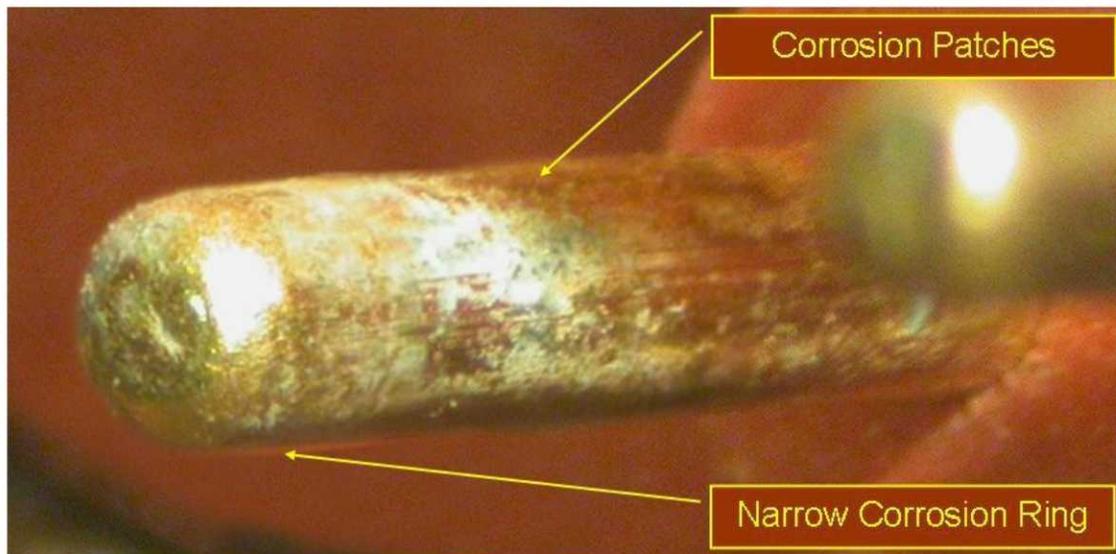
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Corrosion Bands



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Wiping Action

- Of the 19 pins with corrosion, only 10 were electrically connected.
- Continued lack of electrical continuity though the corrosion product after four mate / demate cycles of these 10 pins showed that pin-to-socket mating has limited ability to wipe the connections enough to dislodge the corrosion product.

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Intermittent Connections

- Mechanically controlled mate/demate tests on the 10 electrically connected pins resulted in four intermittent opens that were robust enough to survive at least four mate/demate cycles.

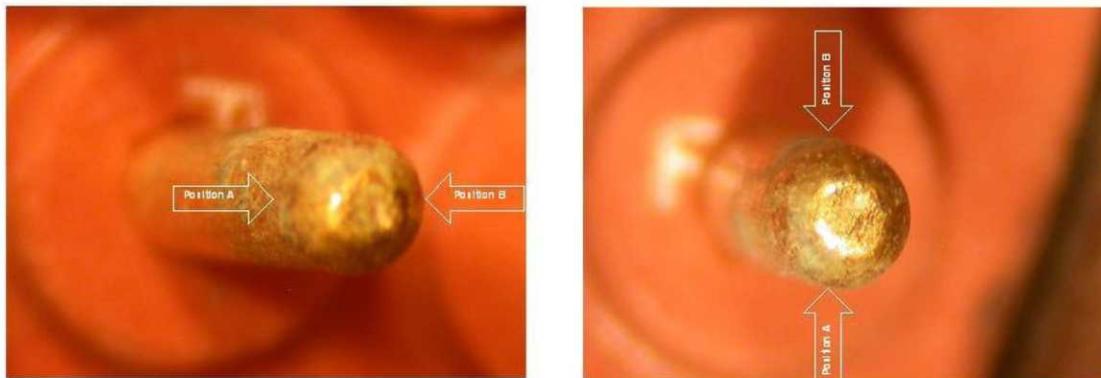
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Mate/Demate Test: Pin Orientation



Arrows show the two socket receptacle contact orientations checked.

