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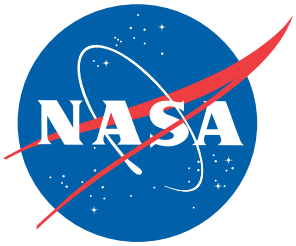

Kennedy Space Center (KSC) Launch Complex 39 (LC-39) Gaseous Hydrogen (GH_2) Vent Arm Behavior Prediction Model Review Technical Assessment Report

Timmy R. Wilson/NESC
Kennedy Space Center, Kennedy Space Center, Florida

Geoffrey Beech and Ian Johnston
Marshall Space Flight Center, Huntsville, Alabama

March 2009

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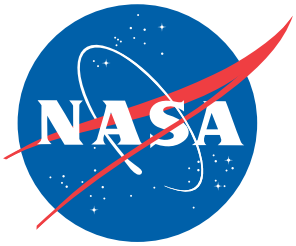

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

March 2009

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Kennedy Space Center (KSC) Launch Complex 39 (LC-39) Gaseous Hydrogen (GH_2) Vent Arm Behavior Prediction Model Review

Technical Assessment Report

October 6, 2005

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Volume I: Technical Assessment Report

1.0 Authorization and Notification

The request to conduct an independent technical assessment (ITA) was submitted to the NASA Engineering and Safety Center (NESC) on March 29, 2005.

Mr. Ralph Roe, Director of the NESC, approved this activity in an out-of-board action on April 4, 2005.

The ITA Plan was developed by Timmy R. Wilson and approved in an out-of-board action by the NESC Review Board (NRB) on May 5, 2005. Follow-up updates to the Plan were approved by the NRB on May 12, 2005.

The NESC team review of the Kennedy Space Center (KSC) Launch Complex 39 (LC-39) math model took place between April 28, 2005 and July 27, 2005.

The final Technical Assessment report was presented to the NRB on October 6, 2005.

2.0 Signature Page

Assessment Team Members

Timmy R. Wilson
NESC Chief Engineer, KSC
Lead

Geoffrey Beech
Systems Analysis Team Lead, MSFC

Ian Johnston, MSFC
Structural and Dynamics Analysis Branch, MSFC

3.0 Team Members, Ex Officio Members, and Consultants

Timmy R. Wilson, NESC Chief Engineer (NCE)
Geoffrey Beech, MSFC
Ian Johnston, MSFC

4.0 Executive Summary

The NESC Assessment Team reviewed a computer simulation of the LC-39 External Tank (ET) GH_2 Vent Umbilical system developed by United Space Alliance (USA) for the Space Shuttle Program (SSP) and designated KSC Analytical Tool ID 451 (KSC AT-451). The team verified that the vent arm kinematics were correctly modeled, but noted that there were relevant system sensitivities. Also, the structural stiffness used in the math model varied somewhat from the analytic calculations. Results of the NESC assessment were communicated to the model developers.

Two significant issues were identified, as follows:

1. The wind environment at the vent arm is not directly measured, but is estimated from data taken at remote locations.
2. The model is not fully validated.

It is recommended that the wind measurement equipment at LC-39 Pads A and B be upgraded to better characterize the wind speed and direction at the vent arm, and additional tests be performed to validate the model.

5.0 Assessment

The scope of this assessment was limited to examining and peer reviewing the GH_2 vent line math model. A plan for this effort was completed and approved by the NRB on May 12, 2005.

6.0 Description of the Problem, Proposed Solutions, and Risk Assessment

The GH_2 vent arm is a pad structure designed to support the Ground Umbilical Carrier Panel (GUCP) and seven-inch hydrogen vent line flex hose during the Space Shuttle pad processing (refer to Figure 6.0-1). At T-0, the GUCP separates from the Space Shuttle ET by means of a pyrotechnic device and the arm drops away from the vehicle and into a restraint (refer to Figures 6.0-2 and 6.0-3).

During the STS-108 launch (December 5, 2001), the arm failed to engage the restraining device and impacted the pad structure with resultant damage to both the arm and the pad. Debris was liberated during the incident which could have caused significant damage to the Space Shuttle flight vehicle had it made contact. Subsequent investigation identified two major contributors: a Pivot Arm shock absorber did not operate properly causing the Pivot Arm to twist and rotate the vent arm to the side as it dropped; and relatively high crosswinds (10-18 knots) during launch pushed the vent arm over.

There were other factors that were considered minor contributors. Drawing and requirements changes were implemented to ensure the pivot arm shocks are lab-tested and adjusted prior to each launch. Additionally, the openings on the Umbilical Retract Deceleration Units at both LC-39 Pads A and B were widened. Clearance on the south side of both Pads A and Pad B Deceleration Unit openings was increased by 9-1/4 inches over STS-108.

The USA-developed computer simulation, KSC AT-451, simulates the kinetics of the relevant subsystems of the ET GH_2 umbilical system when subjected to the two contributors (mentioned previously) and the initial conditions due to the Space Shuttle Main Engine (SSME) startup transient (a.k.a. “twang”). Simulations conducted using this model resulted in reduction of the vent arm wind limit, from 34 to 24 knots, specified by the SSP Launch Commit Criteria (LCC). The KSC Independent Technical Authority (ITA) and Ground Operations Chief Engineer’s Office requested the NESC review the math model to ensure it was not providing overly conservative or restrictive results.

