Independent Peer Review of Communications, Navigation, and Networking re-Configurable Testbed (CoNNeCT) Project Antenna Pointing Subsystem (APS) Integrated Gimbal Assembly (IGA) Structural Analysis

October 21, 2010

Approval and Document Revision History

NOTE: This document was approved at the October 21, 2010, NRB. This document was submitted to the NESC Director on October 26, 2010, for configuration control.

Approved Version:	*Original Signature on File*	10/27/10
1.0	NESC Director	Date

Version	Description of Revision	Author	Effective Date
1.0	Initial Release	Dr. Ivatury Raju, NASA Technical Fellow for Structures, and Joseph Pellicciotti, NASA Technical Fellow for Mechanical Systems	10/21/10

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Volume II: Appendices

A. APS Model Review Questions and Answers

Volume I: Technical Report

1.0 Authorization and Notification

This activity is in response to the effort requested by Glenn Research Center (GRC) to conduct an independent review of the structural analysis and modeling of the Communications, Navigation, and Networking re-Configurable Testbed (CoNNeCT) Project Antenna Pointing Subsystem (APS) Integrated Gimbal Assembly (IGA). The IGA Project has completed its CDR and the GRC Chief Engineer and the CoNNeCT Chief Engineer requested an independent assessment to assure the soundness of the modeling and analysis effort. Mr. Sam Hussey (APS Lead) served as CoNNeCT's point of contact for the effort. CoNNeCT provided the structural model and analysis to the NESC team.

The key stakeholders for this assessment include the Mr. Michael Barrett, GRC Chief Engineer; Ms. Ann Over, GRC CoNNeCT Project Manager; Mr. Glen Horvat, GRC Acting Center Chief Engineer; and Mr. Jim Free, GRC Director of Spaceflight Projects.

2.0 Signature Page

Submitted by:

Dr. Ivatury S. Raju	Date	Dr. Curtis E. Larsen	Date
Mr. Joseph W. Pellicciotti	Date		

Signatories declare the findings and observations compiled in the report are factually based from data extracted from Program/Project documents, contractor reports, and open literature, and/or generated from independently conducted tests, analysis, and inspections.

3.0 Team List

Name	Discipline	Organization/Location
Core Team		
Dr. Ivatury Raju	NASA Lead, Technical Fellow for Structures	LaRC
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Tom Irvine	Dynamic Concepts	MSFC
Pete Mule	Aerospace Engineer	GSFC
Linda Anderson	MTSO Program Analyst	LaRC
Support		
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Tina Dunn-Pittman	Project Coordinator	LaRC, ATK

4.0 Executive Summary

In June 2010, Mr. Michael Barrett, from the Glenn Research Center (GRC) Chief Engineer's Office requested an independent review of the structural analysis and modeling of the Communications, Navigation, and Networking re-Configurable Testbed (CoNNeCT) Project Antenna Pointing Subsystem (APS) Integrated Gimbal Assembly (IGA). At this time, the IGA had completed its critical design review (CDR).

The charter of the team was clarified to be a peer review of the NEi-NASTRAN[1] model of the APS Antenna, and *not* a peer review of the design and the analysis that had been completed by the GRC team for CDR. Thus, only a limited amount of information was provided on the structural analysis. However, the NASA Engineering and Safety Center (NESC) team had difficulty separating analysis concerns from modeling issues. The team studied the NASTRAN model, but did not fully investigate how the model was used by the CoNNeCT Project and how the Project was interpreting the results. The team's findings, observations, and NESC recommendations are based on the clarified peer review effort.

The NESC team received the NASTRAN model on July 14, 2010 and performed a review providing comments and questions to the CoNNeCT Project. These comments ranged from model-specific concerns and system analyses questions. The prime contractor for this subsystem, Sierra Nevada Corporation (SNC), provided responses and the team followed up with a teleconference to address them. Generally, the team was comfortable with the model developed by SNC. However, due to the lack of information regarding the detailed system analyses, it was difficult to comment on the adequacy of the design to meet the mission requirements. A comparison of the hardware build to the model development (i.e., constrained and released degrees of freedom) was not made in the time available, but it was confirmed with the Project that this comparison was covered in the CDR.

The model developed by SNC is a good representation of the CoNNeCT Antenna IGA. The responses to the issues raised by the NESC team were adequately answered by SNC. The contractor is in the process of implementing the team's suggestions and correcting the identified model deficiencies. After the model is revised, the new margins of safety (MOS) need to be evaluated and verified that they are satisfactory.

[1] NASTRAN is a registered trademark of NASA. NEi is a trademark of NEi software, Inc.

5.0 Problem Background and Approach

The CoNNeCT will investigate reprogrammable (software defined) radio technology for use during space exploration missions. This investigation will advance a common, Software Defined Radio (SDR) architecture standard for future use on long duration space exploration missions. CoNNeCT will demonstrate communications from the International Space Station (ISS) to the Tracking and Data Relay Satellite (TDRS) constellation at Ka-band frequency (20 - 30 gigahertz (GHz)); and Global Positioning Satellite (GPS) signals will be received and processed at current and future frequencies comparing performance and integrity.

The Mechanical subsystem includes the support structure for mounting of hardware components. Figure 5.0-1[2] illustrates the testbed components and Figure 5.0-2 illustrates the APS. All Flight System components are mounted to the Enclosure, which is attached to the EXPRESS Pallet Assembly Flight Releasable Attachment Mechanism (ExPA/FRAM) adapter plate. All Flight System components are mounted inside the Enclosure except for the APS, the 18 inch diameter dish Ka-Band high gain antenna (HGA), the S-Band medium gain antenna (MGA), the two S-Band low gain antennas (LGAs), and the L-Band LGA. The APS as shown is mounted off a structural pedestal. This mounting configuration changed after preliminary design review (PDR) as discussed further.

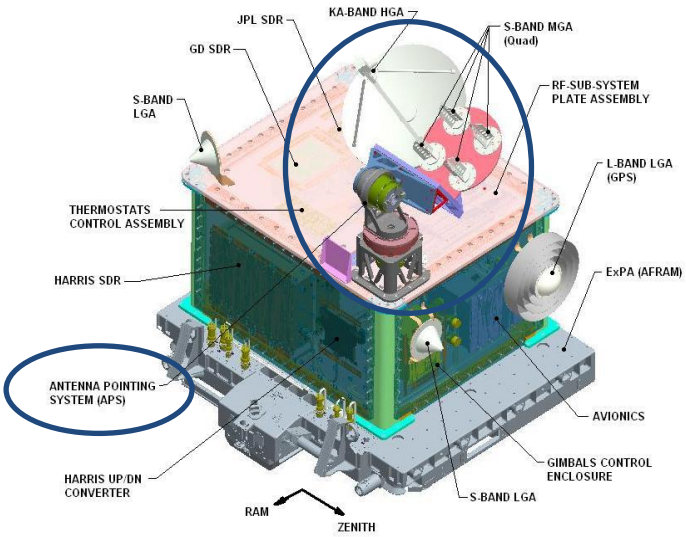

Figure 5.0-1. Testbed mounted onto ExPA AFRAM (Prior to Redesign)

[2] All the figures except Figure 6.1-6 were extracted from documentation provided by GRC or SNC.

Between PDR and CDR, the two axis gimbal assembly was redesigned. The PDR design was such that the nose axis articulation was 180 degrees to get out of the launch locks and position the gimbal in its operational range. This generated a potential catastrophic hazard by illuminating the ISS structure with Ka band radio frequency (RF). The redesign for CDR limited the nose articulation and implemented hard stops to control the illuminating hazard (see Figure 5.0-3). In addition, the CoNNeCT Project adopted the philosophy of Design For Minimum Risk (DFMR) with zero fault tolerance.

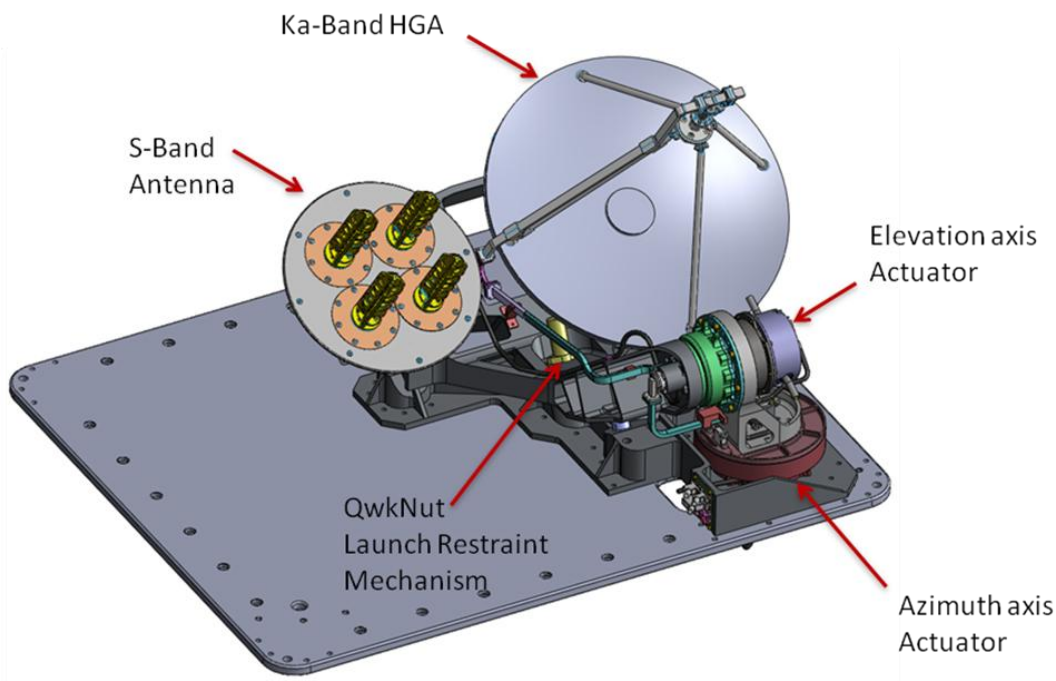

Figure 5.0-2. APS

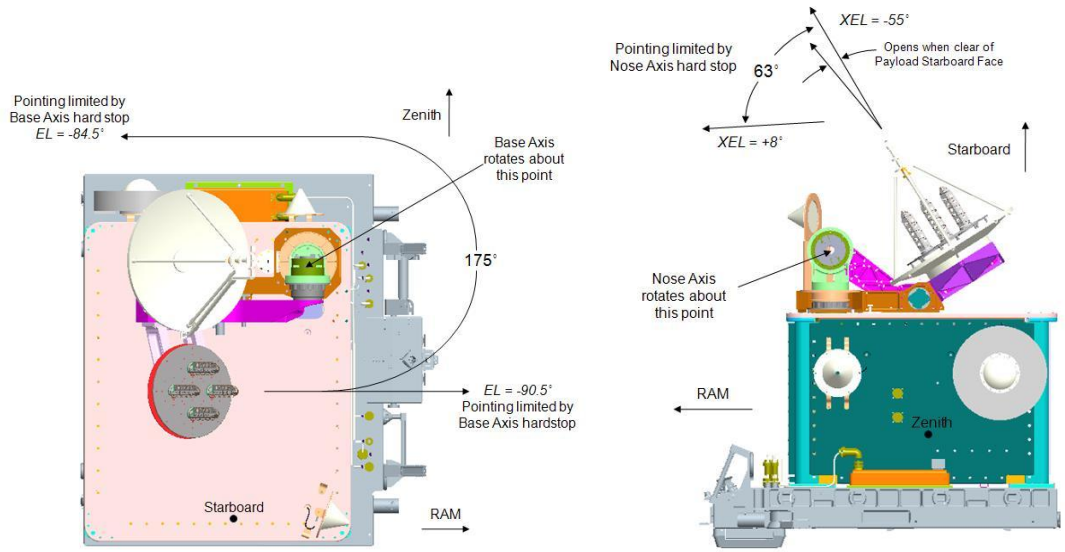

Figure 5.0-3. APS Base (Left) and Nose (Right) Range of Motion

The redesign caused the launch loads on the gimbal assembly to increase, resulting in negative MOS. Restraint modifications and the gimbal mounting scheme were changed and the loads were reduced into an acceptable range, although with small positive MOS in some cases. Figure 5.0-4 illustrates the restraint mechanism design.

