Structural Analysis Report
EFOGM Launcher

Systems & Electronics Inc.

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Forward

After the conclusions and summary, we begin with discussion of criteria, methods, and then loading conditions. Section 6 reports on the capacity of individual components, and Section 8 reports on analysis of the assembly as a whole. Generally the assembly analysis was completed first. Then internal loads taken from the assembly models are used to determine the component capacities.

Stress contour plots of the assembly and selected components, for both static and fatigue, are included to capture an overall cognition of the gross levels. Internal loads, from PSD, inertia, and shock inputs, are extracted at selected points to facilitate checking the capacity of the clevis joints. In most cases the FEM discretizations are sufficiently fine to read component stress levels directly. In some cases, where more detail is needed, fine mesh sub-assembly FEMs are loaded with enforced displacements or freebody loads from the overall assembly FEM.

Index of Revisions

Revision Letter & Date	Pages Affected Revised	Added	Removed	Remarks	Revised By	Approved
B 11/18/96				CDR Review	RM	
E 1/15/97				Stress Review	RM	
F 1/24/97				Update Table 6-2	RM	
G 4/24/97	Table 6-1			5% Damping PSD	RM	
H 5/14/97	All			Convert to Word95	RM	
J 8/20/97		8.8.2		2 DOF Approx.	RM	
K 8/26/97		6-22		Shear tie result	RM	
L 5/30/99	6-1	5-2		Table 6-1, Drop	RM	
		6-22	6-23 RevK	Figure 6-29	RM	

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1. Statement of Work - EFOGM Launcher Structural Analyses

2. **Metallic Materials and Elements for Aerospace Vehicle Structures**, Military Handbook MIL-HDBK-5F, 01 November 1990

3. Fox, Robert W., and Alan T. McDonald, **Introduction to Fluid Mechanics**, 2cd ed., John Wiley & Sons, New York, 1973, pp. 425-428.

4. Sheahan, Pete, EFOGM Fire Unit Launcher Vibration Analysis - Estimate of Damping From NLOS Fire Unit Road Test, 2/14/97

5. Harris, Cyril M., and Charles E. Crede, **Shock and Vibration Handbook**, 4th ed., McGraw-Hill, New York, 1996, pp. 11.8-11.15.

6. Peters, David A., **Vibration Analysis**, Washington University, St. Louis, MO., 1990, p. 83.

List of Abbreviations and Symbols

Symbol	Description
C.G.	Center of Gravity
F_{ty}	Allowable yield tension stress
F_{tu}	Allowable ultimate tension stress
F_{bru}	Allowable bearing ultimate stress
Lat.	Lateral
Long.	Longitudinal
r,R	Radius
t	Thickness
#	Pounds force
"	Inches
¶	Paragraph
Ver.	Vertical
∅	Diameter
μ	Poisson's Ratio
F_{ret}	Actuator retract limit force
F_{ext}	Actuator extend limit force

1. Introduction

The Enhanced Fiber Optic Guided Missile (EFOGM) system is being developed by Raytheon and Systems & Electronics Inc. (SEI). This report has been generated for SEI, by Response Mechanics, Inc., in order to evaluate the structural integrity of the EFOGM system launcher as mounted to the M1097A1 HMMWV. Static, dynamic and fatigue conditions of the launcher have been analyzed as defined by the SOW and defined in Table 5-1. This analysis included the launcher structure itself, plus a significant portion of the structural areas of the HMMWV, which the launcher is mounted to. This analysis has been performed as the final design was being developed and incorporates all revisions to the design through the date of the latest revision which impact the overall results. In some cases these revisions were induced by preliminary stress results which showed potential problem areas in the design.

An electronic version of this report is available from SEI in Microsoft Word Ver. 6.0 format. Additional documentation including NASTRAN files has also been provided to SEI for review and possible additional analysis as required.

2. Conclusions and summary

All load cases, as described in Table 5-1, were generated from the requirements, described in ¶4.2 herein, and have been analyzed. Summaries of the worst case margins of safety, for a given part and given load case, are listed in Table 3-1. All requirements and results contained herein are derived with a full complement of canisters in place during the C130 load conditions. Late in the analysis, the requirement for C130 transport loads was changed from having a full complement of 8 missiles on the launcher to no missiles being on the launcher during C130 transport. Due to the significant decrease in load and the existing margins of safety with a full complement of missiles, these load cases were not rerun in order to save cost and schedule. Load cases 4 through 8 therefore significantly exceed the current requirement.

Static ultimate strength checks of all lugs, clevis joints, and fasteners were made using component loads from kinematic and FEA models. The factor of safety exceeds the requirements in all cases. The results are summarized in Table 6-2 on page 6-3.

Fatigue life checks were made on all portions of the structure using internal loads developed by FEA frequency response with PSD inputs. The fatigue results for the clevis joints are listed in Table 6-3.

The Sideplates and Actuator have positive margins for buckling under the worst case compression condition.

All welded joints have substantial static margins. The highest stressed weld is where the forward cross plate (G670016-5) joins the longitudinal tubes (G670025-301). Margins of safety summaries, for the welded joints, are listed in Table 6-7 on page 6-28.

In general, all areas of the launcher and HMMWV structure exceed the strength requirements except for the few areas of negative margin of safety identified. These areas can be summarized as follows:

2.1 G670017-9 Plate, Stow Latch Backup, Fatigue Condition 64:

Analysis shows a negative margin of safety in a localized area, near the ends of a stitch weld, in a fatigue condition. Based on this analysis, a design change has been implemented which changes the weld of this backup plate from a stitch weld to a continuous full penetration weld. The area was reanalyzed with the continuous weld (Figure 6-21), and now shows a positive margin of safety.

2.2 Negative Margins shown for load cases 4 through 8

As defined above, there is no longer a requirement to have missiles on the launcher during C130 transport. The stresses therefore generated from the launcher with no missiles for the load cases defined will be very small as compared to the results presented here and therefore are not considered a problem area for further review or analysis.

2.3 G670028-1 Rear Mount, Fatigue Condition 3

Table 6-3 shows a negative fatigue margin of safety for the rear mount where the lower link attaches to the rear mount by means of a clevis pin. Condition 3 is when the launcher is driven into the stow brackets and assumes a maximum retraction force on the actuator. Based on this assumption the rear mount only attains 8,009 cycles instead of the required 10,000 prior to crack initiation. Test data obtained on system number one (Figure 8-26 on page 8-26) indicates that the assumption that full actuator force will be applied as the launcher comes into stow is invalid. Actual data show actuator forces 1/3 of maximum. Based on this data, there should not be a fatigue issue associated with the rear mount due to condition 3. No further analysis is planned.

2.4 G670076-5 Angle Bracket - Canister Latch, Fatigue Condition 62

The Canister Latch bracket holds the canister latch that provides all longitudinal restraint of the canisters on the launcher. If this latch yields in the -Y direction (Figure 4-1) then the shear pins in the aft Canister mounts will provide sufficient restraint to prevent the Canister from breaking free. The current Canister Latch bracket (G670076 A) is attached to the Forward Truss with shear fasteners into the 0.375” thick top plate on the Fwd Truss. This configuration has greater than 25% MS for each fatigue, limit, and ultimate criteria.

3. Summary of Minimum Margins of Safety

Table 3-1 Margin of Safety summary

Drawing No.	Description	M.S.	Failure Mode	Cond.	Stress psi	Freq. Hz
G670025-301	Tube Assembly - bending section	0.27	Fatigue	62.00	17493	11.0
G670017-1	Aft Truss Assy near LanNav bracket	0.00	Fatigue	62	22149	11.0
G670017-9	Plate - Stow Latch Backup	0.81	Fatigue	64	11372	23.8
G670076-5 C	Canister Latch - Rev C	0.38	Fatigue	62	15893	12.4
G670076-5 C	Canister Latch - Rev C	0.27	Limit	42	27637	0
G670025-13	Pivot Housing	0.74	Limit	4*	20100	0.0
G670026	Sideplate Assy - upper aft corner	0.18	Limit	4*	29762	0.0
G670082	Stow Stand inboard leg near base	0.85	Limit	5*	18899	0.0
G670029-5	Forward Mount Angle near Stow Stand	0.83	Limit	5*	19168	0.0
G670017-1	Aft Truss / Tube Assy Fwd Weld	3.30	Limit	4*	8133	0.0
	Cbeam	0.29	Limit	5*	27037	0.0
	Dbeam	0.03	Limit	4*	33970	0.0
	Dbeam Intercostal	0.03	Limit	4*	34126	0.0
	Bed Skin Cross Channel	-0.07	Limit	4*	37810	0.0
	* Analysis reflects full compliment of canisters.					

4. Discussion

4.1 Structural Description

The EFOGM launcher has been designed by SEI for installation on the US Army M1097A1 vehicle. The launcher consists of a carriage holding up to 8 missile assembly canisters, supporting struts and linkages, hydraulic positioning actuator (cylinder) and includes a rear pivot support and forward stow support structures. The part design is controlled by the CID705320 Critical Item Development Specification. The part configuration is defined by the 6670015 drawing.

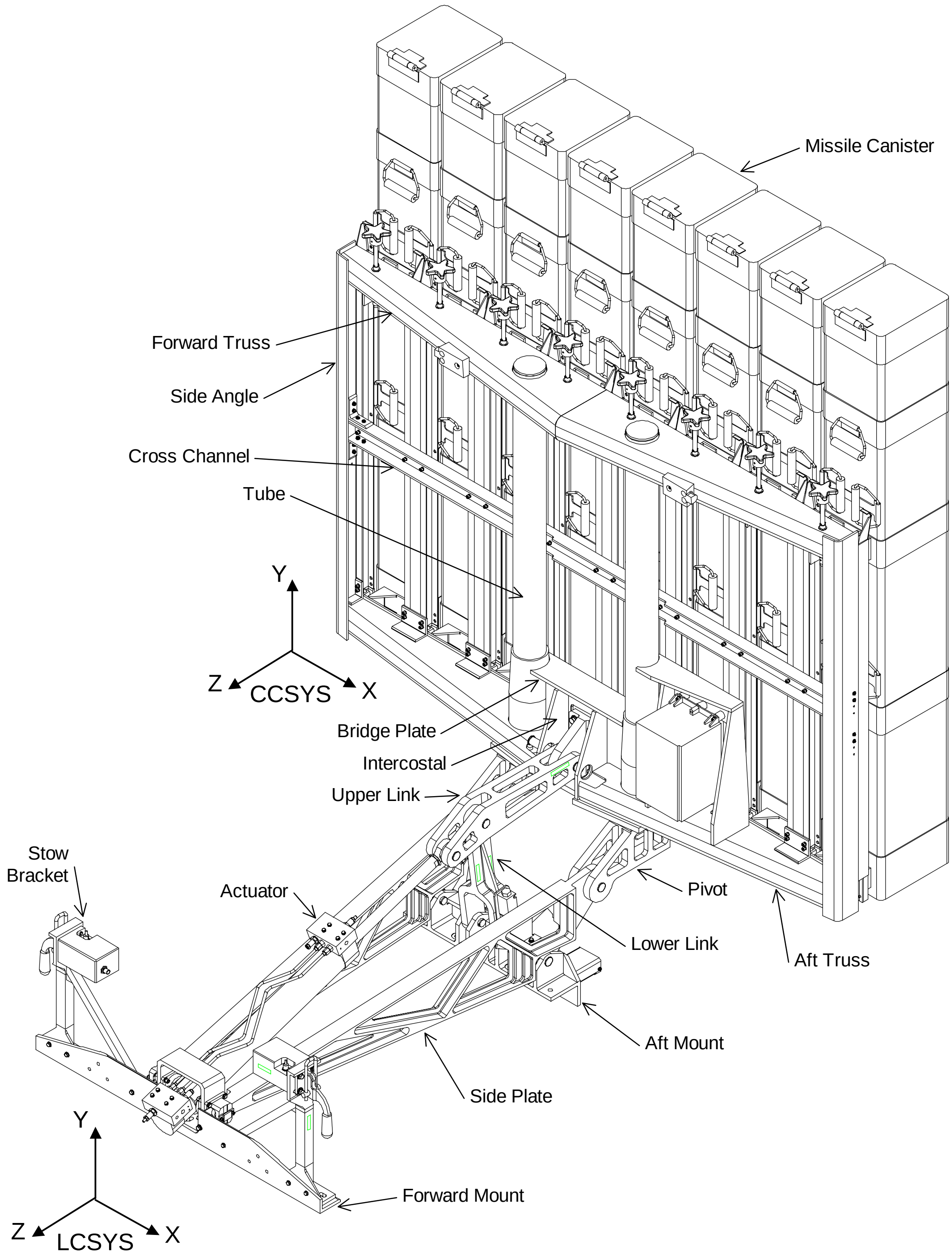


Figure 4-1 EFOGM Launcher Assembly view

The spacing between the missile canisters on the carriage is 10.793 inches. The Launcher coordinate system (LCSYS) shown in Figure 4-1 does not necessarily correspond to any coordinate system defined for the HMMWV vehicle. It is simply the absolute coordinate system in the current ProE and Femap models, used to define and analyze the assembly. The Carriage coordinate system (CCSYS), shown in Figure 4-1, is the

NASTRAN results output CSYS for the components that form the Carriage, and rotates with the Carriage when it is moved to the Stow, fire, or Reload positions.

4.2 Design Requirements and Criteria

4.2.1 General Criteria

It is generally recommended that the limit bearing stress in Teflon lined bearings not exceed 25 ksi.

Use a load equal to 10% of the axial load on lugs as a side load in the absence of a defined value.

Provide stiffeners where load paths change direction.

Any detrimental effect, due to the anticipated wear on parts, shall be included in Margin of Safety calculations.

4.2.2 Static Strength Requirements

No gross yielding at 1.15 x design limit load (DLL) and no failure at ultimate load. Ultimate load is defined as 1.5 x limit load. Limit load shall be the maximum and most critical combination of loads, which can result from authorized use of the launcher. No gross yielding at 3.0 x DLL and no failure at 5.0 x DLL for any single points of failure that could present a hazard to personnel. Detrimental affects of worn parts are included in M.S. calculations. No gross yielding at 5.0 x DLL and no failure at 8.0 x DLL for any single point of failure that could present a hazard to personnel, and is subject to wear.

For all hydraulic components; the burst pressure requirement shall be 4 times the limit operating pressure, and the proof pressure requirement shall be 1.5 times the limit operating pressure.

4.2.3 Deformation Requirements

The structural deformations at limit load shall not inhibit or degrade the mechanical operation of the launcher or cause bindings or interferences between adjacent structures.

Structural deformations at limit load shall not result in permanent buckling or yielding or excessive stresses, which would result in subsequent maintenance actions.

Maintenance in general, and especially maintenance which requires jacking and hoisting of the launcher must not result in structural deformations that result in permanent yielding. This requirement pertains to empty (weight) as well as a fully loaded launcher.

4.2.4 Fatigue Requirements

The launcher structure shall be designed to a crack initiation life (life to 0.01" flaw) of 5 service lifetimes. The one lifetime service environment is defined in ¶5.4 below.

4.3 Method of Analysis

4.3.1 Design Allowables and Material Data

Design allowables and material data used to determine margins of safety were developed from MIL-HDBK-5F.

4.3.2 Internal Loads Methodology

Internal loads are obtained from NASTRAN finite element models (FEM), MECHANICA AMotion models, and kinematic force balance equations. The NASTRAN models of the structure consist of relatively fine mesh Plate and Beam elements. A description of the FEM is given in ¶8.4 herein.

The load and stress distribution in critical joints is determined from refined solid element models of those joints, such as is shown in Figure 6-15 and Figure 6-20.

4.3.3 Stress Analysis Criteria / Methodology

4.3.3.1 Flat Webs

The buckling limit is determined with MSC/NASTRAN Solution 105 (SEBUCKL). A minimum of five grid points per half sine wave (buckled shape) is required. The buckling solution model of a Sideplate is shown in Figure 6-8. Large displacement affects are not included. Offsets in beam, plate, and shell elements can not be used. Solution 106 (NLSTATIC) can be used if it is required to include follower force on large displacement affects. The critical buckling load is equal to the applied load times the lowest eigenvalue.

4.3.3.2 Net section tension checks and principle stress checks

These checks have been done per standard engineering mechanics methods.

4.3.3.3 Plastic Bending and Combined Loading in the Plastic Range

The method of Cozzone (trapezoidal approximation of the non-linear stress-strain curve) is used for sections in bending. In cases where there is a combination of bending, axial, and shear loading; a factor of utilization value, U, is determined for each stress using the formula: U = Actual Stress / Allowable Stress. The final plastic margin of safety is computed using a formula of the form:

$$M.S. = \frac{1}{\sqrt{U_S^2 + U_B^2}} - 1$$

4.3.3.4 Lug ultimate strength

Lugs shall be analyzed for static strength per the following relationship for minimum R/D. This relationship is based on the combined hoop tension and bearing stress theory.

$$\frac{R}{D} = \frac{4 + 3 \cdot (F_{br} / F_{tu})}{8 - 2 \cdot (F_{br} / F_{tu})}$$ Test References: MAC TR 895, 987, 1171, 2113

Additionally the hoop tension stress, in the part of the lug affected by R, plus ¼ of the bearing stress shall not exceed F_{TU} for the proper grain direction.

Lug fixity effect on fasteners as well as gaps shall be taken into account and kept consistent between lug and pin analysis. Magnification of lug bearing stress due to fixity of lug shall be taken into account.

The following experimentally determined relationship for checking laterally loaded lugs shall be used. Multiplication of the axial allowable load of the lug by this correction factor gives the allowable load when the load is applied at an angle θ to the axis of symmetry, for θ between 0° and 90°.

$$\frac{P_\theta}{P_0} = 6.859 \cdot 10^{-7} \cdot \theta^3 - 9.259 \cdot 10^{-5} \cdot \theta^2 + 1$$ Test References: MAC TR 895, 987, 1171, 2388

4.3.3.5 Clevis joint ultimate strength

The design of bolts and pins used in lugs must be based on a consistent load distribution between the bolt and lug. For double shear joints, lugs can be proportioned for zero margin with a uniform bearing stress. Based on this assumption, the bolt bending moments can be determined, including any contribution due to washers, gaps (e), etc. Depending on these various factors, the bolt may be critical in either shear or bending. The basic parameters that must be known are the bolt heat treat, the allowable lug bearing stresses (per ¶4.3.3.4 above), the eccentricity between the lugs, and the amount of clamp-up. Allowable bolt bending moments are based on full plasticity. The allowable load is determined from the following equation.

$$\frac{P_{ALL}}{V_{ALL}} = 1.38 \cdot C \cdot \left\{ \frac{-\frac{e}{D} + \sqrt{\left(\frac{e}{D}\right)^2 + .325 \cdot C \cdot F_{tu} \cdot \left[\frac{1}{F_{br_1}} + \frac{1}{F_{br_2}}\right]}}{.325 \cdot C \cdot F_{TU} \cdot \left[\frac{1}{F_{br_1}} + \frac{1}{F_{br_2}}\right]} \right\}$$

C=1.00	unclamped
C=1.5	shear nut
C=1.8	tension nut

4.3.3.6 Clevis joint fatigue strength

Typically the stress will peak near the edge of the lug due to pin bending. The mono-ball bearing in the center lug of the EFOGM clevis joints eliminates the peaking on the center lug. This is because the ball is thicker and stiffer near the midplane, and the race is relatively thin. This is shown in both a NASTRAN 2D slide line model (Figure 8-21) and also in a Mechnica MStruct model (Figure 6-15).

4.3.3.7 Flanges loaded in compression

The only flanges on the EFOGM structure loaded in compression are those on the sideplates. These are relatively thick and are not subject to local crippling.

4.3.3.8 Column stability

Either NASTRAN SEBUCKL or standard engineering mechanics methods are used to determine column stability.

4.3.3.9 Beam Column

Beam column bending is the result of the compression load acting on the deflected or "bowed" column. The bending moment at any point along the column is equal to the compression load multiplied by the displacement of that point away the load line. This secondary effect is determined with the NASTRAN NLSTATIC solution, after initial offsets are incorporated into the model.

5. External Loading Conditions

Table 5-1 EFOGM Launcher Design Load Conditions

Cond.	Longitudinal Load (Nz)	Lateral Load (Nx)	Vertical Load (Ny)	Actuator Force	Launcher State	Missile Load
1	0 g	0 g	– 1.0 g	F_{ext} limit extend	Stowed	Full
2	0 g	0 g	– 1.0 g	F_{ext} limit extend	Stowed w/ +X latch only	Full
3	0 g	0 g	1 g	F_{ret} limit retract	Stowed	Full
4	+ 8.0 g	0 g	0 g	F_{ret} limit retract	Stowed	Full
5	– 8.0 g	0 g	0 g	F_{ret} limit retract	Stowed	Full
6	0 g	0 g	2.0 g	F_{ret} limit retract	Stowed	Full
7	0 g	0 g	– 4.5 g	F_{ret} limit retract	Stowed	Full
8	0 g	1.5 g	0 g	F_{ret} limit retract	Stowed	Full
9	+ 20 g peak, 200 ms, ½ sin pulse	0 g	0 g	F_{ret} limit retract	Stowed	Full
10	– 20 g peak, 200 ms, ½ sin pulse	0 g	0 g	F_{ret} limit retract	Stowed	Full
11	0 g	0 g	0.79" Δ @ Fwd Mount	F_{ret} limit retract	Stowed	Full
12	+ 8.0 g	0 g	0 g	Removed	Stowed	Full
13	0 g	+ 1.5 g	0 g	Removed	Stowed	Full
14		+ 1.5 g	0 g	Removed	Stowed w/ no lateral latch	Full
15	0 g	+ 1.5 g	0 g	Removed	No -X latch	Full
21	+ 15.0 g	+ 1.0 g	+ 2.0 g	F_{ret} limit retract	Stowed	None
22	– 15.0 g	+ 1.0 g	+ 2.0 g	F_{ret} limit retract	Stowed	None
23	+ 15.0 g	+ 1.0 g	– 2.0 g	F_{ret} limit retract	Stowed	None
24	– 15.0 g	+ 1.0 g	– 2.0 g	F_{ret} limit retract	Stowed	None
25	+ 5.0 g	+ 3.0 g	+ 2.0 g	F_{ret} limit retract	Stowed	None
26	– 5.0 g	+ 3.0 g	+ 2.0 g	F_{ret} limit retract	Stowed	None
27	+ 5.0 g	+ 3.0 g	– 2.0 g	F_{ret} limit retract	Stowed	None
28	– 5.0 g	+ 3.0 g	– 2.0 g	F_{ret} limit retract	Stowed	None
29	+ 5.0 g	+ 1.0 g	+ 3.0 g	F_{ret} limit retract	Stowed	None
30	– 5.0 g	+ 1.0 g	– 3.0 g	F_{ret} limit retract	Stowed	None
31	+ 5.0 g	+ 1.0 g	– 6.0 g	F_{ret} limit retract	Stowed	None
32	– 5.0 g	+ 1.0 g	– 6.0 g	F_{ret} limit retract	Stowed	None
33	0 g	0 g	– 40.0 g	Removed	Stowed	None
40	+29 m/s wind	+29 m/s wind	– 1.0 g	F_{sup}	85 deg.	Full
41	+29 m/s wind	+29 m/s wind	– 875#, 25ms	F_{sup}	85 deg.	Full
42	+29 m/s wind	+29 m/s wind	– 2460#, 20ms	F_{sup}	85 deg.	4 Full 4 Empty
43	+29 m/s wind	+29 m/s wind	– 875#, 25ms	F_{sup}	55 deg.	Full
44	+29 m/s wind	+29 m/s wind	– 875#, 25ms	F_{sup}	125 deg.	Full
50	0 g	0 g	– 1.0 g	F_{sup}	Max retract force angle	Full
51	0 g	0 g	– 1.0 g	Removed	Reload on stops	Full w/1 man
52	0 g	0 g	– 1.0 g	F_{sup}	Reload	4 Full

Cond.	Longitudinal Load (Nz)	Lateral Load (Nx)	Vertical Load (Ny)	Actuator Force	Launcher State	Missile Load
						w/1 man
62	Table 5-3 PSD	0 g	0 g	Removed	Stowed	Full
63	0 g	Table 5-3 PSD	0 g	Removed	Stowed	Full
64	0 g	0 g	Table 5-3 PSD	Removed	Stowed	Full

Environmental requirements per Raytheon Environmental Specification for EFOGM FU and PLV (G602480 Part 2 of 2). The X, Y, & Z directions referred to herein are defined by the Launcher coordinate system shown in Figure 4-1.

5.1 General

The launcher shall input less than 35 g, 5 ms impulse when impacting the Stow or Reload stops or stopping at any other angle.

5.2 Shock

5.2.1 Crash safety

A crash safety load of 20 g peak, 200 ms half-sine shock pulse along the vehicle's longitudinal axis with fully or partially loaded launcher and canisters.

5.2.2 Rail hump

The rail hump 35 g peak, 5 ms, half-sine pulse is only used for lighter weight equipment mounted to the launcher structure. The Patriot ECS quasistatic loads in each row of Table 5-2 act simultaneously, and are used for the heavier components of the structure.

Table 5-2 Patriot ECS quasistatic loads

	Long	Lat	Vert
Max Long	±15.0 g	±1.0 g	±2.0 g
Max Lat	±5.0 g	±3.0 g	±2.0 g
Max Vert	±5.0 g	±1.0 g	+3.0 g, -6.0 g

5.2.3 Missile firings

Missile firings can occur at any launcher angular position from 55° to 125° defined as the "Safe to Fire" window. The load imparted to the launcher by a missile firing is 875# peak, 25 ms, half-sine pulse.

5.2.4 Parachute drop

A 20g, 54ms, square wave pulse is specified for the unpopulated EFOGM Launcher Parachute Drop Case. The maximum amplification of a single degree of freedom system, for cases where the ratio of pulse duration (τ) to structural natural period (T) is greater than one, is 2.0. The vertical launcher structure modes observed, with 8 fully loaded canisters, are at 24Hz. The relative frequency of the empty carriage to the truck bed should be at a higher frequency, which is a shorter period than the square pulse frequency. In these cases the Shock And Vibration Handbook, by Harris, Fig8-15 shows the maximum amplification for the square wave input to be 2.0.

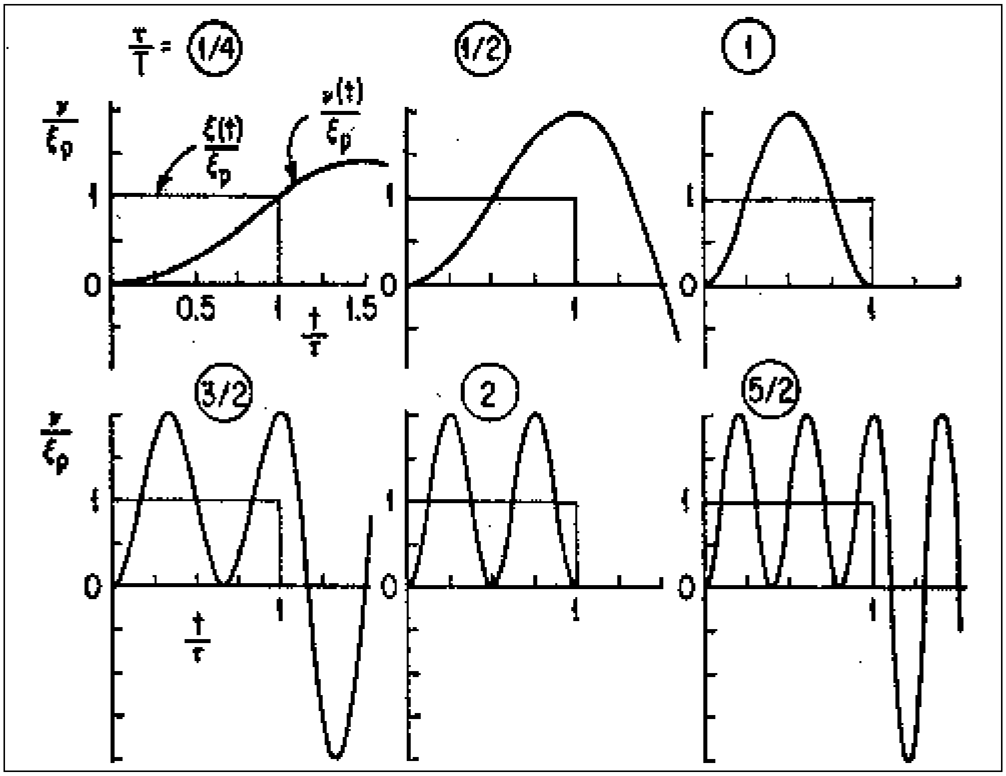


Figure 5-1 Shock and Vibration Handbook Fig 8-15

A new load Cond. 33 is made with a 40g body force down along the N_Y axis. The condition was run without any canisters. This conservatively represents the worst case for any particular mode in the multi DOF model of the structure. The joint forces were extracted and listed in Table 6-1. The body stresses are plotted in Figure 8-25.

5.3 Static

A 1 g vertical load is applicable for all launcher position angles.

5.3.1 Personnel

Personnel walk on loads of 200# limit applied anywhere on a canister in the "reload" position shall be added to the canister weight.

5.3.2 Missile weight

Each of the 8 missile canisters have a weight of 174# loaded and 67# empty. The center of gravity (CG) for the loaded canister is 43.36" ± 2.2" from the aft end of the canister when in the "stow" position.

5.3.3 Actuator force

The extend and retract actuator limit loads are applied to the structure in the stow, just off stow, reload, and just off reload positions. The actuator limit pressure is 2100 psi. The piston OD is 3.25 in and the rod OD is

1.375 in. This produces a limit retract force of 14303 # and a limit extend force of 17421 #. A pressure compensated flow control valve maintains the actuator extend and retract velocity at 0.44 "/sec. There are check valve "cushions" at the end of the actuator stroke in both directions. Hydraulic pressure is required to drive through the "cushions" to meet the stow stop, which leave a residual limit retract force in the actuator at the stow position.

5.3.4 C130 Transport aircraft

The C130 transport environment (AMCP 706-130 / MIL-STD-1791) is 8.0 g forward, 8.0 g aft, 2.0 g up, 4.5 g down, and ±1.5 g lateral acting non-concurrently on the unloaded and stowed launcher structure. **Note:** All analysis herein was done using a full compliment of missiles to generate loads based on the requirements of this paragraph.

5.3.5 Wind

A 29 *m/s* wind gust load is applied simultaneously in any lateral direction. The pressure drag coefficient for a flat rectangular plate, normal to the flow, is $C_D = 1.2$ (Ref. 3). The force due to drag is $F_D = C_D \cdot q \cdot A$ where $q = \frac{1}{2} \cdot \rho \cdot V^2$. The value for ρ for sea-level air is $1.225 \frac{kg}{m^3}$, and thus the value for *q* at the 29 *m/s* air speed is $q = \frac{1}{2} \cdot 1.225 \cdot 29^2 = 515.1 \frac{kg}{m \cdot s^2}$. The front area of the launcher canisters is 4.56 m^2, and the side area is 0.633 m^2.

The front drag force is then $F_D = 1.2 \cdot 515.1 \cdot 4.56 = 2819\,N = 634\#$.

The side drag force is $F_D = 1.2 \cdot 515.1 \cdot 0.633 = 391\,N = 88\#$.

The frictional drag coefficient, even assuming turbulent flow, is at most 0.006, and will result in < 5 # force, and thus is not considered in the loads used herein.

The element XY face area is 6727.1 in^2 and the element YZ face area is 981.03 in^2. The pressure load placed on the elements is 0.094 psi on the XY face and 0.0897 psi on the YZ face.

5.4 Service life

Design life is 10 years with 200 stow-launch-reload cycles per year and also exposure to a 2 hour life random vibration listed in Table 5-3 Straight Line Collapsed PSD Ground Mobile Environment.

5.5 Vibration

Three ground random vibration environments; paved road, cross-country, and washboard, were collapsed into one environment using Minor's rule with an alpha factor of 2.4. This one environment is listed in Table 5-3 herein.

Table 5-3 Straight Line Collapsed PSD Ground Mobile Environment

Vertical Axis 2 hrs - 2.5 grms		Longitudinal Axis 2 hrs - 1.3 grms		Transverse Axis 2 hrs - 1.6 grms	
5	0.0800	5	0.0200	5	0.0200
7	0.1200	7	0.0300	10	0.0700
8	0.4000	10	0.1600	13	0.0500
10	0.4400	11	0.0400	17	0.0160
15	0.0300	15	0.0160	20	0.1300
16	0.0700	16	0.0500	21	0.0200
20	0.0400	20	0.0500	24	0.0200
21	0.0200	23	0.0070	30	0.1000
23	0.0200	30	0.0350	31	0.0150
24	0.0500	31	0.0050	37	0.0120
30	0.0750	38	0.0030	40	0.0500
31	0.0200	40	0.0150	50	0.0080
39	0.0170	73	0.0030	100	0.0020
52	0.0400	138	0.0004	500	0.0020
64	0.0300	200	0.0010		
200	0.0040	500	0.0015		

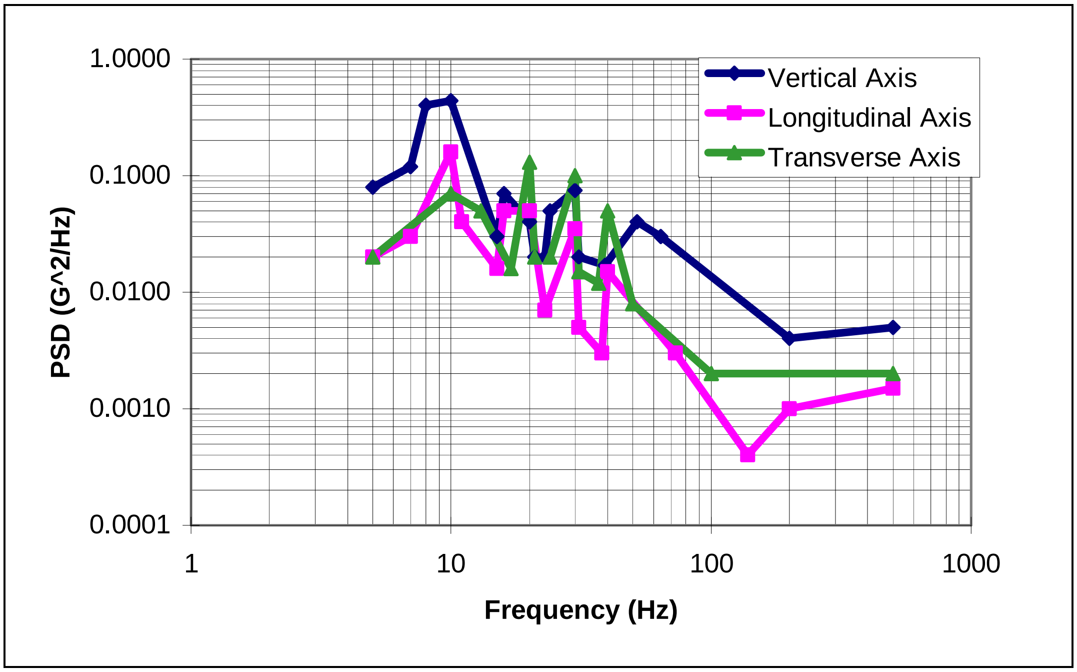


Figure 5-2 Ground Mobile Environments & Collapsed PSD

5.6 Temperature

Room temperature aluminum and steel material properties used for structural analysis.