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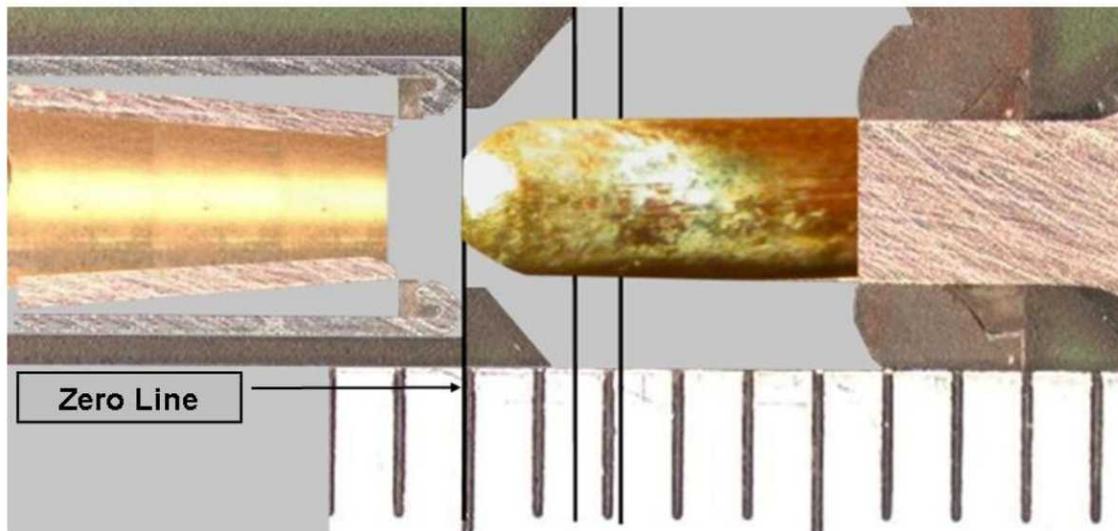
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Mate/Demate Test: Optically Aligned



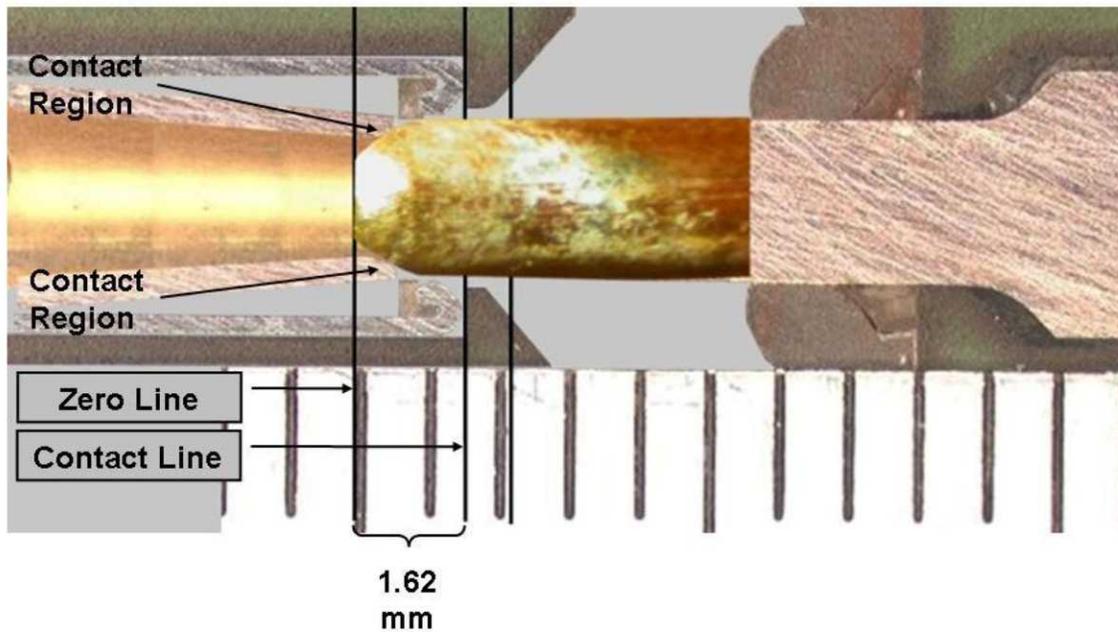
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N. Helmold
Code 562, GSFC

	<p align="center">NASA Engineering and Safety Center Report</p>	<p>Document #: RP-07-01</p>	<p>Version: 1.0</p>
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Mate/Demate Test: Electrical Contact



13 Oct 06

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NASA Engineering and Safety Center Report