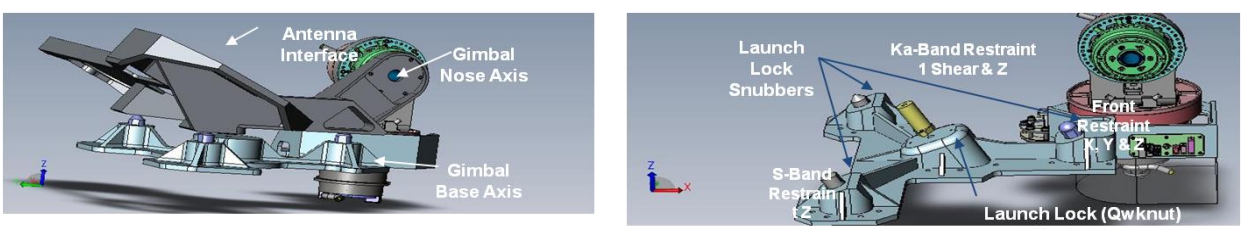

Figure 5.0-4. Gimbal Restraint Mechanism

The result of this redesign activity was the origin of the request from the GRC Chief Engineer's Office to the NESC for an independent review of the APS model to verify that the analysis was sufficiently conservative, and there were not significant deficiencies that could cause negative MOS or a test/flight anomaly.

6.0 Data Analysis

The NESC team received the CoNNeCT Antenna IGA model from SNC. The model was a NEI-NASTRAN finite element model (FEM). GRC and SNC independently developed the models.

SNC performed structural analysis with their model and developed MOS of various components. In this section, this analysis is presented, first. Then the team's review of the model is discussed.

6.1 SNC Structural Analysis

The model consists of the IGA major structural components: Base (part number (P/N): 38544), Arm (P/N: 38553), Biaxial bracket (P/N: 37184), S-band support bracket (P/N: 38558, Bolt catcher base, Actuators (upper and lower), kinematics pins (also called Launch Restraints or Kinematic Launch snubbers or Locks – see Figure 5.0-4) and plates, S-band antenna, and Ka-Band antenna. Figure 6.1-1 shows several views of the NASTRAN model. The FEM was exercised and free-free vibration verification was performed. Figure 6.1-2 shows the results of this analysis. As expected, there are six rigid body modes[3] (modes 1 through 6 with near zero or zero Eigen values).

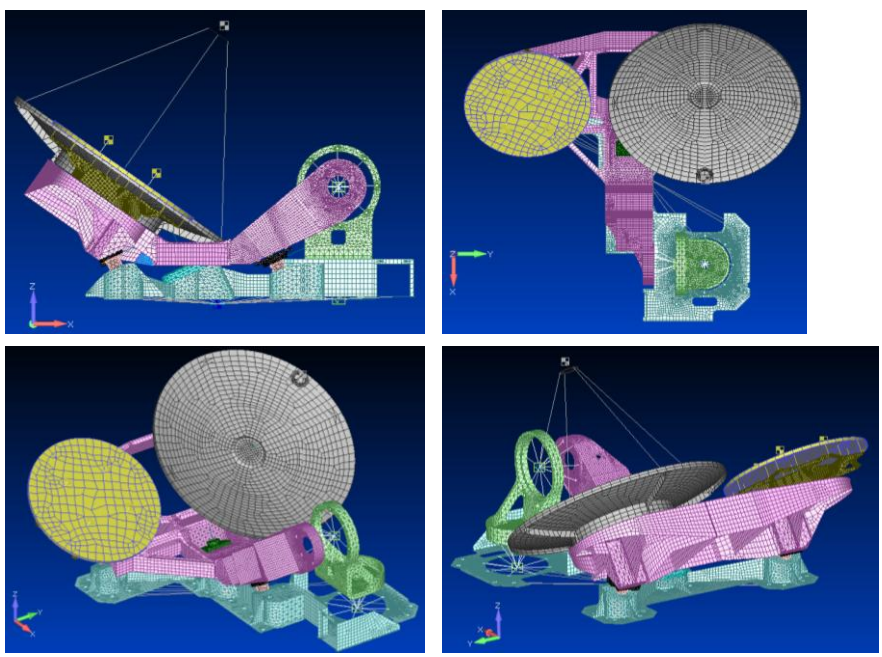

Figure 6.1-1. APS NASTRAN Model

[3]In all NASTRAN runs the T_1, T_2, T_3, R_1, R_2, R_3 correspond to the translations along and rotations about the three orthogonal coordinates directions.

NE1NASTRAN SUBCASE 1

R E A L E I G E N V A L U E S

MODE NUMBER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS	ORTHOGONALITY LOSS	ERROR MEASURE
1	0.000000E+00	0.000000E+00	0.000000E+00	1.000000E+00	0.000000E+00	0.000000E+00	5.226306E-18
2	0.000000E+00	0.000000E+00	0.000000E+00	1.000000E+00	0.000000E+00	2.760475E-06	2.799912E-18
3	0.000000E+00	0.000000E+00	0.000000E+00	1.000000E+00	0.000000E+00	2.760475E-06	8.917354E-19
4	1.157338E-09	3.401967E-05	5.414399E-06	1.000000E+00	2.893345E-06	2.760475E-06	7.208882E-10
5	1.000443E-07	3.162978E-04	5.034036E-05	1.000000E+00	2.501107E-04	2.760475E-06	2.156315E-10
6	2.356362E-07	4.854237E-04	7.725758E-05	1.000000E+00	5.890905E-04	2.760475E-06	8.242060E-10
7	3.622564E+05	6.018774E+02	9.579177E+01	1.000000E+00	3.622564E+05	2.760475E-06	1.123702E-08

R I G I D - B O D Y E I G E N V A L U E S

MODE NUMBER	EIGENVALUE EXTRACTED	EIGENVALUE NORMALIZED	STRAIN ENERGY EXTRACTED	STRAIN ENERGY NORMALIZED
1	0.000000E+00	0.000000E+00	1.893263E-12	5.226306E-18
2	0.000000E+00	0.000000E+00	1.014286E-12	2.799912E-18
3	0.000000E+00	0.000000E+00	3.230369E-13	8.917354E-19
4	1.157338E-09	3.194804E-15	2.640397E-04	7.288752E-10
5	1.000443E-07	2.761698E-13	3.282247E-04	9.060561E-10
6	2.356362E-07	6.504679E-13	2.905165E-04	8.019637E-10

P E R C E N T M O D A L E F F E C T I V E M A S S

MODE NUMBER	T1	T2	T3	R1	R2	R3
1	100.0000	0.0000	0.0000	0.0000	0.1280	32.9694
2	0.0000	100.0000	0.0000	0.2600	0.0000	67.0305
3	0.0000	0.0000	100.0000	99.7400	99.8719	0.0000
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
TOTAL	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

Figure 6.1-2. APS NASTRAN Analysis Results for Free-Free Vibration

The modal effective mass was examined next to determine which modes would participate most significantly to a random base drive excitation. As shown in Figure 6.1-3, the highest modal mass participation in the X- and Y-axes comes from mode 8 at about 198 Hz, and for the Z-axis from mode 34 at 443 Hz. The shapes for these two modes are shown in Figure 6.1-4. The model was analyzed next for response to base drive random vibration (RV) excitations at maximum expected fight levels (MEFL) + 3 decibel (dB). The RV environments as a function of the frequency and the damping used are shown in Figure 6.1-5. These data were provided by GRC.

Mode Number	Hz	T1 Fraction	T2 Fraction	T3 Fraction	R1 Fraction	R2 Fraction	R3 Fraction
1	95.1	9.43E-04	1.29E-04	2.45E-04	1.20E-03	9.26E-02	5.88E-03
2	115.0	8.81E-07	2.65E-03	7.15E-05	5.27E-01	1.05E-02	3.41E-01
3	134.4	1.61E-03	2.30E-03	1.05E-04	1.52E-01	4.05E-01	6.10E-01
4	164.8	7.00E-03	1.32E-03	1.60E-04	3.37E-01	4.24E-01	2.59E+00
5	169.8	3.69E-06	2.27E-03	7.56E-05	3.07E-01	6.39E-02	4.74E-01
6	177.4	3.93E-05	9.52E-04	1.76E-04	6.09E-01	2.91E-02	4.19E-01
7	186.9	2.49E-03	2.56E-03	1.88E-04	6.20E-01	4.53E-01	6.01E-03
8	198.5	1.50E-02	9.90E-03	4.36E-04	7.52E-01	9.91E-01	3.45E-02
9	216.0	2.72E-06	2.54E-05	5.85E-07	7.21E-03	1.02E-08	1.39E-01
10	217.9	3.25E-05	9.97E-06	4.91E-05	8.00E-03	2.05E-02	9.17E-02
11	227.0	9.61E-05	2.66E-04	1.04E-04	5.96E-04	4.67E-02	3.13E-01
12	229.6	5.08E-05	1.55E-04	4.75E-04	1.45E-01	9.57E-02	5.44E-01
13	234.0	2.02E-03	7.42E-04	1.38E-08	1.04E-03	2.51E-01	5.30E-01
14	236.1	7.56E-04	7.98E-06	1.28E-04	1.64E-02	1.76E-01	4.33E-05
15	239.9	1.64E-03	4.72E-05	5.60E-04	5.20E-02	4.77E-01	1.60E-01
16	249.9	7.11E-03	2.37E-03	4.54E-03	3.33E-01	2.70E+00	3.03E+00
17	259.7	5.06E-03	1.10E-06	1.63E-03	1.74E-01	1.54E+00	1.11E-01
18	283.6	1.16E-05	2.30E-06	3.76E-06	1.36E-03	1.10E-04	6.80E-04
19	294.4	1.29E-03	5.60E-04	2.33E-05	1.29E-01	5.05E-02	3.82E-01
20	298.5	2.56E-04	5.75E-03	6.11E-04	5.57E-01	1.33E-02	1.15E-01
21	306.4	4.30E-04	3.72E-04	5.04E-05	5.45E-02	7.33E-02	2.64E-03
22	316.7	6.59E-03	5.62E-03	2.14E-04	4.17E-01	6.08E-01	2.81E-01
23	324.3	1.22E-03	6.13E-03	1.49E-03	2.37E-01	2.19E-02	2.40E-02
24	334.4	1.76E-07	6.04E-03	2.71E-03	1.02E-01	1.22E-01	4.31E-01
25	340.2	5.36E-04	8.76E-04	9.75E-04	1.59E-01	3.26E-01	3.49E-01
26	345.1	2.21E-03	1.42E-03	3.01E-04	2.16E-01	3.01E-01	9.13E-01
27	350.7	1.70E-03	4.09E-03	1.50E-04	3.57E-01	1.87E-01	1.99E+00
28	360.1	3.71E-04	5.43E-04	1.09E-05	5.87E-02	3.74E-03	4.79E-01
29	381.8	1.33E-03	3.09E-05	5.68E-03	1.18E-01	1.09E+00	1.85E-02
30	389.1	1.60E-04	6.27E-03	1.04E-04	1.42E-01	2.41E-02	1.08E+00
31	400.5	2.47E-05	2.53E-06	1.49E-05	2.02E-03	1.80E-03	3.29E-04
32	407.3	4.47E-04	5.66E-03	5.94E-07	3.01E-01	9.31E-03	6.52E-01
33	421.4	2.99E-03	1.28E-06	3.01E-03	1.63E-01	4.80E-01	1.91E-04
34	443.4	2.10E-03	1.10E-04	2.22E-02	2.73E-01	6.97E-02	2.89E-02
35	450.2	5.38E-06	2.03E-03	1.09E-02	2.97E-02	1.85E-02	1.60E-01
36	456.0	8.23E-05	1.24E-07	4.69E-05	1.85E-03	9.81E-06	1.54E-04
37	496.3	1.01E-04	2.12E-04	1.39E-07	4.24E-01	5.63E-03	1.65E-02
38	515.5	3.86E-04	6.43E-03	9.41E-05	5.06E-02	1.24E-01	5.11E-01
39	577.6	4.23E-07	9.56E-05	9.88E-06	1.55E-03	1.61E-04	1.35E-03
40	598.2	3.57E-04	2.65E-05	4.33E-03	3.68E-01	5.02E-01	1.64E-01
41	603.3	9.17E-08	5.73E-04	1.57E-04	2.37E-05	4.40E-02	4.35E-02
42	612.7	8.23E-04	2.57E-03	2.83E-03	4.52E-02	4.54E-01	4.69E-01
43	636.3	1.45E-04	1.93E-03	2.46E-03	1.25E-01	4.93E-01	7.04E-02
44	645.8	8.08E-06	1.24E-05	2.59E-06	2.19E-02	1.92E-05	4.71E-03
45	660.1	2.46E-04	4.72E-04	1.66E-06	2.24E-03	1.99E-03	1.99E-02
46	701.3	4.79E-04	6.02E-04	9.45E-06	1.13E-02	7.63E-03	1.77E-02
47	721.9	1.44E-03	2.57E-04	6.93E-04	1.42E-01	2.26E-01	5.89E-04
48	731.7	1.01E-05	1.03E-04	2.05E-03	8.77E-02	3.78E-01	9.80E-03
49	746.9	1.33E-04	1.24E-04	7.13E-04	1.04E-01	1.00E-01	2.42E-02
50	754.5	9.40E-04	1.45E-06	5.40E-04	1.08E-02	4.11E-02	6.26E-03