6. Internal Loads and Component Capacity

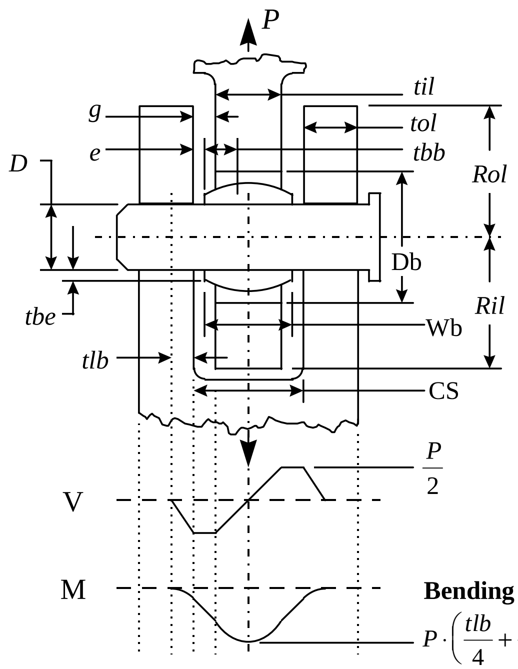
6.1 Interface Loads For Selected Design Conditions

Table 6-1 Latch and Clevis Loads

Latch and Pivot Force Resultants	Location	RMS Cond.	Force #	Freq Hz	Inertia Cond.	Force #	Shock Cond.	Force #
Vertical input load	Canister Latch	64	1258	28.8	7	664		N/A
Lateral input load	Canister Latch	63			8			N/A
Longitudinal input load	Canister Latch				5	1426		
Longitudinal input load	Canister Latch	62	910	12.4	4	1428	9	4350
Vertical input load	Aft Canister	64			7			N/A
Lateral input load	Aft Canister	63			8			
Vertical input load	Stow Latch	64	3040	23.8	7	3524		N/A
Vertical input load	Stow Latch				33	3083		
Longitudinal input load	Stow Latch				5	1819		
Longitudinal input load	Stow Latch	62	1320	10.5	4	3125	9	7259
Vertical input load	Pivot F	64	1079	20.0	7	1181		N/A
Vertical input load	Pivot F				33	4587		
Longitudinal input load	Pivot F				52	1487		
Longitudinal input load	Pivot F				5	7050		
Longitudinal input load	Pivot F	62	4177	10.6	4	8923	9	22182
Vertical input load	Pivot A - SP	64	983	20.7	7	7623		N/A
Vertical input load	Pivot A - SP				1	8069		
Longitudinal input load	Pivot A - SP				3	7945		
Vertical input load	Pivot A - SP				33	5543		
Longitudinal input load	Pivot A - SP				5	13501		
Longitudinal input load	Pivot A - SP	62	3540	10.5	4	2588	9	18478
	Pivot A - LL							
Longitudinal input load	Pivot A - LL	62	466	11.3	3	9696		
Vertical input load	Pivot B	64	178	22.9	7	9490		N/A
Vertical input load	Pivot B				1	8162		
Longitudinal input load	Pivot B				5	4174		
Vertical input load	Pivot B				33	1553		
Longitudinal input load	Pivot B	62	2078	10.4	4	6909	9	9326
Vertical input load	Pivot D	64	N/A		7	12041		N/A
Vertical input load	Pivot D				1	14784		
Longitudinal input load	Pivot D				5	12074		
Longitudinal input load	Pivot D				3			
Longitudinal input load	Pivot D	62	N/A		4	12173		

The locations of "Pivots A through F", referenced above, are shown in Figure 8-1 on page 8-1.

6.2 Clevis joints Ultimate Strength



Joint strength is generally limited by the pin bending allowable for compression and by inner lug bearing allowable for tension. Pin bending is minimized by considering only the portion of the outer lugs that are in bearing (*tlb*).

Compression

$$tlb = \frac{P}{2 \cdot D \cdot F_{Bru}}$$

Tension

$$tlb = \frac{P \cdot (2 \cdot Rol + 3 \cdot D)}{8 \cdot D \cdot F_{tu} \cdot (2 \cdot Rol - D)}$$

Lug bearing allowable

$$F_{br} = 4 \cdot F_{tu} \cdot \frac{(2 \cdot R - D)}{(2 \cdot R + 3 \cdot D)}$$

Bending moment

$$P \cdot \left(\frac{tlb}{4} + \frac{g}{2} + \frac{til}{8} \right) \text{Ultimate}$$

Figure 6-1 Clevis joint geometry and ultimate strength

The pivot bearing locations, labeled A through F in Table 6-2 and Table 6-3 are shown on the structure in Figure 8-1 on page 8-1. The forces on these clevis joints, for the various loading conditions, are summarized in Table 6-1 on page 6-1.

All of the joints meet the required ultimate factor of safety, as outlined in ¶4.2.2, except for the actuator rod end (joint C) which has a factor of safety equal to 4.6 when loaded per Cond. 1. This rod end is the largest reasonable standard part available for this application.

Table 6-2 Clevis Joint Ultimate Strength Factor of Safety

Clevis	A_SP	A_SP	A_SP	A_LL	A_LL	B	B	C	C	D	D	D	E	F	F	F
Load Cond	1	5	10	3	50	1	7	1	3	50	1	3	50	4	10	5
Inner Lug	Tension	Comp.	Tension	Tension	Comp.	Tension	Comp.	Comp.	Tension	Comp.	Comp.	Tension	Tension	Comp.	Tension	Tension
Outer Lug	Tension	Tension	Tension	Tension	Comp.	Tension	Tension	Comp.	Tension	Tension	Tension	Tension	Tension	Tension	Tension	Tension
Limit	8069	13501	13011	9696	7720	8162	9490	17421	14303	14097	14784	12141	10013	8923	16091	7050
Ult	12104	20252	19517	14544	11580	12243	14235	26131	21455	21146	22176	18212	15020	13385	24136	10575
PtP0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.91	1.00	1.00	1.00	1.00	1.00	0.75	0.75	0.75
tlb	0.180	0.301	0.290	0.216	0.086	0.120	0.139	0.195	0.192	0.135	0.141	0.116	0.134	0.093	0.168	0.073
M_Ult	2663	5070	4833	2932	1958	2953	3502	7758	6351	5206	5496	4399	3789	4075	7800	3168
Fbr All. Inner	32983	67000	32983	25455	67000	24191	24191	37230	37230	67000	67000	29559	42462	67000	28206	28206
Fbr All. Outer	33600	33600	33600	33600	67000	81846	81846	67000	56000	78400	78400	78400	56000	72000	72000	72000
MS Pin	10.5	5.0	5.3	9.4	14.6	9.3	7.7	2.9	3.8	4.9	4.5	5.9	7.0	6.5	2.9	8.6
MS IL	2.8	3.6	1.4	2.1	9.1	0.8	0.5	2.1	2.7	6.2	5.9	2.7	6.5	9.6	1.5	4.7
MS OL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Criteria	Lug Brg	Lug Brg	Lug Brg	Lug Brg	Lug Brg	Lug Brg	Lug Brg	Lug Brg	Lug Brg	Pin Bnd	Pin Bnd	Lug Brg	Lug Brg	Pin Bnd	Lug Brg	Lug Brg
FS	5.7	6.9	3.5	4.6	15.2	2.7	2.3	4.6	5.6	8.8	8.3	5.5	11.3	11.2	3.7	8.5
Reqd. FS	1.5	1.5	1.5	1.5	1.5	1.5	1.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	1.5	5.0

	P_Ult
RodEnd -16	80300
RodEnd -8	21900

	M_All. (psi)
Pin	30500

6.3 Clevis Joints Fatigue Strength

The peaking factor due to pin bending is Kt(p) = 1.1 for the inner lug and Kt(p) = 2.50 for the outer lug. The method used to determine these values is discussed in ¶8.9.2 on page 8-22. A 3D Mechanica FEA (Figure 6-15, Figure 6-16, & Figure 8-4) is used to determine the peaking factor for the Aft Mount female lugs. The resulting Kt_Lug = 28ksi / 7.2ksi = 3.89 which is less than that obtained using a Fatigue Analysis Handbook, in some cases.

The Damage Fraction (DF) contributed by each load case for each lug is calculated and listed. Then the fatigue M.S. for lug is determined with a Minor's summation where M.S. = 1/∑DF - 1.

Table 6-3 Clevis Joints Fatigue Life Margin of Safety

	Clevis	A_SP	A_SP	A_LL	A_LL	B	C	C	D	D	E	F
	Cond	62	3	62	3	62	3	50	3	50	50	62
	Outer Lug	Tension	Tension	Tension	Tension	Tension	Tension	Tension	Tension	Tension	Tension	Tension
	Inner Lug	Tension	Comp.	Tension	Tension	Tension	Tension	Tension	Tension	Comp.	Tension	Tension
	RMS Load	3540	7945	466	9696	2078	14303	12600	12141	13601	10512	4177
	Frequency	11.08	0.00	11.30	0.00	10.40	0.00	0.00	0.00	0.00	0.00	10.58
	5 Life Cycles	398802	10000	406817	10000	374338	10000	10000	10000	10000	10000	381038
Inner	KtBearing	3.07	3.07	3.92	3.92	1.00	1.00	1.00	3.55	3.55	2.37	3.57
Inner	Kt_phi	1.27	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Inner	Kt_Lug	4.30	3.37	4.31	4.31	1.00	1.00	1.00	3.90	3.90	2.61	3.92
Inner	S_brg	2528	5675	266	5540	2295	6631	5842	5337	5979	3957	1966
Inner	Kt*S	10873	19148	1147	23872	2295	6631	5842	20816	23319	10317	7715
Inner	Cycles to fail	many	many	many	190991	many	many	many	many	many	many	many
Inner	Damage fraction	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inner	MS	large	large	large	18.10	large	large	large	large	large	large	large
Outer	KtBearing	2.29	2.29	2.29	2.29	1.34	1.80	1.80	1.38	1.38	1.80	1.47
Outer	Kt_phi	1.27	1.00	1.27	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.27
Outer	Kt(p)	1.51	1.51	1.51	1.51	2.53	2.30	2.30	2.53	2.53	2.30	2.50
Outer	Kt_Lug_Hdbk	4.41	3.46	4.41	3.46	3.39	4.15	4.15	3.50	3.50	4.15	4.68
Outer	Kt_Lug_RASNA	3.89	3.89	3.89	3.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Outer	S_brg	2832	6356	466	9696	2418	7152	6300	6071	6801	5256	2089
Outer	Kt*S	11015	21981	1812	33532	8201	29673	26140	21236	23791	21807	9782
Outer	Cycles to fail	many	many	many	8009	many	23311	77966	many	197612	many	many
Outer	Damage fraction	0.00	0.00	0.00	1.25	0.00	0.43	0.13	0.00	0.05	0.00	0.00
Outer	MS	large	large	large	-0.20	large	1.33	6.80	large	18.76	large	large

Kt(p) Inner Lug: 1.1

		Fat. Load
C:	RodEnd-16:	30400
B:	RodEnd-8:	7680

Kt(lug) = Kt(brg) * Kt(phi) * Kt(p)
Kt(brg): Lug stress gradient due to axial loading
Kt(phi): Off axis loading correction factor
Kt(p): Peaking factor due to pin bending and spherical ball effects

The inner edges of the female lugs on the AftMount (Figure 6-15), where the LowerLink attaches, have a fatigue life less than 10,000 cycles when the full Limit Retract Actuator Force is applied. However test have shown that this load level is not observed (Figure 8-26 on page 8-26) during the operation of the Carriage. The actual residual pressure is approximately 1/3 of the limit pressure, and therefore the Aft Mount will have a large Margin of Safety for fatigue.

6.4 Base Structure

Table 6-4 Base Structure Margins of Safety

Drawing No.	Description	M.S.	Failure Mode	Cond.	Stress psi	Freq. Hz
G670026	Sideplate Assy - upper aft corner	0.18	Limit	4*	29762	0.0
G670026	Sideplate Assy - upper aft corner	0.34	Fatigue	62	16599	10.5
G670026	Sideplate Assy		Buckling			
G670074	Reload Stop	7.60	Limit	51	4071	0.0
G670082	Stow Stand vertical leg near base	1.38	Limit	4*	-14700	0.0
G670082	Stow Stand inboard leg near base	0.85	Limit	5*	18899	0.0
G670082	Stow Stand inboard leg near base	0.38	Limit	15	25330	0.0
G670029-5	Forward Mount Angle near Actuator	0.83	Limit	5*	19130	0.0
G670029-5	Forward Mount Angle near Stow Stand	0.83	Limit	5*	19168	0.0
G670032	Upper Link	1.71	Limit	4*	12933	0.0

* Analysis reflects full compliment of canisters.

6.5 Sideplate assembly

6.5.1 Sideplate Fwd Rod-End

This ∅0.625 rod-end has a 573"# moment with 795# axial force for the Reload position Actuator limit load case. This ∅0.625 rod-end has a 3429"# moment with 9333# axial force for Cond 4, and a 2902"# moment with 2701# axial for "Cond 4 without Canisters". The bending allowable is 6250"#, leaving a large margin.

6.5.2 Sideplate machined aluminum frames

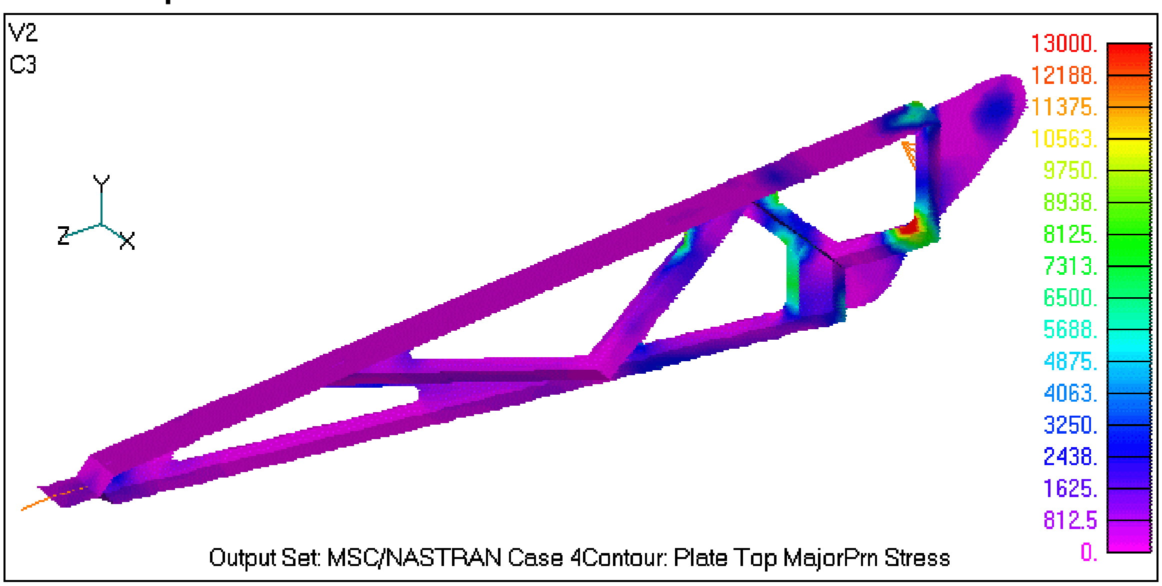


Figure 6-2 Sideplate with Actuator limit load, Stow position, 8g fwd. (Cond 4)

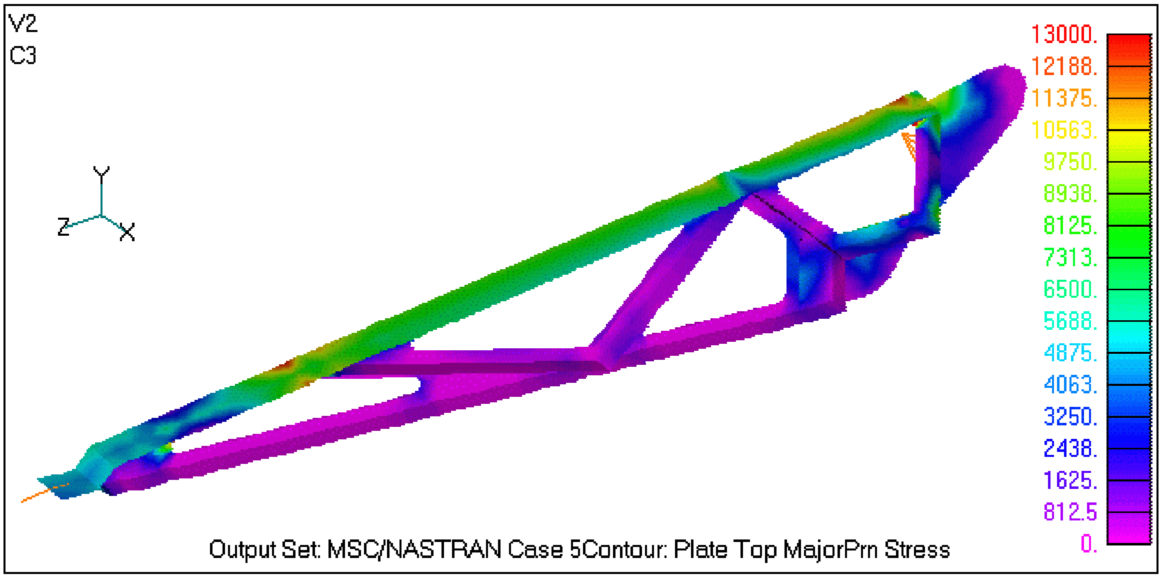


Figure 6-3 Sideplate with limit retract, stow position, 8g aft (Cond 5)

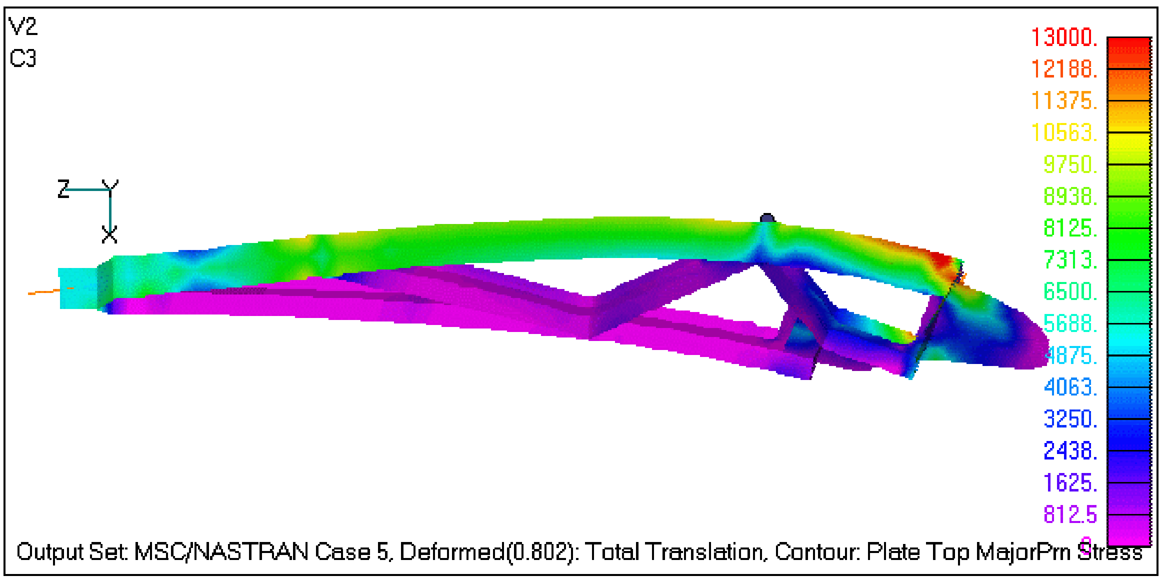


Figure 6-4 Sideplate without Actuator, stow position, 8g aft (Cond.≈5) - Top view

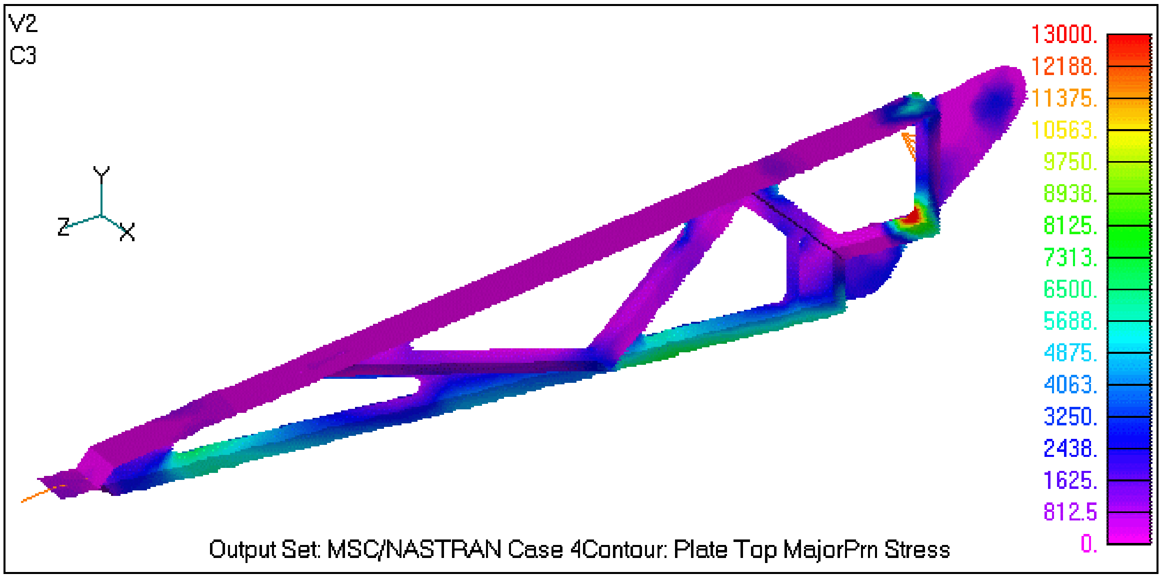


Figure 6-5 Sideplate without actuator, stow position, 8g fwd. (Cond. 12)

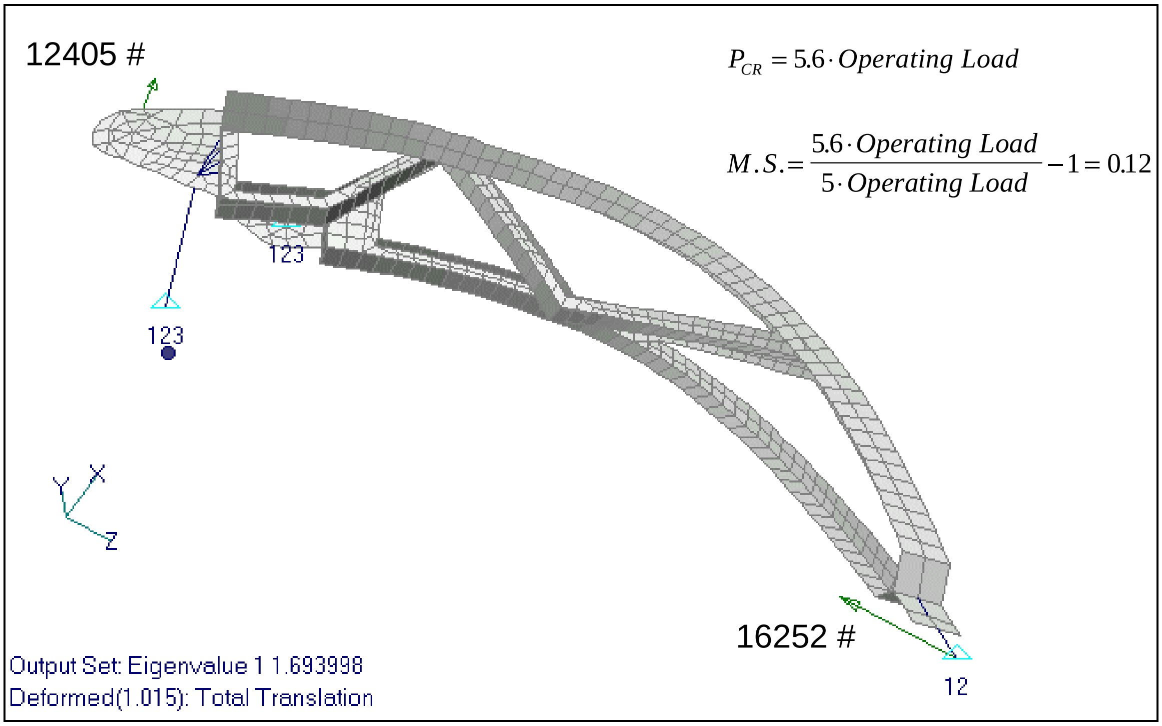


Figure 6-6 Sideplate first buckling mode in Reload position at Actuator limit load

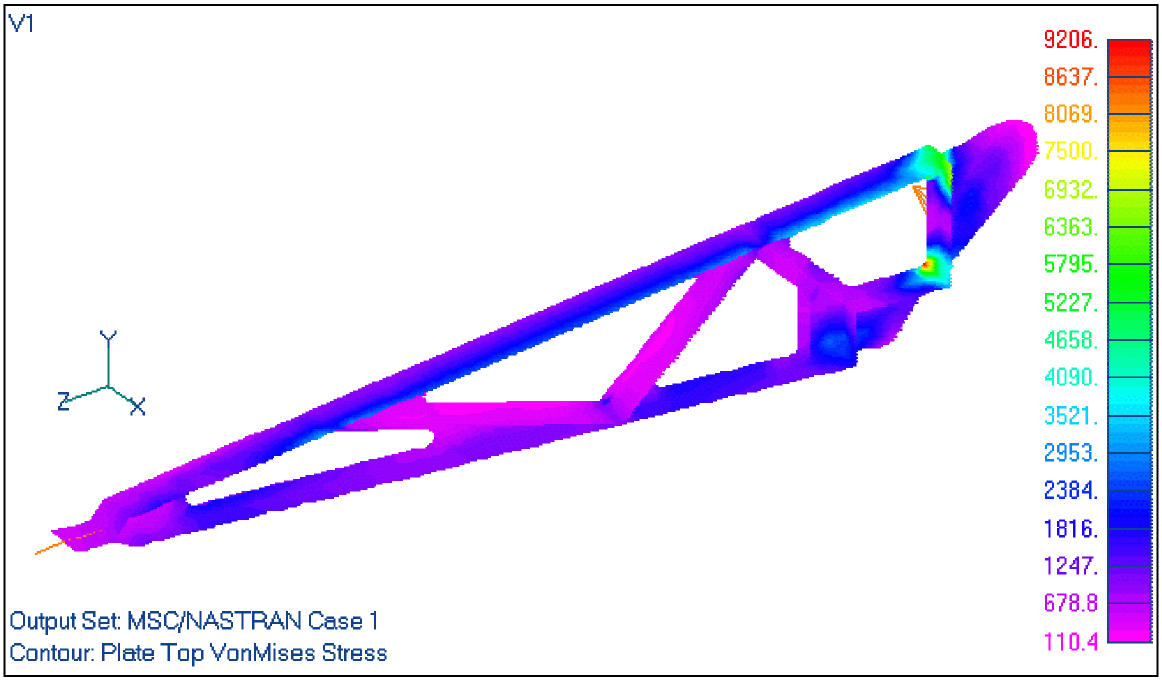


Figure 6-7 Sideplate Fatigue RMS stress for Vert. PSD input

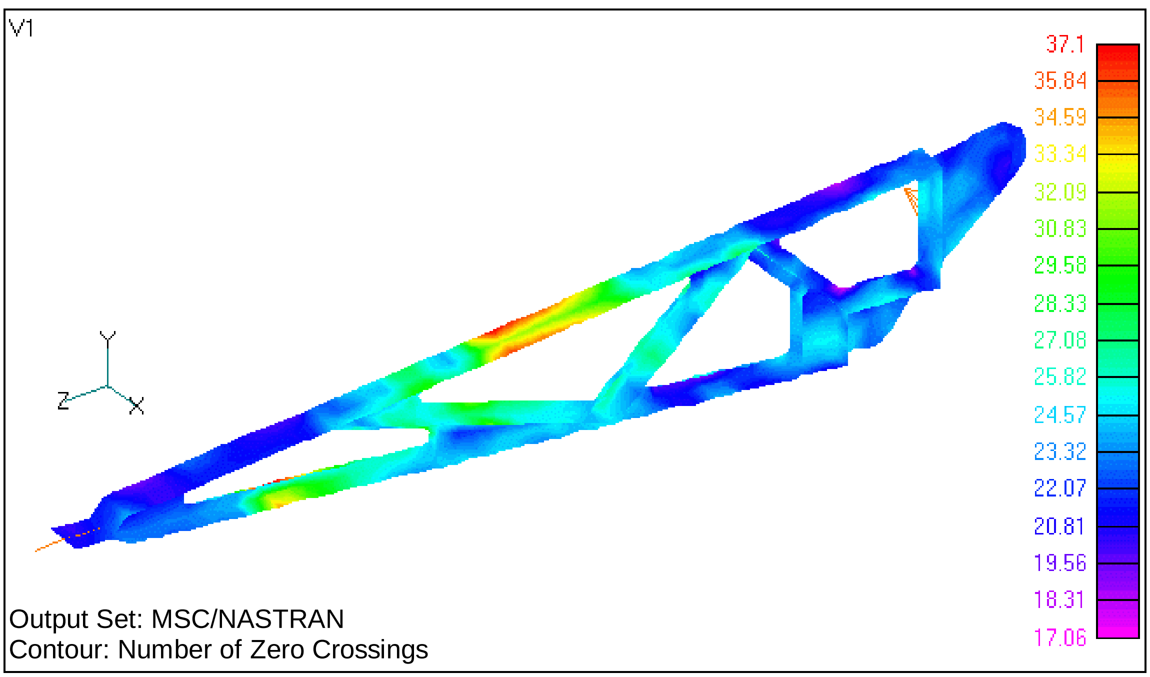


Figure 6-8 Sideplate Equiv. Frequency for Vert. PSD input

6.6 Side Brace adjustable rod

The axial force in this rod is 798# for the Reload position Actuator limit load case, 1154# compression for Cond 4, and 782# tension for Cond 5.

6.7 Lower Link

The analysis of the Lower Link lug ends is covered in the Clevis Joint analysis in ¶6.2 and ¶6.3.

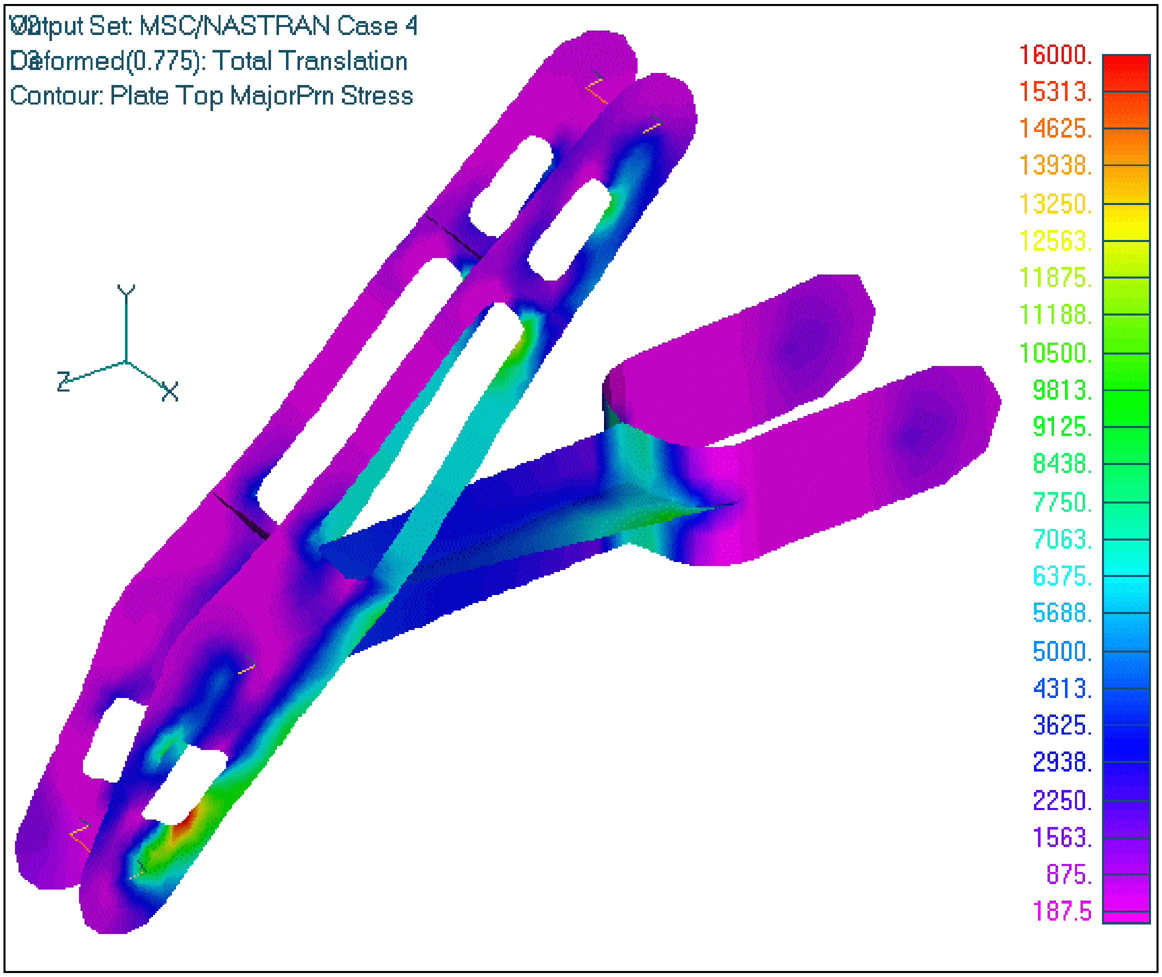


Figure 6-9 Links with Actuator limit retract load and 8g fwd. at Stow position

6.8 Upper Link

The analysis of the Upper Link lug ends is covered in the Clevis Joint analysis in ¶6.2 and ¶6.3. The stresses in the body of the Upper Link are well below the endurance limit for all of the load cases.

