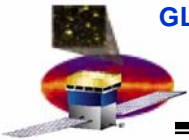


TKR Protoflight Dynamic Test Readiness Review

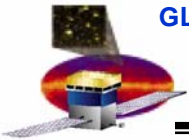
Mike Opie
Eric Roulo

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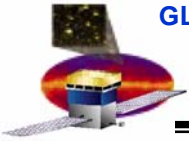
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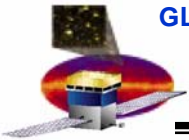
Introduction

- **Purpose**
 - Verify correct methodology and test input levels.
 - Verify that all the correct plans and procedures are up to date.
 - All parties concur on plans and schedules to be executed.
- **Schedule**
 - Full TRR on Monday, December 6, 2004.
 - Target start of test on Thursday, December 9, 2004.
- **Manpower Plans**
 - Test Engineer Michael Opie shall verify levels, review data, and declare load case completion and overall test success.
 - Test Support Engineer Eric Roulo shall aid in verifying levels and reviewing data.
 - Test Support Engineer Paul Baird shall aid in verifying levels and reviewing data.
 - Test Conductor Nicola Mazziotta shall verify test setup and execution conforms to all the applicable test plans and procedures.



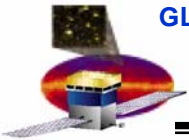
Changes to Test Sequence: Qual vs Proflight

- **Signature sweep rate changed from 2 oct/min to 4 oct/min.**
- **Signature sweep lower abort level changed from -2dB to -4dB.**
- **Signature sweep upper range changed from 1000 Hz to 2000 Hz.**
- **Sine Vibration levels changed to envelope the sine burst levels.**
- **Elimination of -9dB random run.**
- **Full level random duration of 60 seconds.**



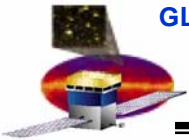
Z axis: Dynamic Test Sequence

Run #	Test Description	Frequency	Comments
1	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
2	Low Level Signature Sweep – RMS mode	Input: 0.15 g 5 – 2000 Hz	
3	¼ level Sinusoidal vibration	5 – 50 Hz	Verification Test
4	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
5	Sinusoidal vibration	5 – 50 Hz	Proto-flight level
6	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
7	Data Dump		
8	Random Vibration (-12 dB)	Input 20 – 2000 Hz	30 Seconds duration
9	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
10	Random Vibration (- 6 dB)	Input: 20 – 2000 Hz	30 Seconds duration
11	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
12	Random Vibration (- 3 dB)	Input: 20 – 2000 Hz	30 Seconds duration
13	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
14	Data Dump		
15	Random Vibration (Full level)	Input: 20 – 2000 Hz	60 sec duration
16	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
17	Low Level Signature Sweep – RMS mode	Input: 0.15 g 5 – 2000 Hz	



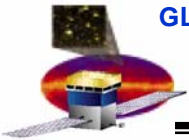
X axis: Dynamic Test Sequence

in #	Test Description	Frequency	Comments
1	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
2	Low Level Signature Sweep – RMS mode	Input: 0.15 g 5 – 2000 Hz	
3	¼ level Sinusoidal vibration	5 – 50 Hz	Verification Test
4	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
5	Sinusoidal vibration	5 – 50 Hz	Proto-flight level
6	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
7	Data Dump		
8	Random Vibration (-12 dB)	Input 20 – 2000 Hz	30 Seconds duration
9	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
10	Random Vibration (- 6 dB)	Input: 20 – 2000 Hz	30 Seconds duration
11	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
12	Random Vibration (- 3 dB)	Input: 20 – 2000 Hz	30 Seconds duration
13	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
14	Data Dump		
15	Random Vibration (Full level)	Input: 20 – 2000 Hz	60 sec duration
16	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
17	Low Level Signature Sweep – RMS mode	Input: 0.15 g 5 – 2000 Hz	



