

MER ARA Pyroshock Test Results

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Biography

Dr. Kurng Y. Chang is a technical leader at the Jet Propulsion Laboratory. He is responsible for establishing dynamics requirements for space flight projects, and coordinating research activities in environmental prediction, definition, and testing. Dr. Chang was the environmental test director of NASA's Galileo, Cassini and Deep Space 1 spacecraft programs. He received a B.S. from Cheng-Kung University in 1964, an M.S. from the University of Iowa in 1967, and his doctor degree in Engineering Mechanics from Columbia University in 1970.

Abstract

This paper presents the shock test results achieved in the MER ARA/brush motor pyroshock qualification. The results of MER flight system pyrofiring tests in comparison with the ARA shock test requirements are discussed herein. Alternate test methods were developed in an effort to qualify the critical MER equipment for adequate performance in the actual flight pyroshock condition. Simulated pyroshock qualification tests were conducted using shakers, mechanical impacts, and explosive charges for excitation. Comparison of excitation and responses of the ARA subjected to different kind of shock tests are included.

Introduction

Two Mars Exploration Rover (MER) spacecraft have been successfully launched for Mars on Delta II launch vehicles. Each spacecraft will deploy identical Mars Landers. The MER Lander descent to the Mars surface will be slowed using atmospheric drag, a parachute, and retrorockets. The final phase of the descent will be a free fall with an airbag system employed to mitigate the inertial impact forces. On the Mars surface the Lander airbags will deflate and the Lander side petals will unlatch and deploy.

Over 60 pyrotechnic device firings are employed on the MER Spacecraft/Rover for the various launch and landing restraint releases and separations. These pyrofirings generate high magnitude, high frequency shocks that can damage nearby electromechanical equipment. One of the equipment items found to be sensitive to pyroshock is the Maxxon brush motors used to deploy the Lander petals and various Rover booms. The airbag retraction actuators (ARA) employed two brush motors, which are located close to pyrotechnic devices and have experienced repeated failures during simulated pyroshock qualification testing. Simulated pyroshock qualification tests were conducted using shakers, mechanical impacts, and explosive charges for excitation.

MER Flight System Pyrofiring Tests

Figure 1 shows the MER Lander with the Rover in the stowed position was stacked on the Lander Assembly Cart for separation test. Four (4) ARA are used in the MER Lander. One is mounted on each side of the Lander side petals and fourth one is on the Lander base petal for all airbag retraction. The test was performed in the JPL Spacecraft Assembly Facility (SAF) at ambient condition. There were two series of test firings. One is the Lander petal unlatch and then following by the Rover stand-up deployment. Each test consisted of firing of several pyrotechnic devices, with the two NSI's in each device fired simultaneously. The pyrofirings were initiated from the MER electronics control module. Tri-axial accelerometers were installed on the test article at selected locations near the shock sources and at ARA assembly support structure interfaces to measure the shock response levels during test firings of the pyrotechnic devices.

In Lander petal unlatches, two firings of the six (6) 3/8" separation nuts were conducted. The first test firing was actuation of the three (3) Separation Nuts installed in the upper latches, and then firing the other three (3) Separation Nuts for the lower latches on the second test. With the MER Rover configured as illustrated in Figure 2, the four (4) 1/2" Separation Nuts, which hold the Rover on the Base petal, were detonated in two firings. The first test firing was actuation of the Separation Nut installed on the rear end corner. The remaining three (3) Separation Nuts in the other three corners were fired simultaneously in the second test. Actuation of these four (4) Separation Nuts provides the release of the Rover main body from the Lander base petal.

Shock measurements made at ARA assembly interfaces are compared with the applicable motor assembly level test specification. However, it must be noted that the measured data are equivalent to the nominal flight levels. Flight Acceptance (FA) levels are ideally based on a 95% Probability with 50% Confidence (P95/50) level from a statistical analysis of the repeated firing data. Figure 3 shows the shock levels in three orthogonal directions measured on the side petal at the ARA mounting interface during the Lander petal unlatch firing. The top portion of this figure presents the response acceleration time histories and the bottom shows the corresponding shock response spectrum (SRS), calculated with $Q = 10$ for these measurements. The ARA motor shock requirement levels, as plotted in the same figure for comparison, correctly envelope the data measured at this location.

Figure 4 presents the shock response levels measured on the ARA mounted on the middle of the Lander base petal due to Rover stand-up from separation nuts releases. The Rover stand-up release firings are the dominant shock sources for this location. Similar shock level is observed at this base ARA location in comparison with the responses at the side ARA during the Lander side petal unlatch.