Document #:
RP-07-01

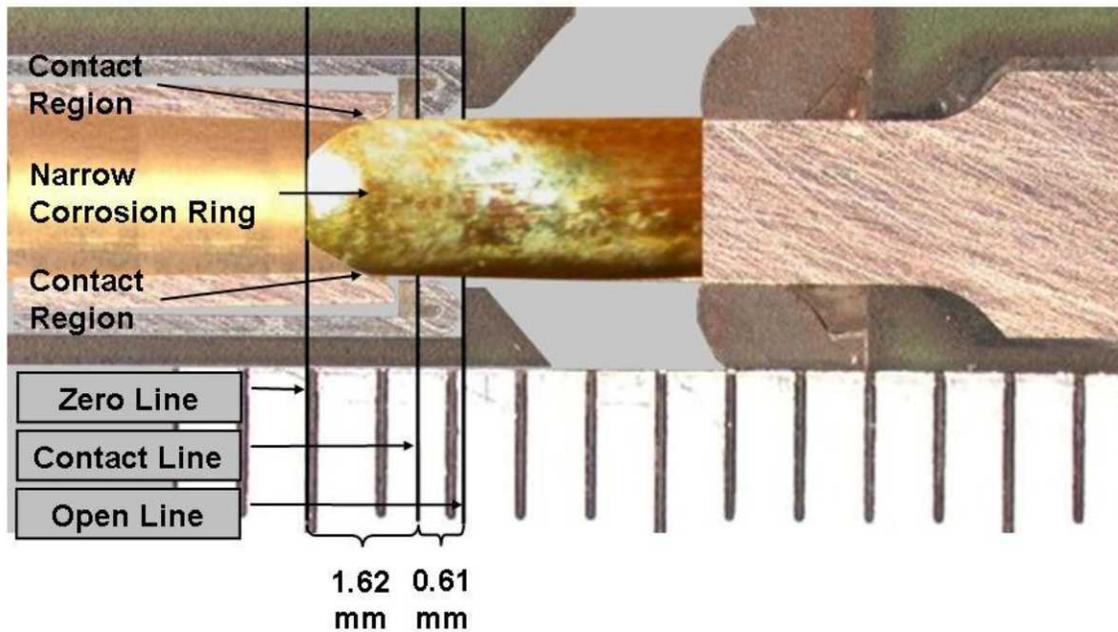
Version:
1.0

Title:

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Mate/Demate Test: Electrical Open



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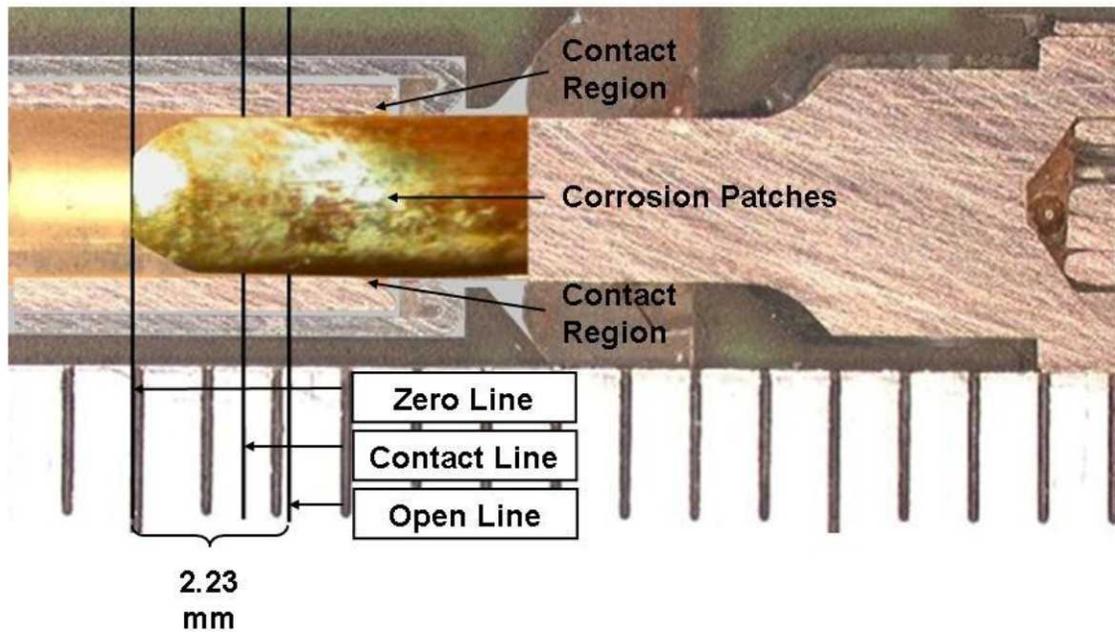
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Mate/Demate Test: Mated



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Corrosion Induced Failure Mechanism

- Socket makes contact with pin in two regions 180 degrees apart.
- Fretting from launch vibration eventually wears away the gold plating at these contact points (linear displacement) and near the tip (angular displacement), exposing the underlying copper.
- Following demating, elements in the SRB combustion products (aluminum, iron, ammonia, chlorine, and oxygen) react with the bare copper to form copper chlorate, whose melting point can be as low as 65°C.
- On a subsequent mating, corrosion products lift the socket leaf off the pin resulting in loss of contact area greater in size than the corrosive patch alone – contact regions vary with socket receptacle orientation in its shell, so this is a stochastic event.