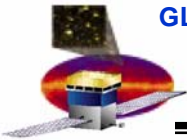
Y axis: Dynamic Test Sequence

Run #	Test Description	Frequency	Comments
1	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
2	Low Level Signature Sweep – RMS mode	Input: 0.15 g 5 – 2000 Hz	
3	¼ level Sinusoidal vibration	5 – 50 Hz	Verification Test
4	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
5	Sinusoidal vibration	5 – 50 Hz	Proto-flight level
6	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
7	Data Dump		
8	Random Vibration (-12 dB)	Input 20 – 2000 Hz	30 Seconds duration
9	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
10	Random Vibration (- 6 dB)	Input: 20 – 2000 Hz	30 Seconds duration
11	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
12	Random Vibration (- 3 dB)	Input: 20 – 2000 Hz	30 Seconds duration
13	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
14	Data Dump		
15	Random Vibration (Full level)	Input: 20 – 2000 Hz	60 sec duration
16	Low Level Signature Sweep	Input: 0.15 g 5 – 2000 Hz	
17	Low Level Signature Sweep – RMS mode	Input: 0.15 g 5 – 2000 Hz	



Low Level Signature Sweep Levels

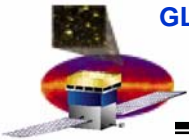
Frequency range	5 ÷ 2000 Hz
Sweep rate	4 oct/min
Target Amplitude	0.15 g _{0-pk}
Alarm Levels	± 1 dB
Upper Abort Level in Input	0.25 g _{0-pk} (+4 dB)
Lower Abort Level in Input	- 4 dB



Sinusoidal Vibration Protoflight Levels

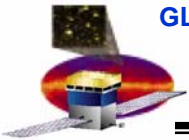
LAI TKR Acceptance Test Levels			
Axis	Freq. (Hz)	Test levels	Sweep Rate [Oct/min]
Thrust (Z)	5 - 20	1.92 g	4
	25 - 35	4.72 g	1.5
	40 - 50	1.6 g	4
Lateral (X&Y)	5 - 15	2.56 g	4
	15 - 25	1.12 g	4
	25 - 35	1.12 g	1.5
	35 - 40	1.12 g	4
	40 - 50	1.84 g	4
LAI TKR Protoflight Test Levels			
Axis	Freq. (Hz)	Test levels	Sweep Rate [Oct/min]
Thrust (Z)	5 - 20	2.4 g	4
	25 - 35	5.9 g	1.5
	40 - 50	2 g	4
Lateral (X&Y)	5 - 15	3.2 g	4
	15 - 25	1.4 g	4
	25 - 35	1.4 g	1.5
	35 - 40	1.4 g	4
	40 - 50	2.3 g	4
LAI TKR Prototype/Qual Test Levels			
Axis	Freq. (Hz)	Test levels	Sweep Rate [Oct/min]
Thrust (Z)	5 - 20	2.4 g	2
	25 - 35	5.9 g	0.75
	40 - 50	2 g	2
Lateral (X&Y)	5 - 15	3.2 g	2
	15 - 25	1.4 g	2
	25 - 35	1.4 g	0.75
	35 - 40	1.4 g	2
	40 - 50	2.3 g	2

- Notes:
- (1) Quarter and Half Level Tests will be performed before testing at full levels
 - (2) Input levels should be notched to that interface forces or response accelerations do not exceed flight loads predictions
 - (3) Linear acceleration transition from 2.4g's at 20 Hz to 5.9g's at 25 Hz
 - (4) Linear acceleration transition from 5.9g's at 35 Hz to 2.0g's at 40 Hz