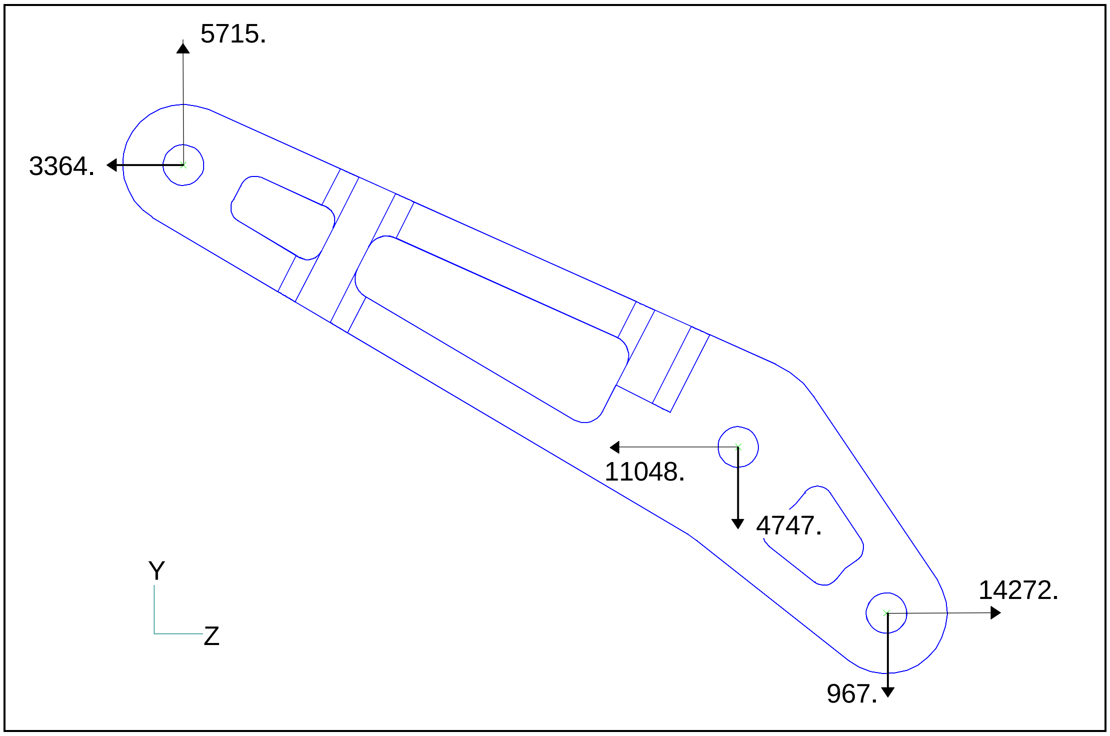


Figure 6-10 Upper Link at Cond. 4, Actuator limit load, 8g fwd. at Stow position

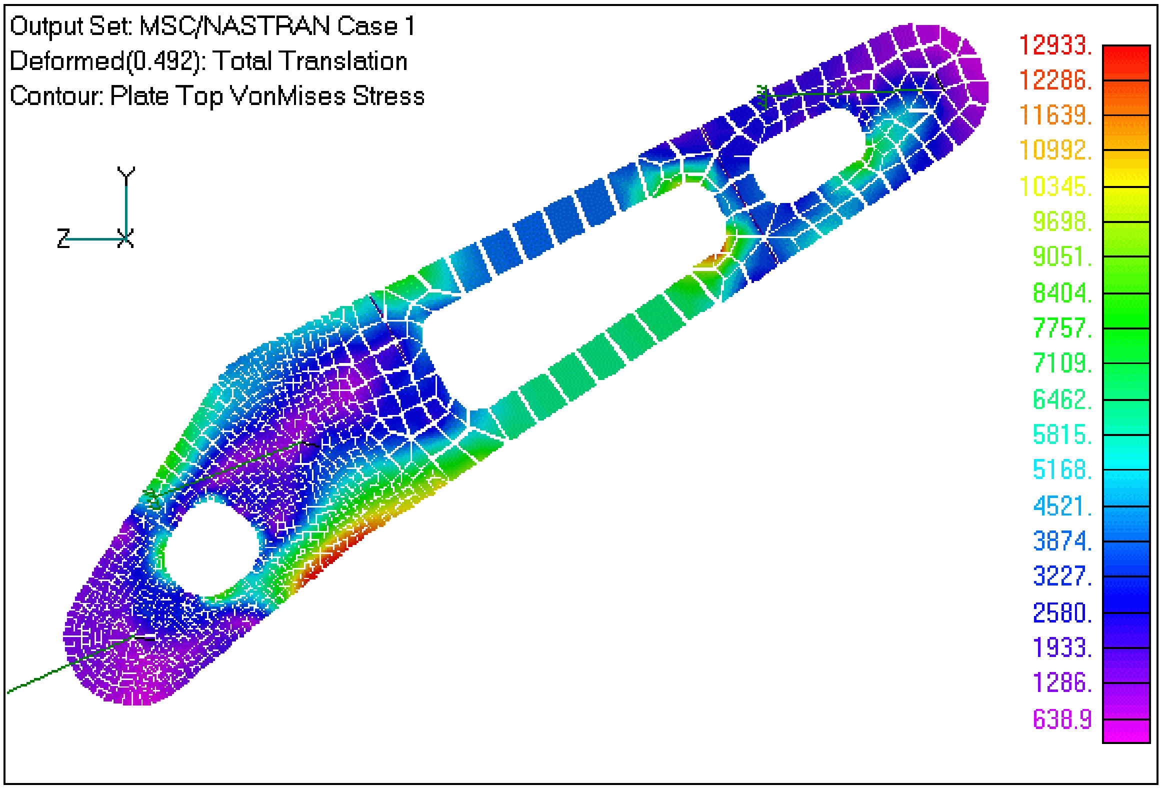


Figure 6-11 Upper link with larger radii and finer mesh for Cond. 4

6.9 Pivot

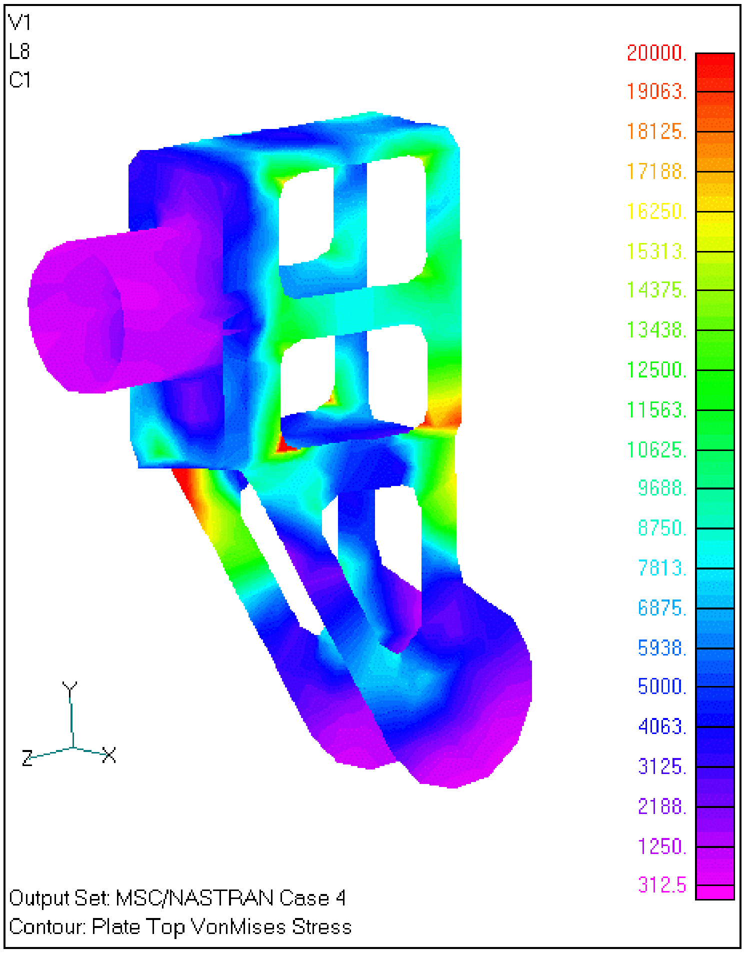


Figure 6-12 Pivot at Condition 4: 8g longitudinal

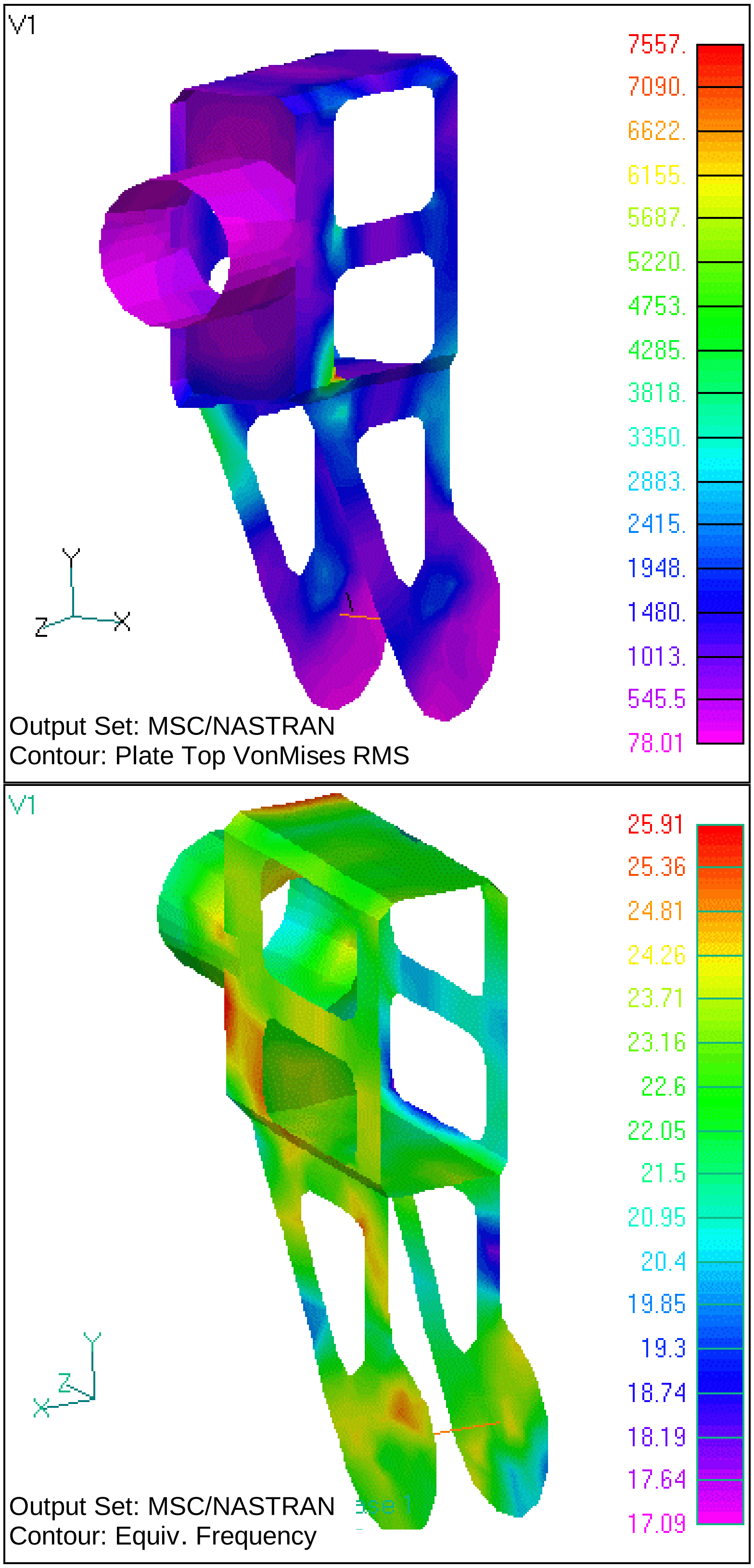


Figure 6-13 Pivot Fatigue RMS stress & Equiv. Frequency

6.10 Actuator

The actuator limit pressure is defined in ¶5.3 above. The center to center distance is 30.916" when retracted and is 57.53" when extended to the reload position. It is extended to approximately 43.37" at the neutral balance point. The following wall thickness is used for element stiffness in the FEM.

Approximate cylinder wall thickness based on hoop stress

$$s = q\cdot\frac{\left[(t+b)^2 + b^2\right]}{\left[(t+b)^2 - b^2\right]}$$

$$b := \frac{3.25}{2} \qquad b = 1.625 \qquad s := 50000 \qquad q := 3750$$

$$t := \frac{1}{(2\cdot(s-q))}\cdot\left(-2\cdot s\cdot b + 2\cdot q\cdot b + 2\cdot b\cdot\sqrt{s^2 - q^2}\right) \qquad t = 0.127$$

6.11 Aft Mount

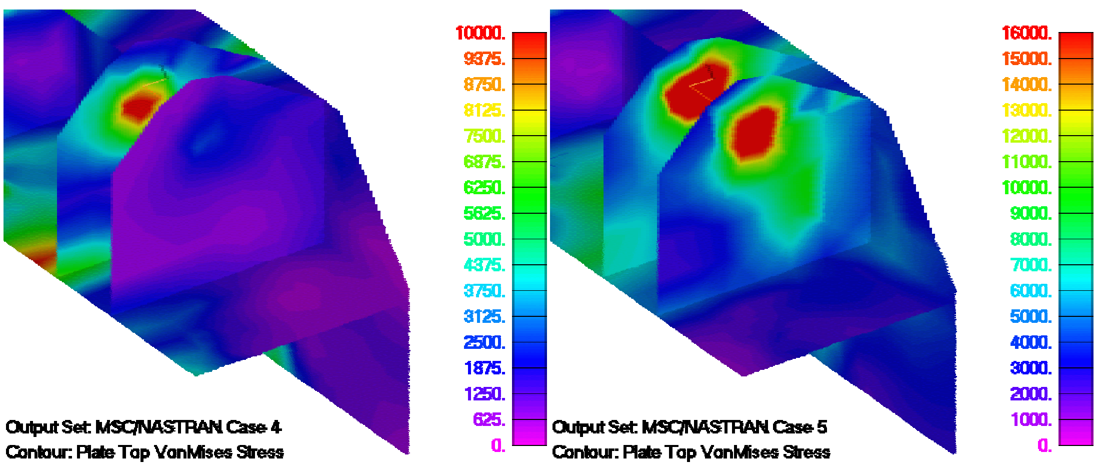


Figure 6-14 Aft Mount Lugs for Side Plate

6.11.1 Aft Mount Female Lug Peaking Factor

A Mechanica FEM, with 3D contact elements to represent the socket affect with pin bending, was used to determine the peaking for clevis A_SP. The "pin bending" peaking occurs at a location 90° from the "lug peaking" effect. Therefore the 3D Mechanica model is generally less conservative than the Fatigue Analysis handbook method. Some results of the Mechanica models are shown in the following figures.

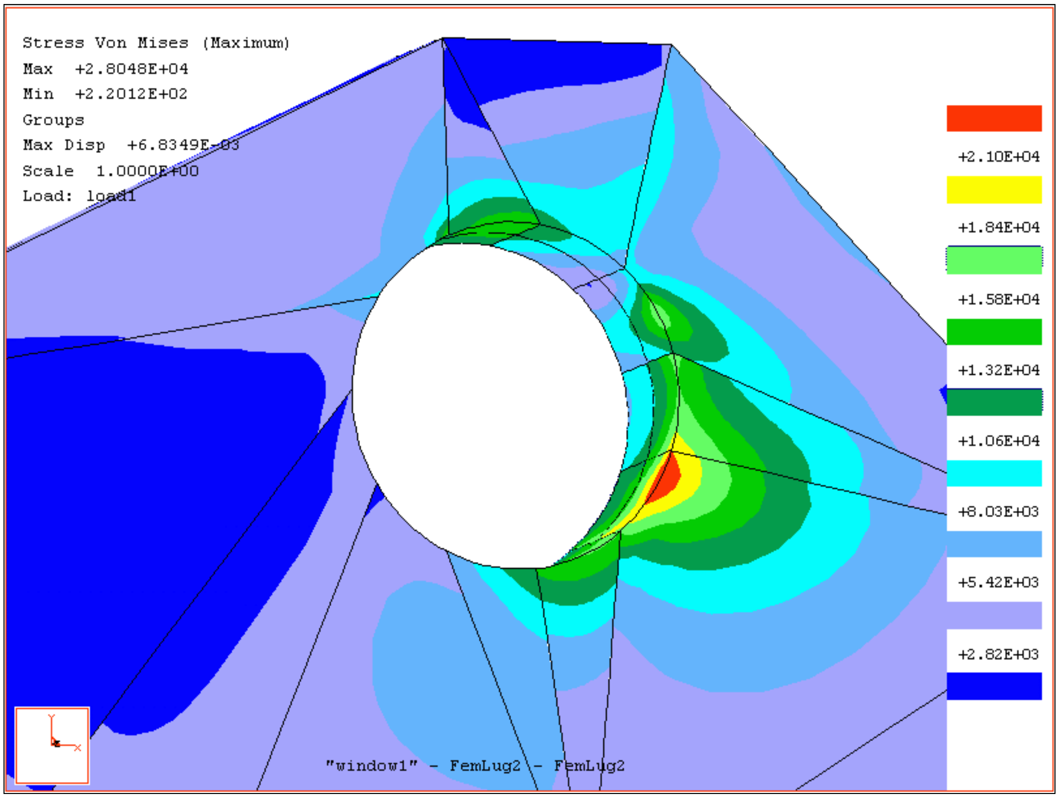


Figure 6-15 Clevis A_SP Mechanica FEA VonMises Stress

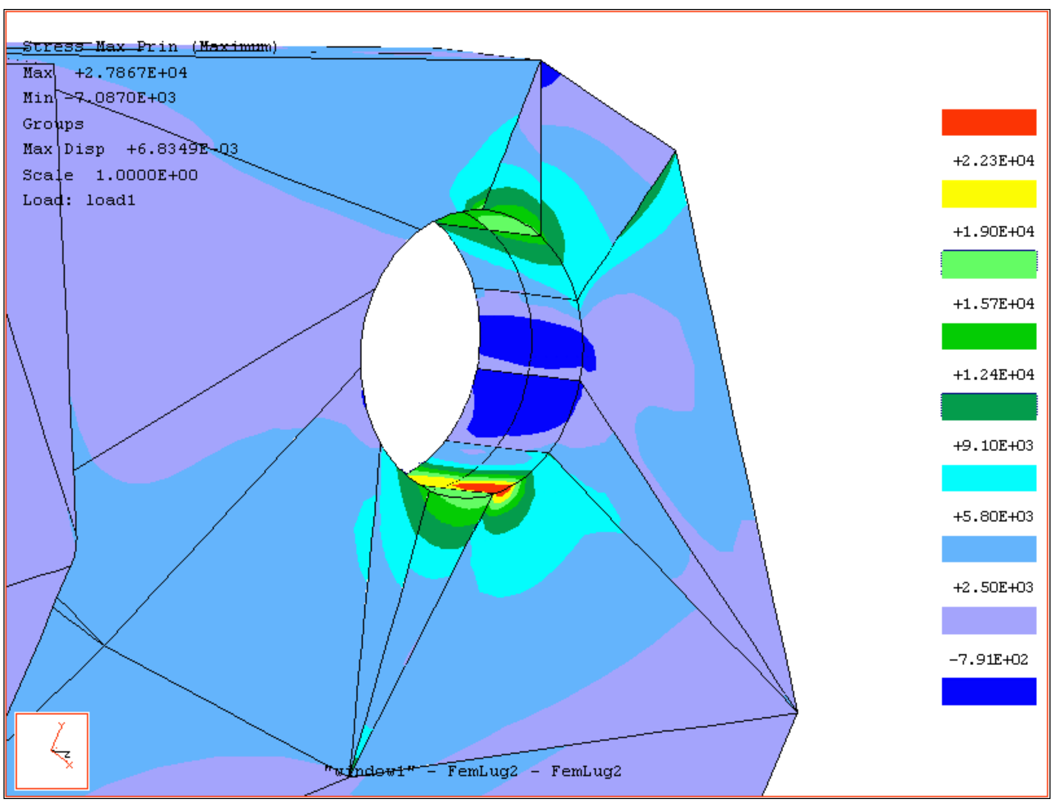


Figure 6-16 Clevis A_SP Mechanica FEA MaxPrinciple Stress

6.12 Forward Mount

6.13 Carriage Assembly

Table 6-5 Carriage Assembly Margins of Safety

Drawing No.	Description	M.S.	Failure Mode	Cond.	Stress psi	Freq. Hz
G670025-301	Tube Assembly - bending section	0.27	Fatigue	62	17493	11.0
G670025-301	Tube Assembly - bending section	1.87	Fatigue	7*	7165	23.8
G670025-301	Tube Assembly - bending section	1.00	Limit	4*	17493	0.0
G670017-1	Aft Truss Assy near G670025-3 PL	1.79	Limit	4*	12528	0.0
G670017-1	Aft Truss Assy near LanNav bracket	0.00	Fatigue	62	22149	11.0
G670017-1	Aft Truss Assy near LanNav bracket	0.26	Ultimate	4*	33224	0.0
G670075-3	Track support (Rail)	1.33	Fatigue	63	9587	10.4
G670075	Track Support Angle	153.2	Limit	C130	227	0.0
G670017-9	Plate - Stow Latch Backup	0.81	Fatigue	64	11372	23.8
G670017-9	Plate - Stow Latch Backup	4.58	Ultimate	7*	4518	0.0
	Aft Canister restraint Shear Pins	0.37	Ultimate	10	42000	0.0
G670076-5 C	Canister Latch - Rev C	0.27	Limit	42	27637	0.0
G670076-5 C	Canister Latch - Rev C	0.38	Fatigue	62	15893	12.4
G670076-5 C	Canister Latch - Rev C	0.26	Ultimate	5*	33250	0.0
G670025-13	Pivot Housing	0.74	Limit	4*	20100	0.0
G670025-13	Pivot Housing	2.05	Fatigue	62	7320	10.4
	* Analysis reflects full compliment of canisters.					

6.14 Forward Truss

It is important to note that the stresses shown in Figure 6-17 are not at an instance in time, like static stress values normally displayed in contour plots. These values represent the square root of the area under the PSD stress response vs. Frequency curve. The apparent frequency is shown in Figure 6-18, which can be used to read the allowable stress in Figure 7-1 Fatigue stress allowable for unnotched 6061-T6 vs. Frequency. The area adjacent to the stow latch hook, where a 0.50 thk. back up plate is welded, currently shows inadequate fatigue strength in the 0.190 thk. plate adjacent to the weld.

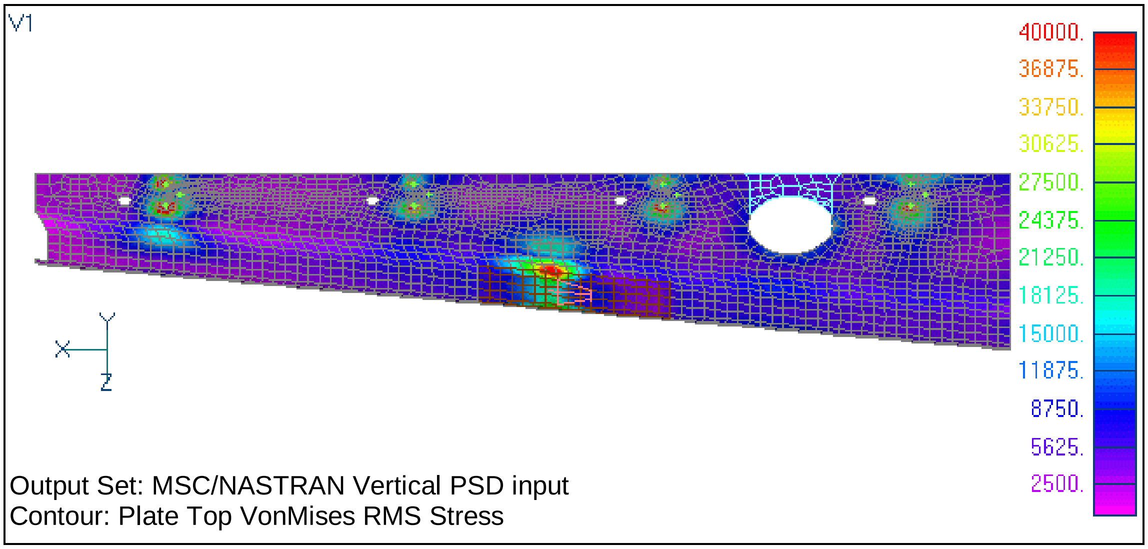


Figure 6-17 Forward Truss Fatigue Stress for Vert. PSD input

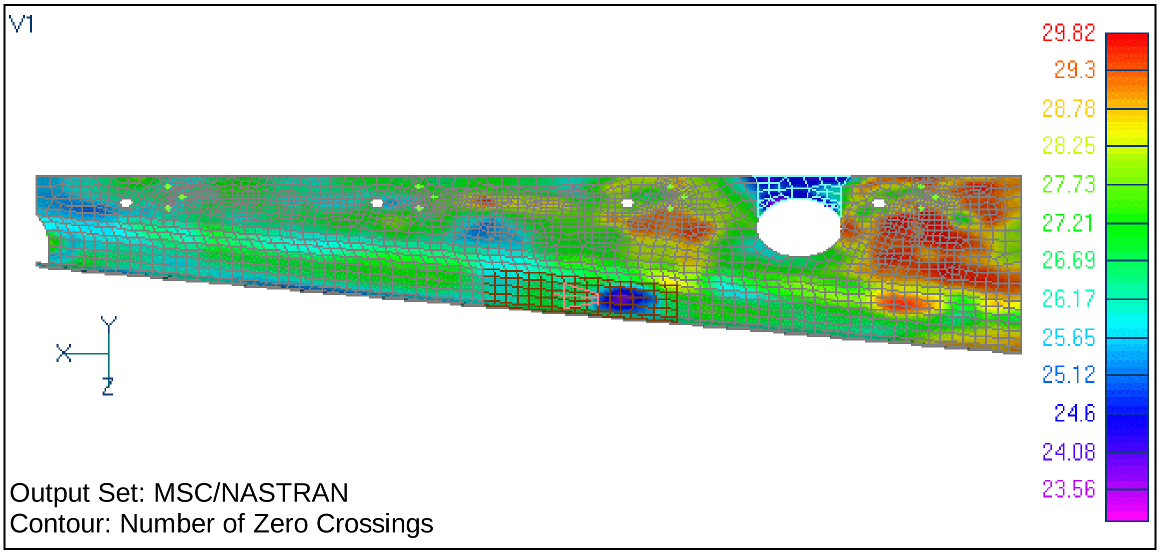


Figure 6-18 Forward Truss No. of Zero Crossing for Vert. PSD input

The large assembly models (Figure 8-9 on page 8-7), used to run the PSD ground mobile environment, only serve to bring attention to an area and do not have sufficient detail to make a conclusion. One half of the Forward Truss was remodeled using two layers through the thickness solid hex elements (Figure 6-19 and Figure 6-22 on page 6-18). There are 19213 eight node hex elements and 28740 nodes in this model. This same model is used to analyze the Canister Latch Angle joint (Figure 6-27).

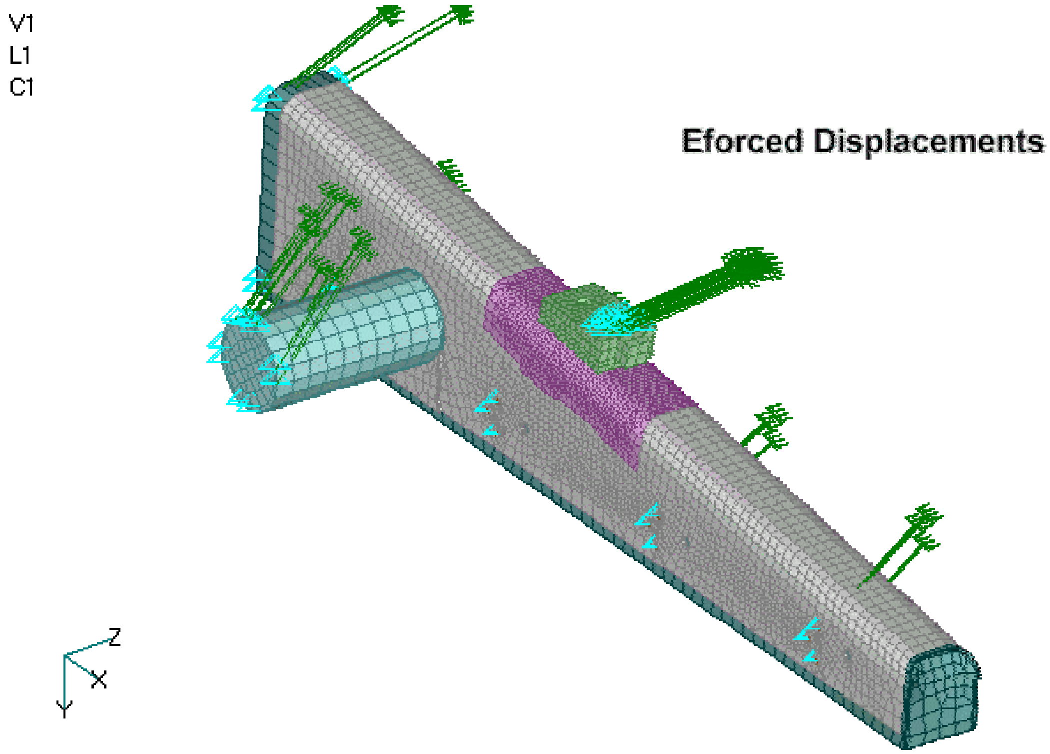


Figure 6-19 Fwd Truss Solid Element freebody loads

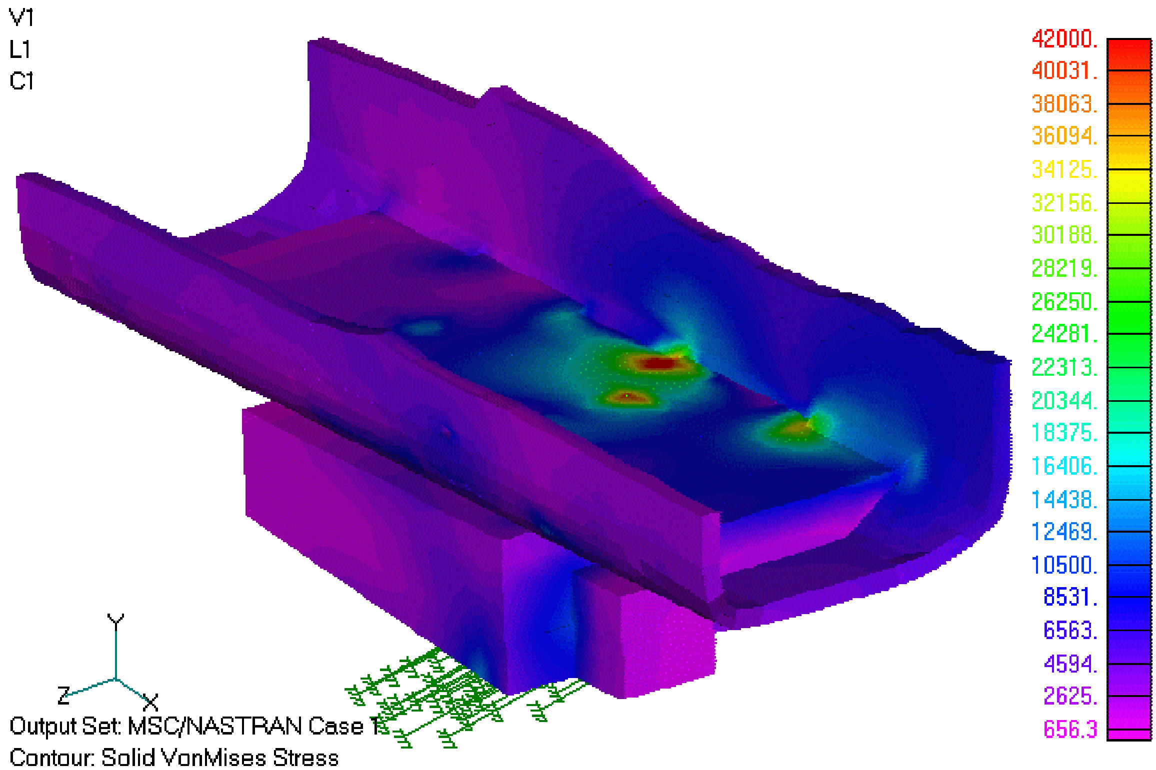


Figure 6-20 Fwd Truss Stow Latch detail FEA

The original analysis of the Stow Latch BackupPlate is done with a stitch weld, and therefore shows a stress concentration near the ends of these welds. This model was revised to include a continuous weld in that area, as shown in Figure 6-21, which eliminates the concentration and results in positive margins of safety for this area.

