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The Aerospace Corporation
El Segundo, CA

Random Vibration Test of Mars Exploration Rover Spacecraft

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Random vibration tests of the Mars Exploration Rover (MER) Flight #1 Spacecraft were conducted at JPL in October 2002. Tests were conducted in each of three mutually perpendicular axes, which corresponded to the spacecraft coordinate system axes, starting with the vertical Z axis and continuing with the lateral X and then the lateral Y axes.

The spacecraft survived a vigorous 3-axis vibration test with no apparent damage. Overtesting was alleviated by a combination of acceleration input tailoring and in-axis force limiting. There was no response limiting. A limit was put on three responses on the Rover base petal as a back-up to the force limiting, but that limit was never exceeded. The responses at some interfaces and assemblies exceeded the input in some prior and subsequent tests. The fundamental frequencies in all three axes were about 20% higher than those predicted by the finite element model (FEM) used in the coupled loads analysis (CLA). Testing in the last of the three axes, the lateral Y axis, was curtailed after the -6 dB run, because it was decided that the marginal benefit from a full-level run in the third axis was not sufficient to justify the risk and wear-and-tear to the flight hardware.

The primary objective of the spacecraft random vibration test was to identify any hardware problems, which might compromise the mission. The test served as a workmanship test of the assembled spacecraft, and a qualification test, of everything but the primary structure, for the launch dynamics environment. A secondary objective was to provide additional validation of the finite element model (FEM) used in the coupled loads analysis (CLA).

The test objectives, configuration, and requirements are briefly described in this presentation, and a representative sample of the measured data is presented.

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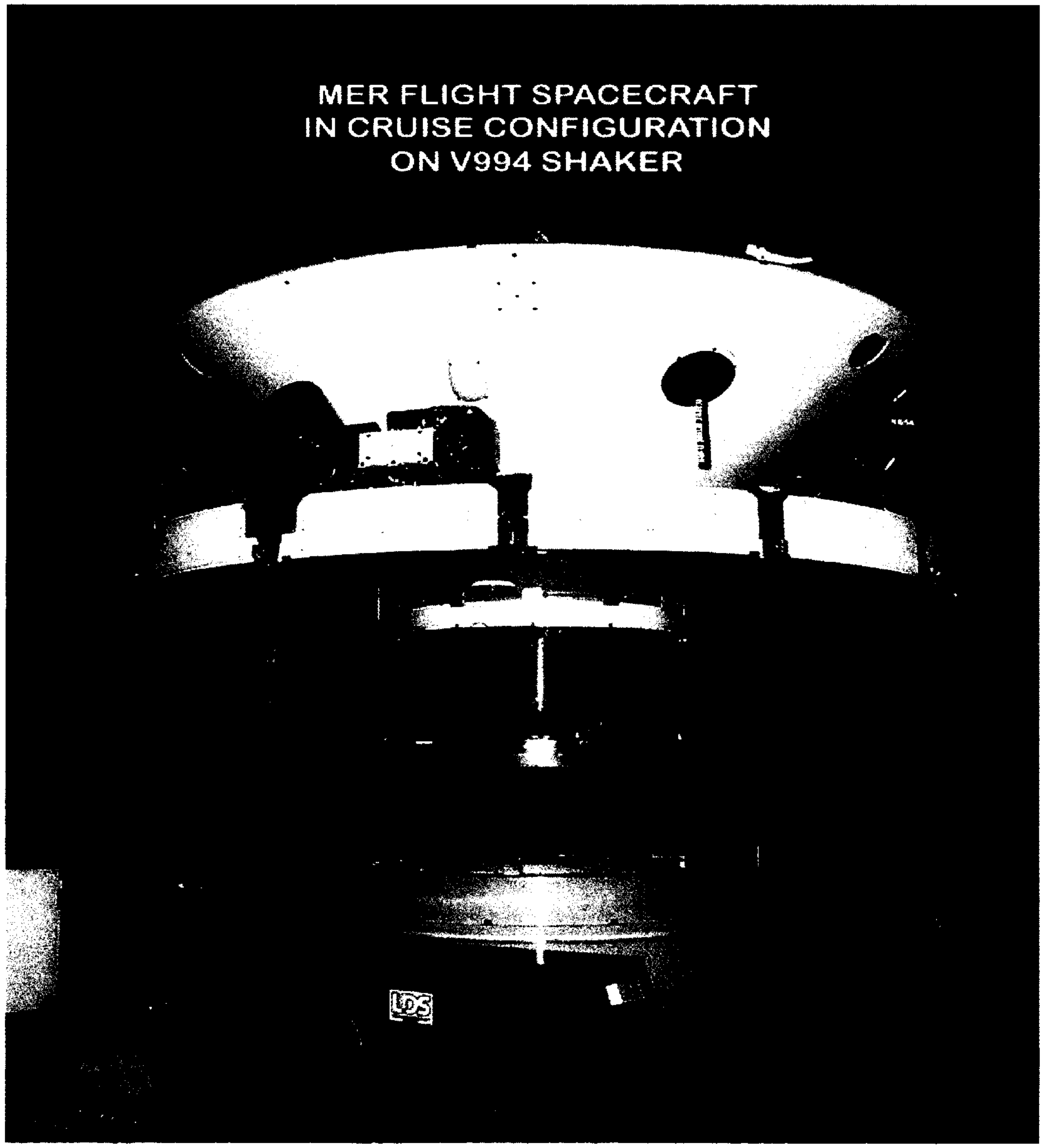
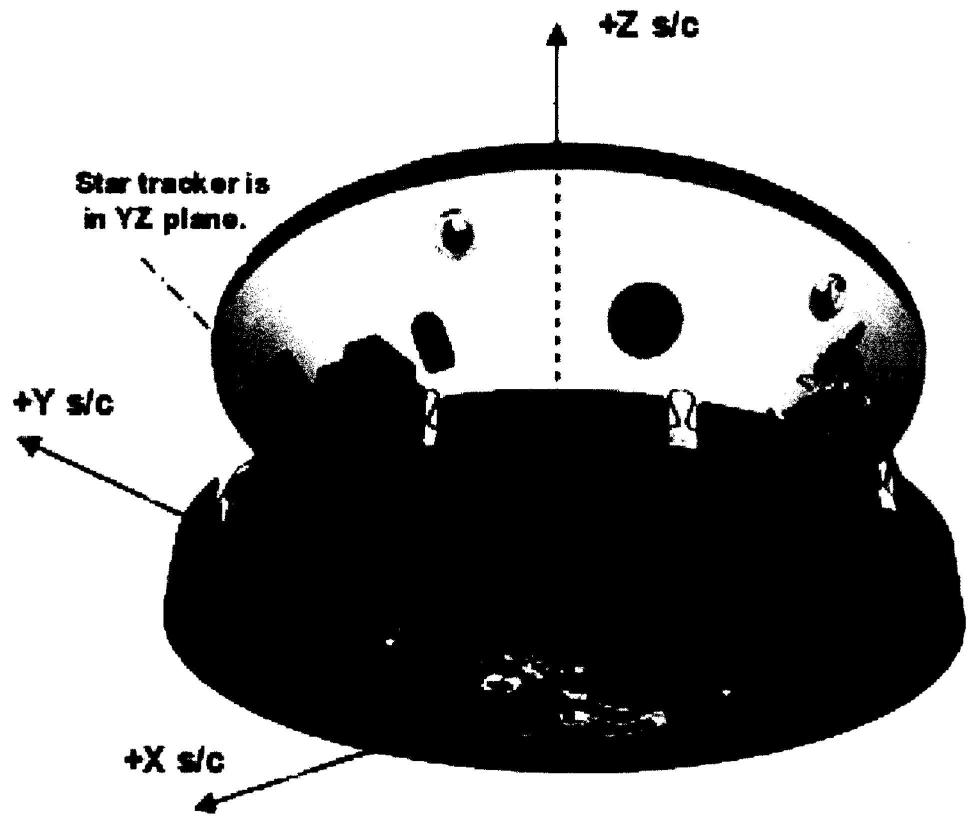
Summary