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SRB Combustion Products

SRB Propellant Mixture

Constituent	Function	Quantity
Aluminum (Al)	Fuel	16.0 %
Ammonium Perchlorate (NH_4ClO_4)	Oxidizer	69.6 %
Iron Oxide (Fe_2O_3)	Catalyst	0.4 %
Polymer and Curing Agent	Binder	14 %

SRB Combustion Products

Aluminum, Ammonium, Iron, Chlorine, and Oxygen

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Exposure to SRB Combustion Products



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**T-0 Signal Failure
Cable Enclosure**

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Appendix G. Quad-redundant Failure Analysis

Probability Estimate of Failures Across the T-0 Interface

22 June 2005

K. P. White, Jr.

Conclusion: A probability estimate for loss of fire function across the T-0 interface is fundamentally hostage to assumptions regarding (i) the veracity of the diagnosis of corrosion and/or poor mating of the connectors as the failure mode and (ii) the effectiveness of the measures implemented to eliminate this failure mode. If the engineering judgment regarding the failure mode is correct, and its elimination total, then there is no reason to believe that loss of fire function (or even failure of a single connector) will be observed on any of the remaining shuttle missions, at least by this mode. If the diagnosis is incorrect, or if the measures implemented are ineffective, then there is a finite and nontrivial probability of loss of fire function.

Analysis: Based on the materials I have reviewed, the current best engineering judgment is that the loss of critical signals across the T-0 interface can be attributed to failure of the connectors resulting from corrosion and/or poor mating. For prior flights with dual redundancy, there is one such connector for PIC System A and one for PIC System B. For future flights with quad-redundancy, there will be two such connectors for the PIC System A and two for PIC System B. It is assumed that the failures are independent and identically distributed for all connectors on any given launch.

With these assumptions, the probability of observing x of t connector failures is distributed binomially $\Pr(x)=\text{bin}(t,p)$, where t is the number of connectors ($t=2$ for the dual-redundancy and $t=4$ for quad redundancy) and p is the probability of a single connector failing. Since all t connectors must fail for loss of fire function (for this failure mode) on any launch, the probability of loss of fire function is $P_f=\Pr(t)=p^t$.

The question then is how best to estimate p . There are (at least) four alternative estimates, each based on alternative assumptions regarding the connector failure mode.

Alternative 1: If we assume that the connector failures are independent and identically distributed across all 113 shuttle missions, that with dual redundancy there were 226 independent opportunities to observe a single failure, and that seven independent failures have been observed, then $p_{est1}=7/(2 \times 113)=0.03097$ for a single connector failure on any launch. For quad-redundancy, the corresponding probability of loss of fire function therefore is $P_f=(7/113)^4=9.2036 \times 10^{-7}$.

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This appears to be an unlikely estimate, given the time-sequence of connector failures over the entire program history. Specifically, there were no reported or suspected failures for STS-1 through STS-104, seven failures for STS-105 through STS-112 (one failure on each of these launches except STS-109), and no failures on STS-113. Evidence suggests that failures resulting from corrosion or poor mating first occurred on STS-105, that these same conditions persisted through STS-112, and that these conditions were corrected thereafter.

Alternative 2: If the judgment based on this evidence is correct, then for the 105 missions (STS-1 through STS-104 plus STS-113) where the couplings have been sound, no individual connectors have failed ($p_{est2}=0$) and P_I is essentially zero. This is the most optimistic, as well as the most likely, estimate, giving full weight to best engineering judgment.

Alternative 3: If the judgment is incorrect, however, and the cause of failures beginning on STS-105 persists and will persist into the future, then for the nine missions STS-105 through STS-113, seven failures have been observed, the estimates are $p_{est3}=7/(2 \times 9)=0.38889$ and $P_I=(7/9)^4=0.022872$. This is the most pessimistic estimate.

Alternative 4: All else being equal (i.e., disregarding the evidence that corrosion or poor mating is the cause of connector failures), then under the same assumptions as Alternative 3, probability of *not* observing any failure of the dual-redundant STS-113 connectors is $(1 - p_{est3})^2=(1 - 0.38889)^2=0.44437$. If this is taken as the probability that Alternative 3 is correct (as opposed to Alternative 2), then $P_I=0.022872 \times 0.44437=0.01016$.

REPORT DOCUMENTATION PAGE

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14. ABSTRACT The NASA Engineering and Safety Center (NESC) was tasked with assessing the validity of an alternate opinion that surfaced during the investigation of recurrent failures at the Space Shuttle T-0 umbilical interface. The most visible problem occurred during the Space Transportation System (STS) -112 launch when pyrotechnics used to separate Solid Rocket Booster (SRB) Hold-Down Post (HDP) frangible nuts failed to fire. Subsequent investigations recommended several improvements to the Ground Support Equipment (GSE) and processing changes were implemented, including replacement of ground-half cables and connectors between flights, along with wiring modifications to make critical circuits quad-redundant across the interface. The alternate opinions maintained that insufficient data existed to exonerate the design, that additional data needed to be gathered under launch conditions, and that the interface should be further modified to ensure additional margin existed to preclude failure. The results of the assessment are contained in this report.					
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