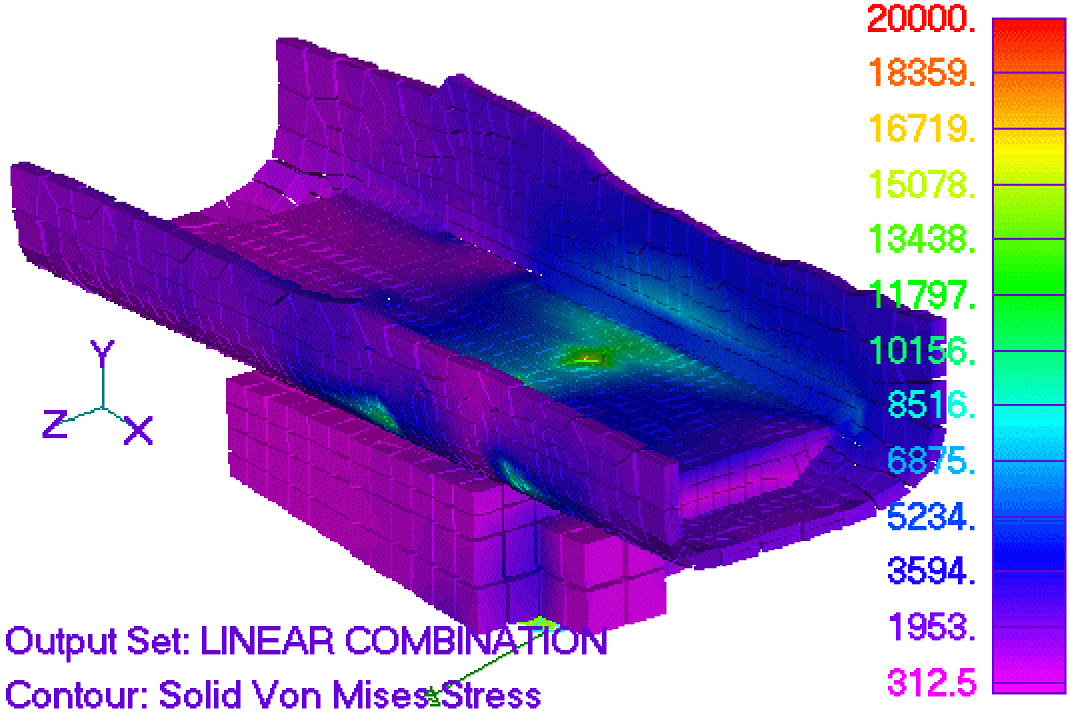


Figure 6-21 Stow Latch Backup Plate with continuous weld

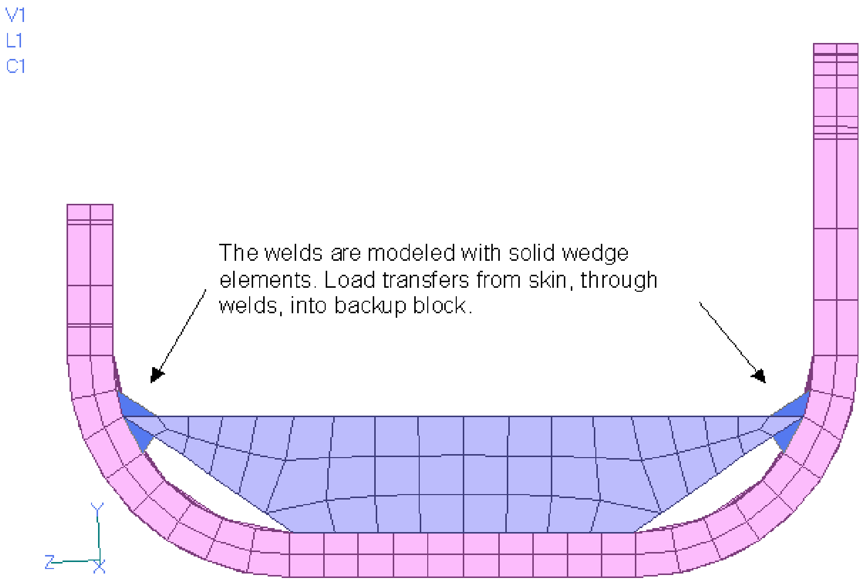


Figure 6-22 Fwd Truss Stow Latch section view

6.15 Restraint Latch Angles

6.15.1 Original latch angle

The original G670076 Latch Angle design uses 0.25” thk aluminum angle. The “Rev A” design uses 0.375” thk angle, and the forward flange extends to the top of the aft flange.

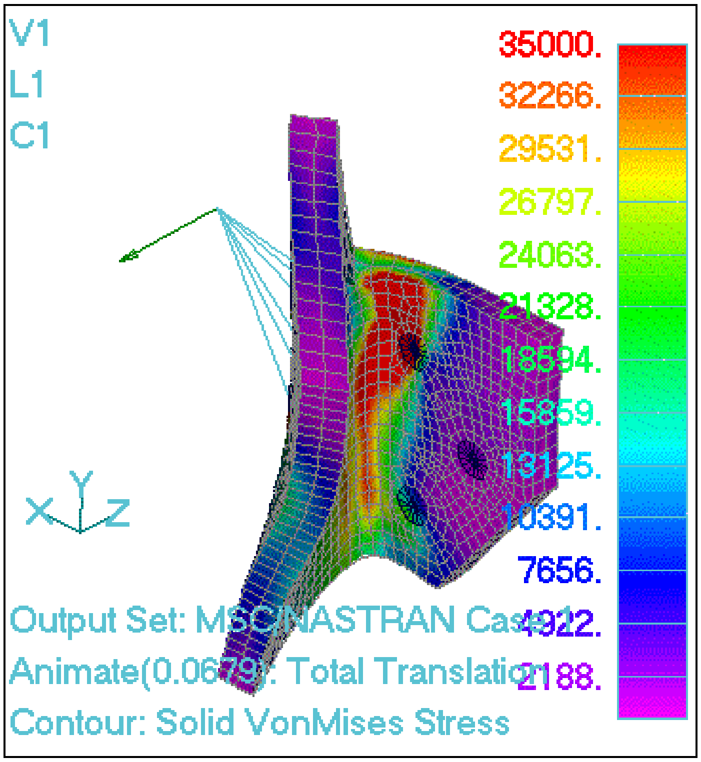


Figure 6-23 Original Angle Bracket with 910# aft RMS load

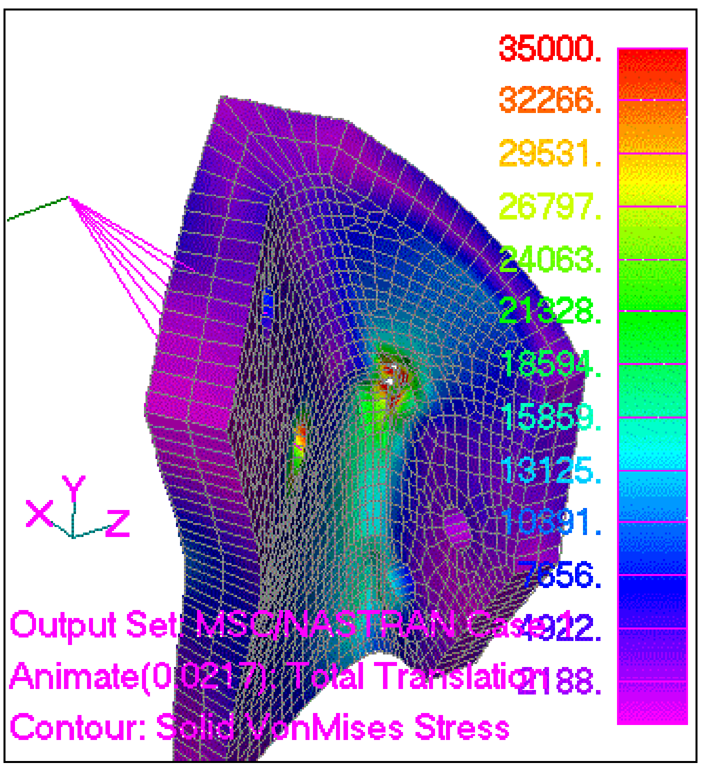


Figure 6-24 Canister restraint latch angle (G670076 A) with 910# aft RMS load

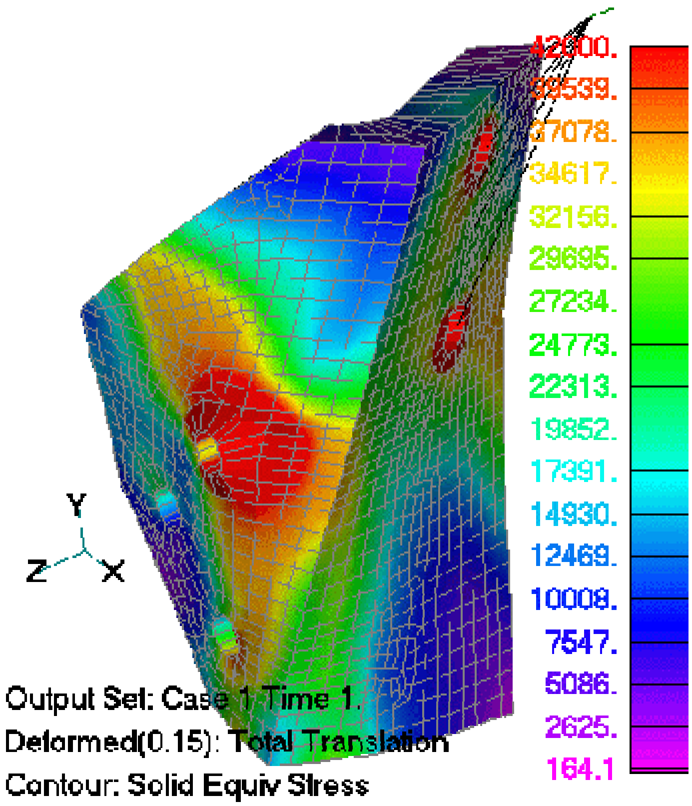


Figure 6-25 Latch Angle G670076 A with 4350# crash load

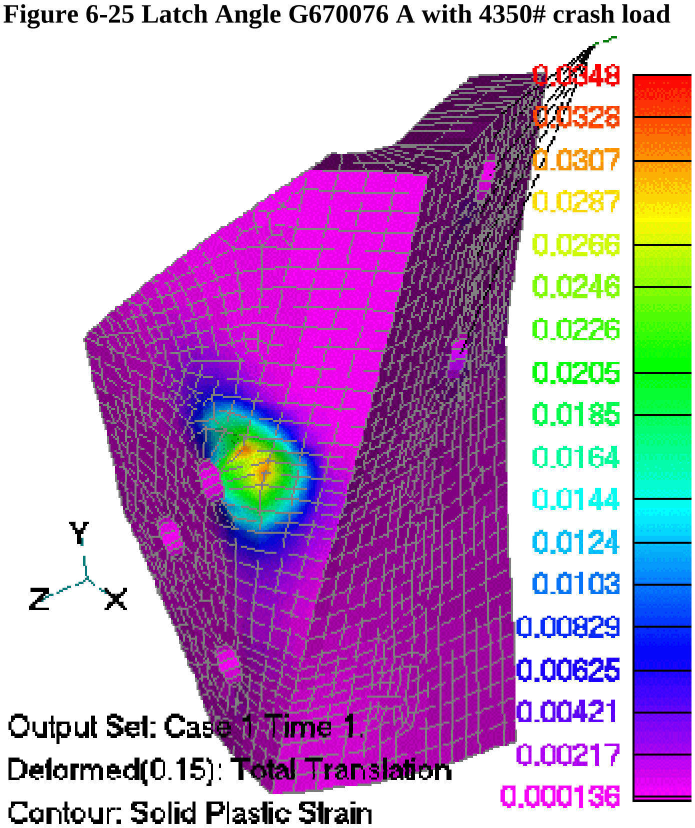


Figure 6-26 Latch Angle G670076 A non-linear strain

The 4350# Crash Load Canister Latch force is applied to the 0.375 thick Latch Angle (G670076 A). Non-linear material properties, and an iterative solution sequence (10 load steps) is used to determine the actual functional distribution in the part. Figure 6-26 shows the material strain past the limit in the area around the upper fastener into the Forward Truss. This is academic however, because the 11492# fastener load will not be achieved because the #4 insert is rated for 4760# ultimate; and will therefore pull out before the angle tears.

The ∅0.25 Ph13-8Mo Canister Stop Pins, in the guides on the Aft Truss, are needed to restrain the Canisters during the -20g Crash Load (Cond. 10). There are two of these pins at the aft end of the Canister. We can ignore the load carrying contribution from the fwd Canister Restraint Latch, and place 60% of the load on one of the pins. Assuming pinned ends and the load at the center of the 0.510" span results in a peak moment of 333"#. The pin bending allowable is 457"#, resulting in M.S.=0.37

Now with the 0.375 thick G670076 A; the 0.19 thick plate around the #4 insert in the Forward Truss becomes the weakest part of the Latch Angle/ Truss joint. The 910# RMS Ground Mobile load produces a 2404# reaction in the upper fastener (in the pattern of three), due to the heel-and-toe affect. In Figure 6-28 we see stresses in the yield range, both at the point where the bottom of the angle bracket bears on the Truss skin, and also in the area around the upper #4 insert. The refined mesh in this area shows a linear stress of 58433psi next to the insert, and 36544psi at 0.10” away from the insert. The apparent frequency at this point is 12.4 Hz, and we read a fatigue stress limit of 22ksi in Figure 7-1 on page 7-1.

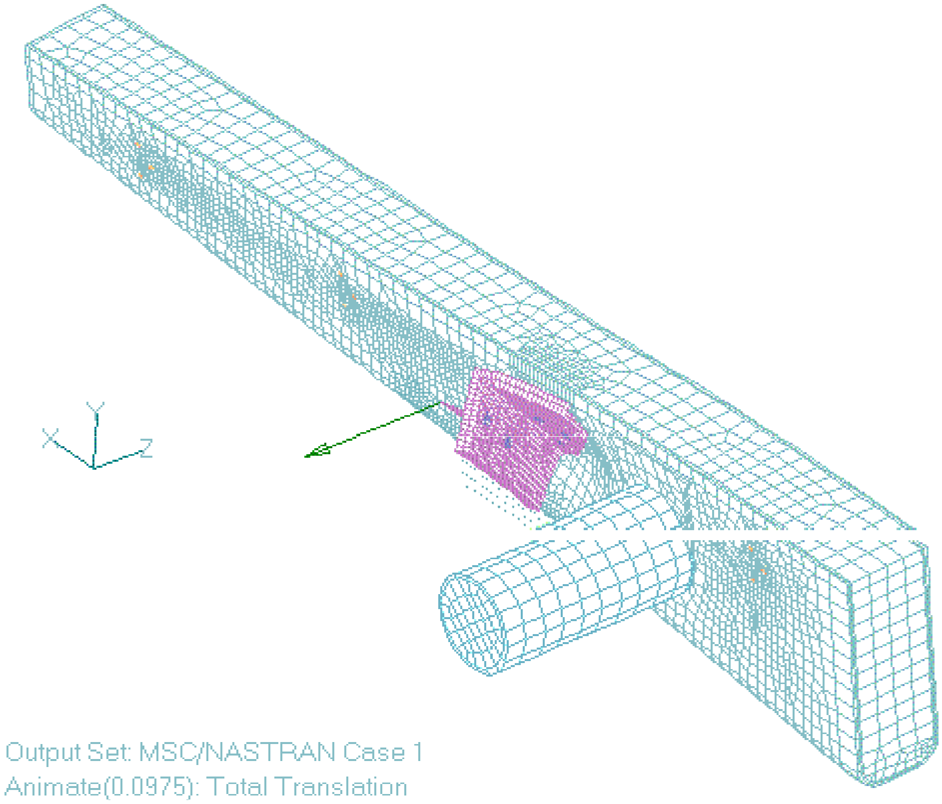


Figure 6-27 One half of Fwd Truss with one Latch Angle

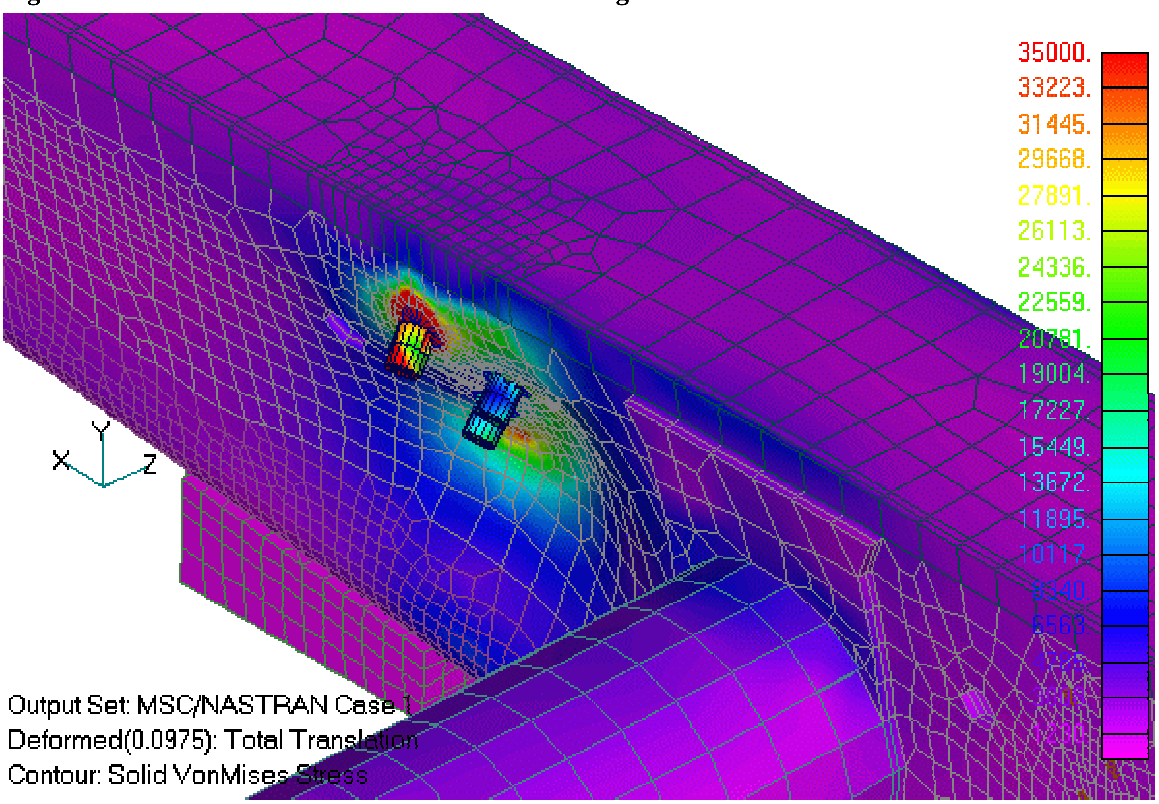


Figure 6-28 Area on Fwd Truss behind Latch Angle

6.15.2 Latch angle Rev-C

We can take advantage of the 0.375” thick top plate on the Forward Truss, and attach the Canister Latch Bracket to this plate with shear fasteners. The result is that the tension load is relieved from the fasteners on the Forward Truss aft face.

This Aluminum Canister latch bracket supports the steel latch device on both sides, thus providing a balanced load path.

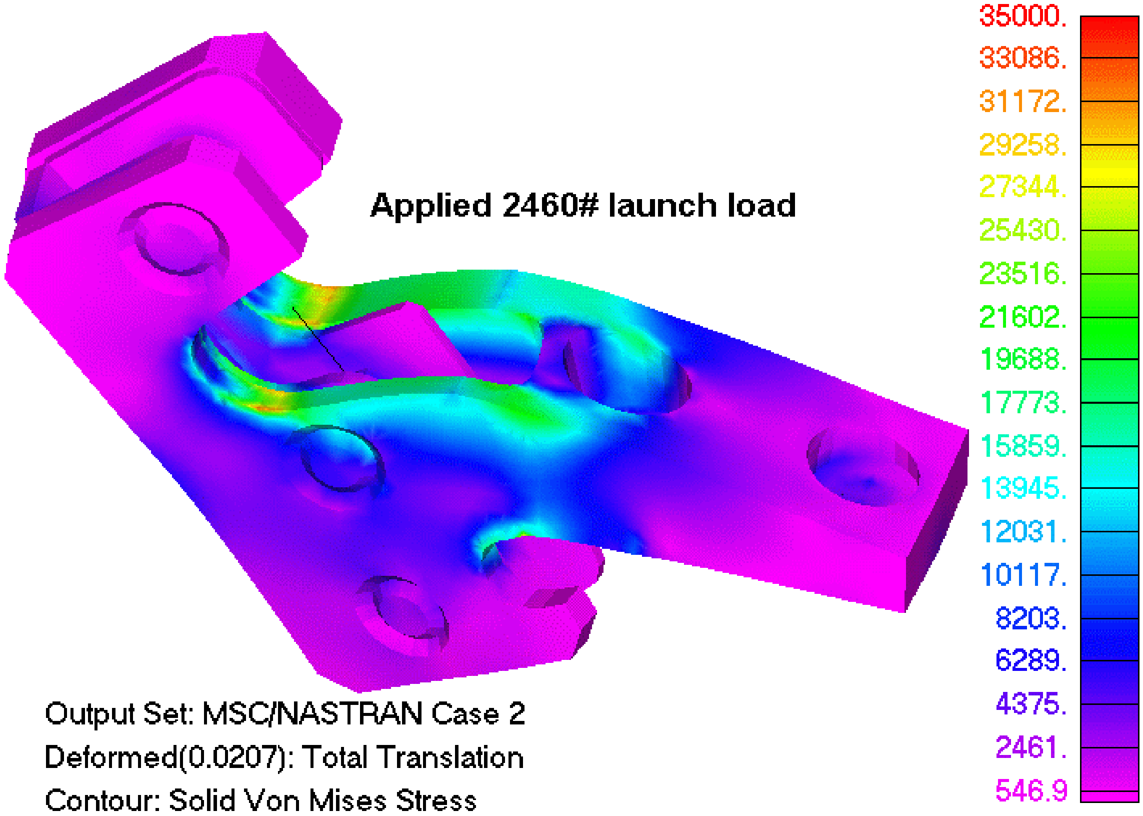


Figure 6-29 Canister latch Rev-C TrussAng3 model with LC42 launch load

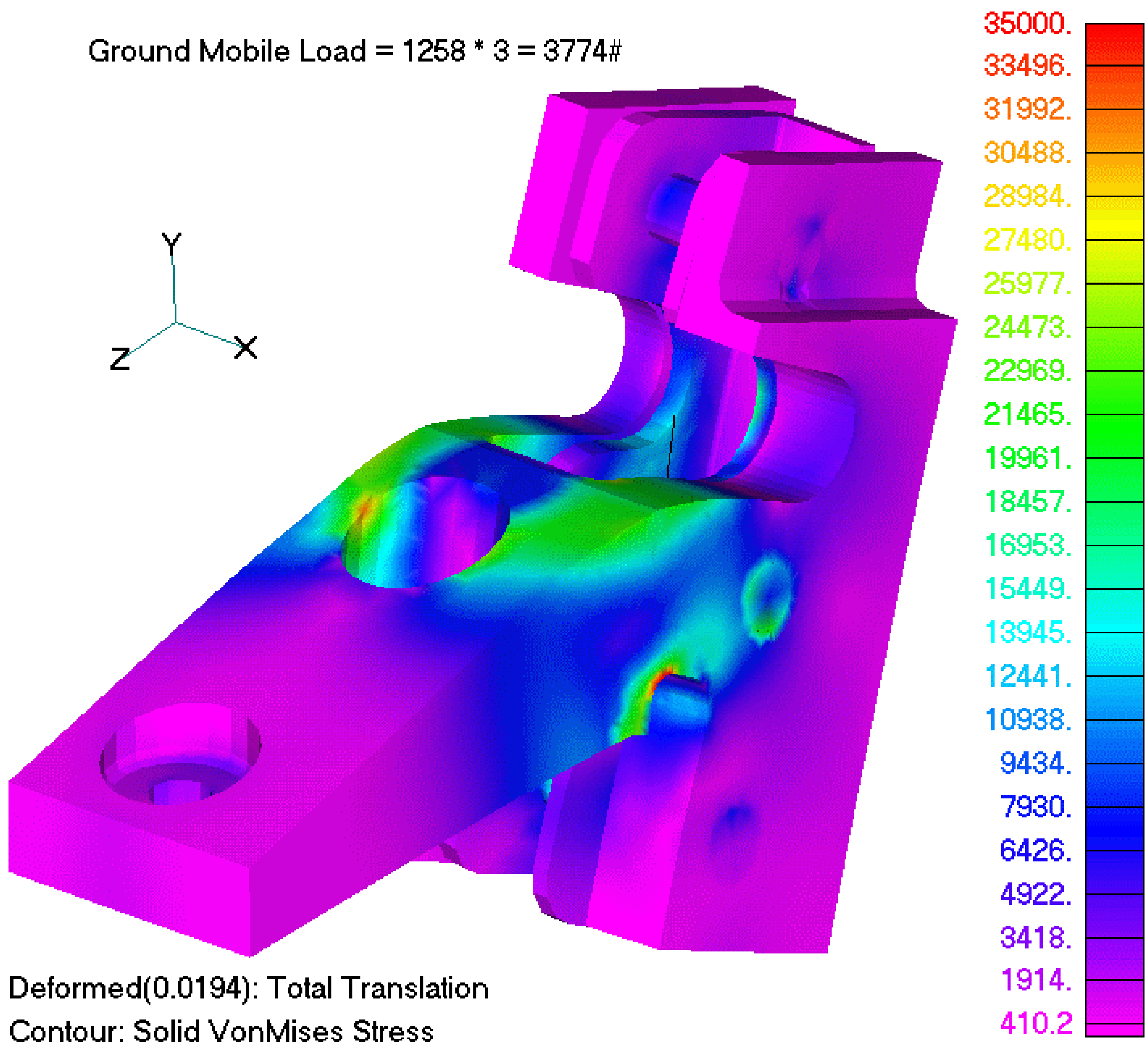


Figure 6-30 Canister latch Rev-C w/ ground mobile load (LC 7)

The peak ground mobile vertical force on the latch (1258# LC64) is multiplied by a 3σ factor to capture the peak vertical force for the latch. We see that there is not any gross yielding with this condition.

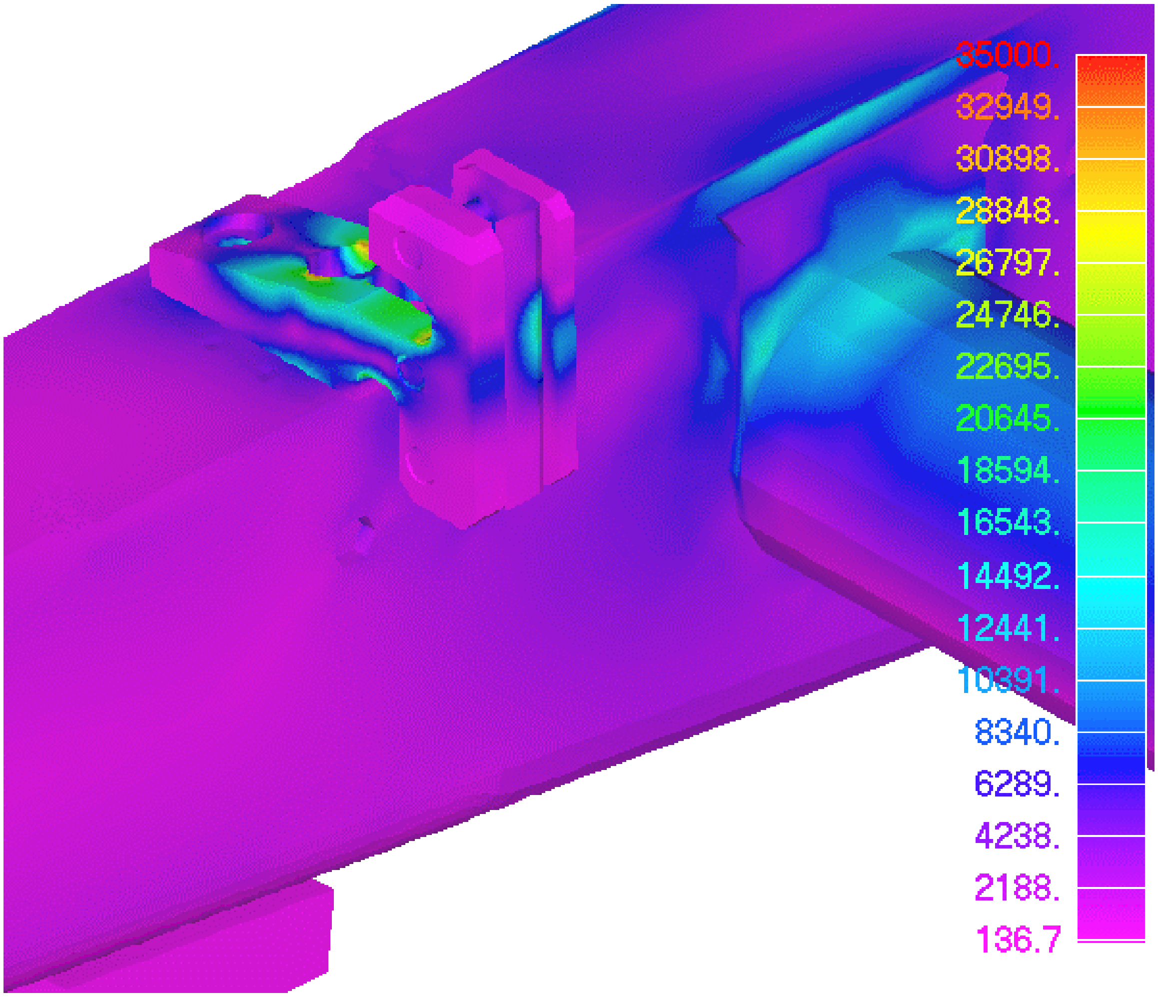


Figure 6-31 Canister latch Rev-C mounted on truss beam w/ launch load

The flexibility of the TrussBeam will reduce the shock load at the latch. The max stress for the static load in this model matches that when a latch FEA model is fixed at the fasteners and run by itself.