Figure 6.1-3. Modal Effective Mass Participation for First 50 Modes

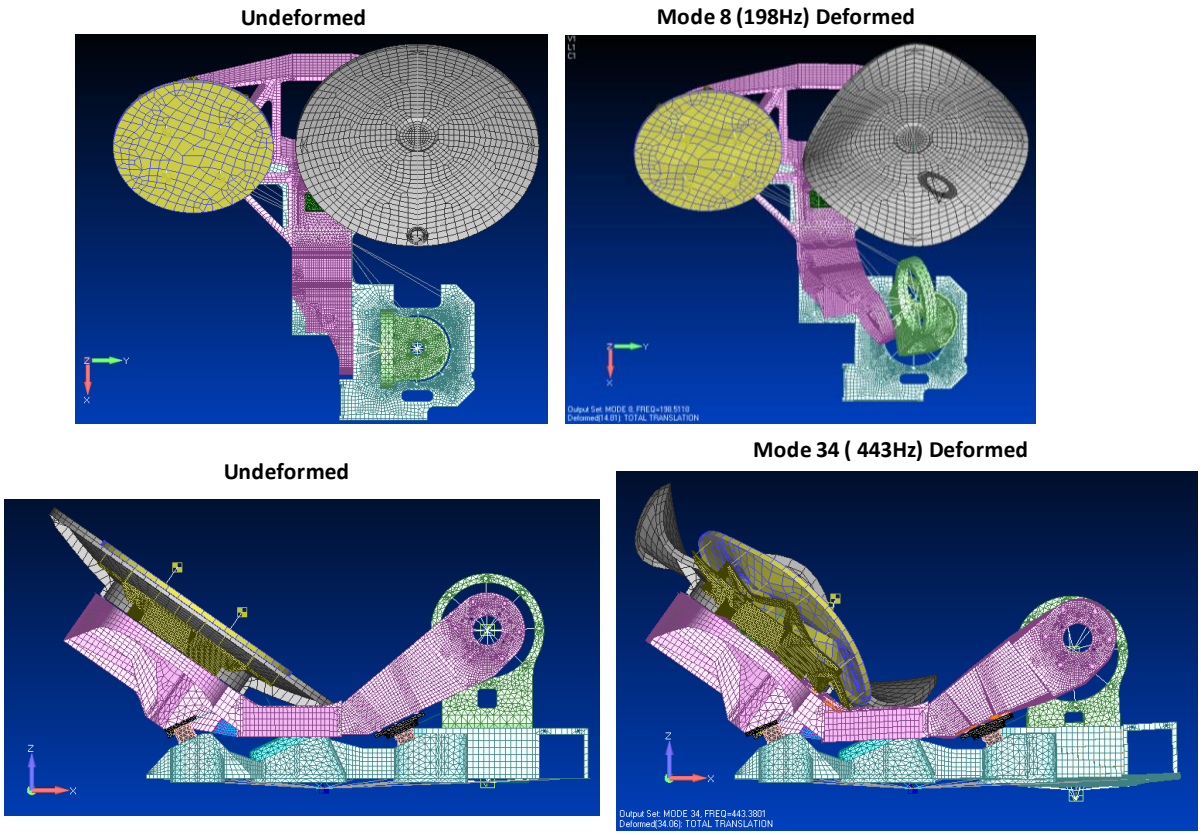

Figure 6.1-4. Mode Shapes for Modes 8 and 34 – Modes with Most Modal Mass Participation

```
$ CoNNeCT Random Vibration Damping Schedule (20-100 Hz 2%, 100.1-200 HZ 3%, 200.1-2000 Hz 4%)
$ John Shaker June 10, 2010
$
TABDMP1     20   CRIT                                +
+        20.    .02   100.    .02  100.1    .03   200.    .03+
+       200.1    .04  2000.    .04ENDT
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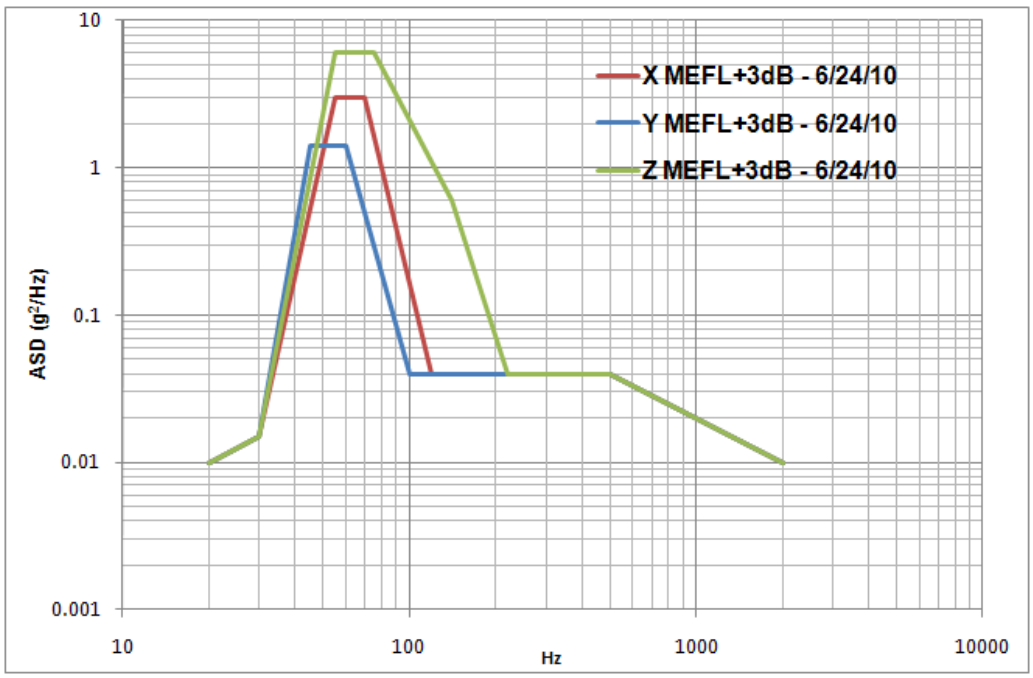

Figure 6.1-5. APS Random Vibration Environment

The reaction forces in the three kinematic pins and loads in both the actuators are critical forces and were scrutinized. The loads in the pins are compared to the allowables in Table 6.1-1. For this environment the response forces are acceptable (i.e., are less than the allowable). However, analysis of the launch restraint system appears to be incomplete. The following are suggestions for the analyses:

(a) Lateral loads on sloped surfaces and geometric layout of the restraints need to be properly accounted for when determining external load on Qwknut and needed pre-load for gapping.

(b) External loads on the Qwknut restraint need to be properly combined with pre-load. With no Bellville washers or other measures to make it a constant-force interface, the external loading would add to the pre-load. One would expect the pre-load to be something just above the expected external load so the restraint

would need to handle double the preload.

(c) Moments into the Qwknut, due to misalignments, mechanical shifts, launch loads, or thermal effects need to be properly accounted. The restraint arm is fixed at the Qwknut and pinned at the antenna bracket.

Table 6.1-1. Loads in the Three Kinematic Pins and Their Allowables (Coefficient of Friction = 0.05, Angle = 60 degrees)

Pins (Figure 5.0-4)	Load set -1 (X) (lbf)	Load set -2 (Y) (lbf)	Load set -3 (Z) (lbf)	Allowable (lbf)
S-Band	303	228	480	578
Ka-Band	464	514	650	826
Front	1440	767	778	1949

The actuator forces and moments are presented in Table 6.1-2. Load set 1 produces torsion in the upper actuator near the allowable torque, while the other cases result in torsion in either the upper or lower actuators below the allowable. Load set 1 applied torque during launch (249 in-lbs) is close to the unpowered holding torque on the actuators (250 in-lbs). Although the actuators can be backdriven without damage according to the vendor, there are secondary concerns for the system if this occurs. Backdriving the actuator could result with a rotor in a position where there is now stored energy or windup of the harmonic drive. The NESC team's concern with this condition is that once the launch restraints are released and the APS is free, that stored energy could release and the APS will shift, potentially causing a deployment hang-up or damage.

The other forces and moments in the actuators were compared to capability in Figure 6.1-6. In this figure, radial load is plotted against the moment. The two straight lines represent the failure boundary that is determined by the combination of axial, radial, and moment loads on the main bearings so as to not affect actuator life. Hence these lines represent the capability limit for that particular value of the axial load in the actuator. The upper line corresponds to a capability limit for an axial load less than or equal to 1,000 pounds (lbs). The lower line corresponds to an axial load of 1,500 lbs. If the axial load is greater than 1,500 lbs, then the actuator will have a negative MOS on some component (probably a bearing).

All points below the lines in this figure represent combinations of radial loads and moments for safe operations (i.e., positive MOS). The root mean square (RMS) values for the radial loads and corresponding moments shown in Table 6.1-2 are plotted on Figure 6.1-6 with black symbols for the upper actuator and blue symbols for the lower actuator. From this figure, there is significant positive MOS for these actuators for a 1,500 lbs axial load capability.

Table 6.1-2. Forces in the Actuators and Comparison with Allowables

Forces and Moments	Load Set 1	Load Set 2	Load Set 3	Allowable (Torque) in-lbs.
Upper Actuator				
Radial X, lbs.	276	192	147	
Axial Y, lbs.	123	183	147	
Radial Z, lbs.	141	213	228	
Moment X, in-lbs.	267	288	285	
Torsion Y, in-lbs.	***249***	**147**	**96**	**250**
Moment Z, in-lbs.	387	231	123	
RMS Values - Radial, Moment (lbs., in-lbs.)	310, 470	287,370	270,310	
Lower Actuator				
Radial X, lbs.	153	84	42	
Radial Y, lbs.	135	192	99	
Axial Z, lbs.	180	285	609	
Moment X, in-lbs.	507	528	312	
Moment Y, in-lbs.	726	462	192	
Torsion Z, in-lbs.	**135**	**87**	**87**	**250**
RMS Values - Radial, Moment (lbs., in-lbs.)	204, 886	210, 702	108, 366	

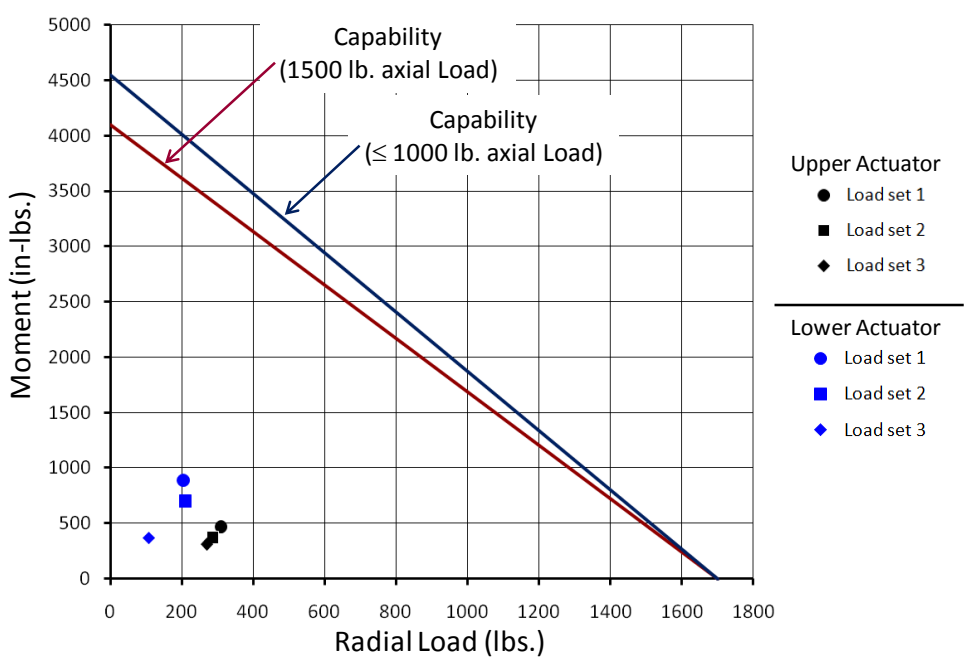

Figure 6.1-6. Gimbal Actuator Capacity (excluding Torsion Limit)

The maximum stresses in the arm, biaxial bracket, base, and the S-Band bracket due to the RV environment and the associated MOS for yield and ultimate are presented in Table 6.1-3. A factor of safety (FOS) of 1.4 on yield and 2.0 on ultimate are used in computing the MOS. In this table, the MOS in fasteners in the model are also included and grouped by bolt type. The margins are calculated using:

$$M \quad \Theta \; S \frac{A \; l \quad l \quad o \, S w t \; b r l \; e e}{M \quad S \; k \quad r * F \quad \Theta \; S} - 1$$

(EQ. 1)

In some cases it appears that the MOS is calculated using a FOS applied to the qualification loads instead of being applied to the design limit loads as defined in NASA-STD-5001A. It is the review team's opinion that this is overly conservative.

In Eq. 1, the allowable stress is either the yield or ultimate stress, and maximum stress is the maximum 3σ von Mises stress. Both 1σ and 3σ stresses are presented in Table 6.1-3. The margins are, however, calculated for the 3σ von Mises stress values. All of the calculated MOS are positive suggesting that various structural components are safe.

The assumption that 3σloading is the worst case may be unconservative, particularly for brittle (low elongation) materials. Systems subjected to RV environments can experience excitations higher than 3σ if the system is subjected to the environment for long enough duration. However, imposing a 4.5σ load requirement in this case appears to be excessive due to multiple apparent conservatisms in the modeling and analysis.

In addition, random loads were applied one axis at a time and analyzed separately. Combined load analyses were not performed. Although such analyses may not be a requirement for this project, the practice is unconservative. Furthermore, it was also not clear if the restraint preload was included in a combined loading analysis.

Table 6.1-3. Stresses in Various Components of the Model and the Computed Margins for Yield and Ultimate Strengths

X Axis

Name	Part Number:	Material:	1σ Max VM Stress (psi)	3σ Max VM Stress (psi)	σyallow (psi)	σuallow (psi)	Margin (yield)	Margin (Ultimate)
Arm	38553	AL 6061-T6	4326	12978	35000	42000	0.93	0.62
Biax Bracket	37184	AL 7075-T651	2139	6417	50000	61000	4.57	3.75
Base	38554	AL 6061-T6	2112	6336	35000	42000	2.95	2.31
S-band Bracket	38558	AL 7075-T651	4339	13017	50000	61000	1.74	1.34

Fastener Analysis

Bolt Type	Tensile bolt Margin	Shear Bolt Margin	Thread Shear Margin	Joint Separation Margin	Insert Internal Thread Margin	Insert External Thread Margin	Parent Material Margin
8-32	0.18	5.20	2.48	1.92	N/A	N/A	0.09
1/4-28	0.17	13.62	2.46	2.66	N/A	N/A	0.08

Y Axis

Name	Part Number:	Material:	1σ Max VM Stress (psi)	3σ Max VM Stress (psi)	σyallow (psi)	σuallow (psi)	Margin (yield)	Margin (Ultimate)
Arm	38553	AL 6061-T6	6663	19989	35000	42000	0.25	0.05
Biax Bracket	37184	AL 7075-T651	1554	4662	50000	61000	6.66	5.54
Base	38554	AL 6061-T6	1755	5265	35000	42000	3.75	2.99
S-band Bracket	38558	AL 6061-T6	3365	10095	35000	42000	1.48	1.08

Fastener Analysis

Bolt Type	Tensile bolt Margin	Shear Bolt Margin	Thread Shear Margin	Joint Separation Margin	Insert Internal Thread Margin	Insert External Thread Margin	Parent Material Margin
8-32	0.19	8.95	2.51	3.23	N/A	N/A	0.09
1/4-28	0.19	28.00	2.50	4.76	N/A	N/A	0.09

Z Axis