- Vibration test of MER flight #1 Spacecraft in October '02
- Launch Two Spacecraft June & July '03; Arrive at Mars Jan. '04
- Primary test objective to identify any hardware problems
  - Workmanship test of the assembled spacecraft,
  - Qualification test, of everything but the primary structure, for the launch dynamics environment.
- Vigorous, three-axis vibration test with no apparent damage
- Overtesting prevented with input tailoring and force limiting
- 137 acceleration responses measured and analyzed. No accelerometer limiting, but one force back-up accelerometer.
- Some responses exceeded input in sub-system tests
- Secondary objective to provide additional validation of the FEM addressed with quasi-fixed base and base-drive modal tests

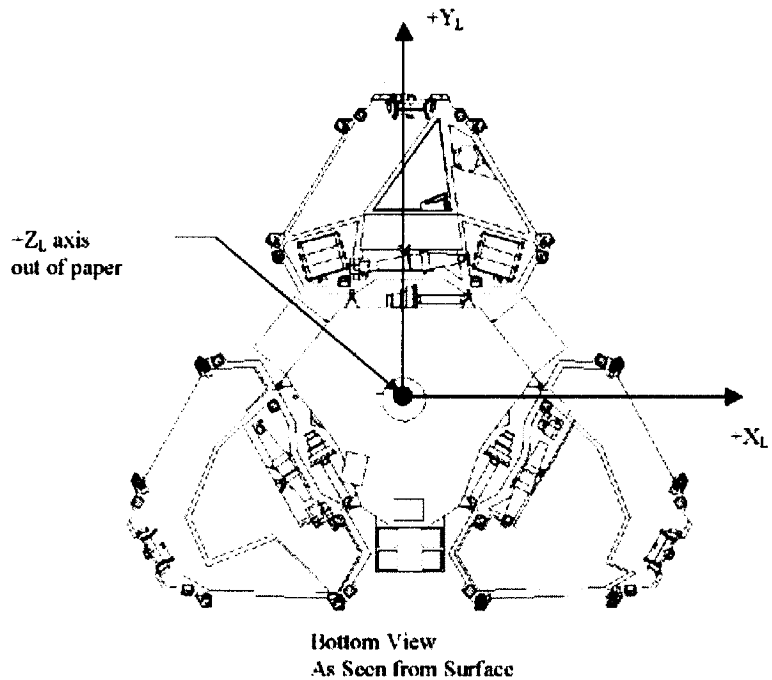
Random Vibration Test of Mars Exploration Rover Spacecraft



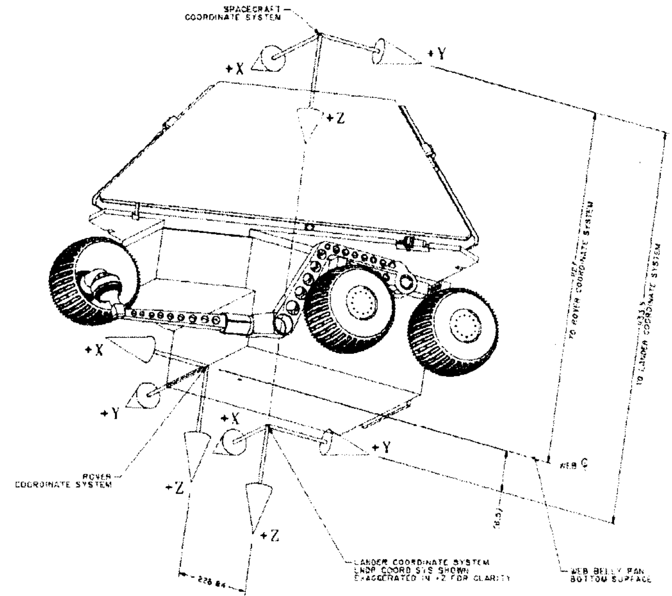


Test Axes Corresponded to the Spacecraft Coordinate System Axes

Random Vibration Test of Mars Exploration Rover Spacecraft



Lander Coordinate System



Spacecraft, Lander, and Rover
Coordinate Systems

Frequency (Hz)	Power Spectral Density
10 to 20 20 to 200 Overall	+6 dB/octave 0.01 g^2/Hz 1.4 grms
Duration: thirty seconds for low-level and one minute for full level test	

Vertical (Z-axis) Random Vibration Test Acceleration Input Levels

Frequency (Hz)	Power Spectral Density
10 to 30 30 to 200 Overall	+12 dB/octave 0.01 g^2/Hz 1.3 grms
Duration: thirty seconds for low-level and one minute for full level test	

Lateral (X and Y axes) Random Vibration Test Acceleration Input Levels

Frequency (Hz)	Force Spectral Density
10 to f_0	$1.1 * 10^6$ [N^2/Hz] $5.4 * 10^4$ [lb^2/Hz]
f_0 to 200	-3 dB/octave, X and Y axes -6 dB/octave, Z axis

MER1 Spacecraft Random Vibration Test Force Limits

(Derived with semi-empirical method with C = 1, Force Limited Vibration Testing, NASA Handbook HDBK-7004B, September 6, 2002.)