6.16 Aft Truss

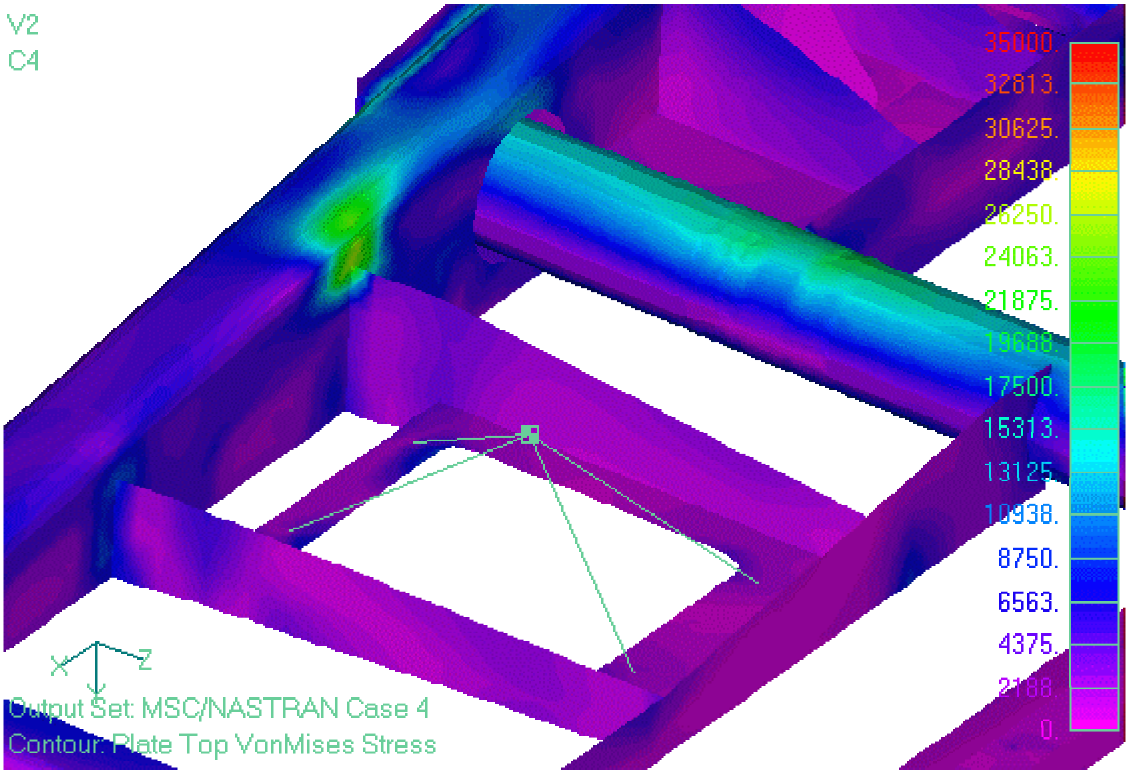


Figure 6-32 Aft Truss LanNav bracket

6.17 Long Support Weldment Tube

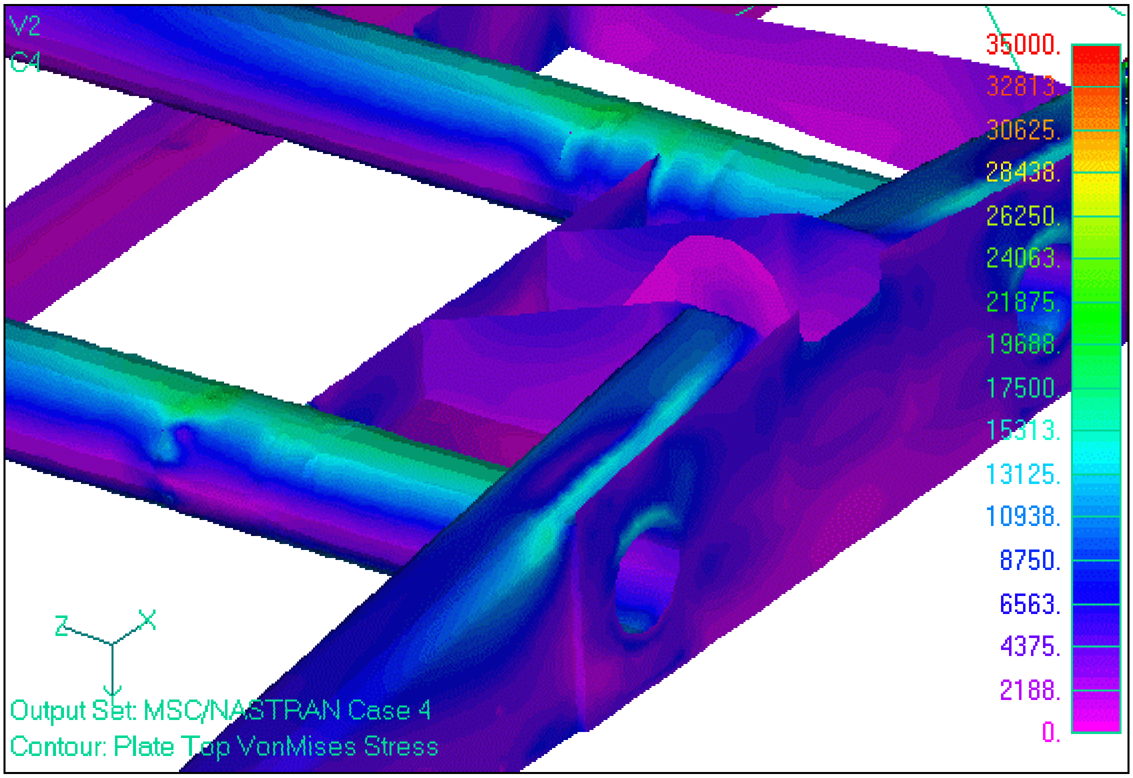


Figure 6-33 Frame welded lug box

6.18 Stow Stand

The maximum bending in the Stow Stand assembly is near the base where it attaches to the Forward Mount. The margins of safety in this area are listed in Table 6-4.

6.19 Reload position Stop

The compression load on each Reload Stop is 3583 #, when the Carriage is in the reload position and the actuator is disconnected. The bending section is A=0.88in^2, I=0.0183 with an effective length = 2.83”. It is not critical for buckling. The compressive yield MS = 7.6.

6.20 Canister axial restraint rod

The axial restraint rod is ∅0.50 and is 6.5" length between the support fittings on the canister. The rod is made from 4340 steel.

6.21 HMMWV Assembly

Table 6-6 HMMWV Margins of Safety

Drawing No.	Description	M.S.	Failure Mode	Cond.	Stress psi	Freq. Hz
	Cbeam	0.29	Limit	5*	27037	0.0
	Dbeam	0.03	Limit	4*	33970	0.0
	Dbeam	0.34	Ultimate	9	20124	5.0
	Dbeam Intercostal	0.03	Limit	4*	34126	0.0
	Bed Skin Cross Channel	-0.07	Limit	4*	37810	0.0

* Analysis reflects full compliment of canisters.

6.22 D-Beam

The cross sectional shear area of the DBeam (1.1in^2) is adequate to carry the ultimate crash load forces.

The fatigue stresses are relatively low in the DBeam as shown in Figure 6-34 below.

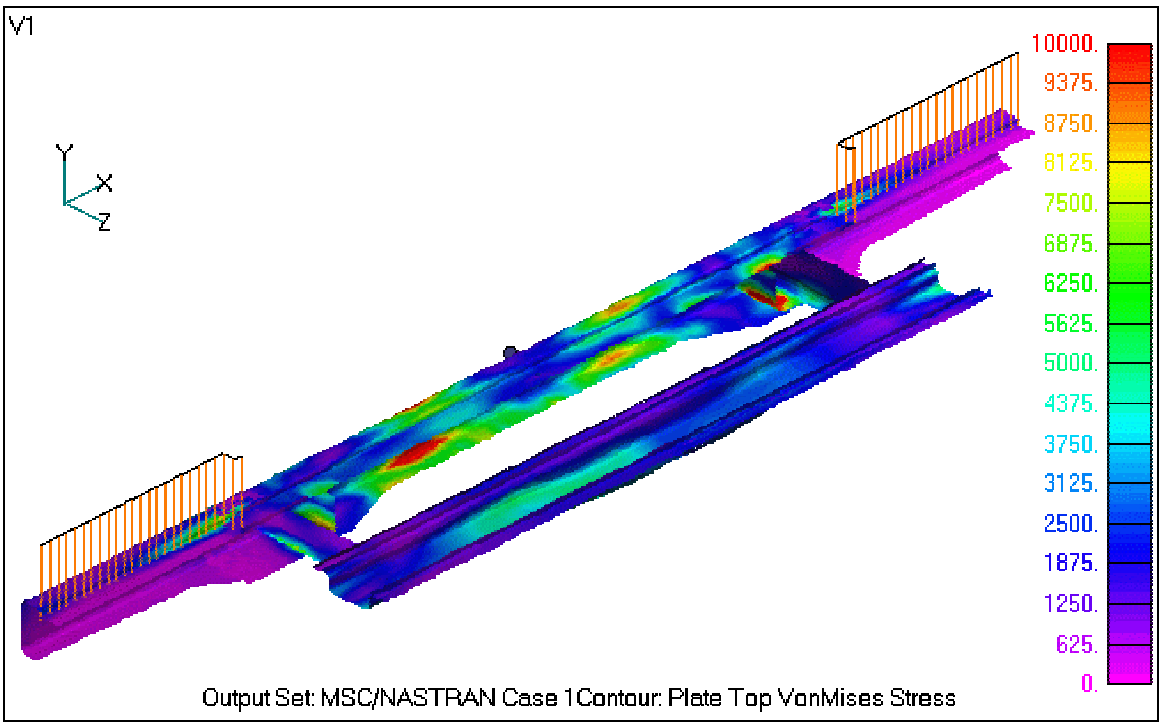


Figure 6-34 D-Beam RMS stress for Vert. PSD input

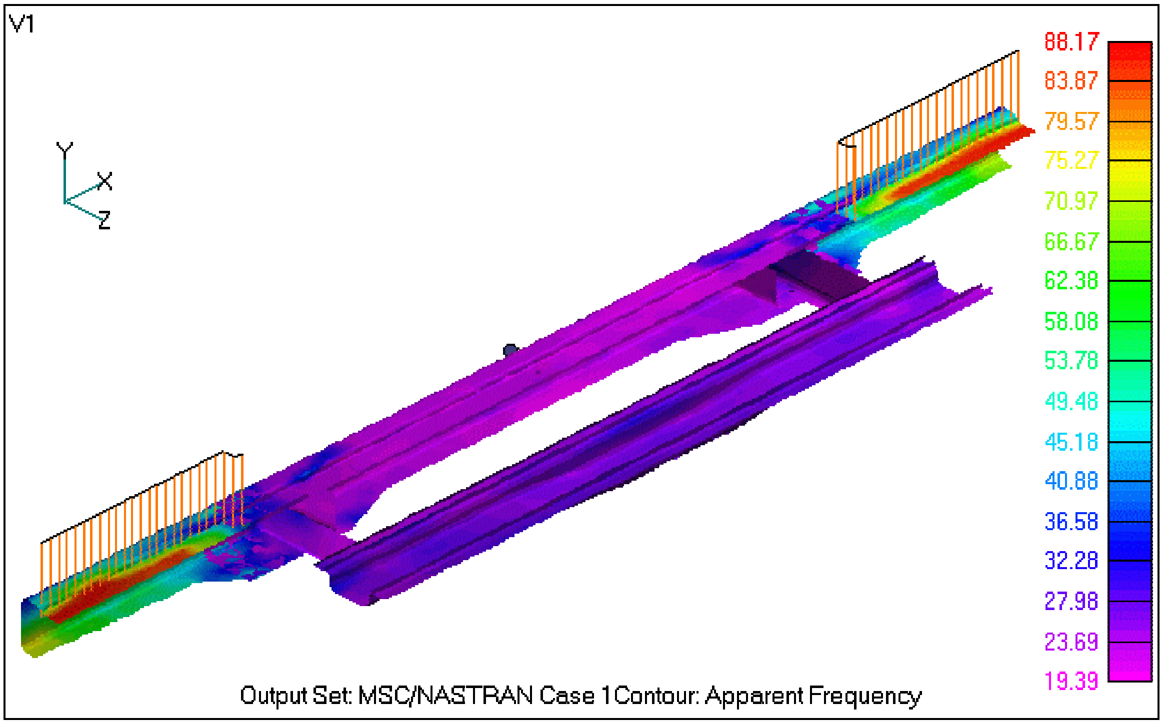


Figure 6-35 D-Beam Apparent Frequency

6.23 Welds

All welds in the EFOGM structure have ample margins. The minimum margin on any weld is where the G670025 Tube assembly is welded to the forward face of the G670017-1 Aft Truss assembly, and the MS there is 3.3.

Table 6-7 Welds Margin of Safety

Drawing No.	Description	M.S.	Failure Mode	Cond.	Stress psi	Freq. Hz
G670017-1	Aft Truss / Tube Assy Fwd Weld	3.30	Limit	4*	8133	0.0
G670016-5	Cross Plate / Tube Weld	11.42	Limit	4*	2818	0.0
	Tube / Forward Truss					
	LanNav support / Aft Truss					
	* Analysis reflects full compliment of canisters.					

7. Material Properties

The applicable material properties are taken from MIL-HDBK-5F

Table 7-1 Material Properties used for Analysis

Spec. / Form	6061-T651 Plate	Ph13-8Mo Round	440C Round	17-4PH Investment Casting	A356 Investment Casting
Condition	T651	H1025		H1025	T6
Thickness		≤ 12.0			
F_{tu}, ksi	42	185	≈170	≈ 150	33
F_{ty}, ksi	35	175	≈155	≈ 130	27
F_{su}, ksi	27	117	≈124	≈ 98	21
F_{bru}, ksi	67	302	≈383	≈ 254	57
F_{bry}, ksi	50	263	≈278	≈ 189	43
e, %	6	11	10	4	3
E, 10^3 ksi	9.9	28.3	29.0	28.5	10.4
G, 10^3 ksi	3.8	11.0	11.0	12.7	3.9
μ	0.33	0.28	0.32	0.27	0.33

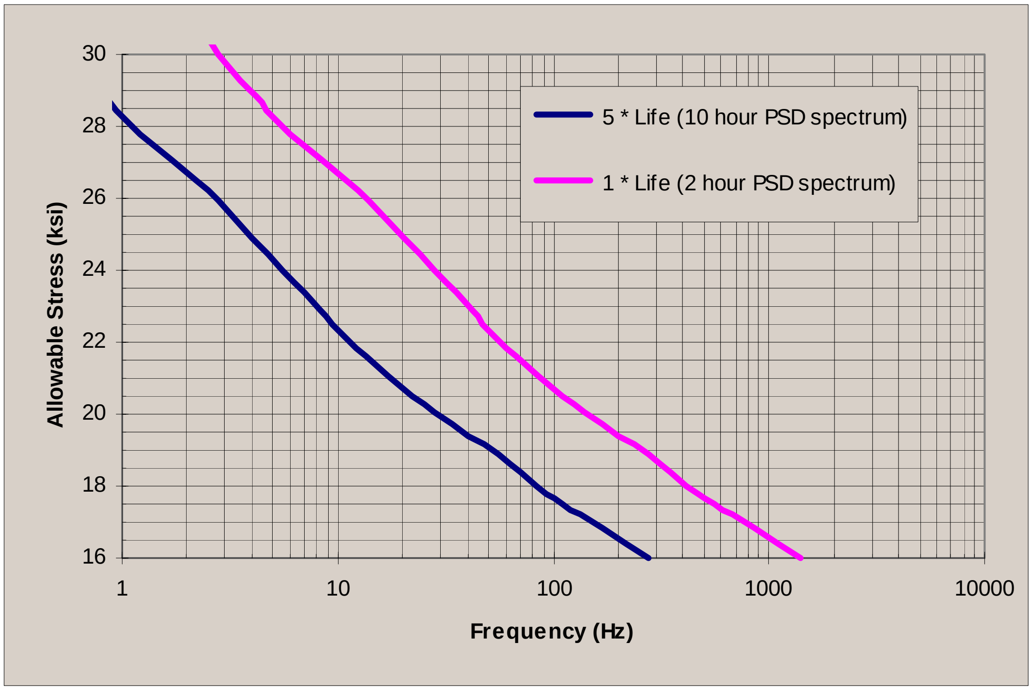


Figure 7-1 Fatigue stress allowable for unnotched 6061-T6 vs. Frequency

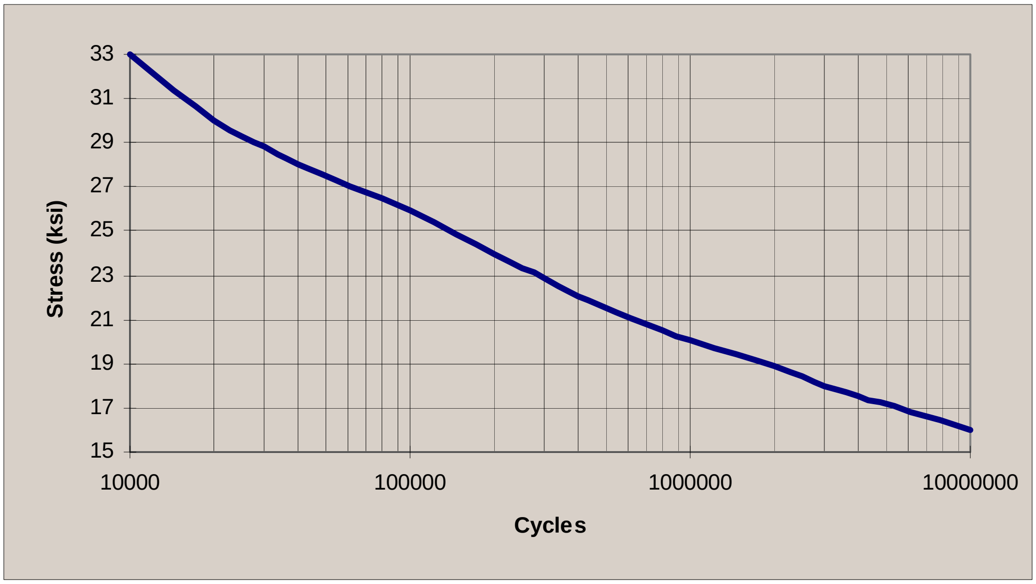


Figure 7-2 S-N curve for 6061-T6 unnotched, Stess Ratio = -1.0

8. Assembly Analysis

8.1 Launcher kinematics

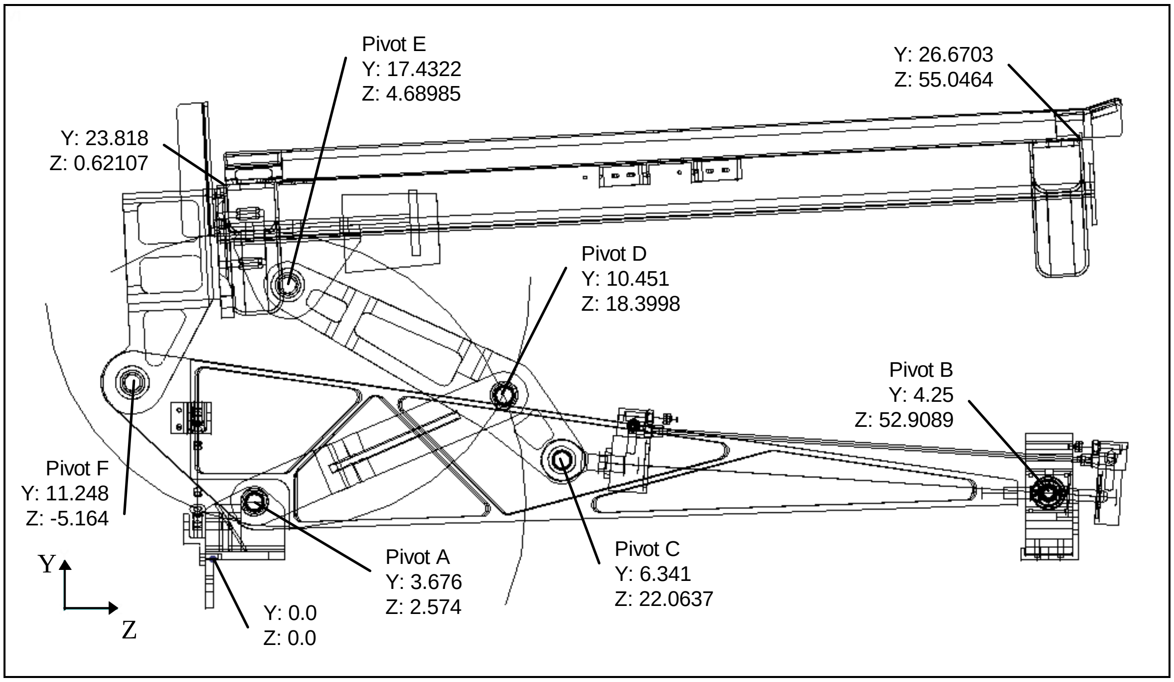
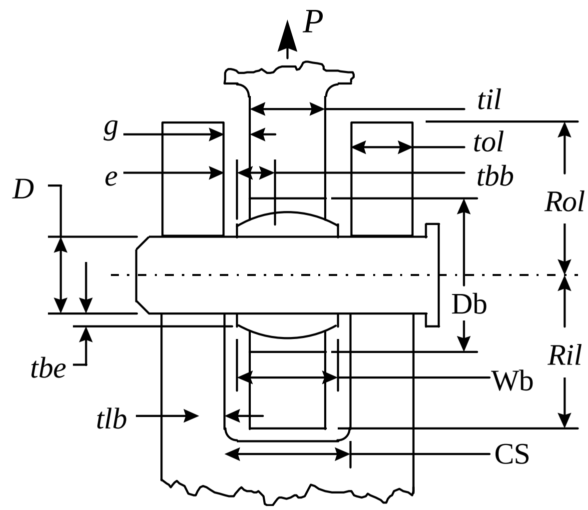


Figure 8-1 Launcher pivot locations

8.2 Clevis Joint Geometry

Clevis	A_SP	A_LL	B	C	D	E	F
til	0.800	1.000	0.690	1.015	1.300	1.250	1.000
tol	0.625	0.500	0.688	1.000	1.000	1.000	1.000
ril	1.730	1.500	1.600	1.388	2.500	2.500	1.920
rol	1.000	1.000	1.500	1.500	2.250	1.500	2.000
Wil	3.460	3.000	3.200	2.775	3.000	5.000	3.840
Wol	2.500	2.500	3.000	3.000	4.500	3.000	4.000
Db (inner)	1.750	1.750	1.312	2.125	1.750	2.125	2.125
D (outer)	1.000	1.000	0.625	1.000	1.000	1.000	1.000
CS	1.100	1.090	1.190	1.500	1.500	1.500	1.625
g	0.150	0.045	0.250	0.243	0.100	0.125	0.313
Wb	1.000	1.000	0.750	1.375	1.000	1.375	1.375
e	0.050	0.045	0.220	0.063	0.250	0.063	0.125
tbe	0.059	0.059	0.062	0.135	0.059	0.134	0.134



8.3 Finite Element Model Methods

8.3.1 Option for large displacement solution

Elements and methods are used that are compatible with MSC/NASTRAN solution 106 (NLSTATIC), that is used to iteratively determine the equilibrium with the load vector a function of displacement. Beam elements are used instead of Bar elements, because beam elements are compatible with NLSTATIC.

8.3.2 Fastener joint shear stiffness

A joint stiffness K_J = 220000 #/in is used. The moment of inertial for the beam element representing the fastener is $I = \frac{K \cdot l^3}{12 \cdot E}$, which results from using a fixed-fixed beam.

8.3.3 HMMWV Bed Skin 2D orthotropic equivalent plate properties

The HMMWV bed skin is corrugated longitudinally and is joined to hat section stiffeners laterally. One cyclic symmetry section of the corrugation is shown in Figure 8-2.

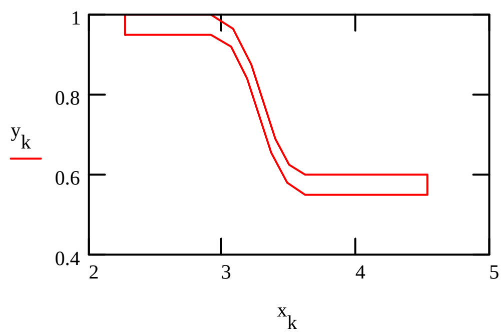


Figure 8-2 Cyclic symmetry corrugation section

The section properties for the boundary shown in Figure 8-2 are A=0.119 in^2 and I = 0.003856 in^4. Planar plate elements are used to model the bed skin. The 2D orthotropic properties used for these plate elements are obtained by matching both the EA and IE in the longitudinal direction, and matching the EA in the lateral direction. The IE in the lateral direction is reasonable when the cross hat section stiffeners are included.

$b := 4.535 - 2.275$ $\qquad b = 2.26$ $\qquad E := 3 \cdot 10^7$

$$E1 := \frac{1}{\left[6 \cdot \left(\sqrt{Ixbar \cdot b}\right)\right]} \cdot \sqrt{3} \cdot E \cdot A^{\left(\frac{3}{2}\right)} \qquad E1 = 2.532 \cdot 10^6$$

$$t := E \cdot \frac{A}{(E1 \cdot b)} \qquad t = 0.624$$

$$E2 := .05 \cdot \frac{E}{t} \qquad E2 = 2.405 \cdot 10^6$$

8.3.4 Spherical Ball Joints

The spherical ball joints are created in the FEM by connecting two coincident nodes with an RBE2 element. The 6 independent DOF of the clevis pin node are linked to 3 translational dependent DOF of the plate element node. The plate elements represent the lug socket, and are 1.0" thick 17-4PH material.

8.4 Finite Element Model Description

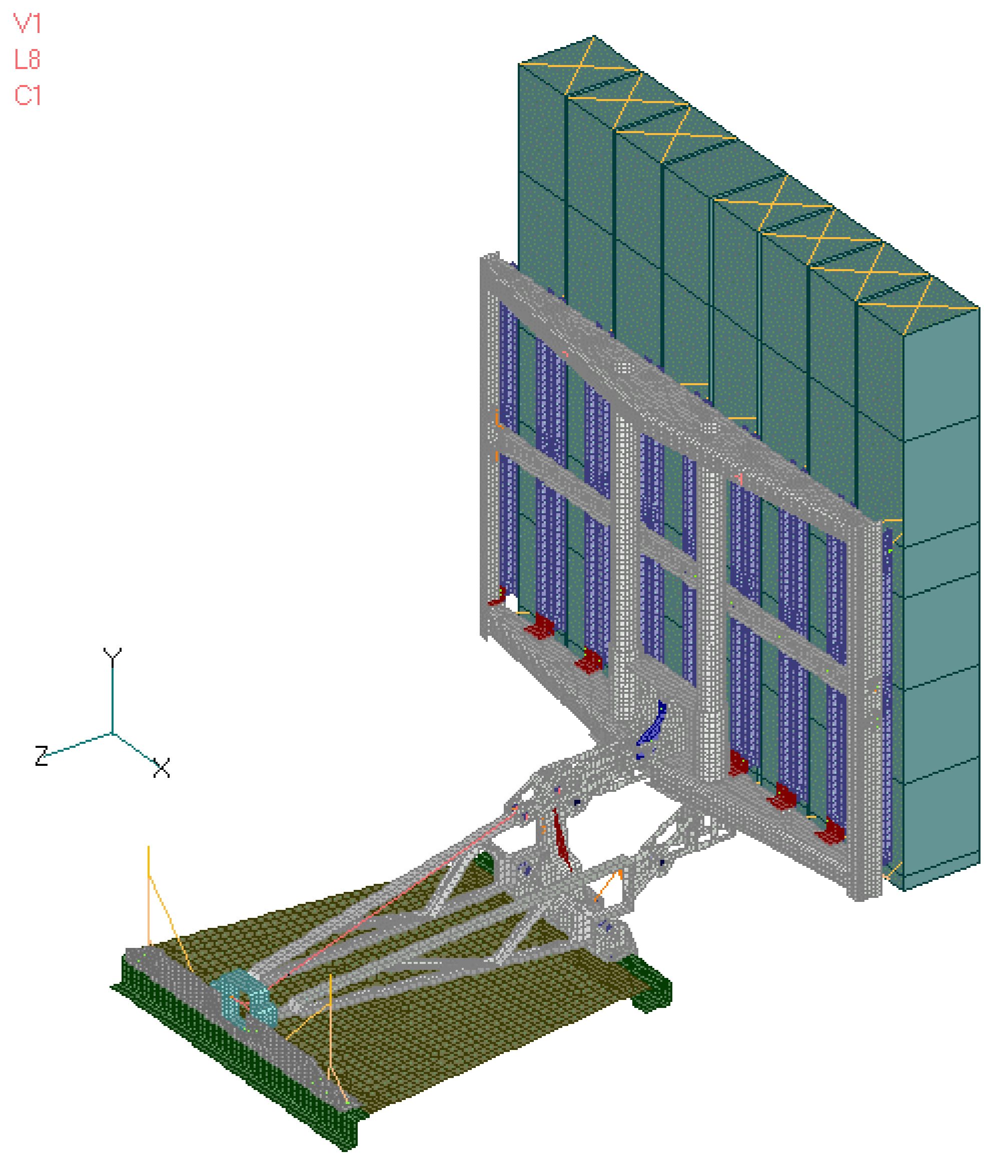


Figure 8-3 FEM Assembly in launch position

The EFOGM assembly FEM has 52908 elements and 52162 nodes. Most of the elements are shell type and there are a few beam, rigid, and multi-point-constraint types as well. The full assembly model is used for all modal, transient, and frequency response runs. Some smaller solid element detail models are used with the internal loads to determine local peaking and distributions in the joints and fittings.

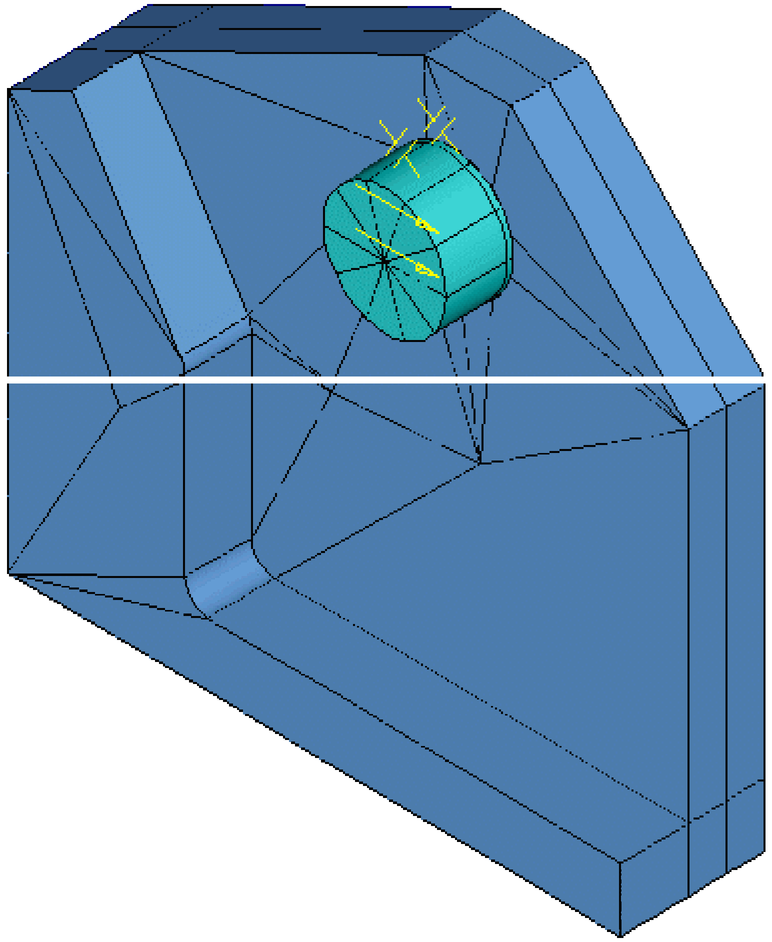


Figure 8-4 Clevis A_SP Mechanica FEM with contact elements

8.4.1 Aft Mount

The Aft Mount FEM (Figure 8-5) is made with 1538 nodes and 1629 plate elements.

One of the lugs, on the Aft Mount, was modeled using Mechanica (Figure 8-4). Large geometric elements work with the p-version FEA method. The two symbols that look like capacitor symbols indicate the location of the 3D contact surface elements.

8.4.2 HMMWV Bed Skin

The HMMWV C-Beam, D-Beam, and bed skin is made from 2188 nodes and 2127 plate elements. The material properties used to approximate the corrugated bed skin are described in ¶8.3.3.

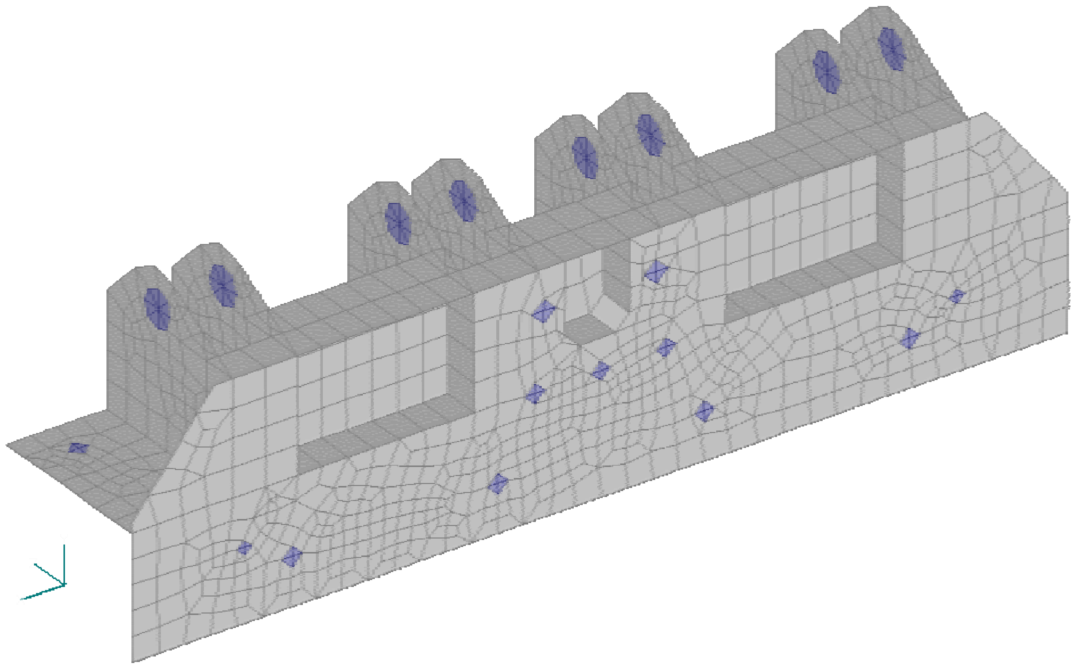


Figure 8-5 Aft Mount FEM

8.4.3 Side Plate

The Side Plate FEM is made with 1128 nodes and 703 plate elements.

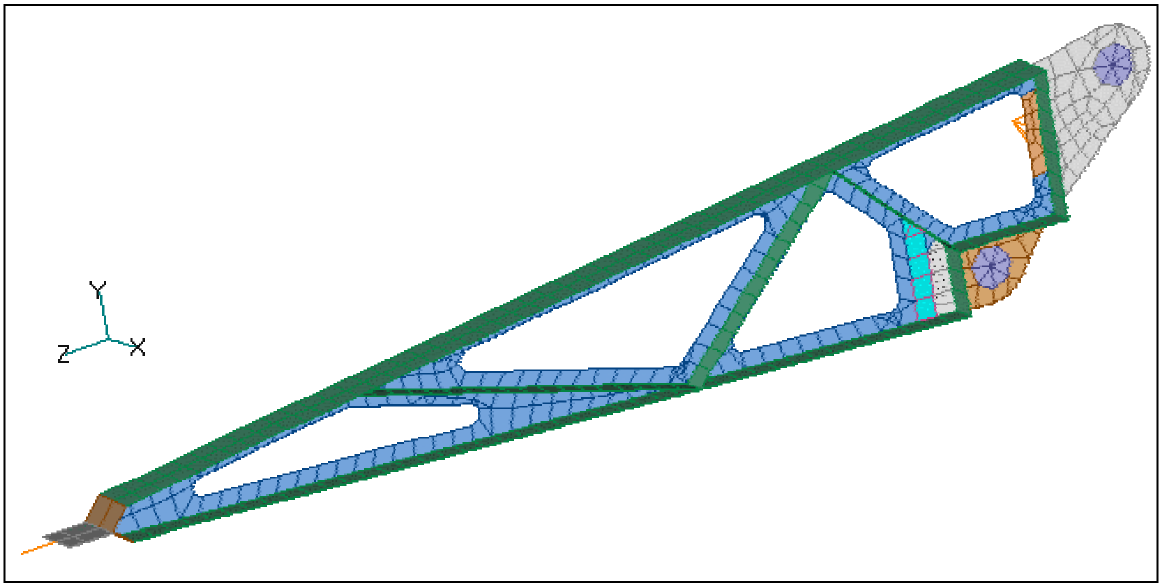


Figure 8-6 Side Plate FEM

Different colors on the Sideplate model indicate different shell element thicknesses.