Name	Part Number:	Material:	1σ Max VM Stress (psi)	3σ Max VM Stress (psi)	σyallow (psi)	σuallow (psi)	Margin (yield)	Margin (Ultimate)
Arm	38553	AL 6061-T6	4889	14667	35000	42000	0.70	0.43
Biax Bracket	37184	AL 7075-T651		0	50000	61000	#DIV/0!	#DIV/0!
Base	38554	AL 6061-T6		0	35000	42000	#DIV/0!	#DIV/0!
S-band Bracket	38558	AL 7075-T651		0	50000	61000	#DIV/0!	#DIV/0!

Fastener Analysis

Bolt Type	Tensile bolt Margin	Shear Bolt Margin	Thread Shear Margin	Joint Separation Margin	Insert Internal Thread Margin	Insert External Thread Margin	Parent Material Margin
8-32	0.19	10.53	2.52	3.83	N/A	N/A	0.09
1/4-28	0.19	28.63	2.51	6.86	N/A	N/A	0.09

6.2 NESC Team Model Review Comments

The SNC IGA FEM was reviewed by the NASTRAN experts in the NESC team[4]. A number of issues were raised by this subteam and they are presented in Appendix A. SNC responded to each of the issues. This section summarizes the issues and the corresponding SNC responses.

1. Minor issues: Several minor book-keeping inconsistencies were found in the model: (a) Coefficients of thermal expansions of materials with identification numbers 3 and 5 and the corresponding reference temperatures are not assigned, (b) Some 279 nodes have no associated elements, loads, or constraints associated with them, and (c) PID 40006 is not used.
    - SNC: As thermal analysis is not being performed, issue (a) is not pertinent. Dummy node numbers exist in the model and they do not participate in the analysis. PID 40006 is not used and is a remnant of previous analysis, and thus items (b) and (c) are benign.
2. Fastener Modeling: Holes for fasteners (assumed as fasteners) as small as 0.125 inch were modeled with local refined meshes. But these round holes appears as hexagon areas in the mesh. It is not clear why features of this size were modeled into a dynamic model.
    - SNC suggested that these features were modeled to accommodate other components not in the primary load path. These other components will be added as the system design/model is finalized. The mesh around the mentioned areas is mainly to provide attachment points for the other hardware. This type of modeling is not expected to lead to or cause stress issues in these regions.
3. Base Plate Boundary Conditions: There is a large RBE2 (rigid element connections) on the base plate that attaches the bolt holes to a central point where a large mass is located. This RBE2 specification effectively rigidly ties these bolt holes together. Thus, when free-free vibration analysis modes are performed, the effect is to rigidize the base plate. It is not clear if this is a desired condition. This boundary condition implementation appears to be in the model to utilize the prior "large mass" method of inducing base acceleration. Current versions of NASTRAN allow direct input of applied acceleration without having to resort to the use of the large mass method.
    - SNC: The “large mass” method is a widely accepted and historically used method of performing random response analysis. This method is typically used by SNC.
    - SNC: The RBE2 constraints on the nodes on the base plate to connect to the node where the mass is located will rigidize the base plate. In reality the base plate is effectively rigid along that interface due to the large number of 0.250-28 fasteners used to secure the base plate.

[4] Ken Hamm –ARC and Pete Mule –GSFC

- SNC: In the free-free mode analyses the RBE2 constraints would tie the plate together and may miss some "free" elements. Therefore, SNC performed the free-free analyses again to demonstrate that no "free" elements exist and that the previous free-free modes analysis is valid. (See Appendix A).

4. Gussets: There are what appear to be gussets or stiffeners plates under the base plate. However, the meshes do not line up so there is no connectivity between the base plate and the stiffener in that area. Is this is an error or is the modeling intentional?
    - SNC will examine this region to determine if there is a connectivity issue in those local areas. The modal analysis will then be updated and the results scrutinized.
5. Interfacing linear and quadratic elements: The current IGA model had areas where Quad 8 elements (8-node quadrilateral elements with corner and mid-side nodes) are directly connected to Quad 4 elements (4-node quadrilateral elements with corner nodes) or Tria 3 elements (3-node triangular elements). Quad 8 elements have quadratic shape functions while Quad 4 elements and Tria 3 elements have linear shape functions. Recommended modeling practice is to interface Quad 8 elements with other Quad 8 elements or other quadratic elements such as Tria 6 elements, and not Quad 4 or Tria 3 elements (i.e., so corner nodes are connected to corner nodes, and mid-side nodes to mid-side nodes). Mixing Quad 4 and Tria 3 elements with Quad 8 elements is not recommended as compatibility across the inter-element boundaries cannot be maintained.
    - SNC is aware of these modeling issues. Apparently, this situation occurred when a local area of the mesh was updated after the majority of the mesh is completed. In the next model revision, all Quad 4 and Tria 3 will be updated to Quad 8 and Tria 6 elements with proper connectivity.
    - SNC agreed to revise the model according to the team's suggestions and will be providing the new margins to the CoNNeCT Project.

7.0 Findings, Observations, and NESC Recommendations

7.1 Findings

The following findings are made:

F-1. There appears to be considerable amount of conservatism in the design and analysis.

F-2. The NASTRAN FEM is overall a good representation of the CoNNeCT Antenna IGA.

F-3. SNC provided satisfactory explanations or agreed to make appropriate corrections to the FEM issues identified.

F-4. Gimbal actuator analytical applied torque during launch is approximately same as the

unpowered, 249 and 250, respectively.

7.2 Observations

The following observations are made:

O-1. The assumption that 3σloading is the worst case may be unconservative.

O-2. Analysis of the launch restraint system appears to be incomplete.

O-3. Application of FOS to qualification level loads appears to be redundant.

O-4. Load combinations used in the margin calculations need to be reported (including restraint pre-load).

7.3 NESC Recommendations

The following NESC recommendations are directed to the CoNNeCT Project:

R-1. The IGA FEM should be exercised using combinations of nominal and zero for actuator rotational stiffness to bound the possible response. ***(F-3)***

R-2. Evaluate if the IGA FEM hardware is mounted to a 0.5 inch radiator panel to determine if some of the loads are missing due to the flexibility of the mounting structures. ***(F-3 and O-2)***

R-3. Verify positive MOS following incorporation of IGA FEM updates. ***(F-3)***

R-4. Incorporate a FOS for the gimbal actuator (250 in-lbs) unpowered torque value and update the analysis to ensure a positive MOS. ***(F-4)***

8.0 Definition of Terms

Corrective Actions

Changes to design processes, work instructions, workmanship practices, training, inspections, tests, procedures, specifications, drawings, tools, equipment, facilities, resources, or material that result in preventing, minimizing, or limiting the potential for recurrence of a problem.

Finding

A conclusion based on facts established during the assessment/inspection by the investigating authority.

Lessons Learned

Knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. A lesson must be significant in that it has real or assumed impact on operations; valid in that it is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or limits the potential for failures and mishaps, or reinforces a positive result.

Observation

A significant factor established during this assessment that supports and influences the conclusions reached in the statement of Findings and Recommendations.

Problem

The subject of the independent technical assessment/inspection.

Recommendation

An action identified by the assessment/inspection team to correct a root cause or deficiency identified during the investigation. The recommendations may be used by the responsible C/P/P/O in the preparation of a corrective action plan.

Root Cause