Frequency (Hz)	Power Spectral Density
5-200	0.00005 g^2/Hz

Wideband: 0.1 grms, Duration: 4 minutes

Low-Level Random Survey Levels

Sequence of Test Runs

- **Low-level random modal survey**
- **-18 dB random test with force limiting**
- **-12 dB random test with force limiting**
- **-6 dB random test with force limiting**
- **Full-level random test with force limiting**
- **Low-level random modal survey**

NASA

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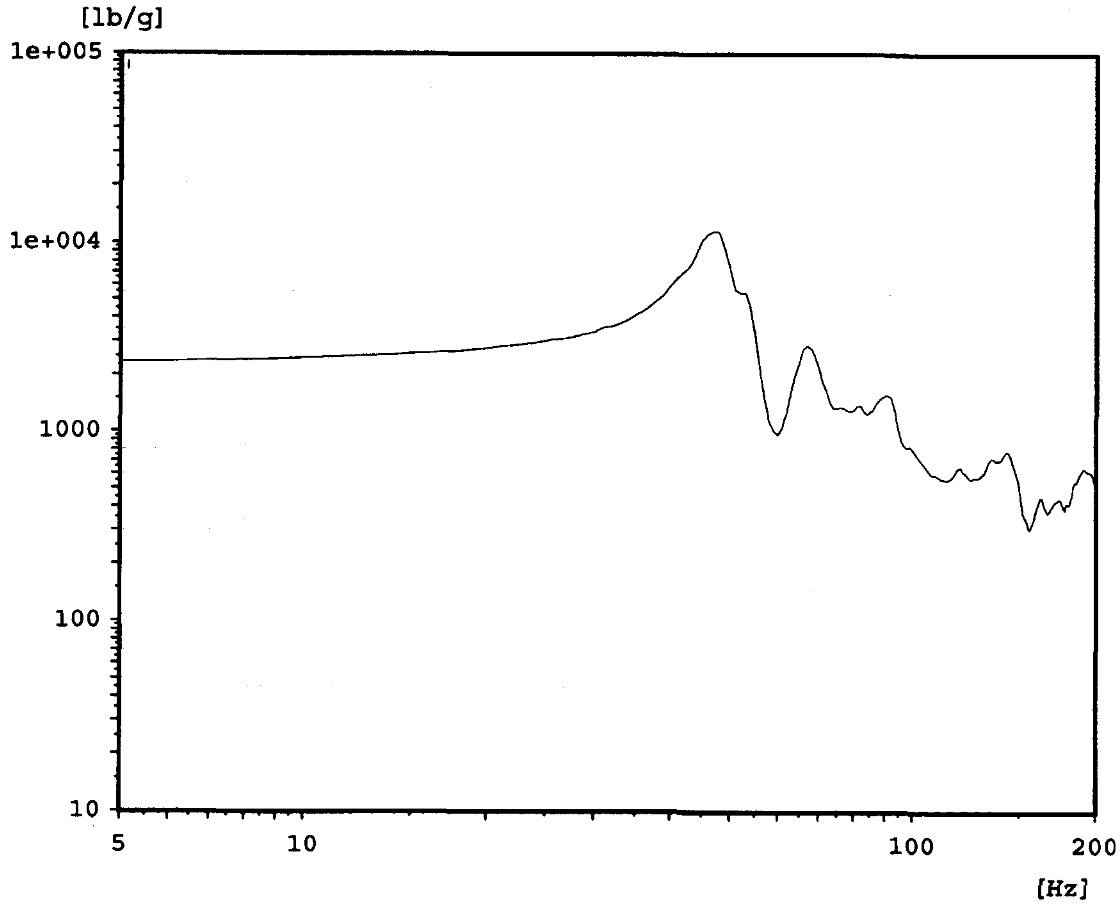
Random Vibration Test of Mars Exploration Rover Spacecraft

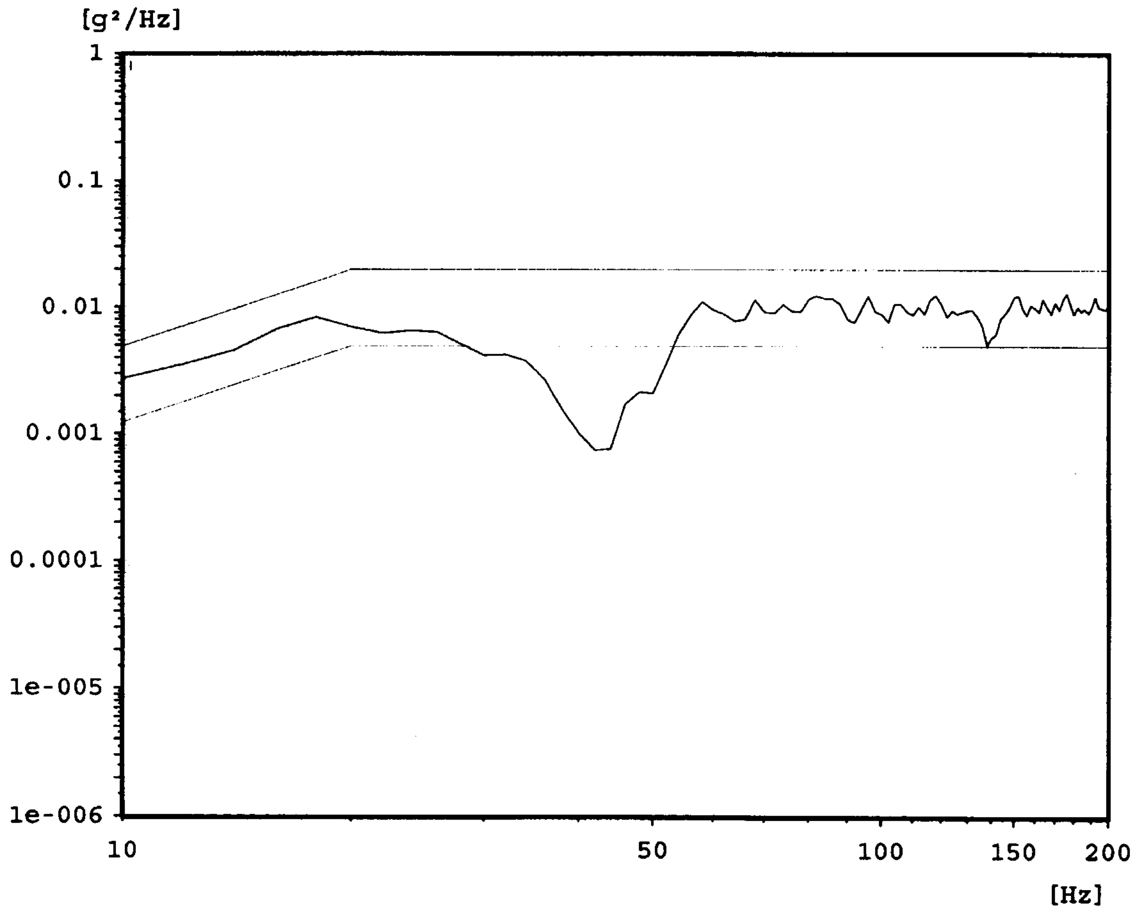
Peak Responses in High-Level Random Vibration Tests