8.4.4 Carriage weldment

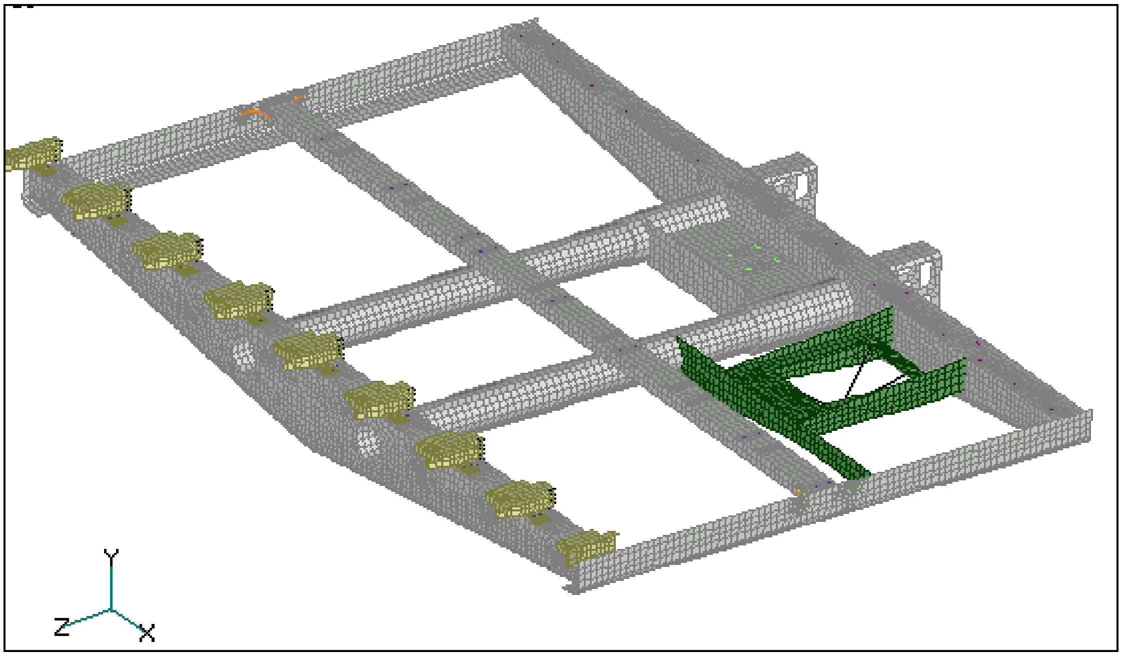


Figure 8-7 Carriage weldment assembly

8.5 Modal

8.5.1 Stow position modes

Table 8-1 Stow position Natural Frequencies

MODE NO.	CYCLES (Hz)	MODE NO.	CYCLES (Hz)	MODE NO.	CYCLES (Hz)
1	8.79	22	28.51	43	73.10
2	10.68	23	29.34	44	73.46
3	11.19	24	35.27	45	74.82
4	16.45	25	36.49	46	75.76
5	17.67	26	36.64	47	80.24
6	19.06	27	37.34	48	82.91
7	19.72	28	37.41	49	85.04
8	20.02	29	37.82	50	85.96
9	20.08	30	44.99	51	86.57
10	20.18	31	49.10	52	89.17
11	20.32	32	50.97	53	94.56
12	20.53	33	56.20	54	96.31
13	21.47	34	56.92	55	97.27
14	21.83	35	62.13	56	99.60
15	22.12	36	62.70	57	102.13
16	22.21	37	66.50	58	108.40
17	22.49	38	68.16	59	111.62
18	22.54	39	69.65	60	113.59
19	24.18	40	69.75	61	116.62
20	25.55	41	70.31	62	119.44
21	26.98	42	71.29		

Frequency (Hz)	Description of motion
19.06	Rolling of outboard canisters, about canister axis, in phase.
20.17	Rolling of canisters, about canister axis. Alternate canisters in and out of phase.
22.12	Translation of canisters, along canister axis. Alternate canisters in and out of phase.
22.5	Same as 22.12 Hz.
25.55	Vertical motion of fwd outboard corners of carriage, coupled with carriage rocking about a Y axis.
28.28	Rotation of Aft Truss about a Y axis, coupled out of phase with lateral motion of Sideplates.
36.5	Rocking of canisters about an X axis, coupled with carriage rocking about a Y axis.

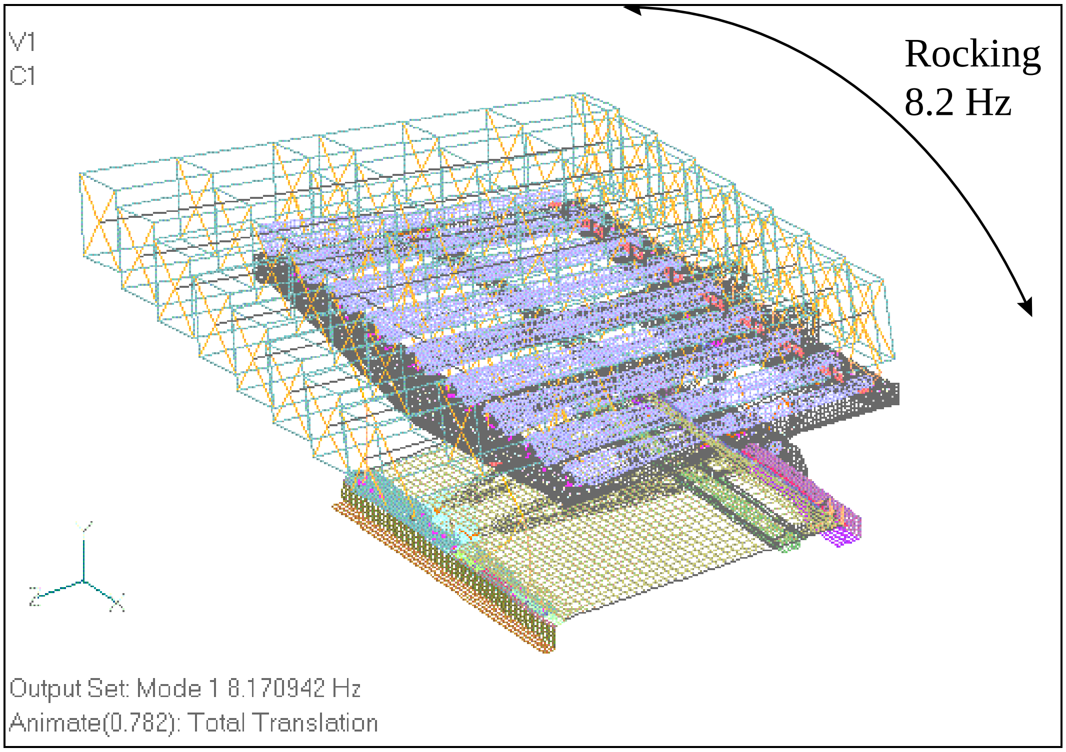


Figure 8-8 First stow position mode shape

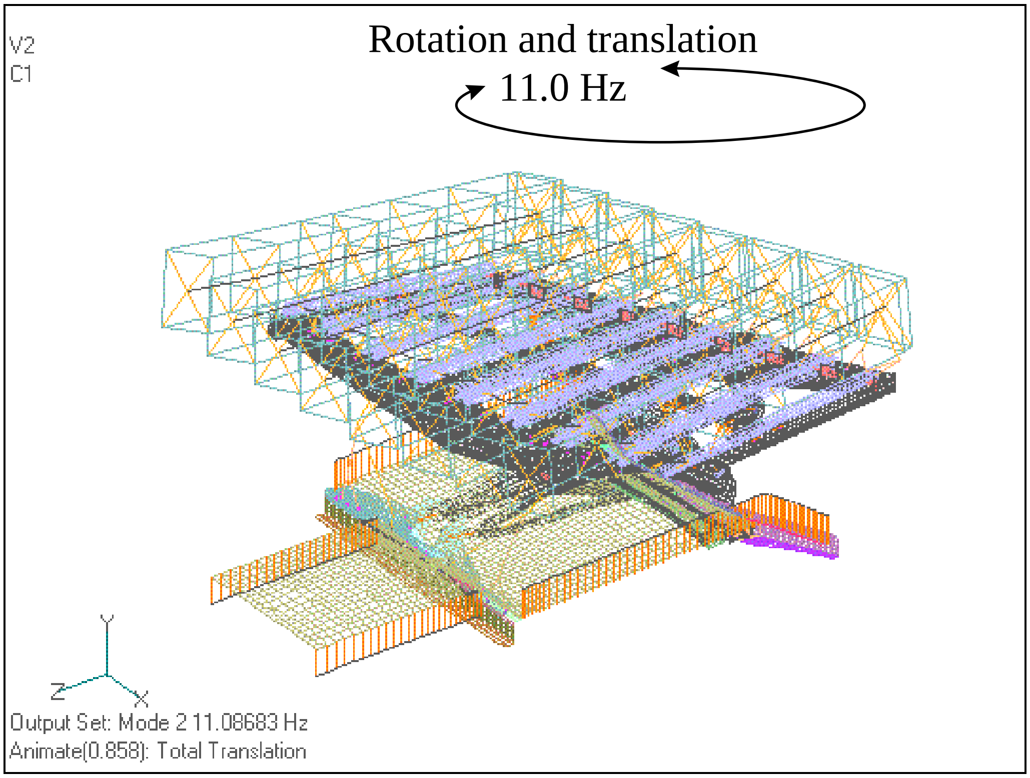


Figure 8-9 Second stow position mode shape

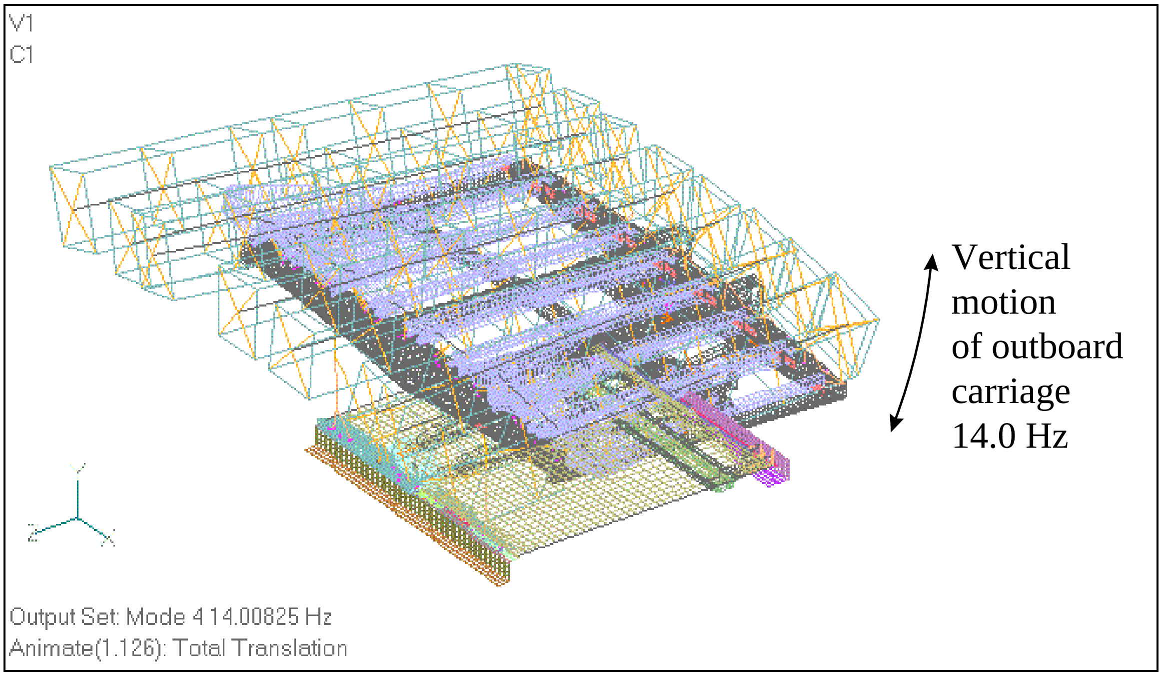


Figure 8-10 Third stow position mode shape

8.5.2 Launch position modes

Table 8-2 Launch position natural frequencies

MODE	CYCLES Hz	MODE	CYCLES Hz	MODE	CYCLES Hz
1	2.6	15	24.2	29	31.4
2	3.7	16	24.2	30	31.6
3	5.7	17	24.6	31	35.2
4	11.0	18	24.8	32	37.2
5	13.9	19	25.4	33	38.0
6	14.1	20	25.4	34	38.2
7	14.3	21	27.2	35	38.3
8	14.3	22	28.1	36	38.7
9	14.6	23	29.3	37	44.8
10	14.7	24	29.6	38	55.5
11	14.8	25	30.7	39	56.8
12	14.8	26	30.8	40	61.5
13	17.5	27	31.1	41	65.6
14	21.8	28	31.1	42	67.9

There are three groupings of modes within all of the launch position modes. Those near 14 Hz are lateral motion of the canisters. These are no longer valid because much stiffer fittings were added to the Fwd Truss to restrain the canister lateral motion. The group near 24 Hz are translation of the canisters along the canister axis, with alternating canisters in and out of phase.

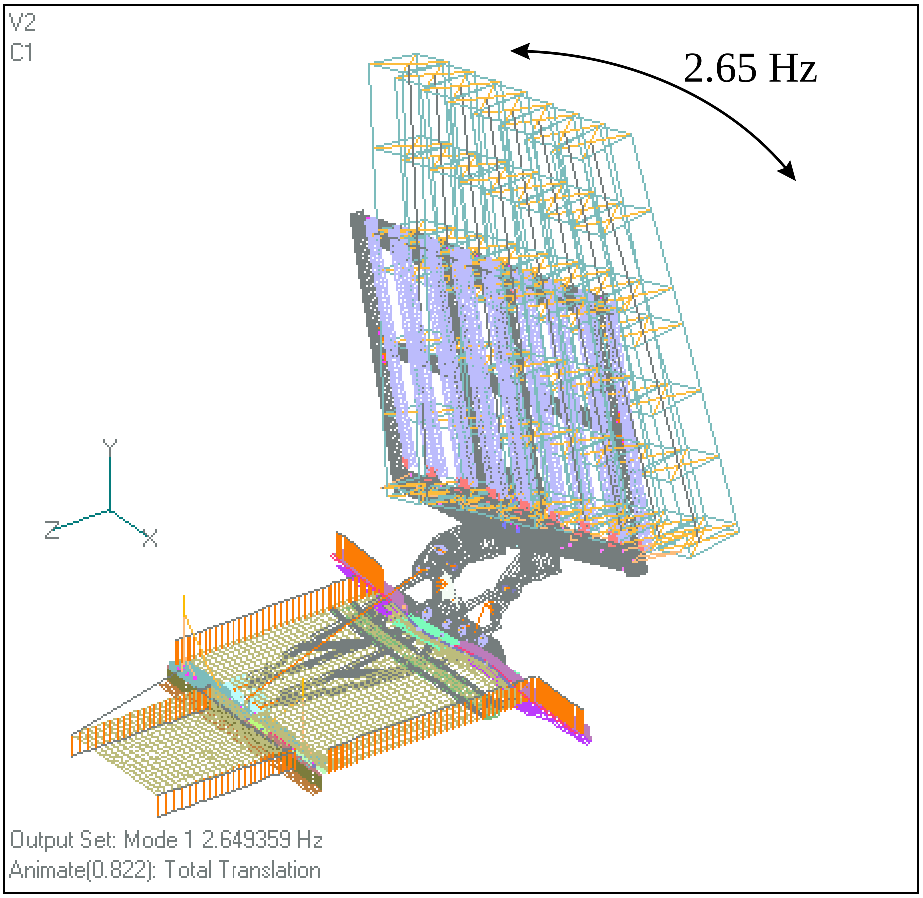


Figure 8-11 First launch position mode shape

Mode shape animations of selected stow and launch position modes can be viewed at http://www.respmech.com/efogm.

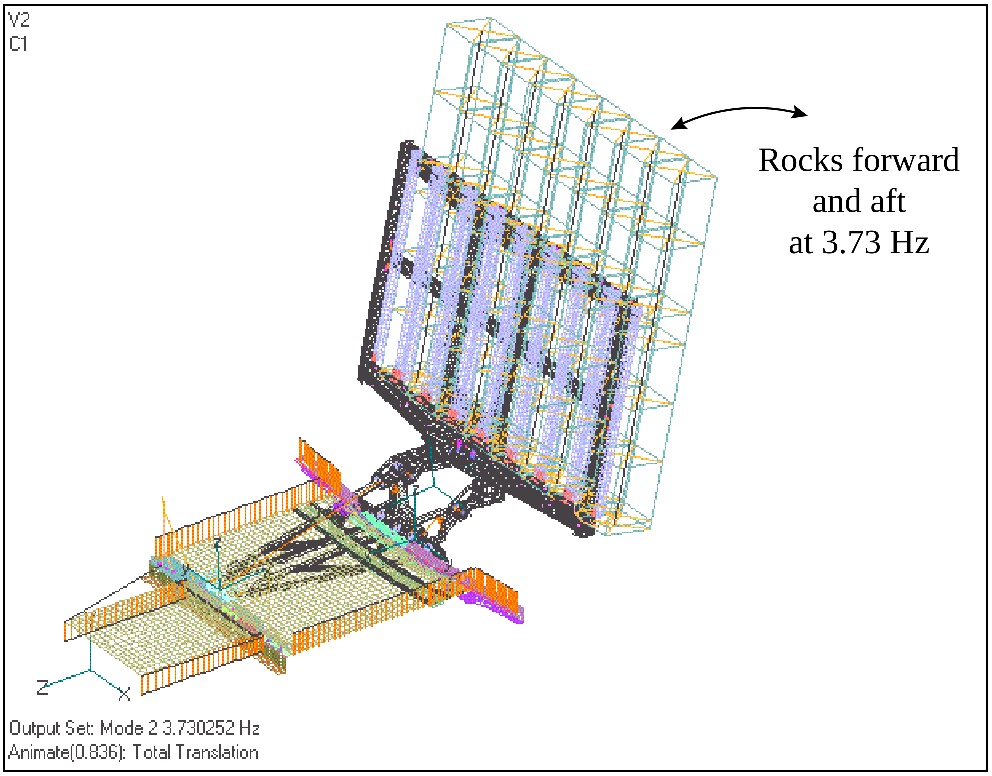


Figure 8-12 Second launch position mode shape

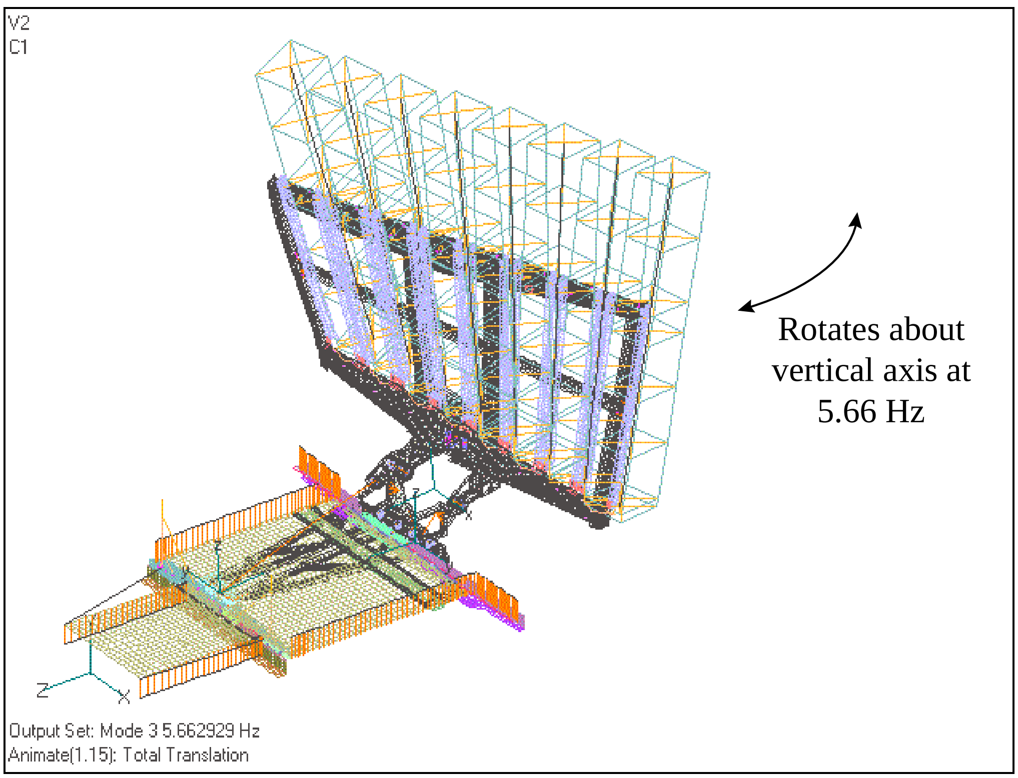


Figure 8-13 Third launch position mode shape

8.6 Shock

The 200ms crash load pulse was calculated in 50 steps during the pulse and 100 steps during the 800ms following the pulse. The pivot locations labeled in Figure 8-14 are defined in Figure 8-1. The peaks shown would result if the launcher assembly were perfectly elastic. Local yielding will reduce these values. A non-linear transient analysis is needed to determine the actual levels.

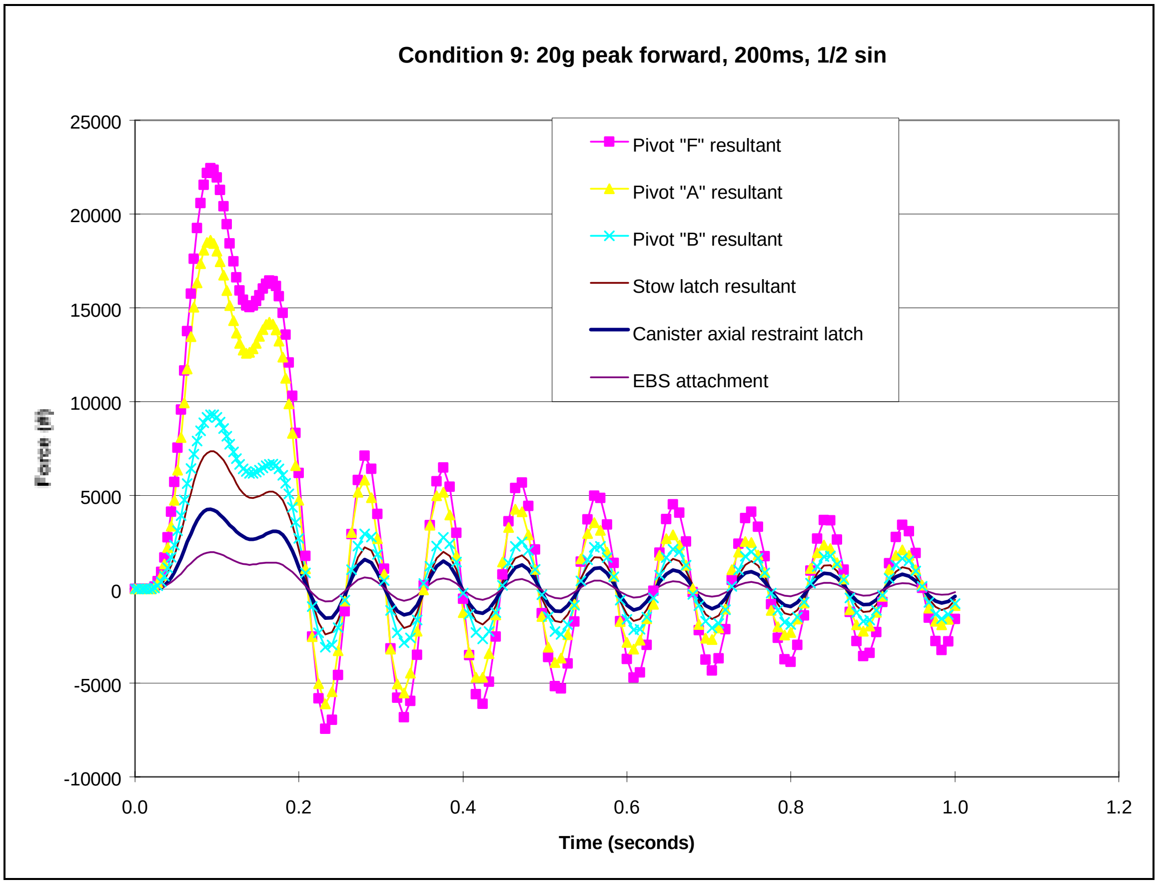


Figure 8-14 Crash load transient response

We can count 10 cycles within the first 1 second of the crash load transient response, corresponding with the 10 Hz longitudinal natural mode.

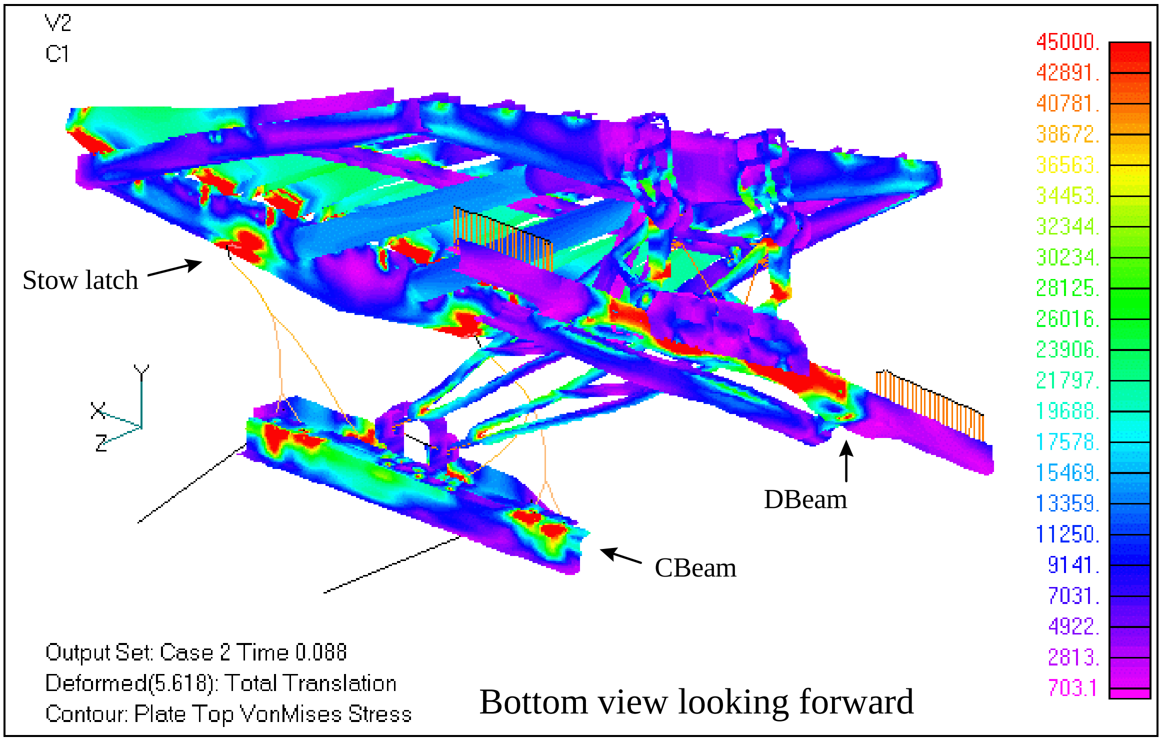


Figure 8-15 Cond. 9 transient response at t = 0.088 sec.

The 25ms boost pulse was calculated in 50 steps during the pulse and 48 steps during the 480ms following the pulse.

The transient crash load stress response shows relatively high stresses near the joints, with steep gradients from the joint to the body of the structure, because at the instant in time the energy has not yet spread out. Local yielding will dissipate energy before large sections of the structure become plastic.

8.6.1 Number of retained modes

All 62 of the stow position modes, from 8.79 Hz to 119 Hz, are used in both the shock and frequency response runs.

8.6.2 Size of the time step

The analysis is started with 50 time steps of 0.004 second each, followed by 100 time steps of 0.008 seconds each. There is an initial delay of 0.016 seconds.

8.7 Frequency Response

In MSC/NASTRAN the seismic mass approach for this base excitation situation. Preliminary runs are made, with the rigid modes included, to verify that the seismic mass does accelerate with a 386 in/s^2 magnitude. Then the frequency response runs are made with the rigid modes excluded in order to output the relative responses.

In general the higher frequency amplitudes reduce and the lower frequency amplitudes increase, as the locations moves from the Sideplate / Pivot hinge bearing, to the Lan Nav CG, to the Missile mass.

8.7.1 Number of retained modes

All non-rigid modes up to 200 Hz are used for the frequency response. Nearly all of the Ground Mobil energy is contained at less than 200 Hz, as shown in Figure 5-2 on page 5-5. The range of mode frequency used, minimally covers the input frequency range. Ideally we would use modes up to 400 Hz in order to increase the accuracy of the higher frequency results. This can not be done with the current FEM and computer, due to resource limitations.

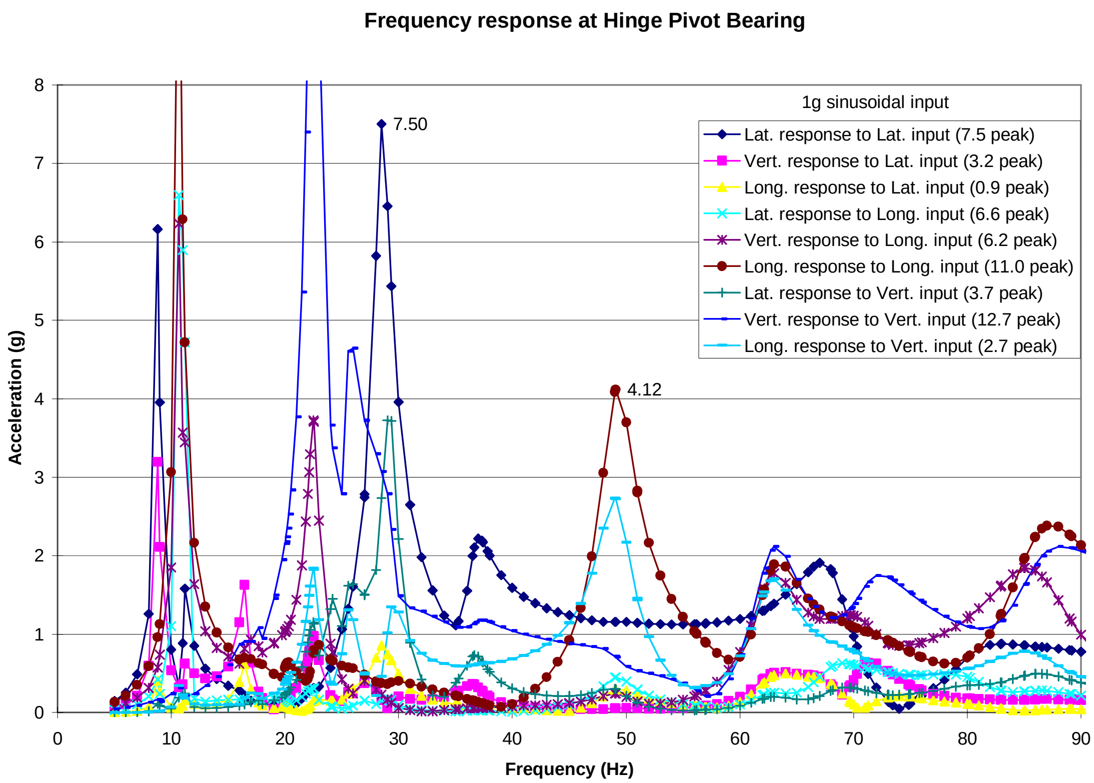


Figure 8-16 Frequency response at Hinge Pivot bearing

8.7.2 Size of the Frequency Increment

Generally a minimum of 5 frequency input points lie between the Half-Power points (peak / √2) for each peak. Each natural frequency up to 200 Hz is used for input, as well as every integer between 5 Hz and 121 Hz, for a total of 179 input excitation frequencies.