The test results indicate that the ARA assembly level shock requirements, which were developed early in the MER program, closely represent the shock environments measured from the MER flight tests. The specified requirement is applicable for all ARA mounted on the Lander side and base petals.

Brush Motor Pyroshock Qualification Tests

All flight hardware is required to verify their functional performance and structural integrity during and after exposure to the pyroshock requirements. A 3 dB design margin above the FA level is required for the qualification test. The brush motors were first tested utilizing the shaker test system. In the shaker qualification test, which was performed at TRW's Test Facility, the brush motor passed the FA 2,800 g SRS level, but failure during the qualification test at 4,000 g SRS level. Since the shaker pyroshock test can not produce the high frequency (>3000 Hz) shock input requirements, the Maxxon brush motors were retested using the JPL Mechanical Impact Pyroshock Simulation (MIPS) facility to achieve the high frequency shock requirements, as well as to compare the results of shaker shock simulation testing. Unfortunately, the brush motors failed (broken brushes) in this initial MIPS shock test at 2000g SRS level, which is equivalent to 3 dB below the FA level. Actually, the test pulse generated by the MIPS table did not meet the test requirement. The MIPS table could only achieve a test level about 6 dB below the nominal SRS requirement at the frequency range between 1000 Hz to 2000 Hz. The table is able to achieve high acceleration at high frequency, and even compliant transmission path. The plots from the MIPS table test are shown in Figures 5 and 6. Figure 5 illustrates the MIPS table test set-up and Figure 6 presents the control SRS and the input acceleration pulse. The shock intensity of the test pulse is comparable with the actual pyrofirings. However, the pulse duration is 40 msec, which is much longer than the shock measured from the actual pyro firings (less than 10 msec). Longer pulse durations are generally considered a more severe test, especially for lightly damped hardware such as is probably the case for the motor brush failures.

ARA Pyroshock Qualification Tests

An assembly-level pyroshock qualification test program was performed to try to demonstrate design margin for the ARA motors. A flight spare ARA unit essentially identical to the MER ARA for pyroshock transmission purposes without the motor cover was mounted on a test fixture, as shown in Figure 7 for shaker simulated pyroshock testing. The test fixture was hollow in the center to provide a high frequency ringing effect to fill in the input levels above 3000 Hz. Failure of one of the brush motors occurred at the test level 9 dB below the requirement. The test data from the shaker vertical test is presented in Figures 8a and 8b. Figure 8a shows the shaker vertical input control pulse. The intensity of the shock pulse as well as the waveform and duration is similar to the actual pyrofirings. Figure 8b illustrates the response in three orthogonal directions at the brush motor gearbox interface and Figure 9 presents the comparison of their SRS levels corresponding to these time plots. The shaker test results show an amplification rather than attenuation of the input waveform (for most frequency ranges) measured between the fixture and the motor gearbox. The shaker excite test item through all mounting interface simultaneously rather than achieving wave propagation. The dissimilarities in mounting interface (structural impedances mismatch due to rigid mount) trend to over-test internal components. The significance of this test result is under debate and is possibly an over test case.

Subsequently, a different shock simulation approach were proposed and implemented by utilizing an ordnance excited shock test system. Test item mounted to metal plate and

the metal plate was suspended on bungee cords represents a more realistic attachment than a rigid fixture. The pyroshock conditions were created by using four (4) Feet explosive cord (7.5 grain per foot) in certain configurations mounted on the edge of the test plate, to achieve the desired shock levels at the test item-mounting interface. Figure 10 illustrates the ordnance shock test plate and the ARA configuration and instrumentation locations. The ARA unit with two brush motors was mounted on the center of the ordnance shock plate. This ARA unit passed the required qualification shock requirements. Figures 11a and 11b present the shock input waveform in the vertical axis and the corresponding SRS at the ARA unit mounting interface in the three orthogonal axes. Figures 12a and 12b present the shock response waveform in the vertical axis and the corresponding SRS's in the three orthogonal axes at the motor gearbox location. Review of the test results showed that the input time history acceleration g levels exceeding 20K g at frequencies above 10K Hz, but the responses at the motor gearbox have a 5 to 10 dB attenuation from the ARA unit input shock.