	FEM wt = 959 kg, test wt = 986 kg				Darlene Lee (Section 352)							
	units are lbs, g's											
	note rover items changed to rover c.s.				X-Dir		Y-Dir		Z-Dir			Maximum
Chan no.	**Item**	**Direction**	**Des Ld**	**CLA**	**Run 17** 0dB		**Run 23** -6 dB		**Run 7** 0 dB			
1	Control 1				3.62		1.77		3.72			3.72
2	Control 2				3.67		1.79		3.77			3.77
3	Current											
4	Voltage											
5	Force 3	z	17912	17864					5454			5454
6	Force 1	x	12744	4879	3576		262		141			3576
7	Force 2	y	12744	4829	564		1780		193			1780
8	Moment	Moment	408373	220836	105258		56352					105258
9	Monitor 1	x		2.1	3.77		1.85		0.42			3.77
10	Monitor 2	y		2.1	0.12		0.05		0.30			0.30
11	Monitor 3	z		7.6	0.22		0.10		3.86			3.86
12	-x Solar Array	9n	33.5	33.5	3.7		4.3		13.9			13.9
13	-x Solar Array	9t	33.5	33.5	6.4		0.9		3.5			6.4
14	+y Solar Array	10n	33.5	33.5	9.5		2.6		8.9			9.5
15	+y Solar Array	10t	33.5	33.5	2.3		2.2		9.0			9.0
16	-y Solar Array	11n	33.5	33.5	8.2		2.7		13.2			13.2
17	-y Solar Array	11v	33.5	33.5	4.4		1.3		6.8			6.8
18	IDD MM, cantilever tip	14x	42	13.6	2.4		2.1		4.6			4.6
19	"	14y	42	12.1	1.8		0.9		1.8			1.8
20	"	14z	42	10.7	1.4		1.2		5.7			5.7
21	Rover Tie Down +x, -y	17x	33	3.5	0.5		0.7		0.8			0.8
22	"	17y	33	3.4	1.1		0.2		0.4			1.1
23	"	17z	33	7.7	1.3		0.6		4.3			4.3
24	Rover Tie Down -x, -y	18y	33	3.5	1.2		0.3		0.6			1.2
25	"	18v	33	3.4	1.4		1.1		3.6			3.6
26	Rover Tie Down -x, +y	19v	33	7.7	1.1		1.1		3.8			3.8
27	REM -X/+Y Corner	126286X+	35.4	7.5	1.6		DEAD		5.0			5.0
28	REM -X/+Y Corner	126286Z-	35.4	4.5	1.8		1.1		3.5			3.5
29	REM +X/-Y Corner	126287Y-	35.4	7.7	1.5		0.6		1.3			1.5
30	Base Petal, -Y Center	81X	33	3.5	0.4		0.7		0.9			0.9
31	"	81Y	33	3.4	1.4		0.2		0.3			1.4
32	"	81Z	33	7.7	0.5		0.6		3.9			3.9

Ratio of Base Reaction Force to Input Acceleration (Transfer Function) in Low-Level Z-axis Vertical Random Vibration Test

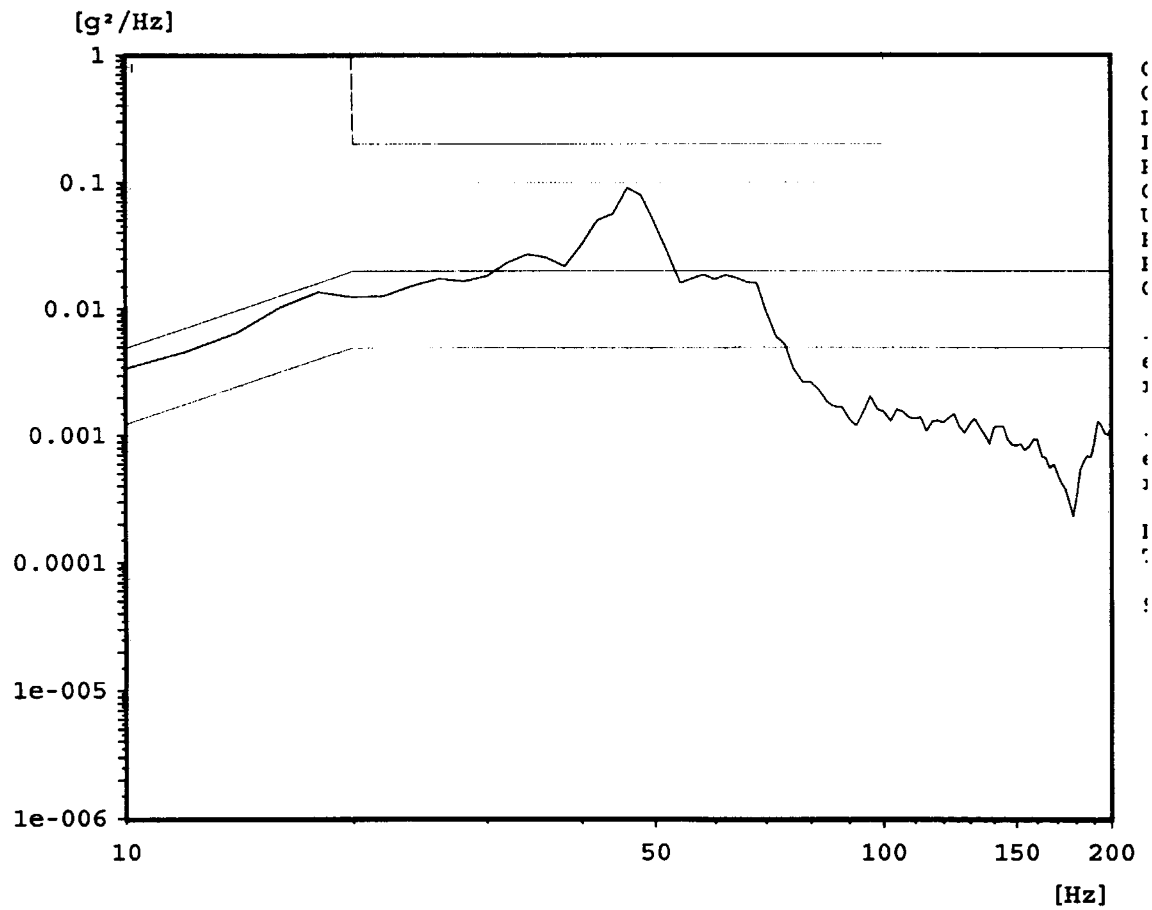


Composite Control Acceleration In Full-Level (0 dB) Z-Axis Vertical Random Vibration Test