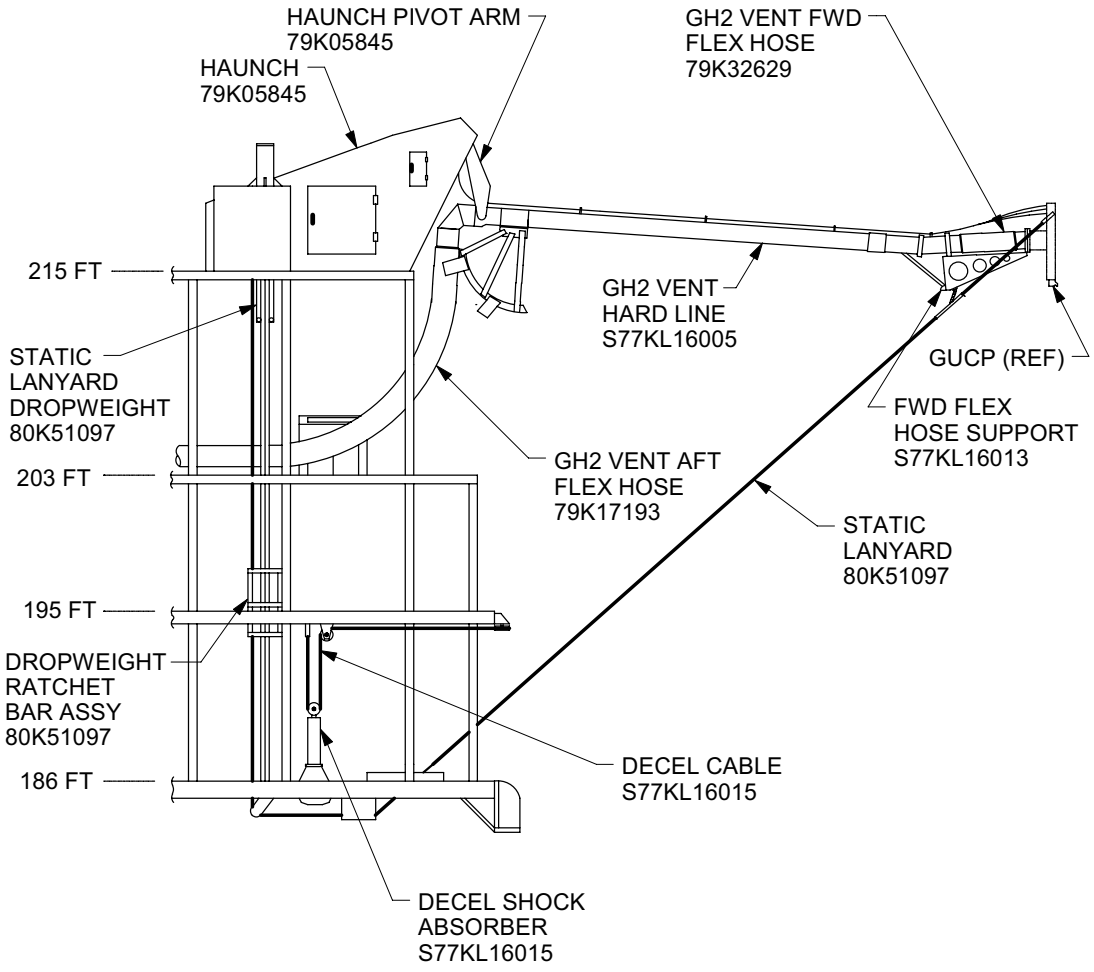

Figure 6.0-1. Tank Vent Umbilical Retraction Mechanism

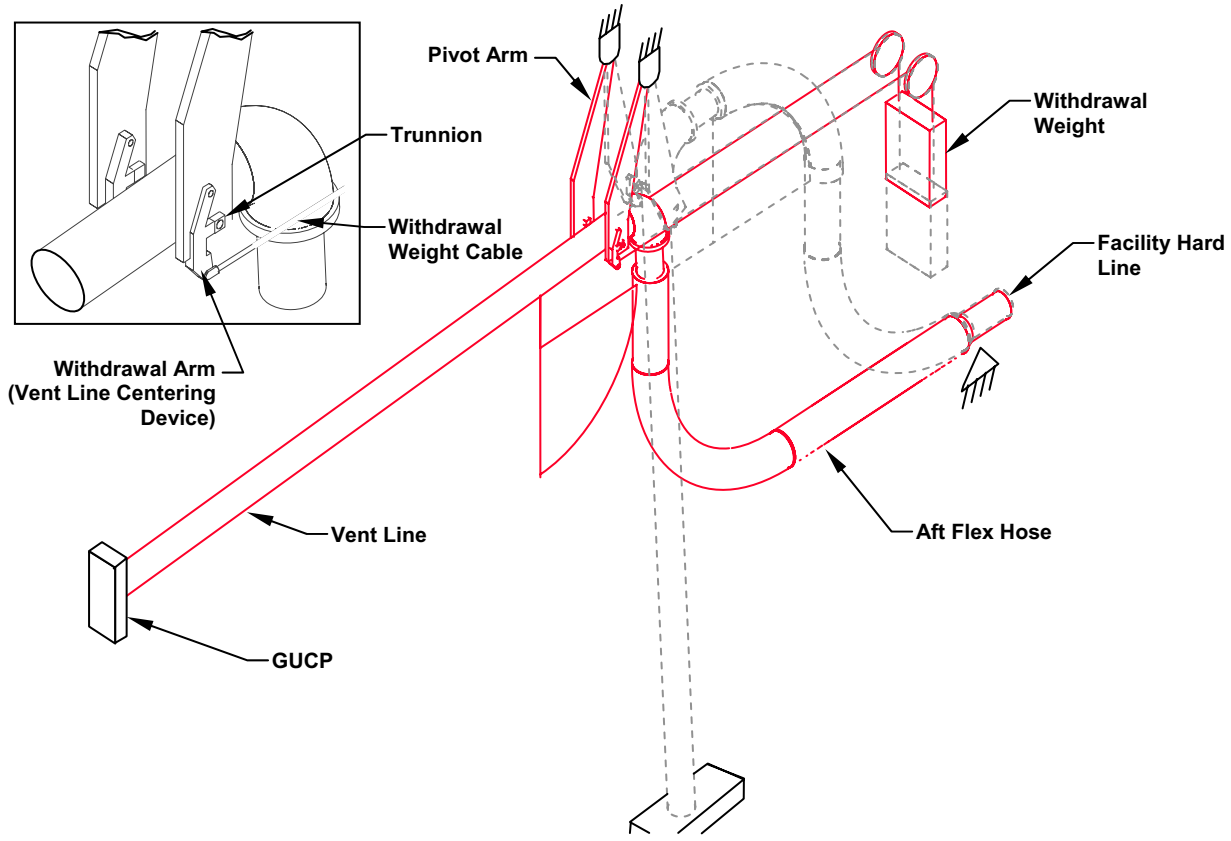

Figure 6.0-2. Static Lanyard Drop-Weight Function

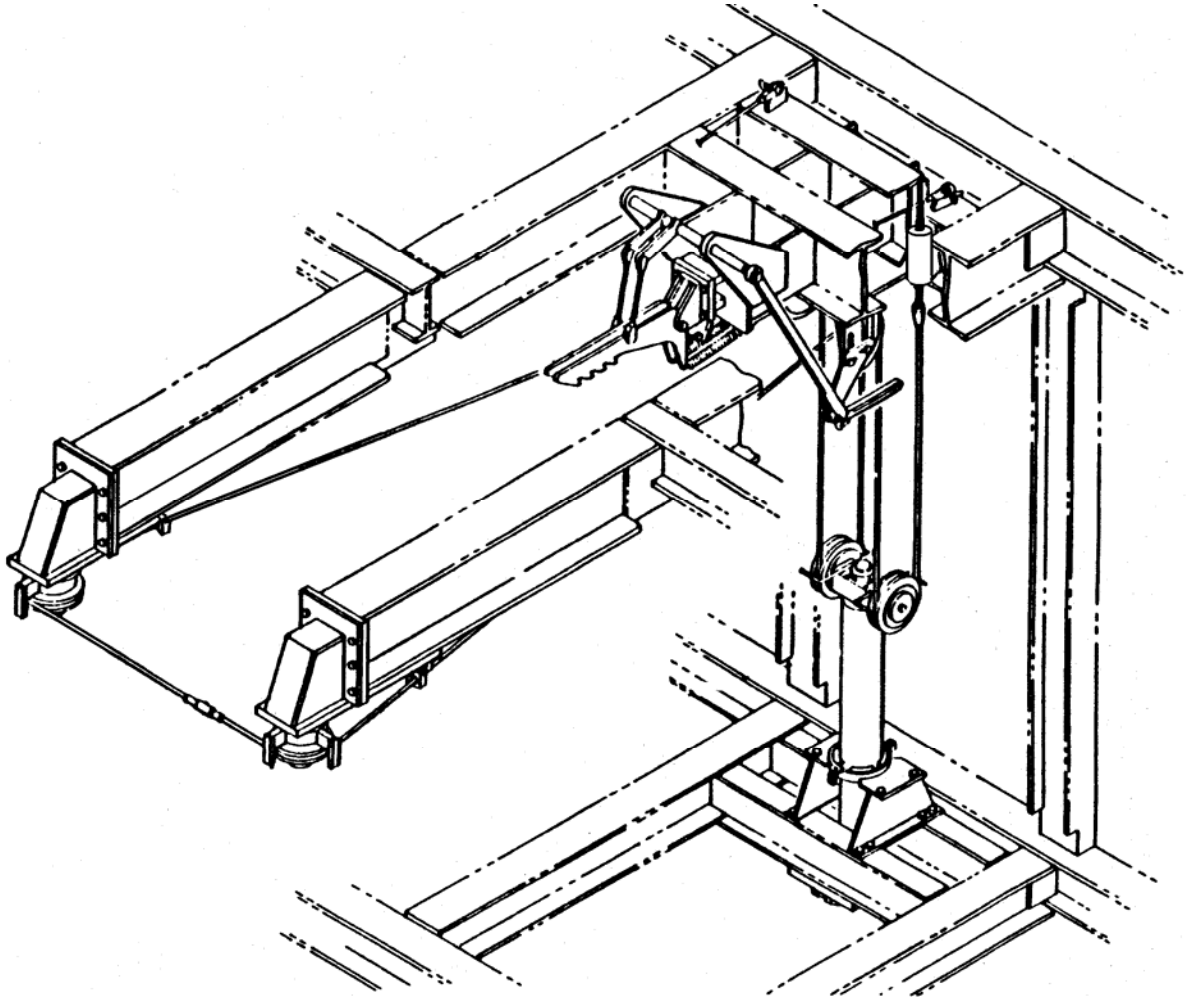

Figure 6.0-3. Umbilical Retention Mechanism

7.0 Data Analysis

7.1 Wind Loading

Wind force predictions on the GH_2 vent arm are extrapolated from the measured winds. Two of the most significant measurements are taken using anemometers on top of 60-foot weather towers in unobstructed areas 1,200 feet from the Pad in the northwest (NW) and southeast (SE) directions. The weather towers are in approximately the same configuration for both Pads A and B. The GH_2 vent arm is at 220 feet elevation and on the Pad, out of the free stream. Winds at the arm are not directly measured.

The wind loads are calculated using American Society of Civil Engineering (ASCE) 7-98. These loads generally are based on the cross-sectional geometry of the vent arm, and the perpendicular velocity of the wind to this cross-section. This calculated drag is proportional to the square of the wind velocity. For this reason, only high winds perpendicular to the vent pipe will yield loads that could result in an anomaly similar to STS-108. This is problematic since there is not a good correlation between the measured wind data and the wind speed at the vent arm. For this reason, it is recommended that a localized wind measurement system on the vent arm, or in close proximity on the Fixed Support System (FSS), be employed.

There are non-moving, ultrasonic type wind anemometers currently on the market at low cost that would not create a debris hazard and could be attached directly to the vent arm to accurately assess the wind speed.