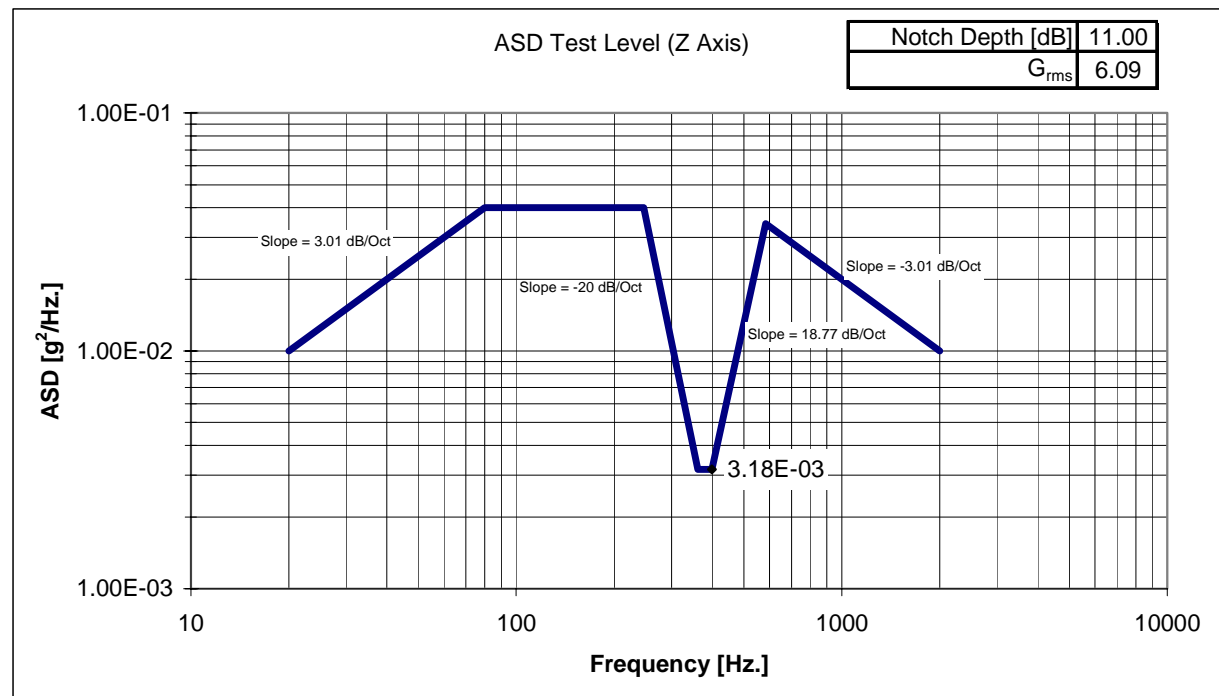
Sinusoidal Vibration Protoflight Levels

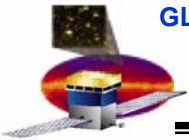
Sine Vibration Proto-flight Test levels			
Axis	Frequency (Hz)	Acceleration Level (g)	Sweep Rate (Oct/Min)
1st run Lateral axis (X & Y)	5 – 8.27	40mm Double Amplitude Displacement	4
	8.27 – 15	5.5	4
	16 – 39	1.4	4
	40 - 50	2.3	4
1st run Thrust axis (Z)	5 – 5.5	40mm Double Amplitude Displacement	4
	5.5 – 20	2.4	4
	25 – 35	8.5	4
	40 – 50	2	4
<i>Notes:</i> <ol style="list-style-type: none">1. ¼ level tests will be performed before testing at full levels.2. The test levels at low frequency are set according to the shaker limitations on maximum displacement3. Input levels should notched to that interface forces or response accelerations do not exceeds flight loads predictions4. Linear acceleration transition whenever the acceleration levels change.5. The abort levels are set at ± 2 dB.			