Along a chain of events leading to a mishap or close call, the first causal action or failure to act that could have been controlled systemically either by policy/practice/procedure or individual adherence to policy/practice/procedure.

9.0 Acronyms List

APS	Antenna Pointing Subsystem
ARC	Ames Research Center
CDR	Critical Design Review
CoNNeCT	Communications, Navigation, and Networking re-Configurable Testbed
dB	decibel
DFMR	Design For Minimum Risk
ExPA	EXPRESS Pallet Assembly
FEM	finite element model

FOS	factor of safety
FRAM	Flight Releasable Attachment Mechanism
GPS	global positioning satellite
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
HGA	high gain antenna
Hz	hertz
IGA	Integrated Gimbal Assembly
ISS	International Space Station
JSC	Johnson Space Center
LaRC	Langley Research Center
LGA	low gain antennas
MEFL	maximum expected fight levels
MGA	medium gain antenna
MOS	margins of safety
MTSO	Management and Technical Support Office
NASA	National Aeronautics and Space Administration
NESC	NASA Engineering and Safety Center
NRB	NESC Review Board
P/N	part number
PDR	Preliminary Design Review
RF	radio frequency
RMS	root mean square
RV	random vibration
SDR	Software Defined Radio
SNC	Sierra Nevada Corporation
TDRS	Tracking and Data Relay Satellite

Volume II: Appendices

A. APS Model Review, July 21, 2010

Appendix A. APS Model Review, July 21, 2019

APS Model Review

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Responses from Chad Herbert	17-33

APS Model Review
July 21, 2010

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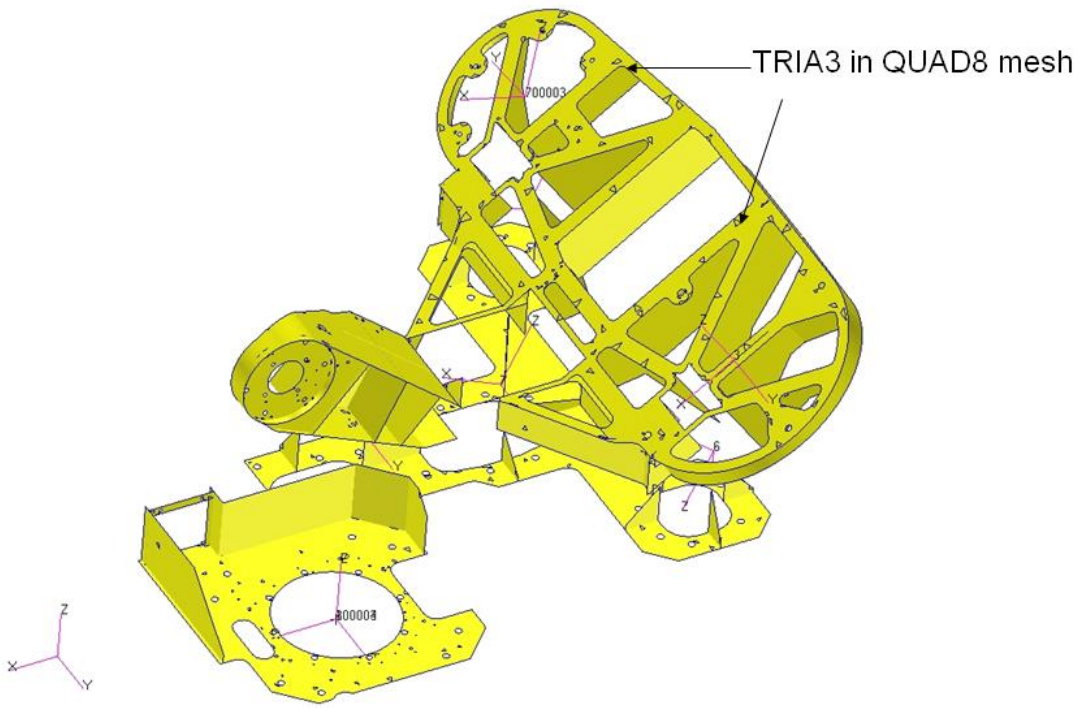
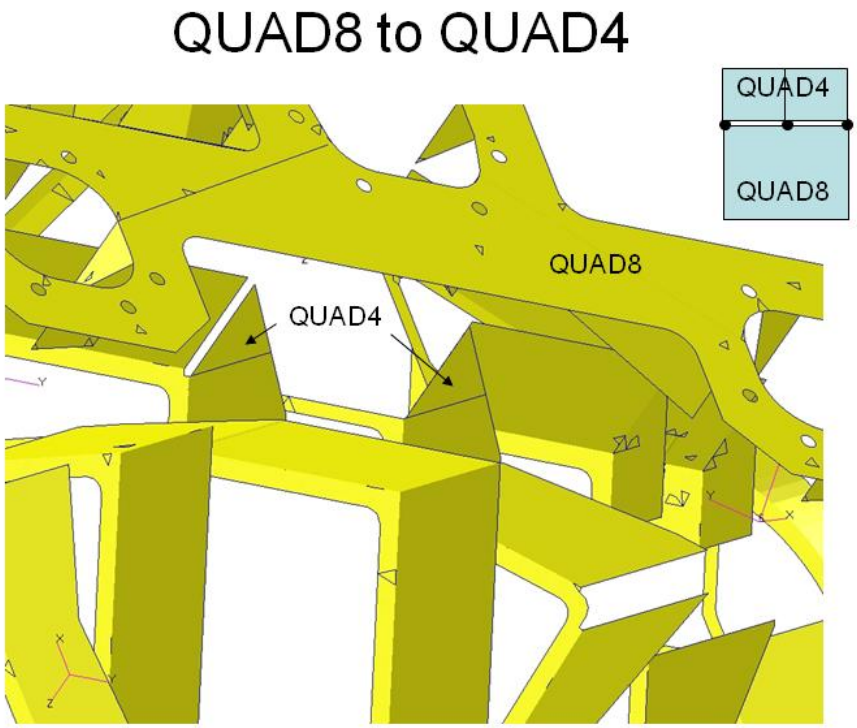
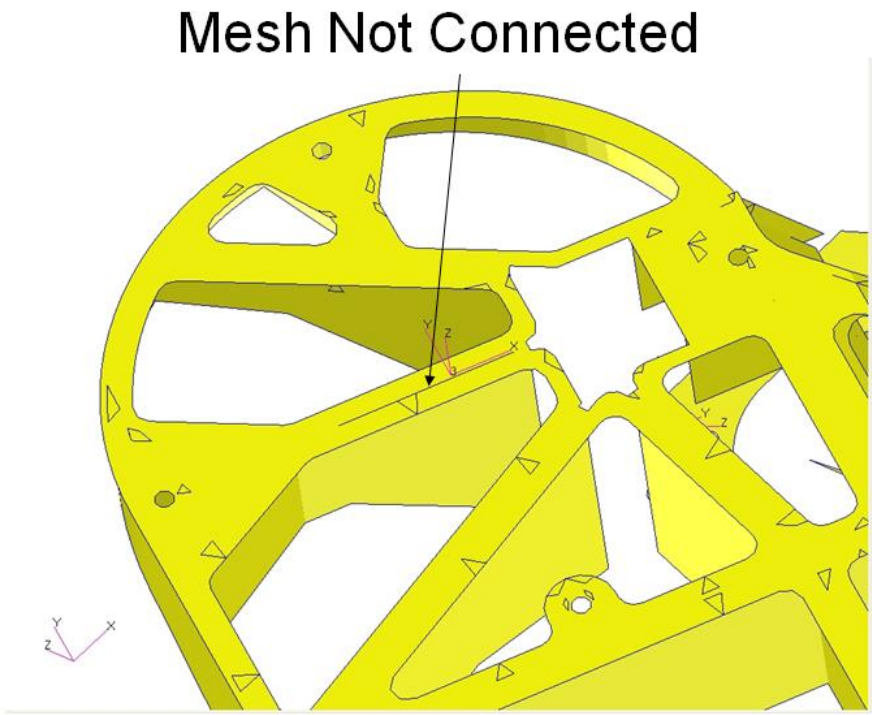
Concerns Identified

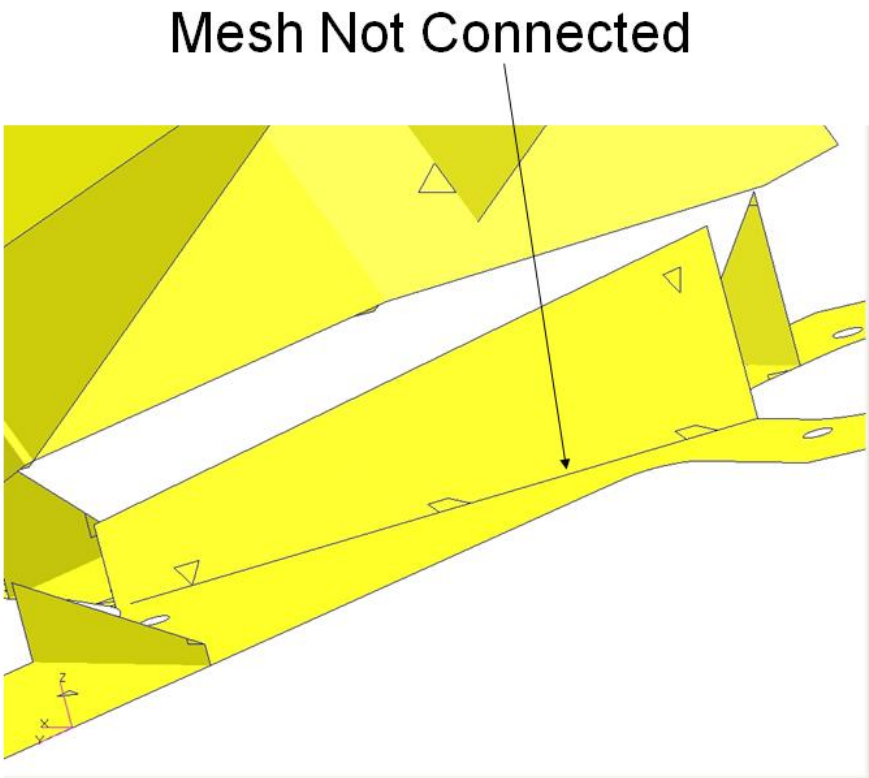
- 1. There are areas where QUAD4 elements are directly connected to QUAD8 elements. However, instead of one to one element connectivity where one of the midside nodes on the QUAD8 is deleted so both edges have a "bilinear" shape function along their shared edge, this model has 2 QUAD4 elements connected to one QUAD8, with the corner node between the QUAD4s connected to the midside node of the QUAD8. This usually isn't good meshing practice.
- 2. There are large areas modeled with QUAD8 elements with TRIA3 elements imbedded in these areas. I would have expected TRIA6 elements so as to be compatible with the QUAD8 elements. Free edge check identifies all of these triangular element boundaries.
- 3. There are what appear to be gussets or stiffeners plates under the baseplate are where the meshes do not line up so there is no connectivity between the baseplate and the stiffener in that area.
- 4. There is a large RBE2 (rigid element) on the baseplate which attaches all the bolt holes to a central point where a large mass is located. This effectively ties these holes together rigidly. So when free-free modes are run as stated in the PowerPoint slides you will get the effect of this rigidization of the baseplate. Not sure if that is what is desired or not. This appears to be in the model to support the old "large mass" method of inducing base acceleration. Newer versions of NASTRAN have allowed you to directly input applied acceleration without having to use the large mass method.
- 5. Holes for fasteners (I presume fasteners anyway) as small as 0.125" have be modeled in with refined meshes to get down to this size. But these round holes end up looking like small little hexagon areas in the mesh.

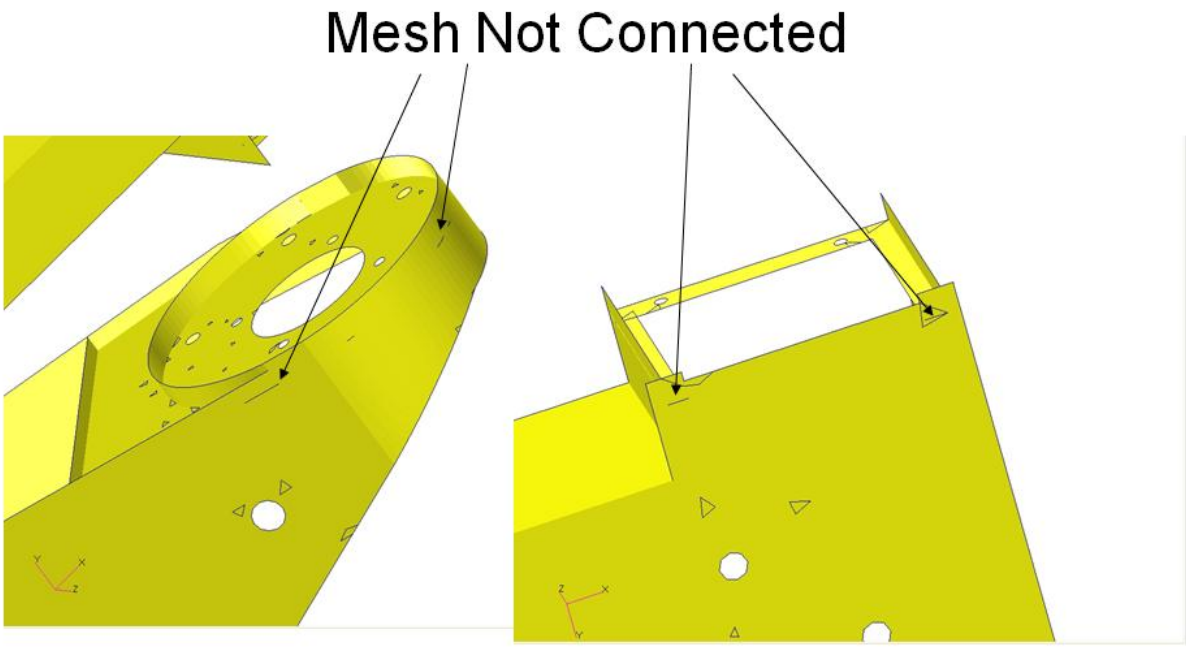
TRIA3 Elements



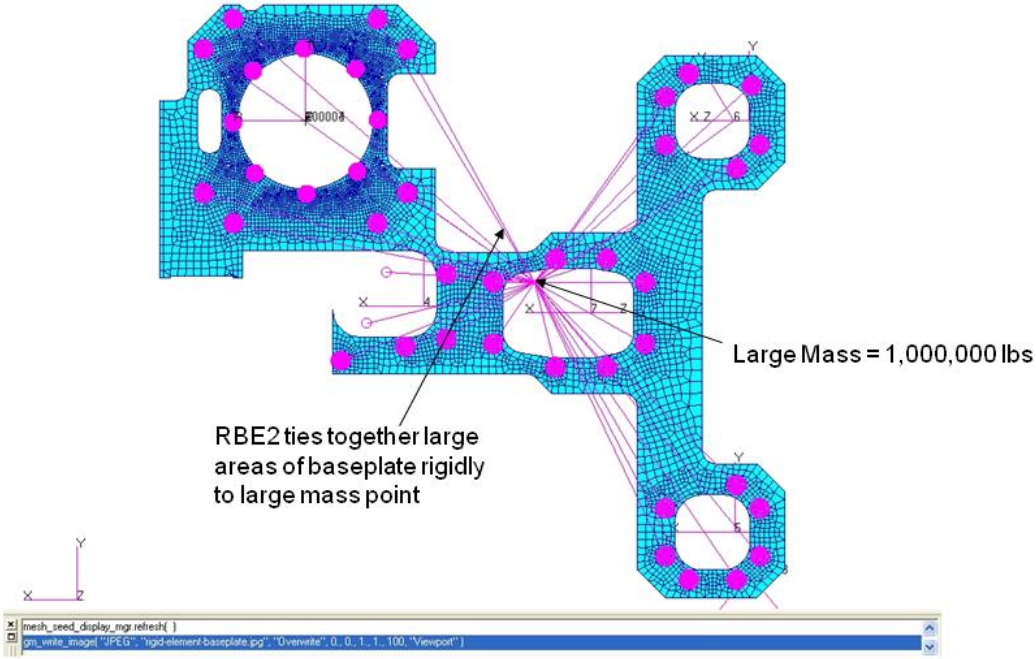

QUAD8 to QUAD4
QUAD4
QUAD8
QUAD8
QUAD4


Mesh Not Connected


Mesh Not Connected


Mesh Not Connected

Rigid Element on Baseplate



Other Items

- Delivered deck is Normal Modes only (SOL 103)
  - No loading included
  - No damping included
  - How were base loads input?
  - Would be good to see this part of the deck
- Constraint SPC 1-6 is included at large mass in modal run
- Have not had much time to do any further investigation
  - Would like to make changes to the mesh and correct errors and see what differences result in modes

P. Mulé Questions

- Environmental requirements for the subsystem.
  - What are all the environmental requirements driving the design?
  - What is the source of the base driven random vibration requirement?
  - What are the CLA results showing for net CG inertial loads?
  - Is structural born vibration from acoustic loading included in the CLA?
    - In general the driving mechanical requirements are design (usually based on CLA), vibroacoustic, and thermal loads. Sine loads are included in the CLA and are therefore covered by design loads for analysis. Because coupled loads should cover all low frequency structural born input it is concerning that the given random profile will likely impart loads at low frequency much higher than the coupled loads. I do think this situation calls form implementing some sort of force limiting in the analysis and test.
- Test and analysis philosophy
  - Are MEFL +3dB the highest test levels (i.e. qualification levels) or are they considered acceptance levels?
  - Are margins calculated on qualification loads using the analysis factors of safety listed?
    - Need to verify analysis is not placing factors on factors and being overly conservative. GSFC analyzes using acceptance (flight) loads and applies a factor of safety when calculating margins. The factor of safety is related to test factors such that a zero margin in analysis means we are testing to yield (example: design loads test factor is 1.25 and analysis FS on yield is 1.25)

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P. Mulé Questions

- Load combinations
  - Random loads are analyzed axis by axis. Is there any requirement to combine results when evaluating design?
    - Margins are shown for load cases but it is not clear if the loads cases are to be combined or case by case.

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P Mulé Questions

- Launch lock
  - Provide more detail of the lock design, modeling in the IGA, pre-load development, and analysis?
    - If the lock is designed to maintain constant load (i.e. using Bellville washers) then analysis should be performed without the lock in the system. Preload should developed based on loads at contact points.
    - If the launch lock is not designed to maintain constant load then it should be included but the analytical loads on the lock must be added to preload when analyzing. Could exceed Quicknut capability.
    - When developing pre-load value for the launch restraint it does not appear to account for the added vertical load due to lateral loading at the supports due to the slope angle. It is also unclear if the analysis accounts for geometry of the layout. Summing the vertical forces will not give the required launch lock preload.
- Low margins in the in the arm.
    - Analysis showed a low margin in the arm and it is not clear if this includes stresses from preload.

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P. Mulé Modeling Comments

- The gimbals' actuator torsion stiffness is high.
  - Is this representative of the stiffness expected in launch (unpowered) and is this a linear stiffness in reality (can it back drive).
  - High stiffness will give the high end of loads on actuator but it will result in lower restraint loads and vice versa.
  - Consider running at low actuator stiffness.
- Restraint includes bar (57043) appears incorrect
  - Bar is hinged (45 released) on end A and fixed on end B.
  - Appears both ends should be pinned (56 released)?
  - Note that releases are in the bar system in which x is along bar axis.
- Modal run of model provided resulted in different modal frequencies and mass participation than those reported (see later slide)
  - Table provided appears to have mass participation in mass units where my table is in mass fraction (% mass participation)
  - Major mass modes appear at similar frequencies but sometimes split among multiple modes.

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P. Mulé Modeling Comments

- Material IDs 3 and 5 do not have CTE and reference temperatures assigned.
  - Not critical unless using for thermal loads run
- Use of single layer of solid elements not recommended.
  - Do not appear to be in critically loaded areas