7.2 Kinematics Analysis

MSFC verified the system kinematics of the ET GH_2 Vent Umbilical retraction using an independent kinematics model developed in Delmia's Envision (www.delmia.com). The kinematics represented in KSC AT-451 was verified to be consistent with the hardware and accurate for nominal and off-nominal situations, such as the STS-108 anomaly. Kinematics analysis at MSFC included the haunch pivot arm, trunnions/slider, vent arm, and pivot arm retraction weights and shocks.

The vent arm is guided inside the capture envelope of the Deceleration Unit by two features. First, while the vent arm is roughly horizontal, the pivot arm retraction weights center the vent arm. A cable attaches a 1,500-lb withdrawal weight to the pivot arm through a pivot, which creates equal tension (750 lb) on either side of the cable. The cable is attached to the withdrawal arm link that contacts the trunnion and leverages the cable tension. This resulting contact force

is 1,500 lbs on the trunnion on either side of the haunch pivot arm creating a restoring moment of 2,250 ft-lbs.

The second centering force occurs when the vent arm is not parallel with slots on the pivot arm. The Haunch Pivot Arm Slots (HPAS) develop contact force between the slider block, which surround the trunnions, as the vent pipe rotates down. The slots in the haunch pivot arm are initially parallel with the vent arm pipe while the GUCP is attached to the ET (refer to Figure 7.2-1). This allows the vent arm to yaw side to side to accommodate the motion of the ET just prior to Solid Rocket Booster (SRB) ignition ("twang').