Random Vibration Test of Mars Exploration Rover Spacecraft

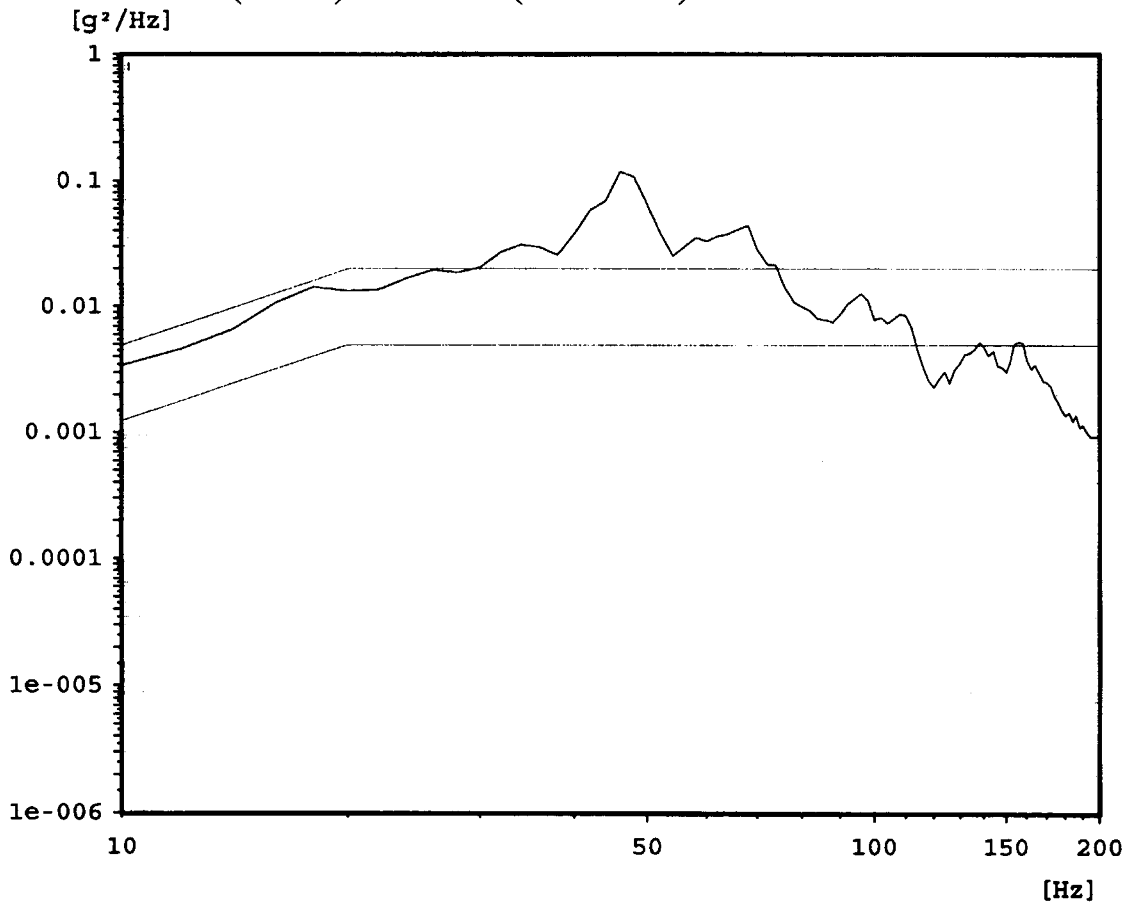
In-Axis Acceleration Response of the Lander Base Petal in Full-Level (0 dB) Z-Axis Vertical Random Vibration Test



Note: In the 30 to 50 Hz frequency range, the base-petal response in the spacecraft test exceeds the 0.02 G^2/Hz input to the base petal in the Flight #2 Rover Base-Petal random vibration test, which was conducted subsequently

Random Vibration Test of Mars Exploration Rover Spacecraft

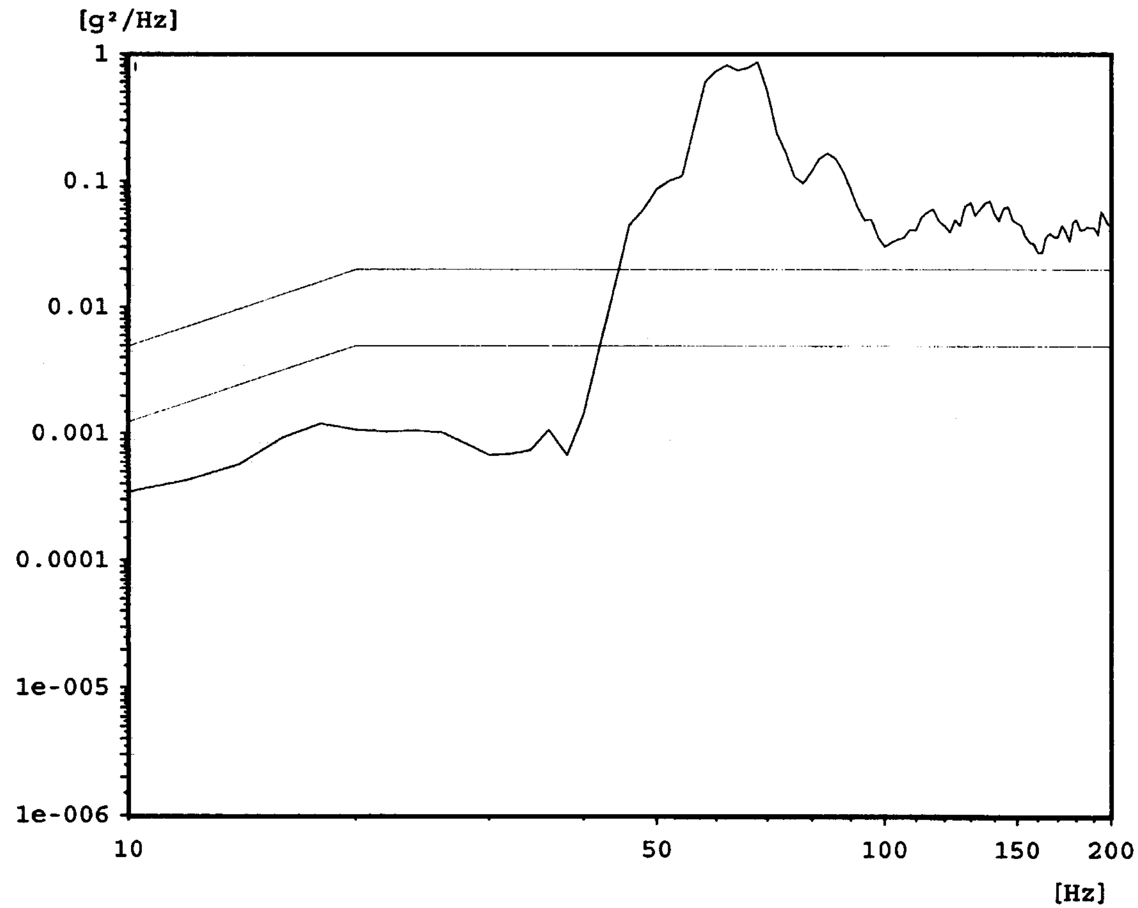
In-Axis Acceleration Response of Rover Electronic Module (REM) in Full-Level (0 dB) Z-Axis (Vertical) Random Vibration Test