ASD Test Level for Z Axis Random Vibration

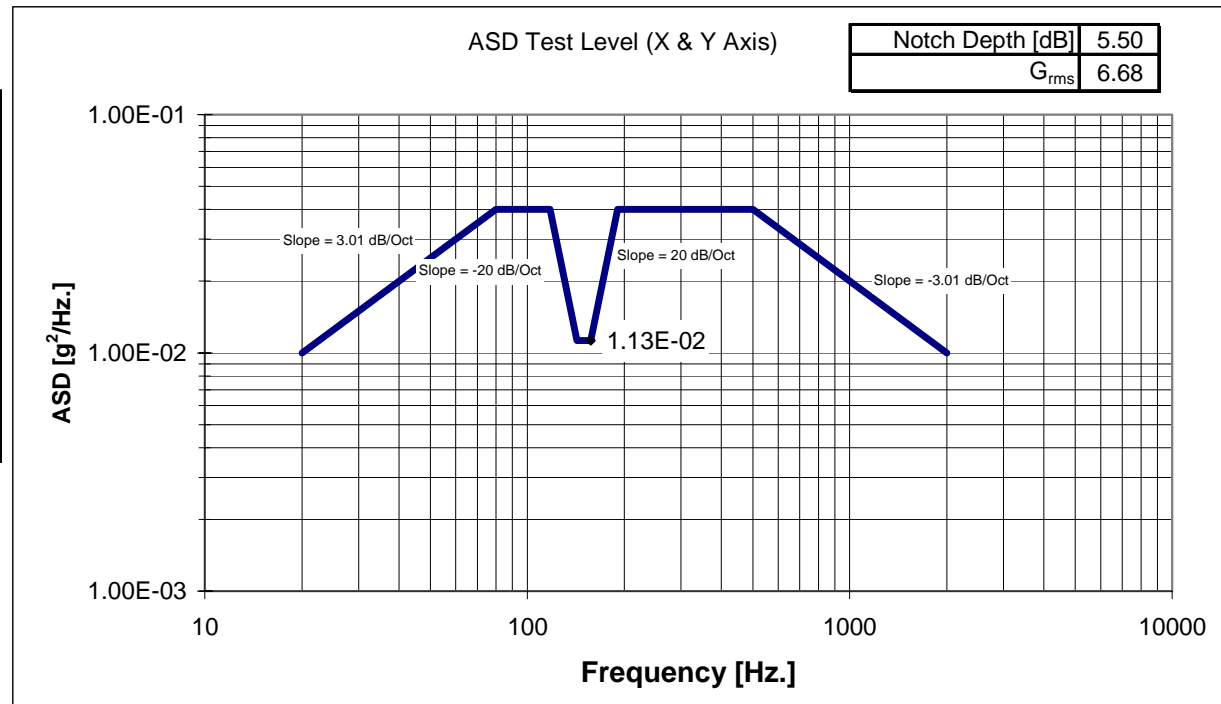
ASD Test Levels (Z Axis)	
Frequency [Hz.]	ASD Test Level [$g^2/Hz.$]
20	1.00E-02
80	4.00E-02
247	4.00E-02
361	3.18E-03
399	3.18E-03
584	3.42E-02
584	3.42E-02
2000	1.00E-02
Overall G_{rms}	6.09
Test Duration = 120 sec/axis	

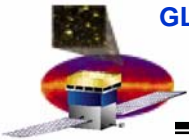




ASD Test Level for X and Y Axes Random Vibration

ASD Test Levels (X & Y Axis)	
Frequency [Hz.]	ASD Test Level [g ² /Hz.]
20	1.00E-02
80	4.00E-02
118	4.00E-02
143	1.13E-02
158	1.13E-02
191	4.00E-02
500	4.00E-02
2000	1.00E-02
Overall G_{rms}	6.68
Test Duration = 120 sec/axis	





Static Equivalent Accelerations and Test Levels for Sine Burst

- Protoflight level is the same as Qual.
- Sine Burst is not tested but the levels are enveloped by the Sine Sweep.

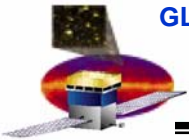
TKR	Design (*)		Accept (+)	Qual (+)	Unit
Launch Event	Lift-Off/ Airloads	MECO			
Lateral (X)	+/-1.71		+/- 4.4	+/- 5.5	g
Lateral (Y)	+/-2.49		+/- 4.4	+/- 5.5	g
Lateral (%)		+/-0.2			g
Axial (Z)	+4.74/-1.91	+6.8	+/- 6.8	+/- 8.5	g
Rot X	+/-54.17	0	0	0	rad/sec ²
Rot Y	+/-15.27	0	0	0	rad/sec ²
Rot Z	+/-9.06	0	0	0	rad/sec ²
Source	(9)	(3)	(9)	(10)	

Comments:

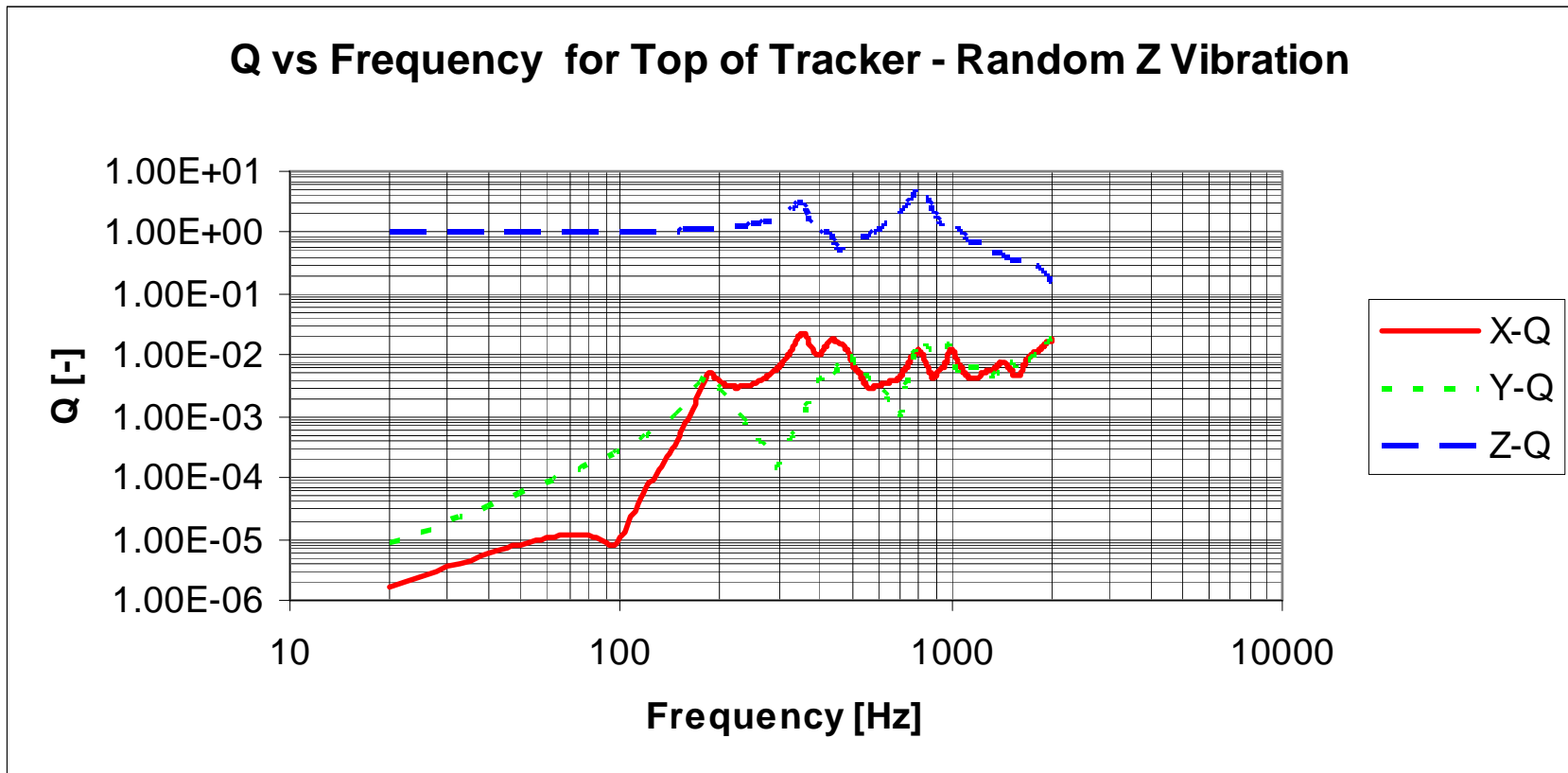
(*) For analysis, apply design accel's simultaneously

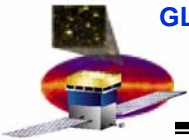
(+) For test, apply test accel's along one axis at a time