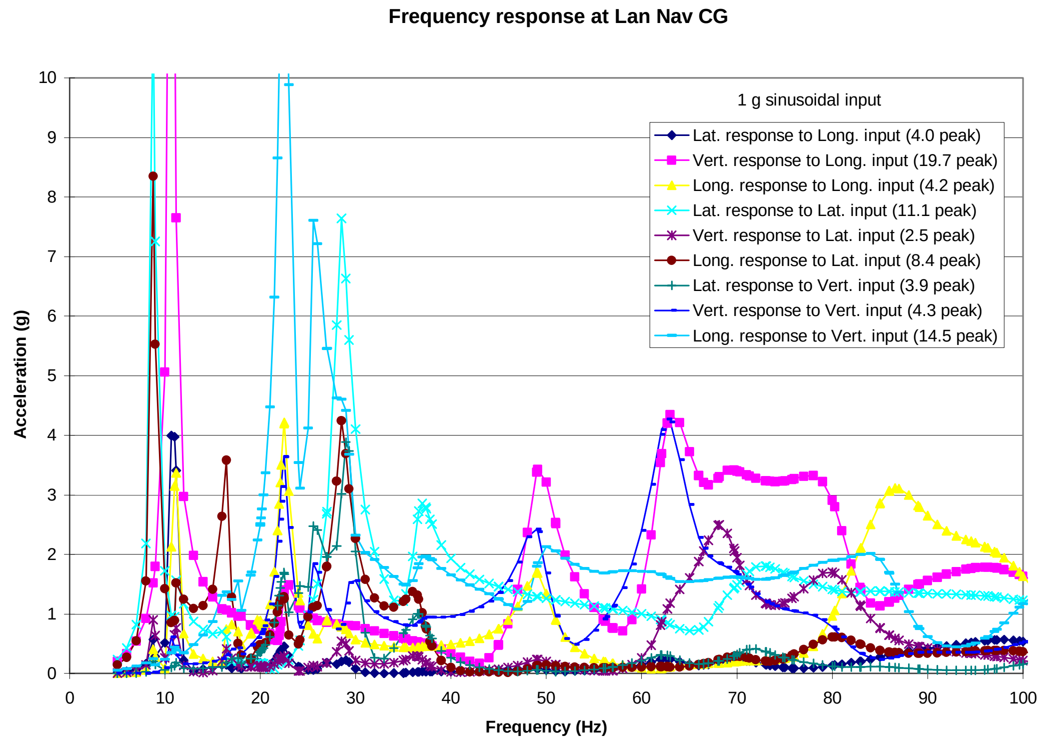


Figure 8-17 Frequency response at Lan Nav CG

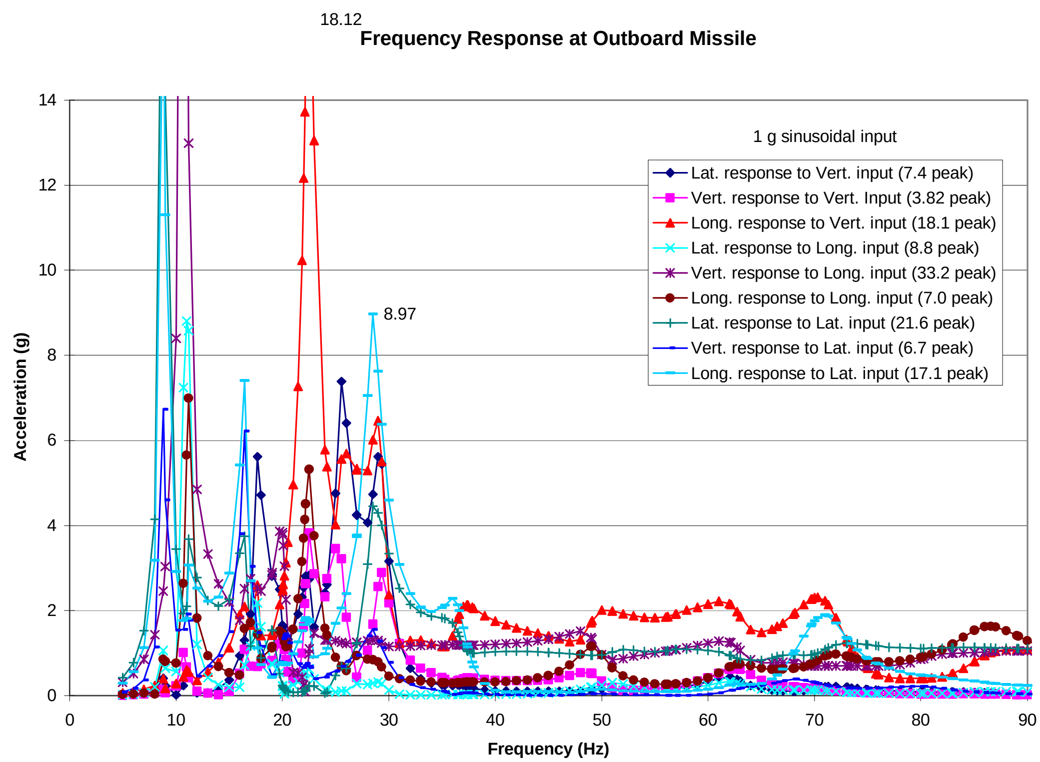


Figure 8-18 Frequency response at outboard Missile

8.7.3 Affect of limit actuator restraint force

The presence of the limit actuator retraction force can affect the mode shapes and thus the frequency response. The mode shapes are run both with and without a rod of equal stiffness as the actuator. A static load can not be applied during the frequency response runs. It is expected that the presence of the static load will reduce the stress ratio and increase the fatigue life.

8.8 Random Vibration

The ground mobile environment is a physical phenomena that result in nondeterministic data where future instantaneous values cannot be predicted in a deterministic sense. The study of the response of physical systems to such unpredictable instantaneous values of excitation leads to the use of random analysis methods. In MSC/NASTRAN, ergodic random analysis is treated as a data reduction activity that is applied to the results of a frequency response analysis. The inputs for these data recovery activities are the output quantities from the frequency response analysis, and user supplied auto- and cross-spectral densities of the loading conditions. The outputs are the power spectral density functions, the autocorrelation functions, the number of positive crossings of the line y(t) = 0 by the response record to a unit time, and the RMS value of the response. These latter two items are of particular importance. The number of positive crossings, N_0, is obtained from the joint probability density function p(y•dy/dt) and is a measure of the apparent frequency of the response. The RMS value of the response is a measure of the standard deviation. These values are displayed in the RMS stress and frequency contour plots herein.

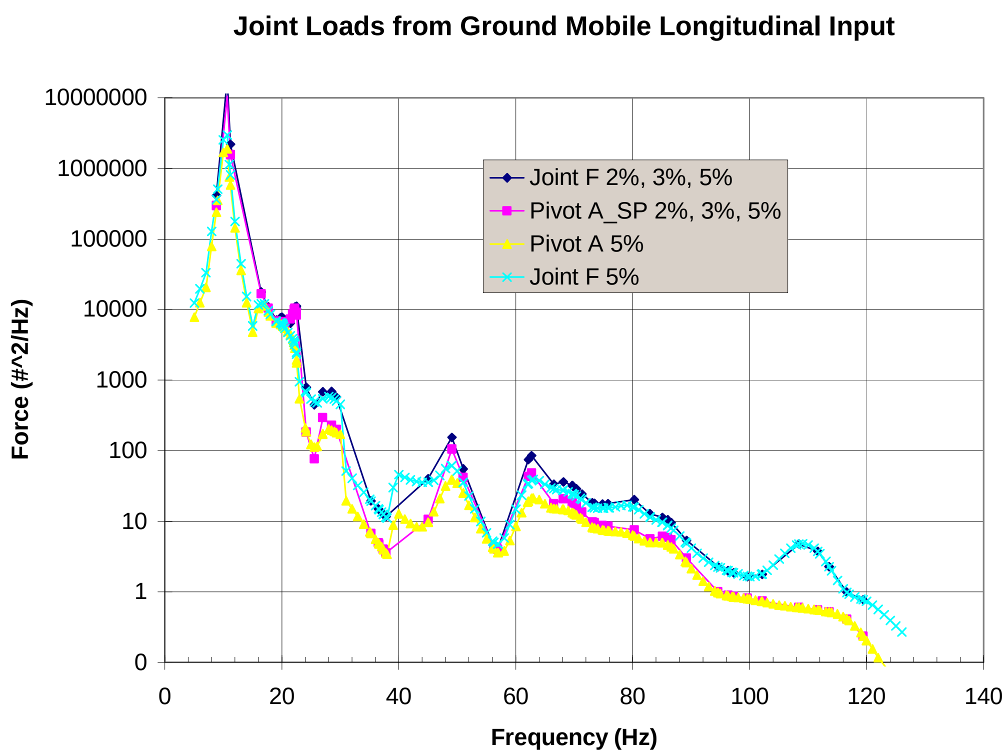


Figure 8-19 Pivot Joint PSD Force Response

8.8.1 Compare SDOF approximation with NASTRAN results

We desire to verify the PSD response of the EFOGM structure that is output from MSC/NASTRAN. The solutions to some simplified lumped mass approximations can be used to this end.

A Single Degree Of Freedom (SDOF) approximation, considering a 1600# missile carriage, 5% dampening, and the PSD longitudinal base motion input at 10Hz of 0.16G2/Hz results in 4206# per side.

Miles' equation: $$F = \frac{1600}{2}\sqrt{\frac{\pi}{4\cdot\zeta}\cdot S(f)\cdot f_n} = \frac{1600}{2}\cdot\sqrt{5\cdot\pi\cdot 0.16\cdot 11} = 4206\#$$ [Ref. 5]

NASTRAN RMS output value on the +X side is = 3540# when 5% dampening is used. This is slightly lower because the longitudinal mode is near 11Hz and looking in Figure 5-1 we see that the $S(f_n)$ is drops off after 10Hz.

Using peak force read from F(PSD out) in Figure 8-19, and assuming that all of the energy is in the peak, results in 4157# per side.

$$F = \sqrt{\frac{\pi}{2}\cdot 2\cdot\zeta\cdot f_n\cdot F_{PSDout}} = \sqrt{\pi\cdot 0.05\cdot 11\cdot 10^7} = 4157\#$$

Having the SDOF calculation match the NASTRAN output verifies that the NASTRAN input case is defined correctly.

8.8.1.1 Lumped masses

We use the MSC/NASTRAN static deflection solution to write the relative stiffness at points on the structure. We show the deflections and masses below.

These "handbook" methods verify the order of magnitude of the MSC/NASTRAN results, while not matching exactly.

Table 8-3 Lumped masses

One Missile and Canister	Carriage and Upper Link	Carriage mount structure
174.4 lb	299.1 lb	127.6 lb

The simplest approximation is lumping all of the mass, from both the canisters and carriage, into one SDOF mass, which can be used to compare the response at the Pivot joint connection. A further simplification is to assume that the PSD input is broadband, and that the PSD level is that at the SDOF natural frequency, and thus move the PSD input factor outside of the summation. Another further simplification is to assume that all of the response energy is contained in the natural frequency peak. All of these simplifications combined is referred to as Mile's equation.

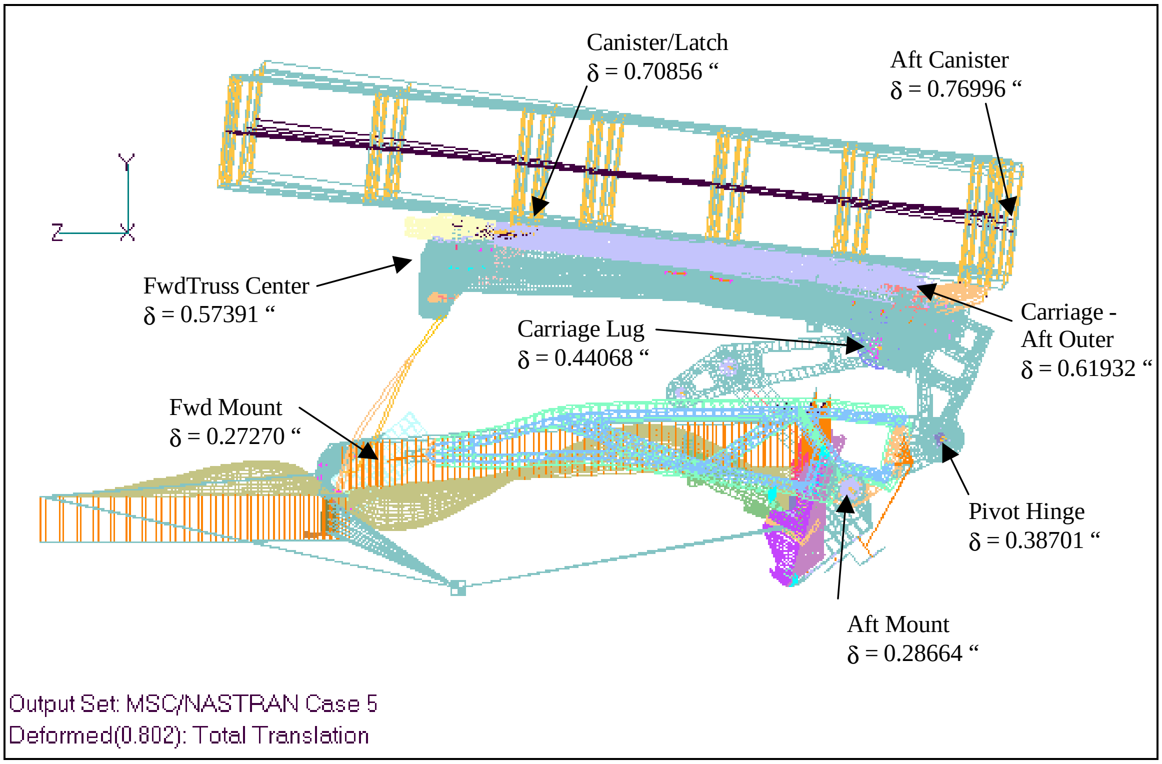


Figure 8-20 Stow position static deflection for 8g aft load

Table 8-4 Miles equation results

All eight missile canisters on carriage mass		
$m := 8\cdot(174.395\,lb) + 299.12\,lb$	$m = 1.694\cdot 10^{3}\cdot lb$	
$k := \frac{(8\cdot(174.395\,lb) + 299.12\,lb)\cdot 8\cdot g}{0.5\cdot((.57391 + .44068)\cdot in)}$	$k = 2.672\cdot 10^{4}\cdot\frac{lbf}{in}$	
$fn := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{k}{m}}$	$fn = 12.419\,sec^{-1}$	$\zeta := .04$
$PSD := .05\cdot\frac{g^{2}}{Hz}$	$aRMS := \sqrt{\frac{PSD\cdot\pi\cdot fn}{4\cdot\zeta}}$	$aRMS = 3.492\cdot g$
One missile canister on carriage plus 1/3 of support structure mass		
$m := 174.395\,lb + 299.12\,lb + \frac{127.6\,lb}{3}$	$m = 516.048\,lb$	
$k := \frac{(8\cdot(174.395\,lb) + 299.12\,lb)\cdot 8\cdot g}{0.5\cdot((.57391 + .44068)\cdot in)}$	$k = 2.672\cdot 10^{4}\cdot\frac{lbf}{in}$	
$fn := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{k}{m}}$	$fn = 22.502\,sec^{-1}$	$\zeta := .04$
$PSD := .028\cdot\frac{g^{2}}{Hz}$	$aRMS := \sqrt{\frac{PSD\cdot\pi\cdot fn}{4\cdot\zeta}}$	$aRMS = 3.517\cdot g$

Picking single point PSD values from the irregular PSD input curve is difficult and inaccurate due to the steep slope of the "PSD curve" between the observed values. A better approach is to use the area under the entire PSD curve, as described next.

8.8.1.2 Integrating under the actual PSD force response curve

The next level toward a more accurate approximation is to remove the broadband PSD input assumption, while still lumping all mass into one SDOF.

Table 8-5 SDOF "area under curve" method

$m := 4.389339\,mug$	$k := 26718\,\frac{lbf}{in}$
$fn := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{k}{m}}$	$fn = 12.419\,sec^{-1}$
$Hf2_j := \frac{1}{(2\cdot\pi\cdot fn)^4\cdot\left[\left[1-\left(\frac{f_j}{fn}\right)^2\right]^2+\left(2\cdot .04\cdot\frac{f_j}{fn}\right)^2\right]}$	
$aRMS := \sqrt{\sum_j (2\cdot\pi\cdot fn)^4\cdot PSD\cdot Hf2_j\cdot df_j}$	$aRMS = 3.08\cdot g$ $Force = 5.218\cdot 10^3\cdot lbf$

Table 8-6 Single DOF "matrix" method

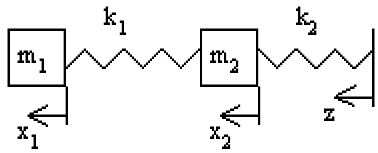
$m := 4.389339\,mug$	$k := 26718\,\frac{lbf}{in}$
$\phi\cdot M\cdot\phi = 1 \quad \phi = 0.024\cdot lb^{-0.5}$	$\omega n := \sqrt{\phi\cdot K\cdot\phi}\,, \quad \omega n = 78.028\,sec^{-1}$
$Szz_j = \frac{\frac{PSD}{2*\pi}}{(\omega_J)^4}$	$H_j = \frac{1}{\omega n^2-\omega_j^2+2\cdot\zeta\cdot\omega n\cdot\omega_j\cdot i}$
$Sxx_j := \phi\cdot\overline{H_j}\cdot\phi\cdot k\cdot Szz_j\cdot k\cdot\phi\cdot H_j\cdot\phi$	$SFF1_j := (k)^2\cdot(Sxx_j)$
$F1rms := \sqrt{\frac{1}{\pi}\cdot\sum_{jn} SFF1_{jn}\cdot d\omega_{jn}}$	$F1rms = 3.821\cdot 10^3\cdot lbf, \quad \frac{F1rms}{m} = 2.255\cdot g$

Table 8-7 MSC/NASTRAN Single DOF result

aRMS = 2.93	Force = 4973.7

8.8.2 Include relative stiffness between the Carriage and Canister with Two DOF

In order to get an approximation of the canister latch force; we include the relative stiffness between the canister and carriage that is due to the latch angle bracket and the ½" diameter steel rod that the latch holds. This model has two lumped masses; one representing the canister and another representing the carriage.



It is desired to find the PSD force response in the springs, given a PSD input acceleration at the base. The first step is to write the system matrix and solve the eigenvalue problem.

Mass matrix	Stiffness matrix	Eigenvectors	Eigenvalues
$M := \begin{pmatrix} m_1 & 0.0 \\ 0.0 & m_2 \end{pmatrix}$	$K := \begin{pmatrix} k_1 & -k_1 \\ -k_1 & k_1 + k_2 \end{pmatrix}$	ϕ such that $\phi^T \cdot M \cdot \phi = [1]$	$\omega n^2 = \phi^T \cdot K \cdot \phi$

In the case with symmetric dampening, it is shown that the terms in the solution are:

Frequency response	$H_j = \begin{bmatrix} \dfrac{1}{\omega n_{1,1}{}^2 - \omega_j{}^2 + 2 \cdot \zeta \cdot \omega n_1 \cdot \omega_j \cdot i} & 0 \\ 0 & \dfrac{1}{\omega n_{2,2}{}^2 - \omega_j{}^2 + 2 \cdot \zeta \cdot \omega n_2 \cdot \omega_j \cdot i} \end{bmatrix}$
Displace-ment response	$Sxx_j = \phi \cdot \overline{H}_j \cdot \phi^T \cdot \begin{pmatrix} 0 \\ k_2 \end{pmatrix} \cdot \dfrac{PSDin}{\omega_j{}^4} \cdot \begin{pmatrix} 0 & k_2 \end{pmatrix} \cdot \phi \cdot H_j \cdot \phi^T$
Force response	$SFF1_j = k_1{}^2 \cdot \left(\left(Sxx_j\right)_{1,1} - \left(Sxx_j\right)_{1,2} - \left(Sxx_j\right)_{2,1} + \left(Sxx_j\right)_{2,2} \right),$ $SFF2_j = k_2{}^2 \cdot \left(Sxx_j\right)_{2,2}$
RMS Force	$F_{RMS} = \dfrac{1}{\pi} \sqrt{\sum_j SFF_j \cdot d\omega_j}$

The overall mode with all 8 canisters is at 12.4 Hz with many individual canister modes at 22.5 Hz, where adjacent canisters are moving longitudinally in opposite directions. With one canister only the overall mode is at 18.4 Hz and the canister mode is at 36.0 Hz. The fact that the canister modes are nearly exactly twice the overall mode; maximizes the coupling between the modes. The flexibility between the carriage and canister does attenuate the acceleration of the canister, as is shown in the 2 DOF solution below.

8.8.2.1 Numerical example

A dimensional analysis in this problem is not sufficient to assure that all factors have been included. Acceleration due to gravity (g) has the same units as absolute acceleration. Frequency stated in rad/sec has the same dimension as that in Hz. Therefore a numerical example is required in order to complete the statement of the solution. Shown are intermediate results for one term in the summation.

$\omega_j = \omega_{53} = 113.097 \cdot \frac{rad}{sec}$, $d\omega_j = 1.571\ sec^{-1}$	$m := \begin{pmatrix} 174.395 \\ 341.65 \end{pmatrix} \cdot lb$, $k := \begin{pmatrix} 10265.0 \\ 26718.0 \end{pmatrix} \cdot \frac{lbf}{in}$
$\phi = \begin{pmatrix} 0.0657 & -0.0376 \\ 0.0269 & 0.047 \end{pmatrix} \cdot lb^{-0.5}$	$\omega n^2 = \begin{bmatrix} 1.343 \cdot 10^4 & 7.276 \cdot 10^{-12} \\ 3.638 \cdot 10^{-12} & 5.109 \cdot 10^4 \end{bmatrix} \cdot sec^{-2}$
$Freq := \begin{bmatrix} 5.0 \\ 7.0 \\ 10.0 \\ 11.0 \\ 15.0 \\ 16.0 \\ 20.0 \\ 23.0 \\ 30.0 \\ 31.0 \\ 38.0 \\ 40.0 \\ 73.0 \\ 138.0 \\ 200.0 \\ 500.0 \end{bmatrix} \cdot Hz$	$PSD := \begin{bmatrix} 0.0200 \\ 0.0300 \\ 0.1600 \\ 0.0400 \\ 0.0160 \\ 0.0500 \\ 0.0500 \\ 0.0070 \\ 0.0350 \\ 0.0050 \\ 0.0030 \\ 0.0150 \\ 0.0030 \\ 0.0004 \\ 0.0010 \\ 0.0015 \end{bmatrix} \cdot \frac{g^2}{Hz}$
$Szz_{53} = 7.25 \cdot 10^{-6} \cdot sec \cdot in^2$	
$H_{53} = \begin{pmatrix} 4.24 \cdot 10^{-4} - 6.95 \cdot 10^{-4} i & 0 \\ 0 & 2.604 \cdot 10^{-5} - 1.39 \cdot 10^{-6} i \end{pmatrix} \cdot sec^2$	
$Sxx_{53} = \begin{pmatrix} 1.539 \cdot 10^{-3} & 6.747 \cdot 10^{-4} + 6.982 \cdot 10^{-5} i \\ 6.747 \cdot 10^{-4} - 6.982 \cdot 10^{-5} i & 2.989 \cdot 10^{-4} \end{pmatrix} \cdot sec \cdot in^2$	
$SFF1_{53} = 5.15 \cdot 10^4 \cdot sec \cdot lbf^2$	$SFF2_{53} = 2.134 \cdot 10^5 \cdot sec \cdot lbf^2$
$F1_{RMS} = 547.886 \cdot lbf$	$F2_{RMS} = 2.062 \cdot 10^3 \cdot lbf$
MSC/NASTRAN $F1_{RMS}$ = 968.4 lbf	MSC/NASTRAN $F2_{RMS}$ = 1772.3 lbf

The 2 DOF model does not capture a mode where some canisters are moving forward and some are moving aft, which will be excited because of the asymmetry of the LanNav mass on the carriage.

Professor Dave Peters, Phd is the head of the Department of Mechanical Engineering at Washington University. He is also the instructor for the advanced vibrations courses there. His background includes years employed at McDonnell Douglas and Bell Helicopter, developing methods to include the interaction of aerodynamic forces and structural elasticity for analyzing the vibrations of rotor blades.

Professor Peters and Ranny Meier have carefully formulated and checked the "handbook methods" used herein.

8.9 Fatigue

8.9.1 RMS Stress contour plots

The stresses shown in the RMS Stress contour plots herein, are not at an instance in time, like static stress values normally displayed in contour plots. These values represent the square root of the area under the PSD stress response vs. Frequency curve. Various parts of the structure are affected by different frequency content in the input spectrum based on the parts natural frequency. The apparent frequency is shown in contour plots. The apparent frequency can be used to read the allowable stress in Figure 7-1 Fatigue stress allowable for unnotched 6061-T6 vs. Frequency.

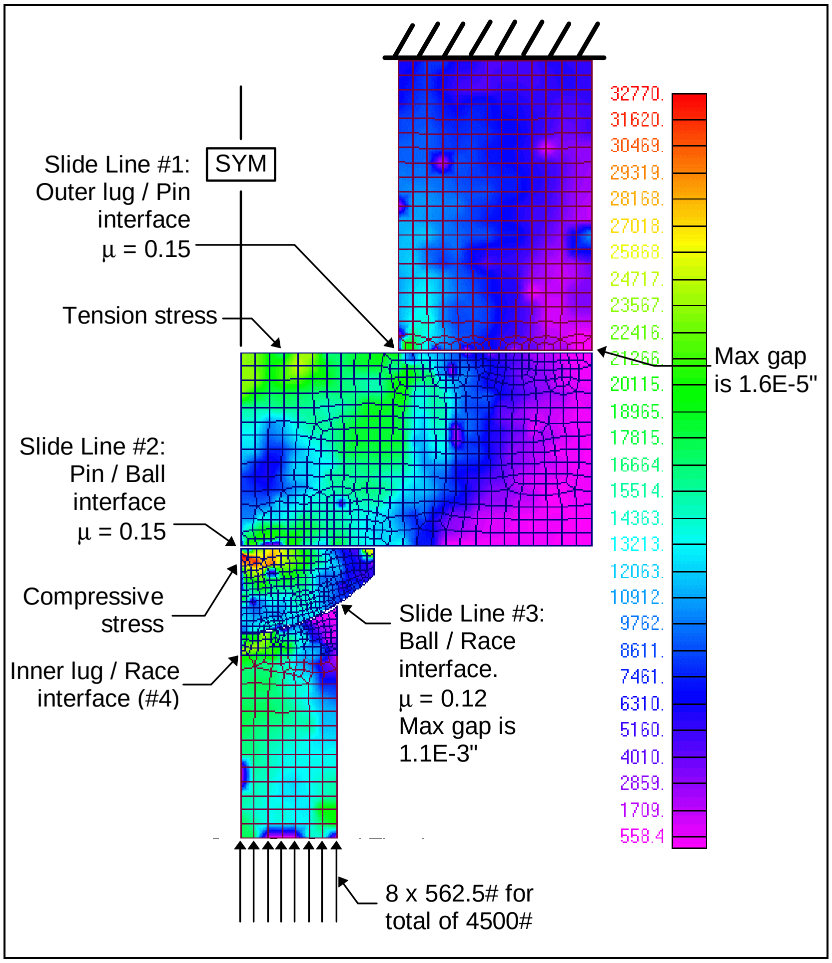


Figure 8-21 Clevis Joint Slide Line FEM

8.9.2 Clevis joint elastic load distribution and peaking factor

No handbook results are available at this time for the "spherical ball bearing in center lug" type clevis joint. The NASTRAN non-linear (gapping) slide line 2D model, shown in Figure 8-21 below, is used to determine the running load distribution along the pin and lug sockets. There is relatively little pin deflection, at the fatigue load levels, as indicated by the "max gaps" in the converged slide line results. Therefore this result is not lacking for socket effects.

The element thickness was set to match the bending stiffness of the actual 1.0" dia. Pin. All of the elements are 0.589" thick and are the Plain Strain type. While this is not a full 3D model, we can get an indication of the actual bearing stress distribution.

Surprisingly the peaking on the inner lug is at the midplane and not at the outer edges, like it would be if the spherical ball bearing were not present. A $K_t(p)$ of 1.47 is found by dividing the peak by the average stress.

The FEM predicts a steep gradient at the inside of the outer lugs. When the "Reasonable stress limit" is used to cut off the maximum the resulting $K_t(p)$ is 2.50 for the outer lug fatigue checks.

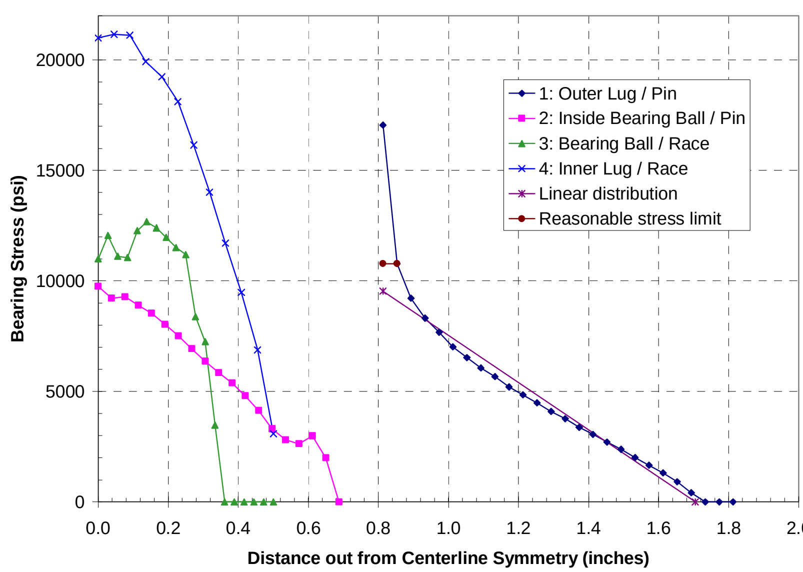


Figure 8-22 Clevis Joint bearing stress distribution

8.10 Strength

8.10.1 Launch position static stresses

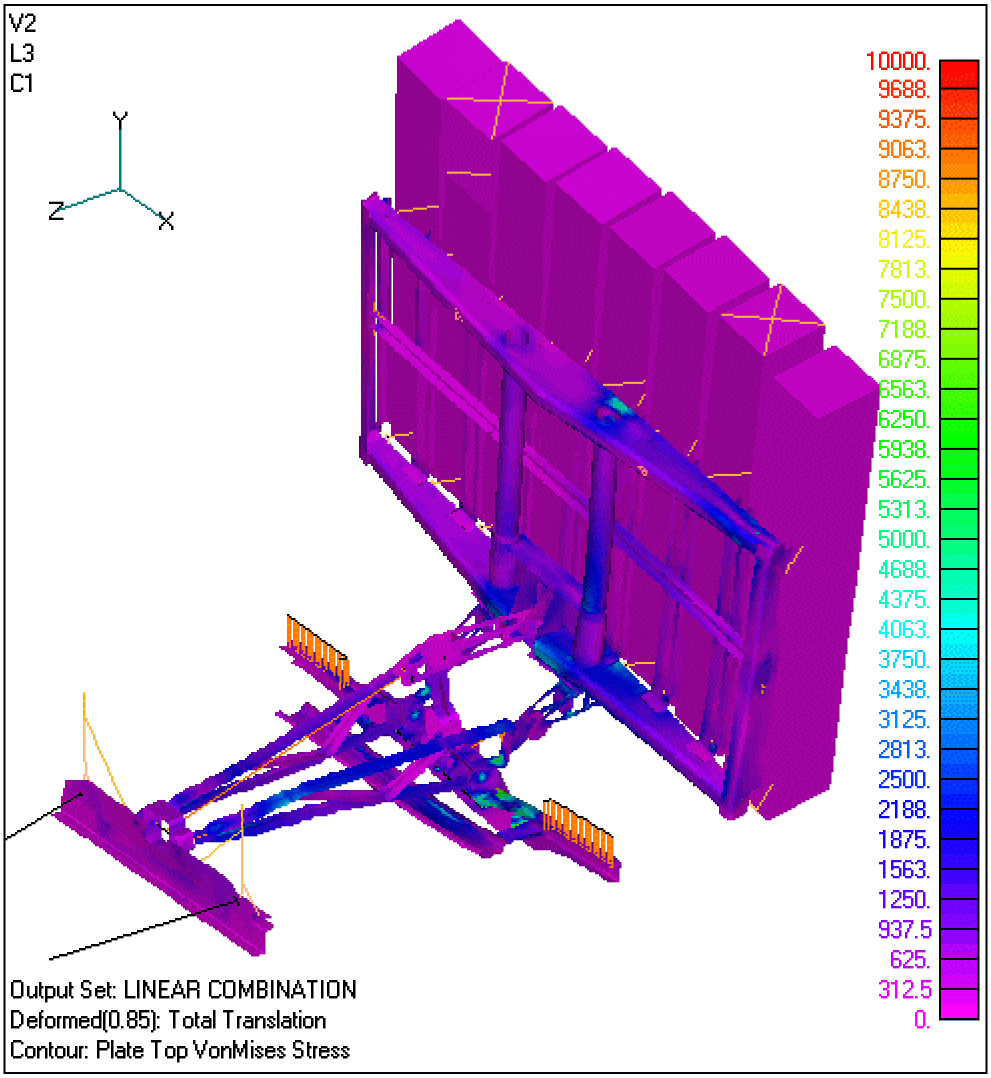


Figure 8-23 Launch position static strength

The 875# launch pulse load is applied statically, along with the wind loads. This is a conservative approach because of the relatively long natural period and short pulse duration.