The maximum spectral density response of the REM in the Spacecraft vibration test was approximately 0.1 G^2/Hz, which corresponds to the maximum input in the Z-axis specification for the MER assembly level REM vibration tests.

Random Vibration Test of Mars Exploration Rover Spacecraft

Normal Acceleration Response of the Rover -Y Solar Array in Full-Level (0 dB) Z-Axis (Vertical) Random Vibration Test



The maximum spectral density response of the solar array in the Spacecraft vibration test was approximately 1 G^2/Hz, and the maximum response of the solar array in the acoustic test of the Flight #1 Spacecraft was only 0.1 G^2/Hz.

Random Vibration Test of Mars Exploration Rover Spacecraft

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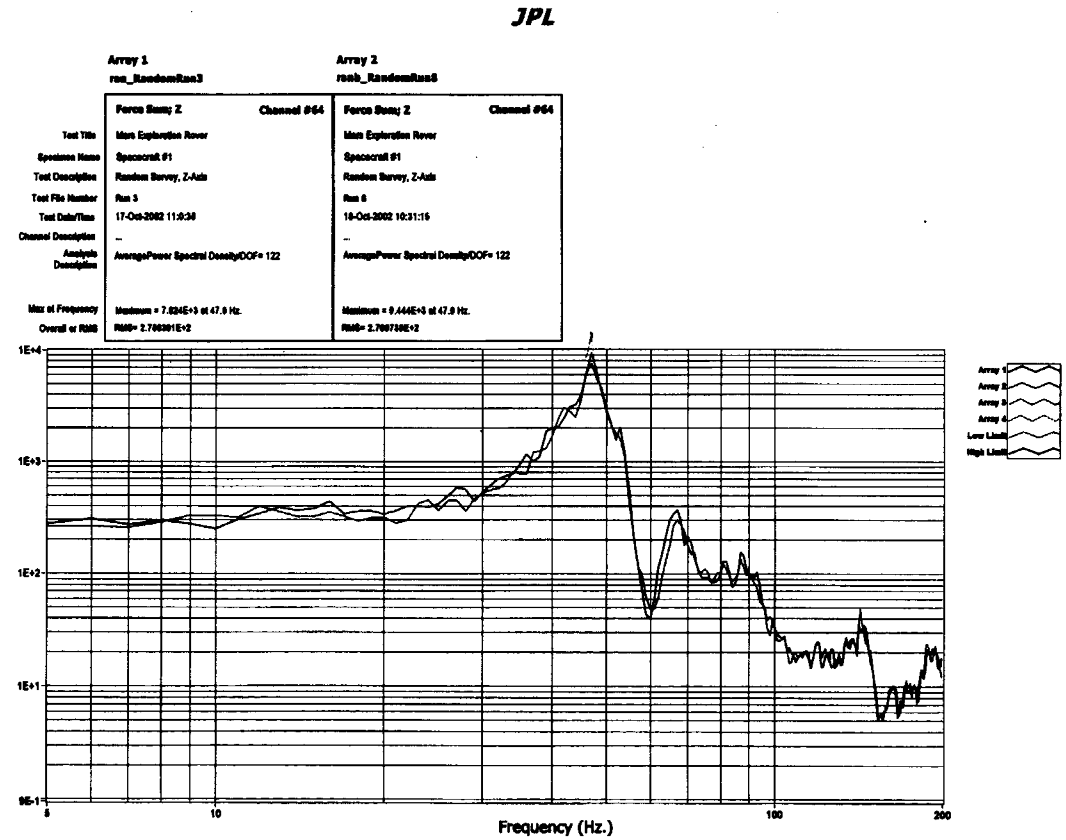
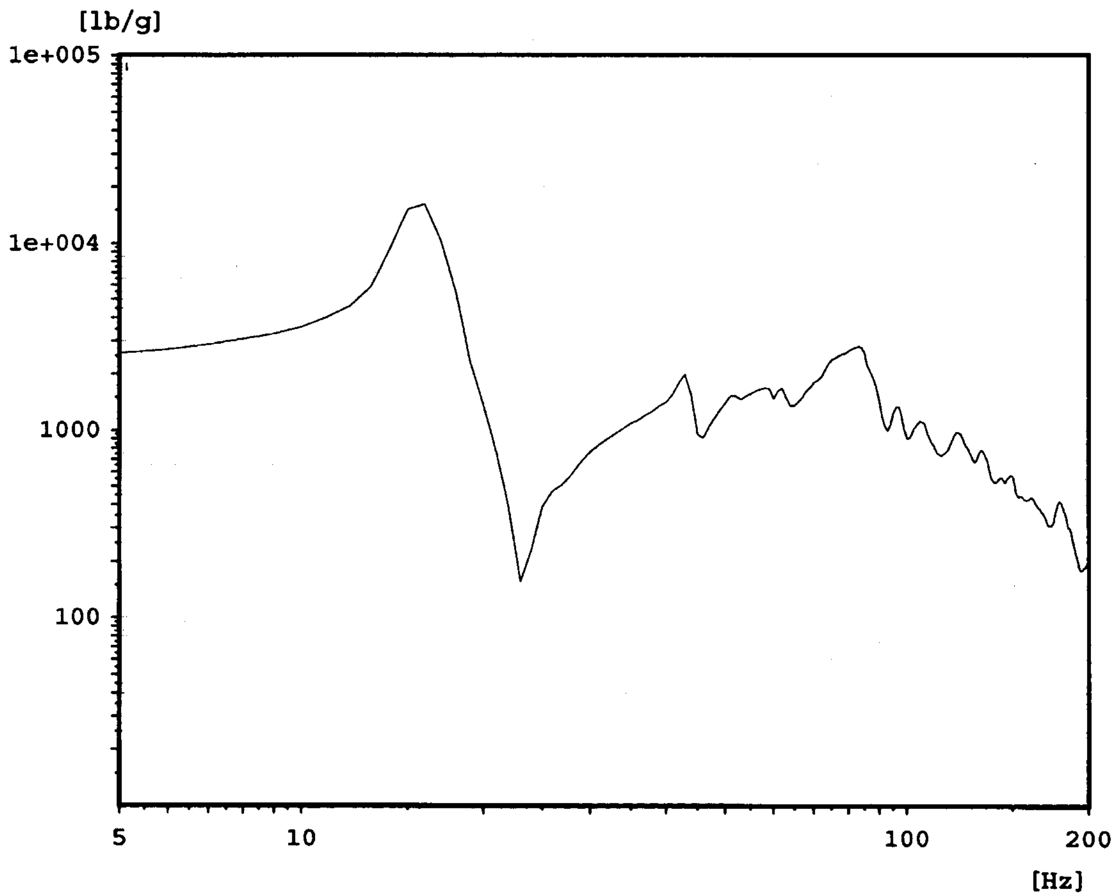
Comparison of the In-Axis Force Measurements in the Pretest and Post-Test Z-Axis Low-Level Random Surveys