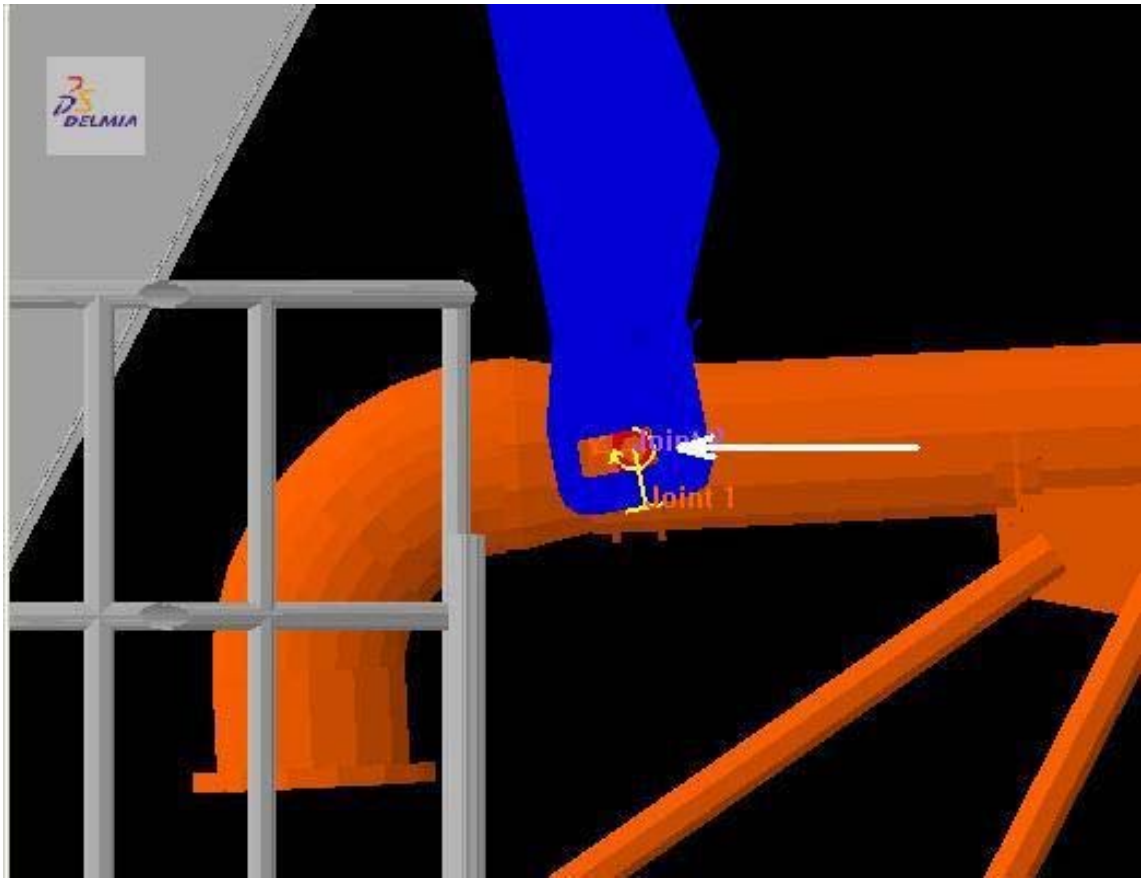

Figure 7.2-1 Haunch Pivot Arm Slots (HPAS)

The arrow indicates the contact force on the slider blocks from the retraction weights.

Once the pipe has rotated so that it is no longer parallel with the HPAS (refer to Figure 7.2-2), any clearance between with the HPAS and the slider block is initially bottomed out, and out-of-

plane excursions cause a contact force between the slider block and the top and bottom of the HPAS. This contact force bottoms-out one trunnion and drives the other trunnion up the HPAS, which will lift the retraction weights as in the first scenario. There will also be an associated vent pipe to roll along its axis, which will twist the aft flex line.

It is expected that the contact forces between the HPAS and the slider blocks vary substantially for different operational conditions and could have been very large. If the forces are large enough, the slider blocks, HPAS, and the bushings and/or bearings will be damaged. Periodic inspections and replacement of this hardware should catch visible damage, but tolerances between parts will vary. Wear and tear tolerances were reviewed subsequent to STS-108 and documented in the investigation report; this was not considered a significant factor in the anomaly.

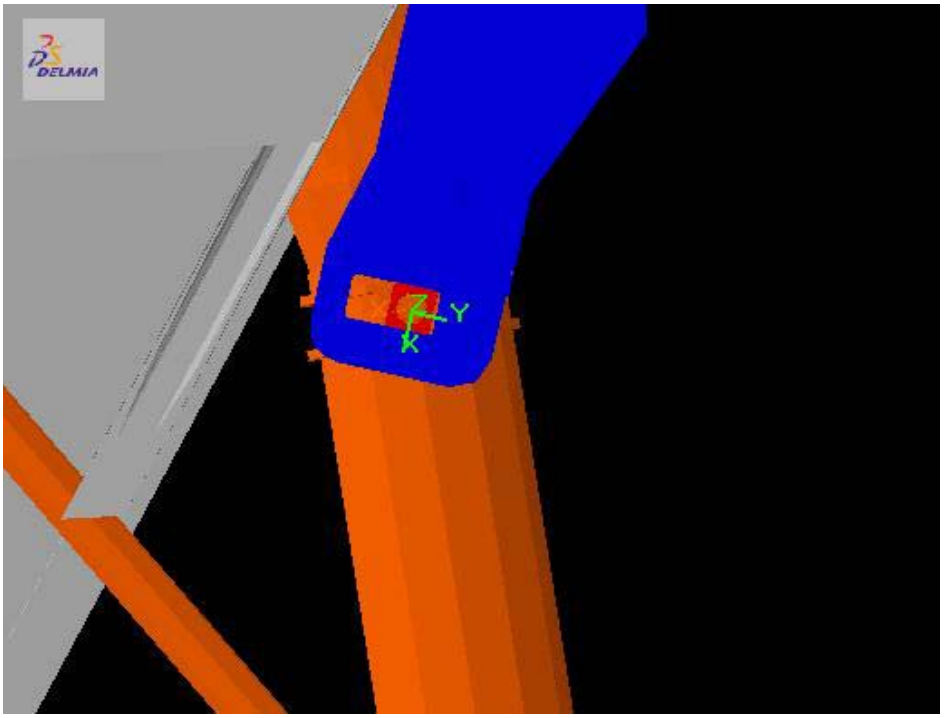

Figure 7.2-2. The HPAS at Approximately 40 Degrees to the Vent Arm

Excursions in this position will cause the vent arm to roll and bend the aft flex base.

The out-of-plane excursions of the vent pipe, as it enters the deceleration unit, are sensitive to torsional flexure of the pivot arm and to any slope in the pivot arm to slider block joint or the slider block to trunnion joint. These sensitivities are illustrated in Appendix B.

Kinematics of the MSFC model as well as the KSC AT-451 represents idealized motion and perfect surface contact between links. Uniqueness of actual parts due to the flaws in the manufacturing process, nominal and off-nominal use of the system, wear and tear on the parts, bushings and bearings, etc., will create differences between an idealized system and an actual system. These differences can be characterized through tests and then be incorporated into the computer model for improvement. If it is expected that the system changes due to wear and tear or other circumstances, then the computer model should be updated for each expected use.

Because of the system's sensitivity to torsion flexure of the pivot arm and potential clearances in the joints, it is recommended that a mechanical hanging (fish) scale be utilized to document the system stiffness on either side of the Deceleration Units of both Pads A and B (reference A-23 of KSC-5600-5969).