8.10.2 Reload position static stress

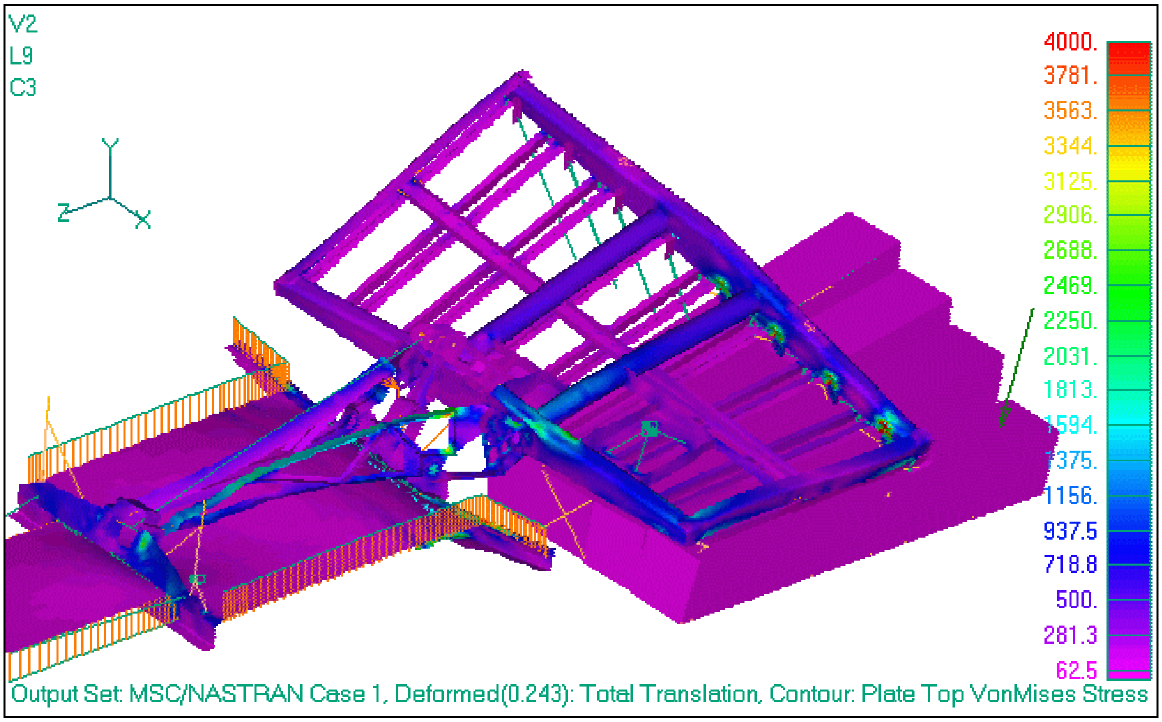


Figure 8-24 Assembly reload position Cond. 52 static stress

8.10.3 Unloaded stow position 40g down stress

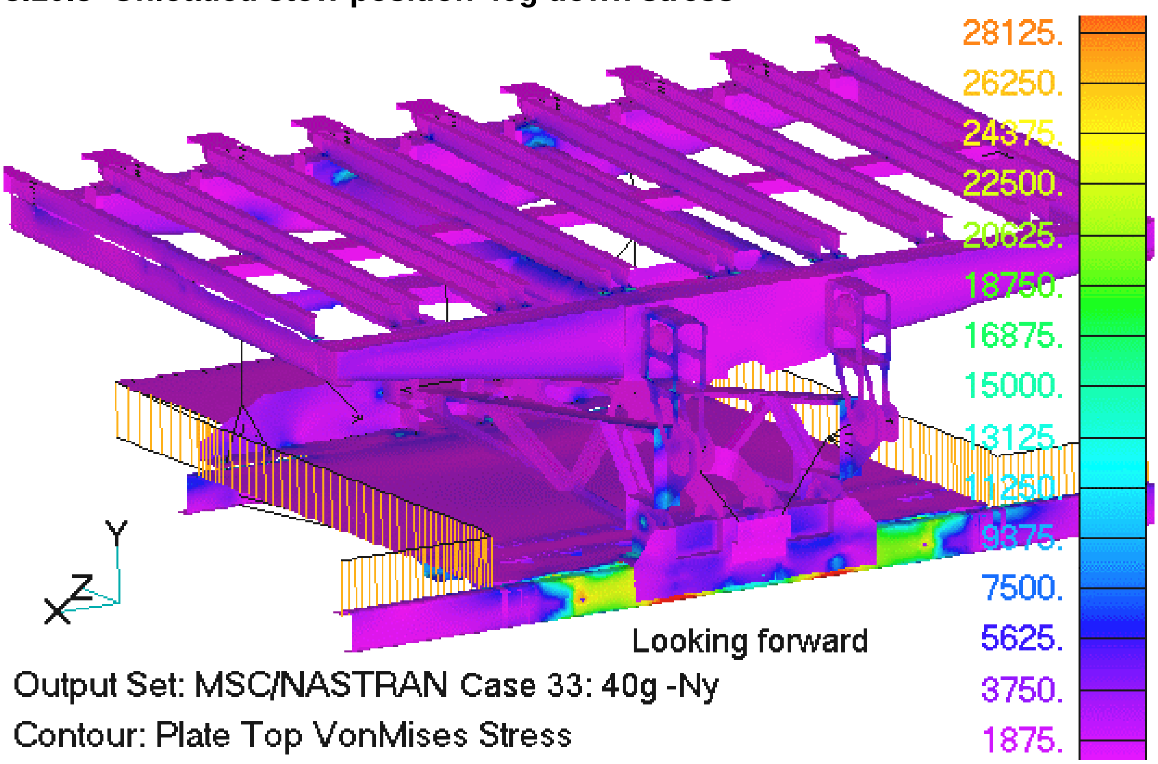


Figure 8-25 Unloaded stow postion, Cond 33, 40g down body stress

8.11 Thermal

Thermal effects were not considered in the analysis contained herein.

8.12 Stability

The NASTRAN SEBUCKL solution was used to check the compression capability of the SidePlates. The SidePlates are in compression when the carriage is being lifted from the reload position (Figure 8-24). The actuator was checked for compression capability, at the fully extended position, using a beam-column analysis.

8.13 Mass Properties

The missile canister weight and C.G. location is defined in ¶5.3 above. The canister is modeled assuming 0.190" thick kevlar epoxy. This missile is modeled as ∅8.00" with 0.25" wall thickness. The missile is modeled with two materials; one forward and one aft of the actual C.G., where the density of each "missile material" is adjusted to cause the cansiter and missile assembly weight and C.G. to match those defined in ¶5.3 above. The result is a reasonable stiffness approximation for the canister assembly.

8.14 Hydraulic actuator cycle pressure

The carriage is pulled down on the stow stand by the hydraulic actuator working against the “check valve cushions”. Typically the switches shut the valve before the pressure rises past 820psig, as shown by the vertical spike at the end of the stroke in Figure 8-26 below.

Figure 8-26 Hydraulic actuator cycle pressure

Appendix A Analysis files

These files are available on CDROM at the SEI EFOGM program office.

Table 8-8 EFOGM Analysis files

Filename	Type	Run Time (min.)	Scratch Size (GB)	Load condition	Description	Notes
Stow32.MOD	Femap			1-8,21-32	C130, Patriot	Stow33.dat & Stow34.dat
Stow33.dat	NAST	303:18	1.2	1-8	C130	
Stow33R.MOD	Femap			1-8, 12, 21-32	C130, Patriot	Results
Stow34.dat	NAST	530:35	1.0	21-32	Patriot	
Stow43.dat	NAST	658:50	1.3	9-10,60	Crash, Mobil	Mode shapes
Stow35R.MOD	Femap			9-10,60	Mode shapes	Results
Stow36.dat	NAST	336:47	1.2	12	C130	Actuator removed
Stow37.dat	NAST	30:17	1.66	9	Crash	Shock response
Stow38.dat	NAST	25:36	1.5	60	1g sin input	Frequency response
Stow46.dat	NAST	37:42	1.36	64 Vertical	PSD input	Vertical Random response 2%
Stow55.dat	NAST	49:31	1.74	64 Vertical	PSD input	Vert. Rand. More frq. 0.05 dp
Stow47.dat	NAST	34:56	1.4	62 Long.	PSD input	Long. Random response 2%
Stow54.dat	NAST	39:17	1.8	62 Long.	PSD input	Long. Rand. more frq. 0.05 dp
Stow48.dat	NAST	35:50	1.36	63 Transverse	PSD input	Transverse Random response
Stow49.dat	NAST			60 w/ Retract	Mode shapes	Affect of actuator stiffness
Stow50.dat	NAST	268:50	1.5	64 Vertical	PSD input	Fwd. Truss results
Stow51.dat	NAST	32:42	1.56	64 Vertical	PSD input	SidePlate results
PlusSidePlate.mod	Femap			64 Vertical	PSD input	SidePlate results
Stow56.dat	NAST	89:02	0.46	62 Long.	PSD input	SidePlate results
Stow52.dat	NAST	27:20	1.6	64 Vertical	PSD input	Pivot results
Stow53.dat	NAST	394:55	1.7	64 Vertical	PSD input	Dbeam results
Stow40.dat	NAST	44:28	0.78	11	Twist	0.79 +Y at CBeam mount
Stow42.dat	NAST	90:11	0.79	13	Latch	−X latch without lateral
Stow45.dat	NAST			14	Latch	Both latches without lateral
Stow61.dat	NAST	15:13	0.78	33 Vertical	Latch	Vert 40g on empty launcher
Vert2.MOD	Femap			42	Launch	Mode shapes
Vert3.dat	NAST	94:22	0.70	42	Launch	Wind and Launch load
Vert3R.MOD	Femap			42	Launch	Wind and Launch load
Reload1.MOD	Femap			51-52	Reload	
Reload1.dat	NAST	96:07	0.75	52	Reload	4 full w/one man
Reload2.dat	NAST	92:23	0.74	51	Reload	
Clevis3.dat	NAST			N/A	9000#	Pivot F clevis joint model
Clevis.MOD	Femap			N/A	9000#	Bearing distribution & peaking
FwdTrsHex.mod	Femap			7	-4.5g Nz	Stow Latch Detail
FwdTrs1.dat	NAST	90:02	0.25	7	-4.5g Nz	Stow Latch Detail
LatchAngle3.mod	Femap	2:54	0.041	62 Long.	PSD Input	Canister Latch Angle
LatchAngle7.dat	NAST	18:24	0.11	5	C130	Non-linear material
TrussAngle.mod	Femap			62 Long.	PSD Input	Latch Angle (Rev A) on Truss
TrussAngle1.dat	NAST	33:13	0.31	62 Long.	PSD Input	Latch Angle (Rev A) on Truss
TrussAng8.dat	NAST	36:41	0.97	64, 42	PSD, Launch	Latch angle (Rev C) on Truss
Lbar7.dat	NAST	20:52	0.62	64,42	PSD, Launch	Latch angle Rev-C

Appendix B Case control

⇒ *C130 Load Case control*

```
ID EFOGM,FEMAP
SOL SESTATICS
TIME 10000
CEND
  TITLE = Outer Tube NOT with Latch Angles
  ECHO = NONE
  DISPLACEMENT = ALL
  SPCFORCE = ALL
  OLOAD = ALL
  STRESS = ALL
  MPCFORCES = ALL
  SET 20 = 1179, 7812, 5625, 3886, 7470, 7471, 5627,
           32790, 38914, 19299, 38915, 7480, 38913,
           7481, 7482, 39452, 39448, 39418, 39417,
           30096, 16323, 40015, 45350, 47402, 35503,
           43110, 41058, 3, 1, 38922, 6214, 38919, 38918
  GPFORCE = 20
  SET 30 = 52257, 52258, 52255, 52256,
           5896, 5895, 6556, 4898, 4899, 5371, 39456,
           39453, 39424, 39421, 6557, 5372,
           4837, 4836, 4835, 4834, 4833, 4832, 4831, 4830,
           7187, 7188, 7185, 7186, 7183, 7184, 32914,
           32913, 19373, 19374,
           45015, 45014, 47404, 47403, 43375, 43376, 40986, 40987,
           43356, 43363
  FORCE = 30
  SPC = 1
$MPC 3 is for Aft load (-Nz)
$MPC 4 is for Fwd load (+Nz)
$
SUBCASE 1
  LABEL = Cond 1: -1.0 Ny & Limit extend
  LOAD = 100
  MPC = 3
$
SUBCASE 3
  LABEL = Cond 3: +1.0 Ny & Limit retract
  LOAD = 103
  MPC = 4
$
SUBCASE 4
  LABEL = Cond 4: +8.0 Nz & Limit retract
  LOAD = 104
  MPC = 4
$
SUBCASE 5
  LABEL = Cond 5: -8.0 Nz & Limit retract
  LOAD = 105
  MPC = 3
$
SUBCASE 6
  LABEL = Cond 6: +2.0 Ny & Limit retract
  LOAD = 106
  MPC = 4
$
SUBCASE 7
  LABEL = Cond 7: -4.5 Ny & Limit retract
  LOAD = 107
  MPC = 3
$
SUBCASE 8
  LABEL = Cond 8: +1.5 Nx & Limit retract
  LOAD = 108
$
BEGIN BULK
$ ***************************************************************************
$   Written by : FEMAP
$   Version    : 4.51
$   Translator : MSC/NASTRAN
```

```
$   From Model : G:\Response\Customer\Sei\EFOGM\Stow32.MOD
$   Date       : Sun Nov 24 19:30:03 1996
$ ***************************************************************************
$
PARAM,AUTOSPC,YES
PARAM,K6ROT,100.0
PARAM,GRDPNT,0
CORD2C         1       0      0.      0.      0.      0.      0.      1.+FEMAPC1
+FEMAPC1      1.      0.      1.
CORD2S         2       0      0.      0.      0.      0.      0.      1.+FEMAPC2
+FEMAPC2      1.      0.      1.
$ FEMAP Coordinate System 4 : CarriageCSYS
CORD2R         4       0      0.  11.248  -5.164      0. 10.2494-5.11166+CS    4
+CS    4      1.  11.248  -5.164
$ FEMAP Coordinate System 5 : SkinCSYS
CORD2R         5       0      0.  -0.225      0.      0.   0.775      0.+CS    5
+CS    5      0.  -0.225      1.
$ FEMAP Coordinate System 6 : ActuatorCSYS
CORD2R         6       0      0.    4.25 52.9089      0. 5.24771 52.9765+CS    6
+CS    6      0. 4.31763 51.9112
$ Load combination
$---1--..---2--..---3--..---4--..---5--..---6--..---7--..---8--..---9--..--10--.
LOAD         100     1.0     1.0      10     1.0       1
LOAD         103     1.0     1.0       3     1.0       2
LOAD         104     1.0     1.0       4     1.0       2
LOAD         105     1.0     1.0       5     1.0       2
LOAD         106     1.0     1.0       6     1.0       2
LOAD         107     1.0     1.0       7     1.0       2
LOAD         108     1.0     1.0       8     1.0       2
$ FEMAP Load Set 1 : ExtensionLimit
$---1--..---2--..---3--..---4--..---5--..---6--..---7--..---8--..---9--..--10--.
FORCE1         1    1179  17421.    7482    1179
FORCE1         1    7482  17421.    1179    7482
GRAV          10       0      1.      0.   -386.      0.
$ FEMAP Load Set 2 : RetractLimit
FORCE1         2    1179  14303.    1179    7482
FORCE1         2    7482  14303.    7482    1179
$ FEMAP Load Set 3 : Case3 1g Ny
GRAV           3       0      1.      0.    386.      0.
$ FEMAP Load Set 4 : Case4 8.0g Nz
GRAV           4       0      1.      0.      0.   3088.
$ FEMAP Load Set 5 : Case5 -8.0g Nz
GRAV           5       0      1.      0.      0.  -3088.
$ FEMAP Load Set 6 : Case6 2g Ny
GRAV           6       0      1.      0.    772.      0.
$ FEMAP Load Set 7 : Case7 -4.5g Ny
GRAV           7       0      1.      0.  -1737.      0.
$ FEMAP Load Set 8 : Case8 1.5g Nx
GRAV           8       0      1.    579.      0.      0.
$ FEMAP Constraint Set 1 : Skin
SPC            1    2126  123456      0.
```

⇒ *Patriot Loads case control*

```
ID EFOGM,FEMAP
SOL SESTATICS
TIME 10000
CEND
  ECHO = NONE
  DISPLACEMENT = ALL
  SPCFORCE = ALL
  OLOAD = ALL
  STRESS = ALL
  MPCFORCES = ALL
  SET 20 = 1179, 7812, 5625, 3886, 7470, 7471, 5627,
           32790, 38914, 19299, 38915, 7480, 38913,
           7481, 7482, 39452, 39448, 39418, 39417,
           30096, 16323, 40015, 45350, 47402, 35503,
           43110, 41058, 3, 1, 38922, 6214, 38919, 38918
  GPFORCE = 20
  SET 30 = 52257, 52258, 52255, 52256,
           5896, 5895, 6556, 4898, 4899, 5371, 39456,
           39453, 39424, 39421, 6557, 5372,
           4837, 4836, 4835, 4834, 4833, 4832, 4831, 4830,
           7187, 7188, 7185, 7186, 7183, 7184, 32914,
           32913, 19373, 19374,
           45015, 45014, 47404, 47403, 43375, 43376, 40986, 40987,
           43356, 43363
  FORCE = 30
  SPC = 1
$MPC 3 is for Aft load (-Nz)
$MPC 4 is for Fwd load (+Nz)
$
SUBCASE 1
  LABEL = Cond 21
  LOAD = 111
  MPC = 4
$
SUBCASE 2
  LABEL = Cond 22
  LOAD = 112
  MPC = 3
$
SUBCASE 3
  LABEL = Cond 23
  LOAD = 113
  MPC = 4
$
SUBCASE 4
  LABEL = Cond 24
  LOAD = 114
  MPC = 3
$
SUBCASE 5
  LABEL = Cond 25
  LOAD = 115
  MPC = 4
$
SUBCASE 6
  LABEL = Cond 26
  LOAD = 116
  MPC = 3
$
SUBCASE 7
  LABEL = Cond 27
  LOAD = 117
  MPC = 4
$
SUBCASE 8
  LABEL = Cond 28
  LOAD = 118
  MPC = 3
$
SUBCASE 9
  LABEL = Cond 29
  LOAD = 119
```

```
  MPC = 4
$
SUBCASE 10
  LABEL = Cond 30
  LOAD = 120
  MPC = 3
$
SUBCASE 11
  LABEL = Cond 31
  LOAD = 121
  MPC = 4
$
SUBCASE 12
  LABEL = Cond 32
  LOAD = 122
  MPC = 3
$
BEGIN BULK
$ ***************************************************************************
$   Written by : FEMAP
$   Version    : 4.51
$   Translator : MSC/NASTRAN
$   From Model : G:\Response\Customer\Sei\EFOGM\Stow32.MOD
$   Date       : Mon Nov 25 07:25:31 1996
$ ***************************************************************************
$
PARAM,AUTOSPC,YES
PARAM,K6ROT,100.0
PARAM,GRDPNT,0
CORD2C         1       0      0.      0.      0.      0.      0.      1.+FEMAPC1
+FEMAPC1      1.      0.      1.
CORD2S         2       0      0.      0.      0.      0.      0.      1.+FEMAPC2
+FEMAPC2      1.      0.      1.
$ FEMAP Coordinate System 4 : CarriageCSYS
CORD2R         4       0      0.  11.248  -5.164      0. 10.2494-5.11166+CS    4
+CS    4      1.  11.248  -5.164
$ FEMAP Coordinate System 5 : SkinCSYS
CORD2R         5       0      0.  -0.225      0.      0.   0.775      0.+CS    5
+CS    5      0.  -0.225      1.
$ FEMAP Coordinate System 6 : ActuatorCSYS
CORD2R         6       0      0.    4.25 52.9089      0. 5.24771 52.9765+CS    6
+CS    6      0. 4.31763 51.9112
$ Load combination
$---1--..---2--..---3--..---4--..---5--..---6--..---7--..---8--..---9--..--10--.
LOAD         111     1.0     1.0     201     1.0     202     1.0     203+LD11
+LD11        1.0       2
LOAD         112     1.0     1.0     201     1.0     202    -1.0     203+LD12
+LD12        1.0       2
LOAD         113     1.0     1.0     201    -1.0     202     1.0     203+LD13
+LD13        1.0       2
LOAD         114     1.0     1.0     201    -1.0     202    -1.0     203+LD14
+LD14        1.0       2
LOAD         115     1.0     1.0     204     1.0     202     1.0     205+LD15
+LD15        1.0       2
LOAD         116     1.0     1.0     204     1.0     202    -1.0     205+LD16
+LD16        1.0       2
LOAD         117     1.0     1.0     204    -1.0     202     1.0     205+LD17
+LD17        1.0       2
LOAD         118     1.0     1.0     204    -1.0     202    -1.0     205+LD18
+LD18        1.0       2
LOAD         119     1.0     1.0     201     1.0     206     1.0     205+LD19
+LD19        1.0       2
LOAD         120     1.0     1.0     201    -1.0     206    -1.0     205+LD20
+LD20        1.0       2
LOAD         121     1.0     1.0     201    -1.0     207     1.0     205+LD21
+LD21        1.0       2
LOAD         122     1.0     1.0     201    -1.0     207    -1.0     205+LD22
+LD22        1.0       2
$ FEMAP Load Set 2 : RetractLimit
FORCE1         2    1179  14303.    1179    7482
FORCE1         2    7482  14303.    7482    1179
$ Inertia loads - max of 9 GRAV cards allowed
$---1--..---2--..---3--..---4--..---5--..---6--..---7--..---8--..---9--..--10--.
GRAV         201       0      1.    386.      0.      0.
GRAV         202       0      1.      0.    772.      0.
GRAV         203       0      1.      0.      0.   5790.
```

```
GRAV         204       0      1.   1158.      0.      0.
GRAV         205       0      1.      0.      0.   1930.
GRAV         206       0      1.      0.   1158.      0.
GRAV         207       0      1.      0.   2316.      0.
$GRAV         11       0      1.    386.    772.   5790.
$GRAV         12       0      1.    386.    772.  -5790.
$GRAV         13       0      1.    386.   -772.   5790.
$GRAV         14       0      1.    386.   -772.  -5790.
$GRAV         15       0      1.   1158.    772.   1930.
$GRAV         16       0      1.   1158.    772.  -1930.
$GRAV         17       0      1.   1158.   -772.   1930.
$GRAV         18       0      1.   1158.   -772.  -1930.
$GRAV         19       0      1.    386.   1158.   1930.
$GRAV         20       0      1.    386.  -1158.  -1930.
$GRAV         21       0      1.    386.  -2316.   1930.
$GRAV         22       0      1.    386.  -2316.  -1930.
$ FEMAP Constraint Set 1 : Skin
SPC            1    2126  123456      0.
```

⇒ ***Crash Load CASE CONTROL***

```
RESTART VERSION=1,KEEP
ASSIGN MASTER='F:\Data\Stow35.MASTER'
ASSIGN DBALL='F:\Data\Stow35.DBALL'
ID EFOGM,FEMAP
SOL SEMTRAN
TIME 10000
CEND
  ECHO = NONE
  TITLE = EFOGM
  SUBTITLE = CRASH
  METHOD = 1
  DLOAD = 1
  TSTEP = 1
  SDAMPING = 1
  SET 20 = 1179, 7812, 5625, 3886, 7470, 7471, 5627,
           32790, 38914, 19299, 38915, 7480, 38913,
           7481, 7482, 39452, 39448, 39418, 39417,
           30096, 16323, 40015, 45350, 47402, 35503,
           43110, 41058, 3, 1, 38922, 6214, 38919, 38918
  ACCELERATION = 20
  GPFORCE = 20
  SET 30 = 52257, 52258, 52255, 52256,
           5896, 5895, 6556, 4898, 4899, 5371, 39456,
           39453, 39424, 39421, 6557, 5372,
           4837, 4836, 4835, 4834, 4833, 4832, 4831, 4830,
           7187, 7188, 7185, 7186, 7183, 7184, 32914,
           32913, 19373, 19374,
           45015, 45014, 47404, 47403, 43375, 43376, 40986, 40987,
           43356, 43363
  FORCE = 30
BEGIN BULK
$
$ FEMAP Load Set 1 : Crash
$PARAM,G,0.03
$   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
TSTEP          1      50   0.004       1                               +TS1
+TS1                 100   0.008       1
$Modal Dampening
TABDMP1        1    CRIT                                               +
+             0.    0.02     20.    0.02     40.    0.03     60.    0.03+
+           100.    0.05    300.    0.05ENDT
$ Dynamic loading
$   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
DLOAD          1     1.0     1.0      11
TLOAD2        11      41      31             0.0   0.200     2.5   -90.0
DELAY         31    2126       3   0.016
$   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
DAREA         41    2126       3-4.17E12
$EARTH GRID is in Global Coordinate System now
ENDDATA
```

⇒ ***Frequency Response Case Control***

```
INIT DBALL LOGI=(DBALL(3072MB))
```

```
INIT SCRATCH LOGI=(SCRATCH(4096MB))
RESTART VERSION=1,KEEP
ASSIGN MASTER='e:\scratch\Stow43.MASTER'
ASSIGN DBALL='e:\scratch\Stow43.DBALL'
ID EFOGM,FEMAP
SOL SEMFREQ
TIME 10000
CEND
  ECHO = NONE
  TITLE = Freq Response
  METHOD = 1
  SET 20 = 1179, 7812, 5625, 3886, 7470, 7471, 5627,
           32790, 38914, 19299, 38915, 7480, 38913,
           7481, 7482, 39452, 39448, 39418, 39417,
           30096, 16323, 40015, 45350, 47402, 35503,
           43110, 41058, 3, 1, 38922, 6214, 38919, 38918,
           20709, 40595, 58001
  ACCELERATION(SORT2,PHASE) = 20
  GPFORCE(SORT2,PHASE) = 20
  SET 30 = 52257, 52258, 52255, 52256,
           5896, 5895, 6556, 4898, 4899, 5371, 39456,
           39453, 39424, 39421, 6557, 5372,
           4837, 4836, 4835, 4834, 4833, 4832, 4831, 4830,
           7187, 7188, 7185, 7186, 7183, 7184, 32914,
           32913, 19373, 19374,
           45015, 45014, 47404, 47403, 43375, 43376, 40986, 40987,
           43356, 43363, 40595, 21677
  FORCE(SORT2,PHASE) = 30
$
SUBCASE 1
  LABEL = Vertical
  DLOAD = 991
  FREQUENCY = 888
  SDAMPING = 777
SUBCASE 2
  LABEL = Longitudinal
  DLOAD = 992
  FREQUENCY = 888
  SDAMPING = 777
SUBCASE 3
  LABEL = Transverse
  DLOAD = 993
  FREQUENCY = 888
  SDAMPING = 777
$
BEGIN BULK
$
PARAM,LFREQ,5.0
$PARAM,DDRMM,-1
$PARAM,CURVPLOT,1
$Input Frequencies
$   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
FREQ         888 8.7889210.6825111.1863116.4465817.6709319.0614819.71998+
+       20.0192920.0828720.1786620.3232420.5322021.4748621.8334222.11522+
+       22.2060122.4870922.5395224.1757225.5524426.9759128.5066129.34163+
+       35.2671736.4900536.6396137.3358437.4087337.8219544.9861549.09791+
+       50.9731356.2042456.9240062.1294762.6986666.4978368.1637069.64610+
+       69.7467370.3112771.2918073.0957673.4635874.8247475.7605580.24315+
+       82.9063285.0397985.9616386.5739489.1706394.5597096.3117897.27020+
+       99.59921102.1259108.3952111.6210113.5929116.6208119.4432
$   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
FREQ1        888     5.0     1.0     121
$Modal Dampening
TABDMP1      777    CRIT                                                   +
+             0.    0.02     20.    0.02     40.    0.03     60.    0.03+
+           100.    0.05    300.    0.05ENDT
$
$Vertical
DLOAD        991      1.      1.     441
RLOAD1       441     551                     666
$
$Longitudinal
DLOAD        992      1.      1.     442
RLOAD1       442     552                     666
$
$Transverse
```

```
DLOAD        993      1.      1.     443
RLOAD1       443     553                     666
$
TABLED1      666                                                   +
+             0.      1.    120.      1.ENDT
$The EFOGM assembly mass is 5.400000E+08 mugs
$   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
DAREA        551    2126       22.085E11
DAREA        552    2126       32.085E11
DAREA        553    2126       12.085E11
ENDDATA
```

⇒ *Random PSD response case control - vertical*

```
INIT DBALL LOGI=(DBALL(3072MB))
INIT SCRATCH LOGI=(SCRATCH(4096MB))
RESTART VERSION=1,KEEP
ASSIGN MASTER='e:\scratch\Stow43.MASTER'
ASSIGN DBALL='e:\scratch\Stow43.DBALL'
ID EFOGM,FEMAP
SOL SEMFREQ
TIME 10000
CEND
  ECHO = NONE
  TITLE = Vertical Random Response
  METHOD = 1
  DLOAD = 991
  FREQUENCY = 888
  SDAMPING = 777
  RANDOM = 221
OUTPUT(XYOUT)
INCLUDE 'E:\Response\Customer\SEI\EFOGM\Stow44_PSD_OUT.dat'
$
BEGIN BULK
$
PARAM,LFREQ,5.0
$Input Frequencies
$   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
FREQ         888 8.7889210.6825111.1863116.4465817.6709319.0614819.71998+
+       20.0192920.0828720.1786620.3232420.5322021.4748621.8334222.11522+
+       22.2060122.4870922.5395224.1757225.5524426.9759128.5066129.34163+
+       35.2671736.4900536.6396137.3358437.4087337.8219544.9861549.09791+
+       50.9731356.2042456.9240062.1294762.6986666.4978368.1637069.64610+
+       69.7467370.3112771.2918073.0957673.4635874.8247475.7605580.24315+
+       82.9063285.0397985.9616386.5739489.1706394.5597096.3117897.27020+
+       99.59921102.1259108.3952111.6210113.5929116.6208119.4432
$   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
$FREQ1       888     5.0     1.0     121
$Modal Dampening
TABDMP1      777    CRIT                                               +
+             0.    0.02     20.    0.02     40.    0.03     60.    0.03+
+           100.    0.05    300.    0.05ENDT
$   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
RANDPS       221       1       1      1.      0.       2
$ FEMAP Function 2 : PSD Vertical
TABRND1        2                                                       +
+             5.    0.08      7.    0.12      8.     0.4     10.    0.44+
+            15.    0.03     16.    0.07     20.    0.04     21.    0.02+
+            23.    0.02     24.    0.05     30.   0.075     31.    0.02+
+            39.   0.017     52.    0.04     64.    0.03    200.   0.004+
+       ENDT
$   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
DLOAD        991      1.      1.     441
RLOAD1       441     551                     666
TABLED1      666                                                       +
+             0.      1.    120.      1.ENDT
$The EFOGM assembly mass is 5.400000E+08 mugs
DAREA        551    2126       22.085E11
$
ENDDATA
```

⇒ *XYPEAK Output request*

```
$ Complex Force results
$ Item Code 6 =   End A Plane1 Shear
```

```
$ Item Code 7 =   End A Plane2 Shear
$ Item Code 166 = End B Plane1 Shear
$ Item Code 167 = End B Plane2 Shear
$
$ Outboard restraint latch
XYPEAK FORCE PSDF / 40987(6)
XYPEAK FORCE PSDF / 40987(7)
XYPEAK FORCE PSDF / 40987(8)
XYPEAK FORCE PSDF / 40986(166)
XYPEAK FORCE PSDF / 40986(167)
XYPEAK FORCE PSDF / 40986(168)
$
.
.
.
$
$ Upper link / Actuator bearing
XYPEAK FORCE PSDF / 7188(6)
XYPEAK FORCE PSDF / 7188(7)
XYPEAK FORCE PSDF / 7188(8)
XYPEAK FORCE PSDF / 7187(166)
XYPEAK FORCE PSDF / 7187(167)
XYPEAK FORCE PSDF / 7187(168)
$
$ Complex CQUAD stress results
$ Item Code 3 =  Normal X Magnitude at Z1
$ Item Code 5 =  Normal Y Magnitude at Z1
$ Item Code 7 =  Shear XY Magnitude at Z1
$ Item Code 10 = Normal X Magnitude at Z2
$ Item Code 12 = Normal Y Magnitude at Z2
$ Item Code 14 = Shear XY Magnitude at Z2
$
$ Under tube fwd of cross beam
XYPEAK STRESS PSDF / 21665(3)
XYPEAK STRESS PSDF / 21665(5)
XYPEAK STRESS PSDF / 21665(7)
XYPEAK STRESS PSDF / 21665(10)
XYPEAK STRESS PSDF / 21665(12)
XYPEAK STRESS PSDF / 21665(14)
$
.
.
.
```

⇒ ***Clevis joint Slide Line model***

```
ID G:\Response\Customer\Sei\,FEMAP
SOL NLSTATIC
TIME 10000
CEND
  ECHO = NONE
  TITLE = EFOGM
  SUBTITLE = Clevis Joint Peaking
  DISPLACEMENT = ALL
  STRESS = ALL
  ESE = ALL
  SPCFORCE = ALL
  SPC = 1
  LOAD = 1
  NLPARM = 1
  BOUTPUT(SORT1)=ALL
BEGIN BULK
$ Define Slide Lines
$---1--..---2--..---3--..---4--..---5--..---6--..---7--..---8--..---9--..--10--.
$ Pin and outer lug ID
BCONP         10      11      12                      13
BLSEG         12      27      26      25      24      23      22      21+
+             20      19      18      17      16      15      14      13+
+             12      11      10       9       8       7       6       5+
+              4       3       2       1
BLSEG         11     631     630     629     628     627     626     625+
+            624     623     622     621     620     619     618     617+
+            616     615     614     613     612     611     610     609+
+            608     607     606
BFRIC         13          54000.    0.12
```

```
$
$ Pin and bearing ID
BCONP         20      21      22                      13
BLSEG         22    1071    1070    1069    1068    1067    1066    1065+
+           1064    1063    1062    1061    1060    1059    1058    1057+
+           1056    1055    1054
BLSEG         21      69      68      67      66      65      64      63+
+             62      61      60      59      58      57      56      55+
+             54      53      52      51
$
$ Teflon bearing
BCONP         30      31      32                      33
BLSEG         32    1339    1338    1337    1336    1335    1334    1333+
+           1332    1331    1330    1329    1328    1327    1326    1325+
+           1324    1323    1322
BLSEG         31    1103    1102    1101    1100    1099    1098    1097+
+           1096    1095    1094    1093    1092    1091    1090    1089+
+           1088    1087    1086    1085
BFRIC         33          67500.    0.15
$ ***************************************************************************
$   Written by : FEMAP
$   Version    : 4.51
$   Translator : MSC/NASTRAN
$   From Model : G:\Response\Customer\Sei\EFOGM\Clevis.MOD
$   Date       : Wed Nov 12 15:25:40 1996
$ ***************************************************************************
$
NLPARM         1      10            ITER       1                       +
+                                                                      +
+
PARAM,LGDISP,1
PARAM,AUTOSPC,YES
PARAM,GRDPNT,0
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.
.
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