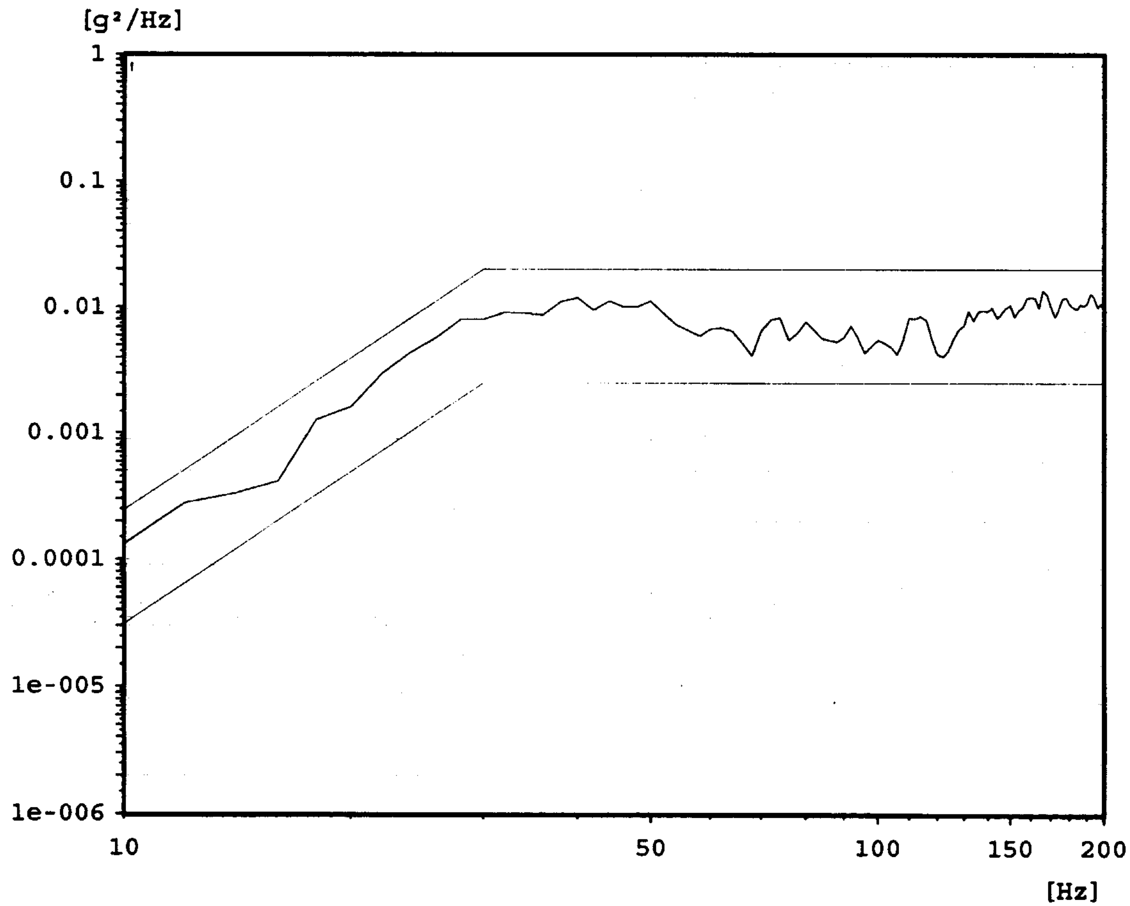


Random Vibration Test of Mars Exploration Rover Spacecraft

Ratio of Base Reaction Force to Acceleration Input (Transfer Function) in Low-Level X-Axis (Lateral) Random Vibration Test