7.3 Stiffness Verification

MSFC independently calculated component stiffness and compared them to the values used in the KSC AT-451. The two largest components, most susceptible to flexure are the pivot arm and vent arm. The stiffness of these components is critical to predicting the performance of the ET GH_2 umbilical system in high wind conditions. As there is no validation (empirical measured) data for either these components or the performance of the system in as a whole under high wind conditions, the verification and validation of the model is incomplete.

A Finite Element (FE) model of the pivot arm was created using MSC PATRAN®. The FE model was subjected to a known torque at the cross-section corresponding to the interface of the pivot arm and pivot arm shocks. The resulting angular rotation at this cross-section provides the stiffness for the first section of the pivot arm (stiffness between hinge and shock interface location) using the formula $K = M/\theta$. This approach was then repeated by applying a torque at the trunnion location. The angular rotation at the trunnions was then used to compute the overall stiffness of the pivot arm. From the following relationship, the second section stiffness (stiffness between shock interface location and the trunnions) can be computed as: $1 / K_t = 1 / K_1 + 1 / K_2$. These stiffnesses were then compared to those used in the KSC AT-451.

The calculated stiffnesses were 38 percent lower for the first section stiffness and 20 percent lower for the second section. This difference was discussed with Roy Burton of USA. It was stated that the pivot arm stiffness had to be adjusted by this amount to correlate drop test timing results with the model. Pictures of the FE model and the associated calculations are provided in Appendix C.

A hand-calculated stiffness value of the vent pipe was computed using the known pipe sizes of the primary double-walled pipe. This stiffness value was approximately half of the stiffness value used in the KSC AT-451. This difference was discussed with Roy Burton/USA and resulted in the discovery of erroneous values in the KSC AT-451. The values were corrected in the model, but resulted in only minor changes in results. The hand calculations are also provided in Appendix C.

In the post flight investigation, the out-of-plane stiffness of the vent arm was measured while the vent arm was hanging vertically from the pivot arm near the Deceleration Unit. It is assumed that the pivot arm was latched in the haunch for all of these tests. While this test was performed to identify any obvious malfunctions of the system, rather than to characterize the stiffness of the system, the results are useful. These tests showed the overall system stiffness to be much less than that of any of the components discussed above (reference A-23 of KSC-5600-5969). This indicates that the overall out-of-plane system stiffness is dependent on additional factors. A mechanical hanging (fish) scale test of the system would validate the overall stiffness employed by the model.

8.0 Findings, Observations and Recommendations

8.1 Findings

While KSC AT-451 represents an exceptional effort at modeling the GH_2 vent arm kinetics, it has not been substantially validated and relies on estimated wind data, not on measurements made at the arm. The relative contribution of the pivot arm shock anomaly to the impact of the vent arm on the Deceleration Unit on STS-108 cannot be understood without further testing.

With regard specifically to lowering the LCC for wind loads, it is recommended that the LCC be lowered for future Space Shuttle missions as described in the briefing prepared by Armand Gosselin and Gary Hopkins of USA in the interest of safety and conservatism.

8.2 Recommendations

If the LCC is to be relaxed to the pre-STS-114 criteria, the Assessment Team recommends the following:

R-1. Use a mechanical hanging (fish) scale to measure the flexibility of the vent arm system at horizontal, 45 degrees, and vertical. Measurements should be taken at half-inch excursion intervals for both Pads A and B, and in both NW and SE directions. This data should be used to validate the KSC AT-451.

R-2. Add a wind measurement device to the vent arm structure. LCC should be based on this measurement.

R-3. Add instrumentation, such as cameras, infrared, targets, etc., as necessary to ascertain the motion of the vent arm on future missions, for sustained engineering and on-going validation.

9.0 Lessons Learned

No significant lessons-learned were generated.

10.0 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.

11.0 Minority Report (Dissenting Opinions)

There were no dissenting opinions during this consultation.

Volume II: Appendices

A ITA/I Request Form (NESC-PR-003-FM-01)
B Vent Arm Sensitivities
C Hand Calculations
D List of Acronyms

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

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) 3/28/2005 12:00 AM	Status: New	Reference #: 05-013-E
Initiator Name: Jimmy Alexander	E-mail: jimmy.a.alexander@usa-spaceops.com	Center: KSC, UNITED SPACE ALLIANCE
Phone: (321)-861-2156, Ext _____	Mail Stop:	
Short Title: GH2 Vent Arm Behavior prediction Model Review		
Description: This request is to do a peer review of the model used to predict GH2 vent arm behavior under wind loads. Refinements done to that model recently have resulted in a decrease in allowable launch winds from 34 knots to 24 knots; i.e., in winds higher than 24 knots the GH2 vent arm may hit structure as it comes down instead of dropping into the opening of the deceleration device. An answer is needed quickly since the implication is that the LCC would need to be changed before RTF.		
Source (e.g. email, phone call, posted on web): email		
Type of Request: Assessment		
Proposed Need Date:		
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): 3/29/2005 12:00 AM		
Potential ITA/I candidate? ☐ Yes ☒ No		
Assigned Initial Evaluator (IE):		
Date assigned (mm/dd/yyyy):		
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, review, with Tim Wilson to present the results as a position paper to the NRB for close-out		
Actionee: Tim Wilson		
Is follow-up required? ☒ Yes ☐ No If yes: Due Date: 4/28/2005		
Follow-up status/date:		
If no:		
NESC Director Concurrence (signature):		
Request closure date: .		

NESC Request Form
NESC-PR-003-FM-01, v1.0

Page 1 of 3

Section 3: Initial Evaluation		
Received by IE: (mm/dd/yyyy h:mm am/pm):		
Screening complete date:		
Valid ITA/I candidate? ☐ Yes ☐ No		
Initial Evaluation Report #: NESC-PN-		
Target NRB Review Date:		
Section 4: NRB Review and Disposition of NCE Response Report		
ITA/I Approved: ☐ Yes ☐ No	Date Approved:	Priority: - Select -
ITA/I Lead: , Phone ( ) - , x		
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? ☐ Yes ☐ No		
Section 6: Follow-up		
Date Findings Briefed to Customer:		
Follow-up Accepted: ☐ Yes ☐ 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:		

Form Approval and Document Revision History

Approved: _____ _____
NESC Director Date

Version	Description of Revision	Office of Primary Responsibility	Effective Date
1.0	Initial Release	Principal Engineers Office	29 Jan 04