(%) Apply load along +/- X and Y axes and each 45 degree vector

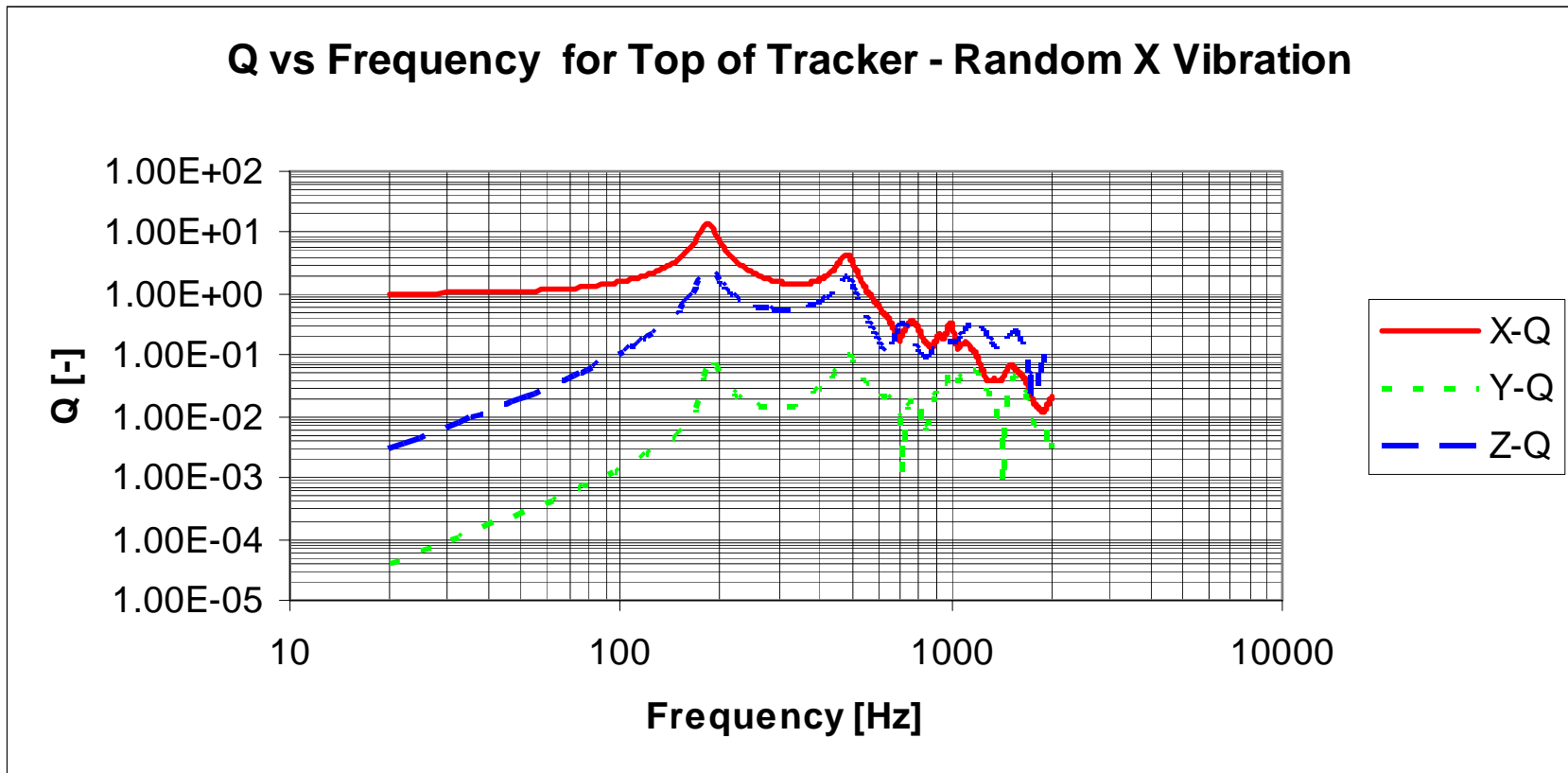


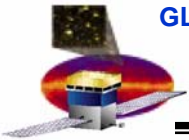
Response Predictions – Random Vibration



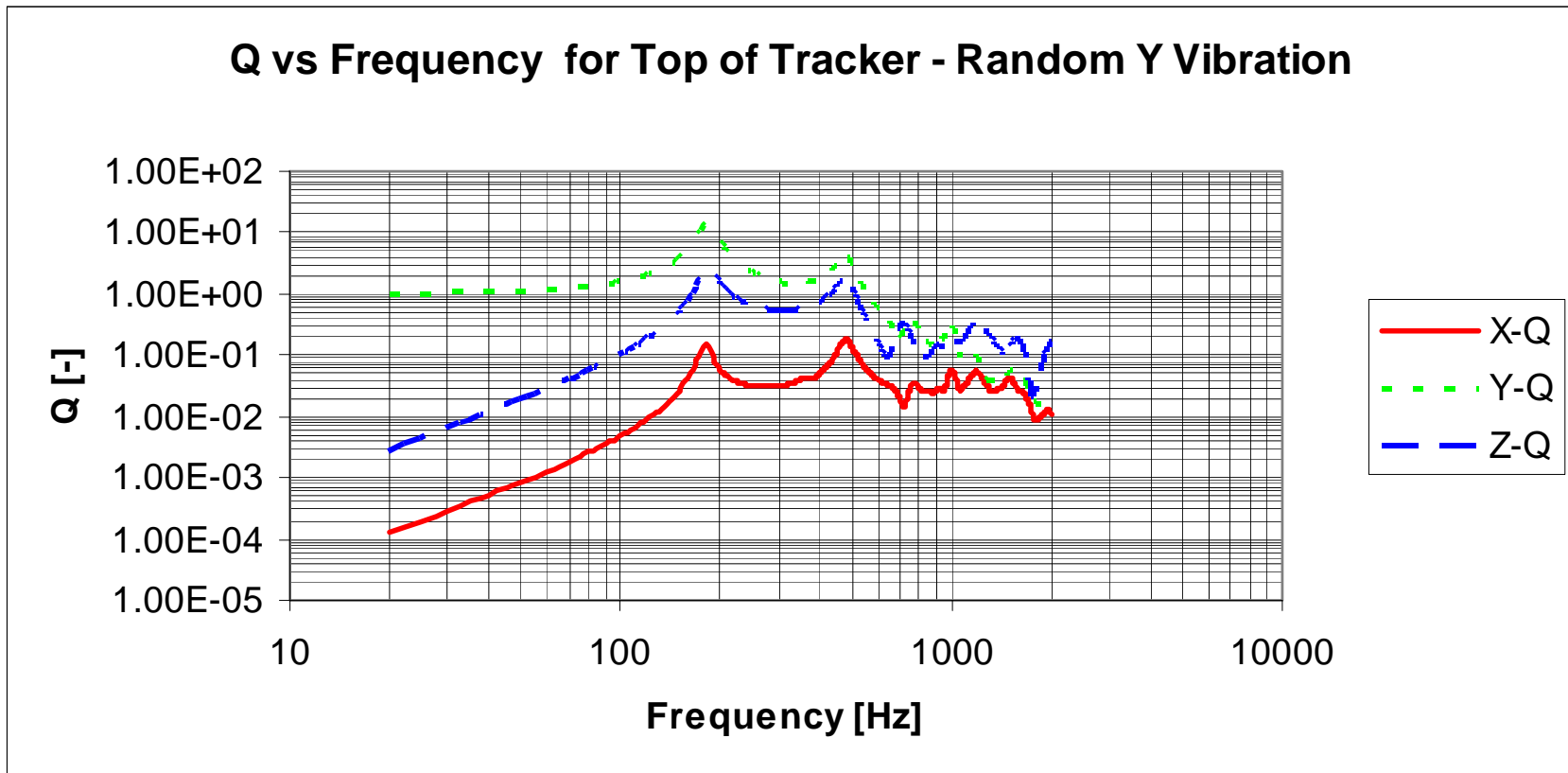


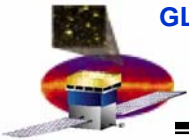
Response Predictions – Random Vibration





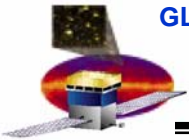
Response Predictions – Random Vibration





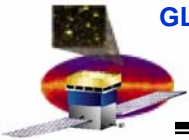
Z Random Vibration Flexure Forces

Flexure Forces for Random Z-Shake						Force from	Margin on
	EID	Direction	RMS Force per Element [N]	Total RMS Force [N]	3-H Peak [N]	Static Load Test	Static Test Load
Corner	324001	X - strong	0.8	2.1	6.3	878.0	137.76
	324002		0.7				
	324003		0.6				
+x Midside	324050	X - strong	0.9	2.8	8.3	2767.0	333.65
	324051		0.9				
	324052		0.9				
+y Midside	324055	X - strong	0.8	2.4	7.2	2767.0	385.39
	324056		0.8				
	324057		0.8				
Corner	324001	Y - weak	0.0	0.1	0.3	3.0	9.01
	324002		0.0				
	324003		0.0				
+x Midside	324050	Y - weak	0.8	2.3	6.8	27.0	2.96
	324051		0.8				
	324052		0.8				
+y Midside	324055	Y - weak	1.0	2.9	8.6	27.0	2.13
	324056		1.0				
	324057		1.0				
Corner	324001	Z - axial	127.8	389.9	1169.7	3949.0	2.38
	324002		130.0				
	324003		132.2				
+x Midside	324050	Z - axial	57.8	126.3	379.0	1206.0	2.18
	324051		36.7				
	324052		31.8				
+y Midside	324055	Z - axial	76.2	149.4	448.1	1206.0	1.69
	324056		46.1				
	324057		27.1				