- Have interface forces (SPC forces of constraint GRID 47) from random run been reviewed.
  - This output would give predict of the peak interface force (assume 3 x rms) and some idea if a base driven random vibration test to these levels is appropriate. The supporting structure can only impart so much load.
- 279 Nodes with no associated elements, loads, constraints, etc.
  - Just output from a model check
- PID 400006 (38553_Arm_0.1875in_Plate) unused.
  - Information only

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P. Mulé Model Comments

Mode	Freq (Hz)	Modal Mass Fraction					
		T1	T2	T3	R1	R2	R3
1	73.81	0%	0%	0%	0%	0%	0%
2	115.29	0%	2%	0%	4%	0%	1%
3	126.42	1%	1%	0%	1%	2%	1%
4	153.22	3%	1%	0%	4%	1%	10%
5	163.58	0%	1%	0%	1%	0%	1%
6	168.02	1%	3%	0%	5%	1%	0%
7	176.80	0%	0%	0%	3%	0%	1%
8	185.93	0%	0%	0%	0%	0%	0%
9	186.59	0%	0%	0%	0%	0%	0%
10	192.66	0%	0%	0%	0%	0%	0%
11	196.00	0%	0%	0%	0%	0%	0%
12	199.26	10%	6%	0%	5%	5%	0%
13	199.42	0%	0%	0%	0%	0%	0%
14	200.42	0%	0%	0%	0%	0%	0%
15	226.35	1%	1%	2%	4%	4%	13%
16	238.25	7%	0%	2%	2%	15%	2%
17	257.22	1%	0%	0%	0%	3%	0%
18	268.06	0%	0%	0%	1%	0%	0%
19	282.06	0%	0%	0%	0%	0%	0%
20	292.08	1%	0%	0%	0%	2%	2%
21	295.73	0%	3%	0%	3%	1%	3%
22	298.47	0%	1%	0%	2%	1%	0%
23	307.25	0%	0%	0%	0%	0%	0%
24	319.49	4%	10%	2%	7%	1%	0%
25	326.89	2%	1%	0%	2%	0%	9%
26	331.61	3%	0%	0%	0%	3%	4%
27	347.17	0%	0%	0%	0%	1%	0%
28	353.15	0%	2%	1%	0%	1%	1%
29	364.04	0%	2%	1%	0%	1%	2%
30	374.51	0%	3%	3%	0%	3%	3%

Mode Number	Hz	T1 Fraction	T2 Fraction	T3 Fraction	R1 Fraction	R2 Fraction	R3 Fraction
1	95.1	9.43E-04	1.29E-04	2.45E-04	1.20E-03	9.26E-02	5.88E-03
2	115.0	8.81E-07	2.65E-03	7.15E-05	5.27E-01	1.05E-02	3.41E-01
3	134.4	1.61E-03	2.30E-03	1.05E-04	1.52E-01	4.05E-01	6.10E-01
4	164.8	7.00E-03	1.32E-03	1.60E-04	3.37E-01	4.24E-01	2.59E+00
5	169.8	3.69E-06	2.27E-03	7.56E-05	3.07E-01	6.39E-02	4.74E-01
6	177.4	3.93E-05	9.52E-04	1.76E-04	6.09E-01	2.91E-02	4.19E-01
7	186.9	2.49E-03	2.56E-03	1.88E-04	6.20E-01	4.53E-01	6.01E-03
8	198.5	1.50E-02	9.90E-03	4.36E-04	7.52E-01	9.91E-01	3.45E-02
9	216.0	2.72E-06	2.54E-05	5.85E-07	7.21E-03	1.02E-08	1.39E-01
10	217.9	3.25E-05	9.97E-06	4.91E-05	8.00E-03	2.05E-02	9.17E-02
11	227.0	9.61E-05	2.66E-04	1.04E-04	5.96E-04	4.67E-02	3.13E-01
12	229.6	5.08E-05	1.55E-04	4.75E-04	1.45E-01	9.57E-02	5.44E-01
13	234.0	2.02E-03	7.42E-04	1.38E-08	1.04E-03	2.51E-01	5.30E-01
14	236.1	7.56E-04	7.98E-06	1.28E-04	1.64E-02	1.76E-01	4.33E-05
15	239.9	1.64E-03	4.72E-05	5.60E-04	5.20E-02	4.77E-01	1.60E-01
16	249.9	7.11E-03	2.37E-03	4.54E-03	3.33E-01	2.70E+00	3.03E+00
17	259.7	5.06E-03	1.10E-06	1.63E-03	1.74E-01	1.54E+00	1.11E-01
18	283.6	1.16E-05	2.30E-06	3.76E-06	1.36E-03	1.10E-04	6.80E-04
19	294.4	1.29E-03	5.60E-04	2.33E-05	1.29E-01	5.05E-02	3.82E-01
20	298.5	2.56E-04	5.75E-03	6.11E-04	5.57E-01	1.33E-02	1.15E-01
21	306.4	4.30E-04	3.72E-04	5.04E-05	5.45E-02	7.33E-02	2.64E-03
22	316.7	6.59E-03	5.62E-03	2.14E-04	4.17E-01	6.08E-01	2.81E-01
23	324.3	1.22E-03	6.13E-03	1.49E-03	2.37E-01	2.19E-02	2.40E-02
24	334.4	1.76E-07	6.04E-03	2.71E-03	1.02E-01	1.22E-01	4.31E-01
25	340.2	5.36E-04	8.76E-04	9.75E-04	1.59E-01	3.26E-01	3.49E-01
26	345.1	2.21E-03	1.42E-03	3.01E-04	2.16E-01	3.01E-01	9.13E-01
27	350.7	1.70E-03	4.09E-03	1.50E-04	3.57E-01	1.87E-01	1.99E+00
28	360.1	3.71E-04	5.43E-04	1.09E-05	5.87E-02	3.74E-03	4.79E-01
29	381.8	1.33E-03	3.09E-05	5.68E-03	1.18E-01	1.09E+00	1.85E-02
30	389.1	1.60E-04	6.27E-03	1.04E-04	1.42E-01	2.41E-02	1.08E+00
31	400.5	2.47E-05	2.53E-06	1.49E-05	2.02E-03	1.80E-03	3.29E-04
32	407.3	4.47E-04	5.66E-03	5.94E-07	3.01E-01	9.31E-03	6.52E-01
33	421.4	2.99E-03	1.28E-06	3.01E-03	1.63E-01	4.80E-01	1.91E-04
34	443.4	2.10E-03	1.10E-04	2.22E-02	2.73E-01	6.97E-02	2.89E-02
35	450.2	5.38E-06	2.03E-03	1.09E-02	2.97E-02	1.85E-02	1.60E-01

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111093 – CoNNect

SNC Response to NESC Questions/Requests #1

Chad Hebert
July 21, 2010

17

NESC Questions/Requests #1

- The following is the list of questions/requests from NESC to SNC about the IGA FEA model which was received from NASA/GRC on July 2010.

1. Restraint includes bar (57034) appears incorrect
2. Bar is hinged (45 released) on end A and fixed on end B.
3. Appears both ends should be pinned (56 released)?
4. Note that releases are in the bar system in which x is along bar axis.
5. Modal run of model provided resulted in different modal frequencies and mass participation than those reported (see later slide)
6. Material IDs 3 and 5 do not have CTE and reference temperatures assigned.
7. Use of single layer of solid elements not recommended.
8. Have interface forces (SPC forces of constraint GRID 47) from random run been reviewed.
9. 279 Nodes with no associated elements, loads, constraints, etc.
10. PID 400006 (38553_Arm_0.1875in_Plate) unused.
11. There are areas where QUAD4 elements are directly connected to QUAD8 elements. However, instead of one to one element connectivity where one of the midside nodes on the QUAD8 is deleted so both edges have a "bilinear" shape function along their shared edge, this model has 2 QUAD4 elements connected to one QUAD8, with the corner node between the QUAD4s connected to the midside node of the QUAD8. This usually isn't good meshing practice. This seems to be used as some kind of mesh transition device since the mesh where the QUAD4 elements are is finer than the QUAD8 side. I have looked and haven't found any other mesh transition devices in those areas.
12. There are large areas modeled with QUAD8 elements with TRIA3 elements imbedded in these areas. I would have expected TRIA6 elements so as to be compatible with the QUAD8 elements. But there are no TRIA6 elements anywhere in the deck. So when you look for free edges all of these triangular element boundaries show up where the mesh is not compatible. I have no idea how you would get a mesher to do this. You would probably need to do it manually.
13. There are what appear to be gussets or stiffeners plates under the base plate are where the meshes do not line up so there is no connectivity between the base plate and the stiffener in that area. I am not sure if this is a mistake or by design.
14. There is a large RBE2 (rigid element) on the base plate which attaches all the bolt holes to a central point where a large mass is located. This effectively ties these holes together rigidly. So when free-free modes are run as stated in the PowerPoint slides you will get the effect of this rigidization of the base plate. Not sure if that is what is desired or not. This appears to be in the model to support the old "large mass" method of inducing base acceleration. Newer versions of NASTRAN have allowed you to directly input applied acceleration without having to use the large mass method.
15. Holes for fasteners (I presume fasteners anyway) as small as 0.125" have be modeled in with refined meshes to get down to this size. But these round holes end up looking like small little hexagon areas in the mesh. I am not sure of the reason for having features of this size modeled into a dynamic model.

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NESC Q's #1-4

1. Restraint includes bar (57034) appears incorrect
2. Bar is hinged (45 released) on end A and fixed on end B.
3. Appears both ends should be pinned (56 released)?
4. Note that releases are in the bar system in which x is along bar axis.

SNC Response for 2-4

- The beam element in question should be ID 57043 and is representing the bolt in the Qwknut assembly. End A is on a spherical interface and should have been released in 56 not 45. The torsion about the beam is the 4 direction and can be released at both ends.
- Therefore, the model was re-analyzed with the above changes to the ELEMID 57043, which is the beam representing the bolt in the Qwknut assembly.
- The significant modal frequencies were investigated to see the effect of this change. The mode with the most mass participation is mode 8 at 198.5 Hz in the original model. The new model has mode with the most mass participation is still mode 8 at 198.2 Hz. The change in frequency is essentially negligible. Therefore, there should be no effect on the loads/stresses recovered from the random vibration analysis either.
- The modal participation is shown on the next slide to help validate this point.