Appendix B. Vent Pipe Sensitivities

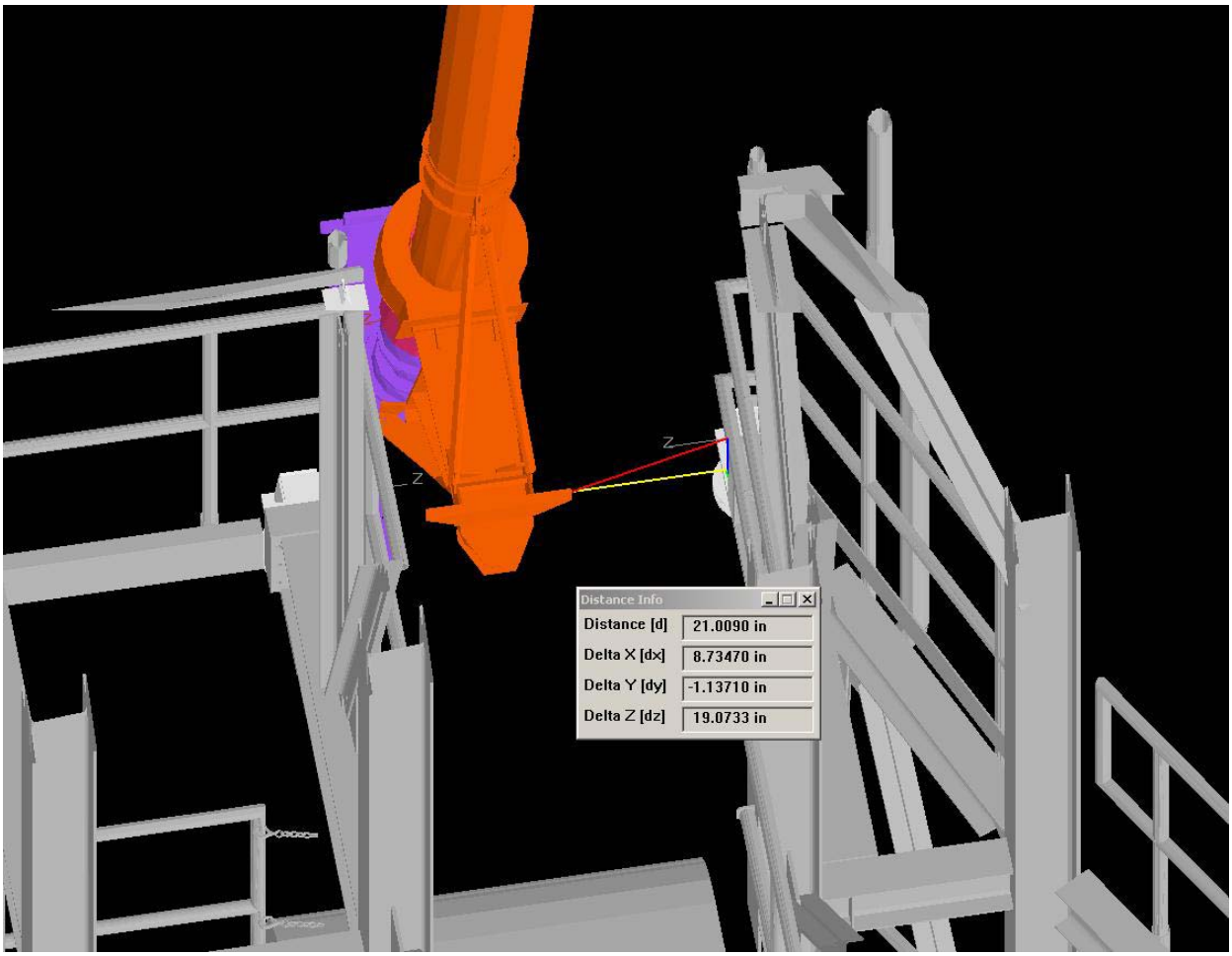

Figure B.1. End of Vent Arm as it Enters Deceleration Unit

Model contains post STS-108 update to the Structure and a horizontal clearance of 19.07".