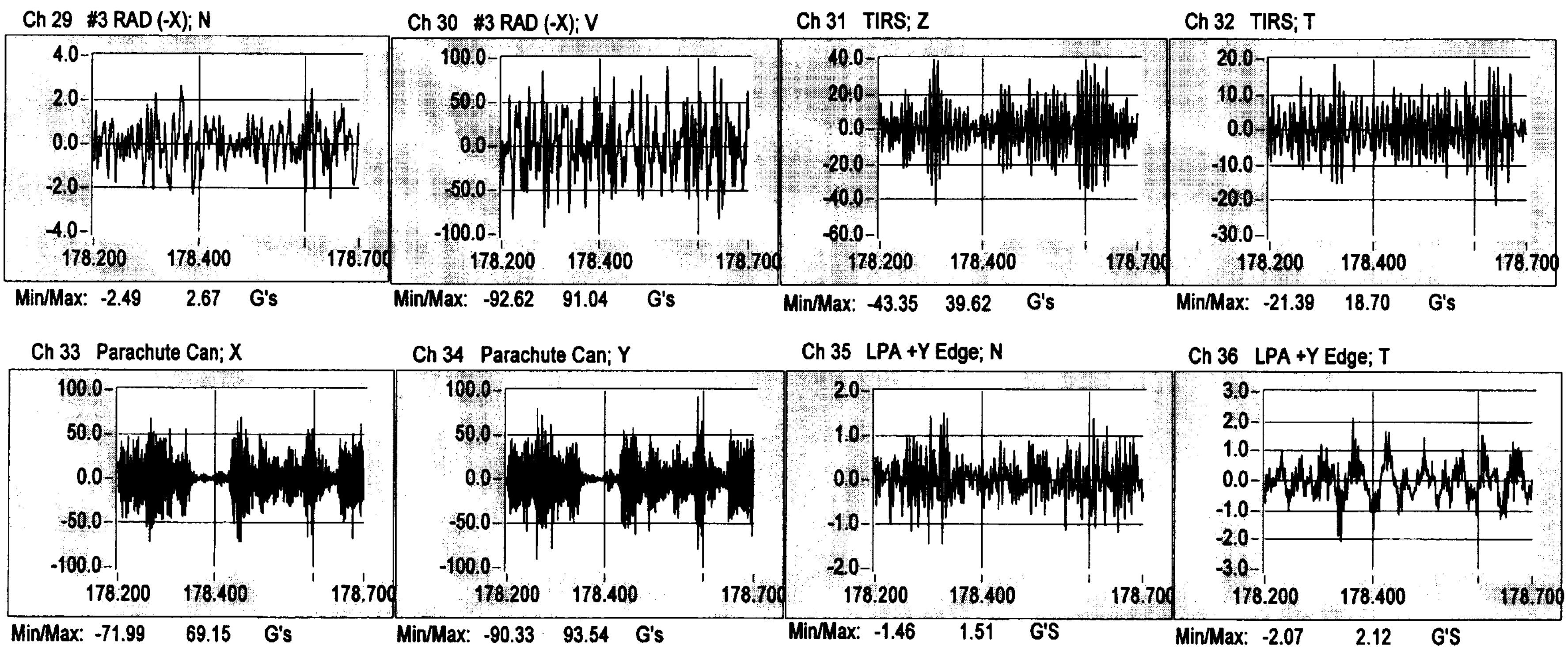


Composite Control Acceleration In Full-Level X-Axis (Lateral) Random Vibration Test



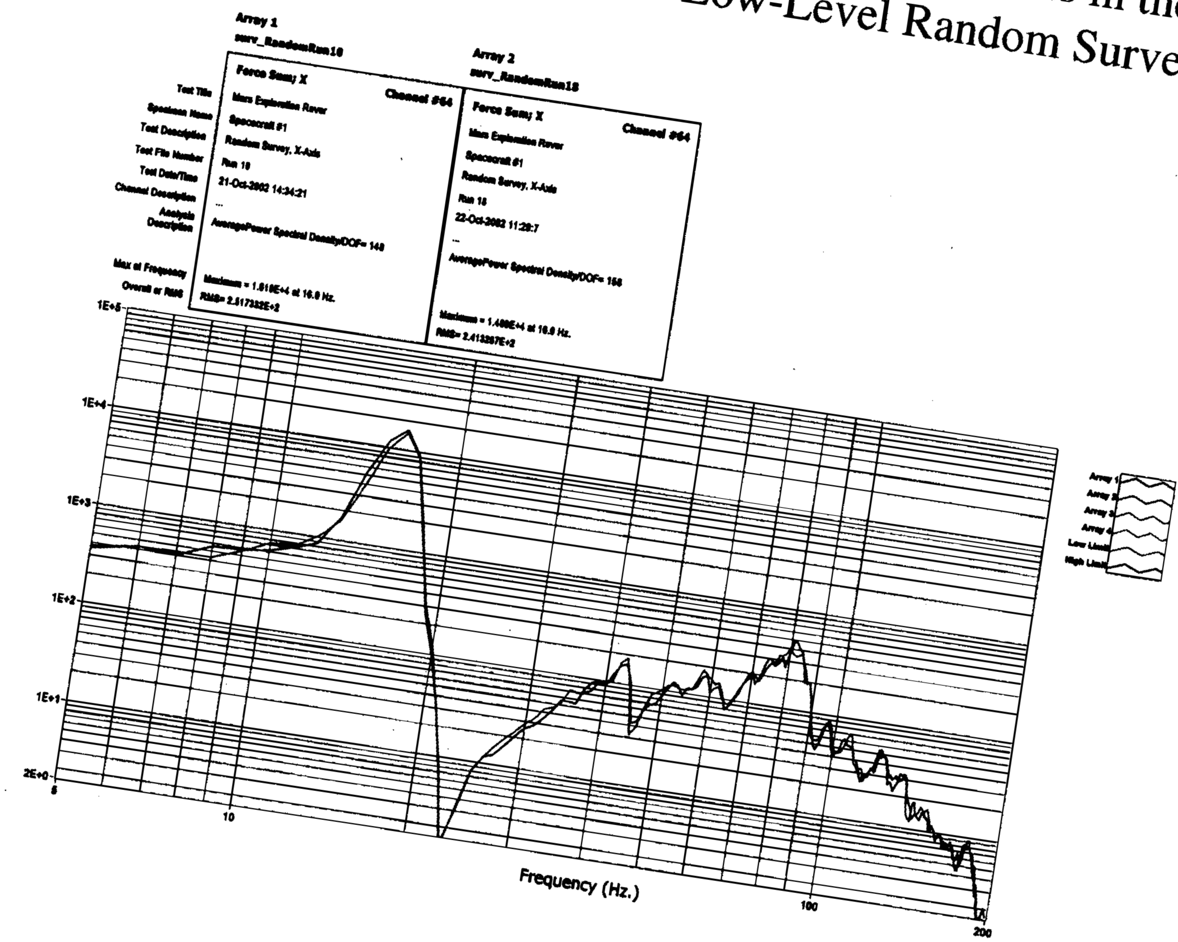
Random Vibration Test of Mars Exploration Rover Spacecraft

Time Histories of Selected Acceleration Responses in Full-Level (0 dB) X-Axis (Lateral) Random Vibration Test



Random Vibration Test of Mars Exploration Rover Spacecraft

Comparison of the In-Axis Force Measurements in the Pretest and Post-Test X-Axis Low-Level Random Surveys



Conclusions

- Vigorous, three-axis vibration test with no apparent damage
- Some responses exceeded input in sub-system tests
- Rattles, impacts, and associated high frequency bursts caused considerable concern
- Modal data obtained with separate modal accelerometer set superior to that obtained with environmental accelerometers
- Frequencies of three fundamental modes ~ 20% higher than FEM submitted for CLA (Probably because of added stiffness of face plates on composite truss structures of Lander petals.)
- Second lateral axis test curtailed after -6 dB, because it was decided that the marginal benefit of a full-level run in the third axis was not sufficient to justify the risk and wear-and-tear to the flight hardware. (The test director lost his courage.)