1.0 Introduction

NESC Request No. 05-012-E	
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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.	
Date Received: 3/17/2005	**Date ITA/I Initiated:** 3/23/05
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2.0 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 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.

3.0 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.

4.0 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 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 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 as 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.

5.0 Modeling

The NESC 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 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.

6.0 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 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.

7.0 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 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.

8.0 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.

9.0 Review Team Members

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10. 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

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.

Report Approval and Document Revision History

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