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NESC Q's #1-4 Cont

07/13/10 Model

Mode Number	Hz	T1 Fraction	T2 Fraction	T3 Fraction	R1 Fraction	R2 Fraction	R3 Fraction
1	95.1	9.43E-04	1.29E-04	2.45E-04	1.20E-03	9.26E-02	5.88E-03
2	115.0	8.81E-07	2.65E-03	7.15E-05	5.27E-01	1.05E-02	3.41E-01
3	134.4	1.61E-03	2.30E-03	1.05E-04	1.52E-01	4.05E-01	6.10E-01
4	164.8	7.00E-03	1.32E-03	1.60E-04	3.37E-01	4.24E-01	2.59E+00
5	169.8	3.69E-06	2.27E-03	7.56E-05	3.07E-01	6.39E-02	4.74E-01
6	177.4	3.93E-05	9.52E-04	1.76E-04	6.09E-01	2.91E-02	4.19E-01
7	186.9	2.49E-03	2.56E-03	1.88E-04	6.20E-01	4.53E-01	6.01E-03
8	198.5	1.50E-02	9.90E-03	4.36E-04	7.52E-01	9.91E-01	3.45E-02
9	216.0	2.72E-06	2.54E-05	5.85E-07	7.21E-03	1.02E-08	1.39E-01
10	217.9	3.25E-05	9.97E-06	4.91E-05	8.00E-03	2.05E-02	9.17E-02
11	227.0	9.61E-05	2.66E-04	1.04E-04	5.96E-04	4.67E-02	3.13E-01
12	229.6	5.08E-05	1.55E-04	4.75E-04	1.45E-01	9.57E-02	5.44E-01
13	234.0	2.02E-03	7.42E-04	1.38E-08	1.04E-03	2.51E-01	5.30E-01
14	236.1	7.56E-04	7.98E-06	1.28E-04	1.64E-02	1.76E-01	4.33E-05
15	239.9	1.64E-03	4.72E-05	5.60E-04	5.20E-02	4.77E-01	1.60E-01
16	249.9	7.11E-03	2.37E-03	4.54E-03	3.33E-01	2.70E+00	3.03E+00
17	259.7	5.06E-03	1.10E-06	1.63E-03	1.74E-01	1.54E+00	1.11E-01
18	283.6	1.16E-05	2.30E-06	3.76E-06	1.36E-03	1.10E-04	6.80E-04
19	294.4	1.29E-03	5.60E-04	2.33E-05	1.29E-01	5.05E-02	3.82E-01
20	298.5	2.56E-04	5.75E-03	6.11E-04	5.57E-01	1.33E-02	1.15E-01
21	306.4	4.30E-04	3.72E-04	5.04E-05	5.45E-02	7.33E-02	2.64E-03
22	316.7	6.59E-03	5.62E-03	2.14E-04	4.17E-01	6.08E-01	2.81E-01
23	324.3	1.22E-03	6.13E-03	1.49E-03	2.37E-01	2.19E-02	2.40E-02
24	334.4	1.76E-07	6.04E-03	2.71E-03	1.02E-01	1.22E-01	4.31E-01
25	340.2	5.36E-04	8.76E-04	9.75E-04	1.59E-01	3.26E-01	3.49E-01
26	345.1	2.21E-03	1.42E-03	3.01E-04	2.16E-01	3.01E-01	9.13E-01
27	350.7	1.70E-03	4.09E-03	1.50E-04	3.57E-01	1.87E-01	1.99E+00
28	360.1	3.71E-04	5.43E-04	1.09E-05	5.87E-02	3.74E-03	4.79E-01
29	381.8	1.33E-03	3.09E-05	5.68E-03	1.18E-01	1.09E+00	1.85E-02
30	389.1	1.60E-04	6.27E-03	1.04E-04	1.42E-01	2.41E-02	1.08E+00
31	400.5	2.47E-05	2.53E-06	1.49E-05	2.02E-03	1.80E-03	3.29E-04
32	407.3	4.47E-04	5.66E-03	5.94E-07	3.01E-01	9.31E-03	6.52E-01
33	421.4	2.99E-03	1.28E-06	3.01E-03	1.63E-01	4.80E-01	1.91E-04
34	443.4	2.10E-03	1.10E-04	2.22E-02	2.73E-01	6.97E-02	2.89E-02
35	450.2	5.38E-06	2.03E-03	1.09E-02	2.97E-02	1.85E-02	1.60E-01

07/20/10 NESC Fixes Model

Mode Number	Hz	T1 Fraction	T2 Fraction	T3 Fraction	R1 Fraction	R2 Fraction	R3 Fraction
1	95.1	9.43E-04	1.28E-04	2.45E-04	1.17E-03	9.27E-02	5.72E-03
2	114.9	1.04E-06	2.77E-03	7.78E-05	5.33E-01	1.14E-02	3.64E-01
3	134.4	1.60E-03	2.27E-03	1.03E-04	1.52E-01	4.06E-01	6.03E-01
4	164.7	7.03E-03	1.16E-03	1.65E-04	3.14E-01	4.27E-01	2.46E+00
5	169.7	9.95E-07	2.50E-03	7.52E-05	3.40E-01	5.96E-02	5.65E-01
6	176.9	3.57E-05	1.08E-03	1.34E-04	6.00E-01	2.24E-02	5.14E-01
7	186.9	2.51E-03	2.52E-03	1.64E-04	5.87E-01	4.44E-01	4.34E-03
8	198.2	1.43E-02	9.50E-03	5.14E-04	7.89E-01	9.04E-01	1.72E-02
9	216.0	2.14E-06	2.74E-05	7.23E-07	7.18E-03	8.04E-06	1.42E-01
10	217.9	4.12E-05	1.55E-05	5.41E-05	8.14E-03	2.37E-02	1.01E-01
11	227.0	1.36E-04	3.56E-04	1.40E-04	1.37E-03	6.34E-02	3.88E-01
12	229.4	9.16E-05	2.68E-04	5.56E-04	1.48E-01	1.23E-01	6.57E-01
13	233.9	1.59E-03	9.44E-04	3.99E-06	8.98E-04	1.82E-01	6.15E-01
14	236.1	8.17E-04	6.63E-06	1.36E-04	1.65E-02	1.89E-01	9.49E-05
15	239.8	2.02E-03	8.98E-05	6.66E-04	5.44E-02	5.77E-01	2.04E-01
16	248.7	8.23E-03	3.05E-03	4.70E-03	2.81E-01	2.94E+00	3.21E+00
17	259.6	4.80E-03	2.42E-07	1.45E-03	1.42E-01	1.42E+00	8.55E-02
18	283.6	1.37E-05	7.05E-06	4.12E-06	2.51E-03	1.03E-04	1.37E-03
19	293.0	1.21E-03	1.72E-03	3.01E-06	2.74E-01	5.39E-02	5.33E-01
20	298.2	3.91E-04	5.67E-03	6.38E-04	5.13E-01	7.64E-03	8.41E-02
21	306.4	4.28E-04	3.71E-04	5.05E-05	5.41E-02	7.32E-02	2.73E-03
22	316.5	6.60E-03	4.88E-03	1.71E-04	3.84E-01	6.16E-01	3.32E-01
23	324.2	1.25E-03	7.05E-03	1.63E-03	2.72E-01	2.09E-02	3.98E-02
24	333.4	3.11E-05	8.05E-03	2.79E-03	1.74E-01	1.59E-01	7.36E-01
25	340.2	5.27E-04	8.84E-04	9.78E-04	1.60E-01	3.25E-01	3.53E-01
26	343.8	2.98E-03	2.57E-03	1.92E-04	3.37E-01	3.36E-01	1.53E+00
27	349.0	6.53E-04	2.74E-03	1.49E-05	1.91E-01	5.07E-02	1.16E+00
28	360.0	2.98E-04	4.75E-04	1.47E-05	4.73E-02	1.59E-03	4.08E-01
29	380.4	7.48E-04	4.58E-04	5.03E-03	8.56E-02	8.22E-01	8.50E-04
30	387.6	5.78E-04	6.42E-03	7.28E-05	1.86E-01	1.80E-01	1.01E+00
31	400.5	2.50E-05	2.66E-06	1.52E-05	2.05E-03	1.84E-03	3.28E-04
32	405.3	4.36E-04	4.36E-03	3.93E-05	2.15E-01	2.50E-02	3.93E-01
33	420.6	2.95E-03	4.58E-05	2.35E-03	2.17E-01	4.10E-01	1.91E-02
34	443.2	1.95E-03	7.15E-05	1.92E-02	2.62E-01	5.48E-02	2.84E-02
35	448.8	2.73E-05	1.89E-03	1.47E-02	4.10E-02	2.65E-04	1.02E-01

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NESC Q#5

5. Modal run of model provided resulted in different modal frequencies and mass participation than those reported (see later slide).

GRC Modal Results

Mode	Freq (Hz)	Modal Mass Fraction					
		T1	T2	T3	R1	R2	R3
1	73.81	0%	0%	0%	0%	0%	0%
2	115.29	0%	2%	0%	4%	0%	1%
3	126.42	1%	1%	0%	1%	2%	1%
4	153.22	3%	1%	0%	4%	1%	10%
5	163.58	0%	1%	0%	1%	0%	1%
6	168.02	1%	3%	0%	5%	1%	0%
7	176.80	0%	0%	0%	3%	0%	1%
8	185.93	0%	0%	0%	0%	0%	0%
9	186.59	0%	0%	0%	0%	0%	0%
10	192.66	0%	0%	0%	0%	0%	0%
11	196.00	0%	0%	0%	0%	0%	0%
12	199.26	10%	6%	0%	5%	5%	0%
13	199.42	0%	0%	0%	0%	0%	0%
14	200.42	0%	0%	0%	0%	0%	0%
15	226.35	1%	1%	2%	4%	4%	13%
16	238.25	7%	0%	2%	2%	15%	2%
17	257.22	1%	0%	0%	0%	3%	0%

SNC Modal Results

Mode Number	Hz	T1 Fraction	T2 Fraction	T3 Fraction	R1 Fraction	R2 Fraction	R3 Fraction
1	95.1	9.43E-04	1.29E-04	2.45E-04	1.20E-03	9.26E-02	5.88E-03
2	115.0	8.81E-07	2.65E-03	7.15E-05	5.27E-01	1.05E-02	3.41E-01
3	134.4	1.61E-03	2.30E-03	1.05E-04	1.52E-01	4.05E-01	6.10E-01
4	164.8	7.00E-03	1.32E-03	1.60E-04	3.37E-01	4.24E-01	2.59E+00
5	169.8	3.69E-06	2.27E-03	7.56E-05	3.07E-01	6.39E-02	4.74E-01
6	177.4	3.93E-05	9.52E-04	1.76E-04	6.09E-01	2.91E-02	4.19E-01
7	186.9	2.49E-03	2.56E-03	1.88E-04	6.20E-01	4.53E-01	6.01E-03
8	198.5	1.50E-02	9.90E-03	4.36E-04	7.52E-01	9.91E-01	3.45E-02
9	216.0	2.72E-06	2.54E-05	5.85E-07	7.21E-03	1.02E-08	1.39E-01
10	217.9	3.25E-05	9.97E-06	4.91E-05	8.00E-03	2.05E-02	9.17E-02
11	227.0	9.61E-05	2.66E-04	1.04E-04	5.96E-04	4.67E-02	3.13E-01
12	229.6	5.08E-05	1.55E-04	4.75E-04	1.45E-01	9.57E-02	5.44E-01
13	234.0	2.02E-03	7.42E-04	1.38E-08	1.04E-03	2.51E-01	5.30E-01
14	236.1	7.56E-04	7.98E-06	1.28E-04	1.64E-02	1.76E-01	4.33E-05
15	239.9	1.64E-03	4.72E-05	5.60E-04	5.20E-02	4.77E-01	1.60E-01
16	249.9	7.11E-03	2.37E-03	4.54E-03	3.33E-01	2.70E+00	3.03E+00
17	259.7	5.06E-03	1.10E-06	1.63E-03	1.74E-01	1.54E+00	1.11E-01

SNC Response

- The frequencies vs mode number has been different between modal analysis runs done by GRC and SNC before. This is mostly due to the KA-Band antenna FEA model sent to SNC by GRC. For example the first mode at 74Hz (GRC) and 95Hz (SNC) is the rotation of the feed and arms on the KA-Band antenna. This is due to the fact of how that antenna is modeled and how the different NASTRAN solvers treat the COUPMASS and K6ROT parameters.
- The modes with the most mass participation in the critical axis which is X are very similar. GRC has a mode at 199.2 Hz and SNC has that mode at 198.5 Hz. This is the mode that drives the critical design features in IGA with the X axis being the most critical. The Y Axis is driven by this same mode and it contains the 2nd highest loads and stresses.

21

NESC Q#6

6. Material IDs 3 and 5 do not have CTE and reference temperatures assigned.

SNC Response

- That is correct. However, there is no thermal analysis being performed by this model, so thus the materials not having those properties have no effect on the results. They can be added in if deemed necessary in future analyses.

22

NESC Q#7

7. Use of single layer of solid elements not recommended.

SNC Response

- Requested additional clarification from NASA GRC.

23

NESC Q#8

8. Have interface forces (SPC forces of constraint GRID 47) from random run been reviewed.

SNC Response

- Requested additional clarification from NASA GRC.

24

NESC Q#9

9. 279 Nodes with no associated elements, loads, constraints, etc.

SNC Response

- These nodes are extraneous and will be deleted in future analyses. Since they are not connected to the model, there is no effect on the results.

25