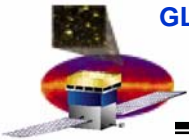
X Random Vibration Flexure Forces

Flexure Forces for Random X-Shake						Force from	Margin on
	EID	Direction	RMS Force per Element [N]	Total RMS Force [N]	3-H Peak [N]	Static Load Test	Static Test Load
Corner	324001	X - strong	80.0	242.9	728.7	878.0	0.20
	324002		81.0				
	324003		81.9				
+x Midside	324050	X - strong	2.3	6.8	20.5	2767.0	134.19
	324051		2.3				
	324052		2.3				
+y Midside	324055	X - strong	221.6	654.3	1962.8	2767.0	0.41
	324056		218.1				
	324057		214.6				
Corner	324001	Y - weak	0.3	0.8	2.3	3.0	0.30
	324002		0.3				
	324003		0.3				
+x Midside	324050	Y - weak	1.0	2.9	8.7	27.0	2.12
	324051		1.0				
	324052		1.0				
+y Midside	324055	Y - weak	0.0	0.0	0.1	27.0	516.70
	324056		0.0				
	324057		0.0				
Corner	324001	Z - axial	314.3	972.4	2917.2	3949.0	0.35
	324002		324.1				
	324003		334.0				
+x Midside	324050	Z - axial	127.1	233.3	699.9	1206.0	0.72
	324051		77.7				
	324052		28.5				
+y Midside	324055	Z - axial	0.9	1.7	5.0	1206.0	242.32
	324056		0.5				
	324057		0.3				



Y Random Vibration Flexure Forces

Flexure Forces for Random Y-Shake						Force from	Margin on
	EID	Direction	RMS Force per Element [N]	Total RMS Force [N]	3-H Peak [N]	Static Load Test	Static Test Load
Corner	324001	X - strong	81.2	245.0	735.1	878.0	0.19
	324002		81.7				
	324003		82.1				
+x Midside	324050	X - strong	222.8	663.6	1990.8	2767.0	0.39
	324051		221.2				
	324052		219.6				
+y Midside	324055	X - strong	2.4	7.1	21.2	2767.0	129.75
	324056		2.4				
	324057		2.3				
Corner	324001	Y - weak	0.3	0.8	2.3	3.0	0.30
	324002		0.3				
	324003		0.3				
+x Midside	324050	Y - weak	0.0	0.0	0.1	27.0	506.84
	324051		0.0				
	324052		0.0				
+y Midside	324055	Y - weak	1.1	3.2	9.6	27.0	1.80
	324056		1.1				
	324057		1.1				
Corner	324001	Z - axial	312.6	963.9	2891.7	3949.0	0.37
	324002		321.3				
	324003		330.0				
+x Midside	324050	Z - axial	0.5	1.0	2.9	1206.0	411.85
	324051		0.3				
	324052		0.3				
+y Midside	324055	Z - axial	157.5	283.5	850.4	1206.0	0.42
	324056		94.4				
	324057		31.6				



Run-Time Data Analysis and Pass/Fail Criteria

- Damping will be investigated after low level signature sweeps to verify that the analysis assumptions are valid.
- Fundamental modes will be identified and random input notch adjusted accordingly.
- Pre- and Post-Signature sweep overlays will be checked for frequency and amplitude shifts.
- Response Grms will be compared to predictions to verify that demonstrated static loads are not exceeded during random vibration runs.
- A test run will be considered to have passed when:
 - Linearity between increases in input level has been demonstrated.
 - All data channels appear to be reading accurately.
 - Maximum responses are checked against predictions.
 - No audible anomalies, no visual anomalies.
- Progressive downward shifts in frequency and/or amplitude indicate a potential problem. All appreciable shifts must be justified before the test is allowed to proceed to a higher input level. Diagnostic runs should be performed to try to isolate the anomaly.