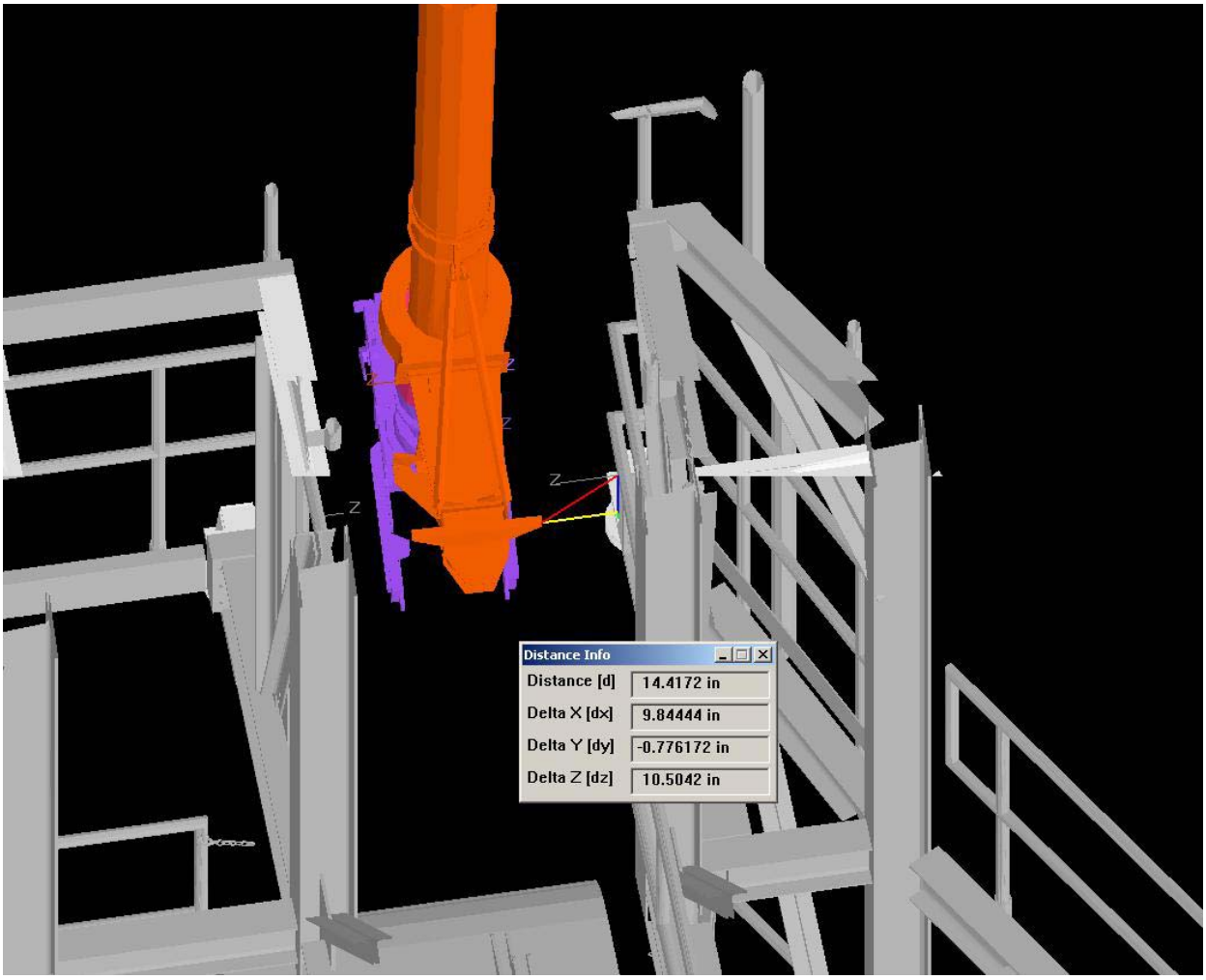

Figure B.2. Pivot Arm Flexure Sensitivity

End of vent arm clearance with the Deceleration Unit when the pivot arm is flexed 3 degrees from joint with FSS and joint with Slider Block. Clearance is reduced from 19.07" to 10.5" on the modified Deceleration Unit.

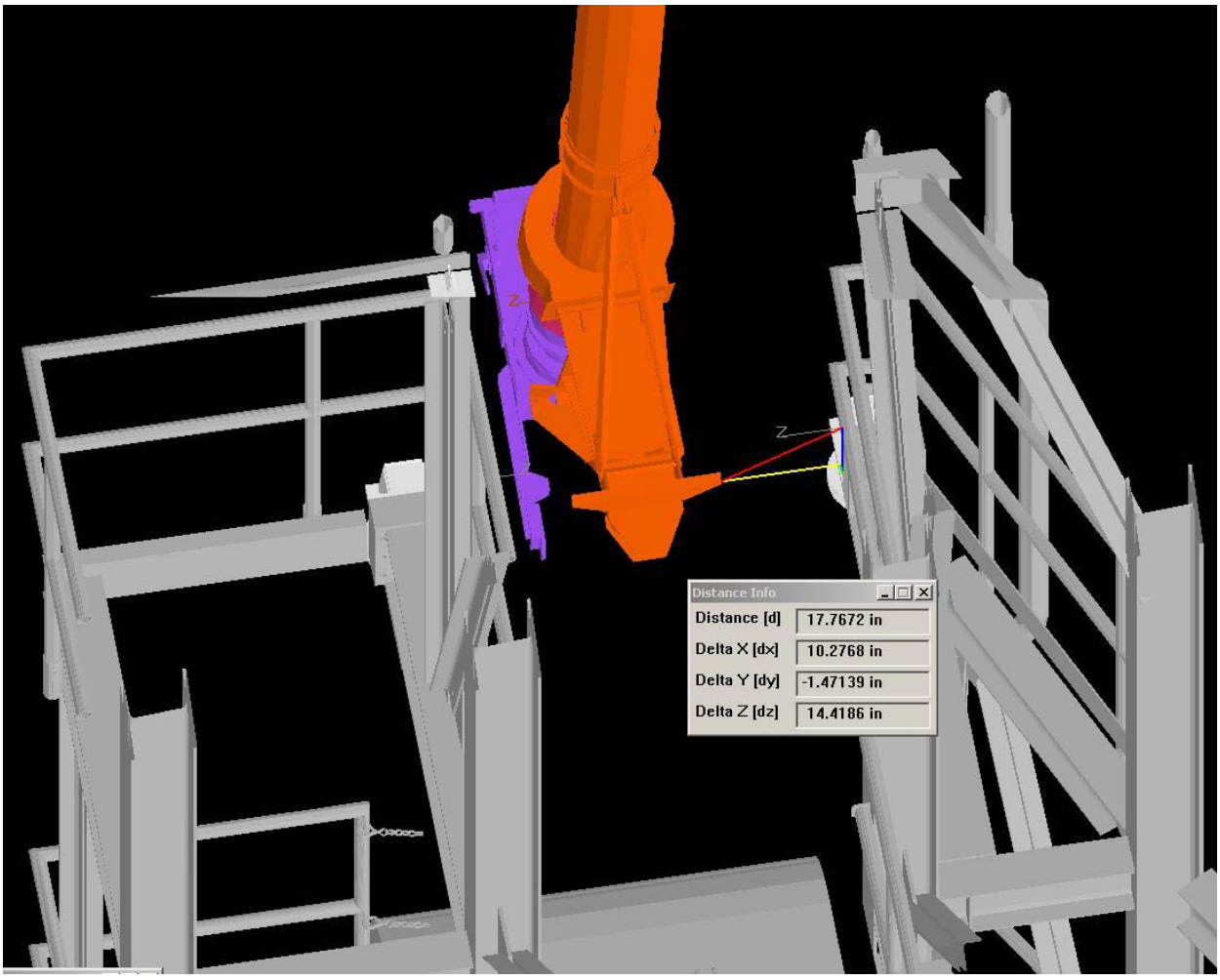

Figure B.3. Joint Stop Sensitivity

End of arm clearance with the Deceleration Unit when the two joints between the pivot arm and the Slider Block and the Slider Block and the Trunnions have a combined slope equal to one degree. Clearance is reduced from 19.07" to 14.41" on the modified Deceleration Unit.

Appendix C. Pictures of the FE Model and the Associated Calculations

Marshall Space Flight Center
ER41 - Structural & Dynamics Analysis Branch

M. Ian Johnston
7/15/2005
Page 1 of 3

CMM 234 - Review

Vent Pipe Stiffness Calculations

Length of vent arm: $L_{pipe} := 275 \cdot in$

Inner pipe (8" Sch. 5)

$OD_8 := 8.625 \cdot in$ $ID_8 := 8.407 \cdot in$

$A_8 := \frac{\pi}{4} \cdot \left(OD_8^{\,2} - ID_8^{\,2} \right)$ $A_8 = 2.916\,in^2$

$I_8 := \frac{\pi}{64} \cdot \left(OD_8^{\,4} - ID_8^{\,4} \right)$ $I_8 = 26.44\,in^4$

Outer pipe (10" Sch. 10)

$OD_{10} := 10.750 \cdot in$ $ID_{10} := 10.42 \cdot in$

$A_{10} := \frac{\pi}{4} \cdot \left(OD_{10}^{\,2} - ID_{10}^{\,2} \right)$ $A_{10} = 5.487\,in^2$

$I_{10} := \frac{\pi}{64} \cdot \left(OD_{10}^{\,4} - ID_{10}^{\,4} \right)$ $I_{10} = 76.864\,in^4$

Combined Area's and Moments of Inertia

$I_c := I_{10} + I_8$ $I_c = 103.304\,in^4$

$A_c := A_{10} + A_8$ $A_c = 8.403\,in^2$

Data from hand calculations:

$E_{steel} := 29000 \cdot ksi$

$k_{hand} := \frac{3 \cdot E_{steel} \cdot I_c}{L_{pipe}^{\,3}}$ $k_{hand} = 432.154\,\frac{lbf}{in}$ (cantilever pipe with point load at end)

Data used in Adams Model

$E_{pipe} := 29000 \cdot ksi$ per Roy Burton e-mail

$G_{pipe} := 11154 \cdot ksi$ per Roy Burton e-mail

$\nu_{pipe} := \frac{E_{pipe}}{2 \cdot G_{pipe}} - 1$ $\nu_{pipe} = 0.3$ Poisson's Ratio

$I_{roy} := 83.379 \cdot in^4$ per Roy Burton e-mail

$k_{roy} := \frac{3 \cdot E_{pipe} \cdot I_{roy}}{L_{pipe}^{\,3}}$ $k_{roy} = 348.801\,\frac{lbf}{in}$

$diff_{pipe} := \frac{k_{hand} - k_{roy}}{mean(k_{hand}, k_{roy})}$ $diff_{pipe} = 21.346\,\%$

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Pivot Arm Stiffness Calculations

$M := 18000 \cdot in \cdot lbf$ Moment applied to FEM about y-axis

Compute K_1 from Finite Element Model (Stiffness between pivot and shock interface)

Node Number (at shock interface location)	Rotational displacement about y-axis from FEM results	
Node 7641	$\theta y_{7641} := 2.943 \cdot 10^{-3} \cdot rad$	$\theta y_{7641} = 0.169\ deg$
Node 9079	$\theta y_{9079} := 2.941 \cdot 10^{-3} \cdot rad$	$\theta y_{9079} = 0.169\ deg$

$K_1 := \frac{M}{mean(\theta y_{7641}, \theta y_{9079})}$ $K_1 = 1.068 \times 10^5 \frac{in \cdot lbf}{deg}$ Section 1 stiffness

$Kl_{cmm234} := 1.576 \cdot 10^5 \cdot \frac{in \cdot lbf}{deg}$ Stiffness used in CMM 234

$diff_1 := \frac{Kl_{cmm234} - K_1}{mean(K_1, Kl_{cmm234})}$ $diff_1 = 38.4\,\%$

Compute K_t from Finite Element Model (Stiffness of entire pivot arm)

Node Number (at trunnion location)	Rotational displacement about y-axis from FEM results	
Node 15742	$\theta y_{15742} := 9.687 \cdot 10^{-3} \cdot rad$	$\theta y_{15742} = 0.555\ deg$
Node 15743	$\theta y_{15743} := 9.687 \cdot 10^{-3} \cdot rad$	$\theta y_{15743} = 0.555\ deg$

$K_t := \frac{M}{mean(\theta y_{15742}, \theta y_{15743})}$ $K_t = 3.243 \times 10^4 \frac{in \cdot lbf}{deg}$ Overall stiffness

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Compute K_2 (Stiffness between shocks and trunnion)

Compute second section stiffness using the following relationship.

$$\frac{1}{K_t} = \frac{1}{K_1} + \frac{1}{K_2}$$ for springs in series

$$K_2 := -K_t \cdot \frac{K_1}{-K_1 + K_t} \qquad K_2 = 4.658 \times 10^4 \frac{in \cdot lbf}{deg}$$ Section 2 stiffness

$$K2_{cmm234} := 5.7065 \cdot 10^4 \cdot \frac{in \cdot lbf}{deg}$$ Stiffness used in CMM 234

$$diff_2 := \frac{K2_{cmm234} - K_2}{mean(K_2, K2_{cmm234})} \qquad diff_2 = 20.2\,\%$$

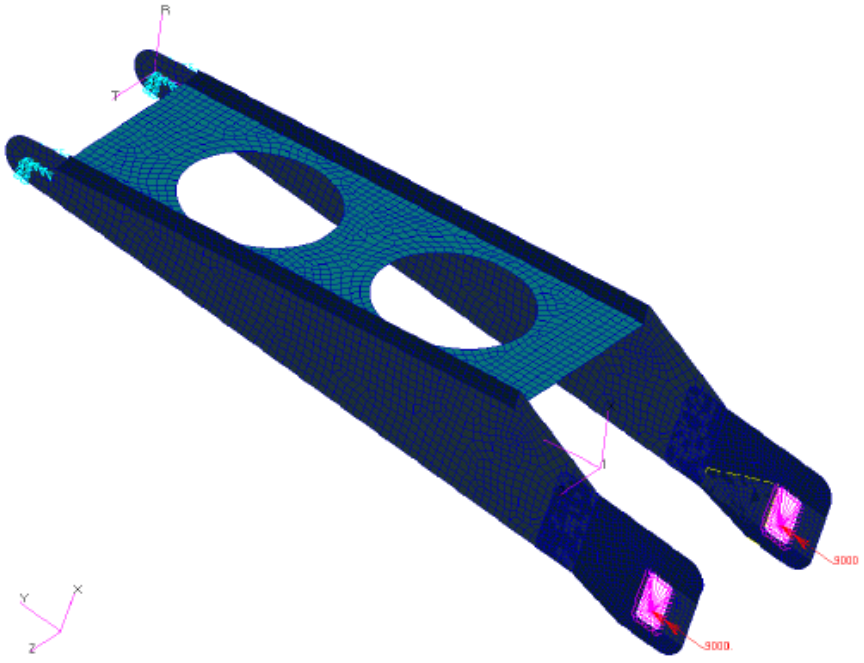

Figure 1: Pivot Arm FE Model

Appendix D. List of Acronyms

ASCE	American Society of Civil Engineering
AT	Analytical Tool
ET	External Tank
FE	Finite Element
FSS	Fixed Support System
GH_2	Gaseous Hydrogen
GUCP	Ground Umbilical Carrier Panel
HPAS	Haunch Pivot Arm Slot
KSC	Kennedy Space Center
LC-39	Launch Complex 39
LCC	Launch Commit Criteria
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NCE	NESC Chief Engineer
NESC	NASA Engineering and Safety Center
NW	Northwest
SE	Southeast
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
SSP	Space Shuttle Program
USA	United Space Alliance

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The NESC Assessment Team reviewed a computer simulation of the LC-39 External Tank (ET) GH2 Vent Umbilical system developed by United Space Alliance (USA) for the Space Shuttle Program (SSP) and designated KSC Analytical Tool ID 451 (KSC AT-451). The team verified that the vent arm kinematics were correctly modeled, but noted that there were relevant system sensitivities. Also, the structural stiffness used in the math model varied somewhat from the analytic calculations. Results of the NESC assessment were communicated to the model developers.

15. SUBJECT TERMS

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