NESC Q#10

10. PID 400006 (38553_Arm_0.1875in_Plate) unused.

SNC Response

- That is correct. This is a remnant of previous analysis versions. However, since it is not used in the analysis, there is no effect on the results.

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NESC Q#11

11. There are areas where QUAD4 elements are directly connected to QUAD8 elements. However, instead of one to one element connectivity where one of the midside nodes on the QUAD8 is deleted so both edges have a "bilinear" shape function along their shared edge, this model has 2 QUAD4 elements connected to one QUAD8, with the corner node between the QUAD4s connected to the midside node of the QUAD8. This usually isn't good meshing practice. This seems to be used as some kind of mesh transition device since the mesh where the QUAD4 elements are is finer than the QUAD8 side. I have looked and haven't found any other mesh transition devices in those areas.

SNC Response

- This occurred when a local area of the mesh was updated after the majority of the arm mesh was completed. It is understood that this is not the best practice but was thought to be suitable to get the load/force results that were critical for the interim review.
- This can be updated as the design/analysis is continued. All the QUAD4 elements will be updated to QUAD8 with the proper connectivity.

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NESC Q#12

12. There are large areas modeled with QUAD8 elements with TRIA3 elements imbedded in these areas. I would have expected TRIA6 elements so as to be compatible with the QUAD8 elements. But there are no TRIA6 elements anywhere in the deck. So when you look for free edges all of these triangular element boundaries show up where the mesh is not compatible. I have no idea how you would get a mesher to do this. You would probably need to do it manually.

SNC Response

- This was done as a temporary fix due to issues during random vibration with TRIA6 elements. The initial modal analysis and load recovery of critical features from the MEFL+3dB random vibration was performed with the TRIA6 elements in place of the TRIA3 elements. When analysis was done to recover stress results in the arm and the base where TRIA6 elements are located errors were noticed in the stress results. Stresses in these TRIA6 elements were many orders of magnitude higher than the neighboring elements. So as a preliminary look to continue with the interim review these elements were converted to TRIA3 elements for stress recovery only while understanding their limitations.
- NEI Nastran was made aware of this issue and is in concurrence. They have been able to replicate the issue and are in the process of fixing it. In information received earlier today, these erroneous stresses in the TRIA6 elements are isolated to those type of elements and the issue is how the stresses/strains were being calculated in the latest version of the solver. All other parameters such as displacement and acceleration are unaffected. NEI Nastran is releasing an updated version of their solver immediately and this software bug will be fixed.
- Future analysis models of the IGA will use the TRIA6 elements in the arm and base to maintain proper connectivity to other elements.

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NESC Q#13

13. There are what appear to be gussets or stiffeners plates under the base plate are where the meshes do not line up so there is no connectivity between the base plate and the stiffener in that area. I am not sure if this is a mistake or by design.

SNC Response

- SNC agrees with this and will work on fixing this connectivity issue in those local areas. The modal analysis will then be redone to see what effect if any occurs.

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NESC Q#14

14. There is a large RBE2 (rigid element) on the base plate which attaches all the bolt holes to a central point where a large mass is located. This effectively ties these holes together rigidly. So when free-free modes are run as stated in the PowerPoint slides you will get the effect of this rigidization of the base plate. Not sure if that is what is desired or not. This appears to be in the model to support the old "large mass" method of inducing base acceleration. Newer versions of NASTRAN have allowed you to directly input applied acceleration without having to use the large mass method.

SNC Response

- The "large mass" method is a widely accepted and historically used method of performing random response analysis. This is what is typically used by SNC.
- The RBE2 on the base plate which connects to the node where the large mass is located will rigidize the base plate. In reality the base plate will be effectively rigid along that interface due to the large number of 1/4-28 fasteners used to secure the base plate.
- In the free-free modes run this would tie the plate together and may miss some "free" elements. Therefore, SNC has re-run the free-free modes to show that no "free" elements exist and that the previous free-free modes analysis is valid. The results are shown on the next slide.

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NESC Q#14 Cont

- Free-free vibration verification was performed with the RBE2 on the base removed.

NE1NASTRAN SUBCASE 1

R E A L E I G E N V A L U E S

MODE NUMBER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS	ORTHOGONALITY LOSS	ERROR MEASURE
1	1.690572E-09	4.111656E-05	6.543904E-06	1.000000E+00	4.226429E-06	0.000000E+00	1.763021E-09
2	3.489383E-08	1.867989E-04	2.972997E-05	1.000000E+00	8.723458E-05	2.937706E-06	2.913776E-10
3	7.333457E-08	2.708036E-04	4.309972E-05	1.000000E+00	1.833364E-04	2.937706E-06	5.781818E-09
4	1.377464E-07	3.711420E-04	5.906908E-05	1.000000E+00	3.443659E-04	2.937706E-06	6.359158E-10
5	3.357349E-07	5.794264E-04	9.221857E-05	1.000000E+00	8.393373E-04	2.937706E-06	4.818367E-11
6	1.222358E-06	1.105603E-03	1.759622E-04	1.000000E+00	3.055894E-03	2.937706E-06	7.958079E-09
7	3.404017E+05	5.834396E+02	9.285729E+01	1.000000E+00	3.404017E+05	2.937706E-06	5.932718E-08

R I G I D - B O D Y E I G E N V A L U E S

MODE NUMBER	EIGENVALUE EXTRACTED	EIGENVALUE NORMALIZED	STRAIN ENERGY EXTRACTED	STRAIN ENERGY NORMALIZED
1	1.690572E-09	4.966402E-15	6.043619E-04	1.775437E-09
2	3.489383E-08	1.025078E-13	1.864200E-04	5.476472E-10
3	7.333457E-08	2.154354E-13	2.151477E-03	6.320406E-09
4	1.377464E-07	4.046583E-13	5.608327E-04	1.647562E-09
5	3.357349E-07	9.862904E-13	8.229355E-04	2.417542E-09
6	1.222358E-06	3.590927E-12	3.469505E-04	1.019239E-09

P E R C E N T M O D A L E F F E C T I V E M A S S

MODE NUMBER	T1	T2	T3	R1	R2	R3
1	100.0000	0.0000	0.0000	0.0000	11.8931	13.9888
2	0.0000	100.0000	0.0000	19.7640	0.0000	35.3757
3	0.0000	0.0000	100.0000	27.1951	41.3843	0.0000
4	0.0000	0.0000	0.0000	47.6326	0.0000	0.0000
5	0.0000	0.0000	0.0000	4.7319	46.7041	0.0000
6	0.0000	0.0000	0.0000	0.6764	0.0185	50.6355
7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
TOTAL	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

NESC Q#15

15. Holes for fasteners (I presume fasteners anyway) as small as 0.125" have be modeled in with refined meshes to get down to this size. But these round holes end up looking like small little hexagon areas in the mesh. I am not sure of the reason for having features of this size modeled into a dynamic model.

SNC Response

- These features are modeled to accommodate other components which are not in the primary load path. These components will be added as the system design/model is finalized. The coarse mesh around the mentioned areas is mainly to provide attachment points for the other hardware. There is not expected to be an stress issues in these regions.

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Other Items From Kenneth Hamm 07/21/10

- Delivered deck is Normal Modes only (SOL 103)
  - No loading included
  - No damping included
  - How were base loads input?
  - Would be good to see this part of the deck
- Constraint SPC 1-6 is included at large mass in modal run
- Have not had much time to do any further investigation
  - Would like to make changes to the mesh and correct errors and see what differences result in modes

SNC Response
- These additional requests can be provided as required.