Concluding Remarks

- The ARA brush motors survived the shock environment from flight Lander and Rover deployment pyrofirings and have also survived numerous flight instrument pyrofirings without failure. The ARA shock requirements developed early in the MER program closely represent the shock environments measured from the MER flight tests.
- Alternate test methods were developed in an effort to qualify the critical MER equipment for adequate performance in the actual flight pyroshock condition.
- Comparisons of excitation and responses of ARA subjected to various types of shock qualification tests, which include classical shaker, classical MIPS table, shaker/fixture simulation, and explosive ordnance excitation, were performed.
- The results of this comparison presented herein are oriented towards the different test means to reproduce the shock conditions at MER equipment mounting interfaces by the actual pyro firings. No test mean is perfectly reproducing the effects of the actual shock environments; each has its advantages and disadvantages and must be used with the appropriate engineering judgment.
- The shock pulse duration (40 msec) generated in the MIPS shock simulation testing is much longer than the shock measured from the actual pyro firings (less than 5 msec) and even longer than the shaker testing, which is about 10 msec. Longer pulse durations are generally considered a more severe test, especially for lightly damped hardware.
- Experience shows that an item that fails in shaker shock test may survive mechanical impact or explosive charge test. The ARA/brush motor assembly has passed the qualification requirements by utilizing the ordnance simulated pyroshock tests.

Acknowledgments

The work described in this paper was carried out by the Jet Propulsion Laboratory (JPL) California Institute of Technology under a contract with the National Aeronautics and Space Administration (NASA). The many contributions of the personnel in the JPL Dynamics Environments Group and its supervisor, Dennis Kern, are appreciated.



Figure 1. MER Flight Lander/Rover Configuration (not Airbag Attached) for Petal Unlatch

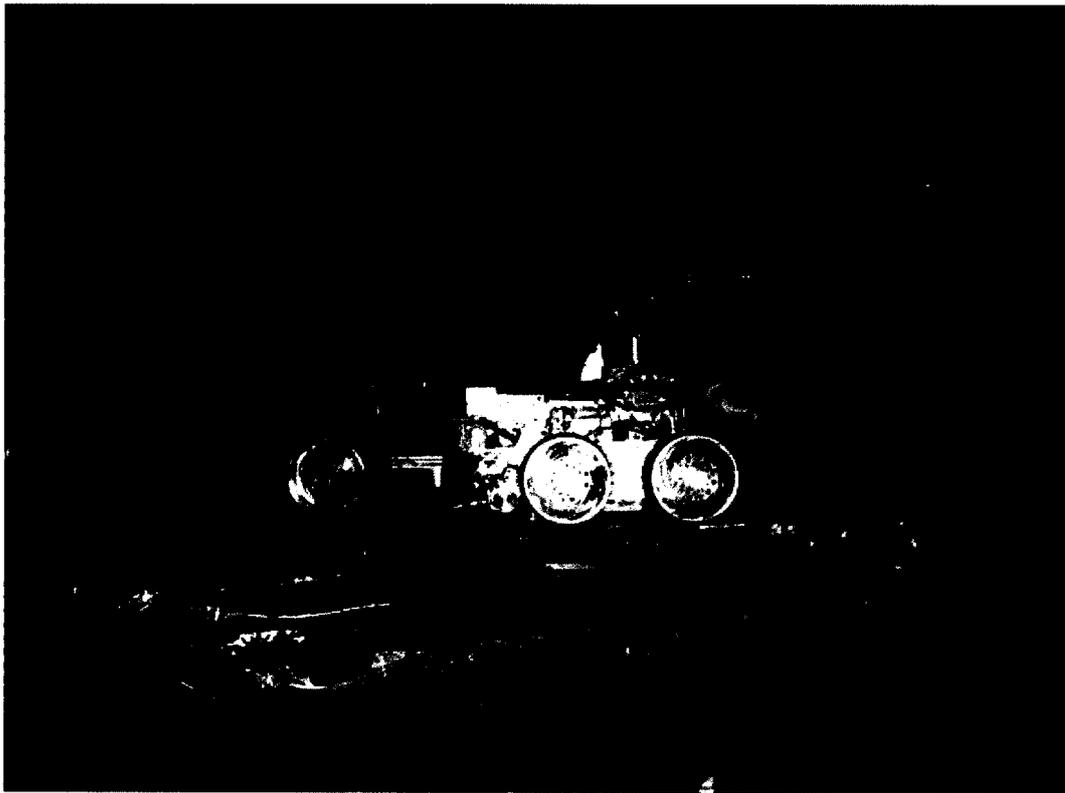


Figure 2. MER Flight Lander/Rover Configuration after Petal Unlatch for Rover Stand-up

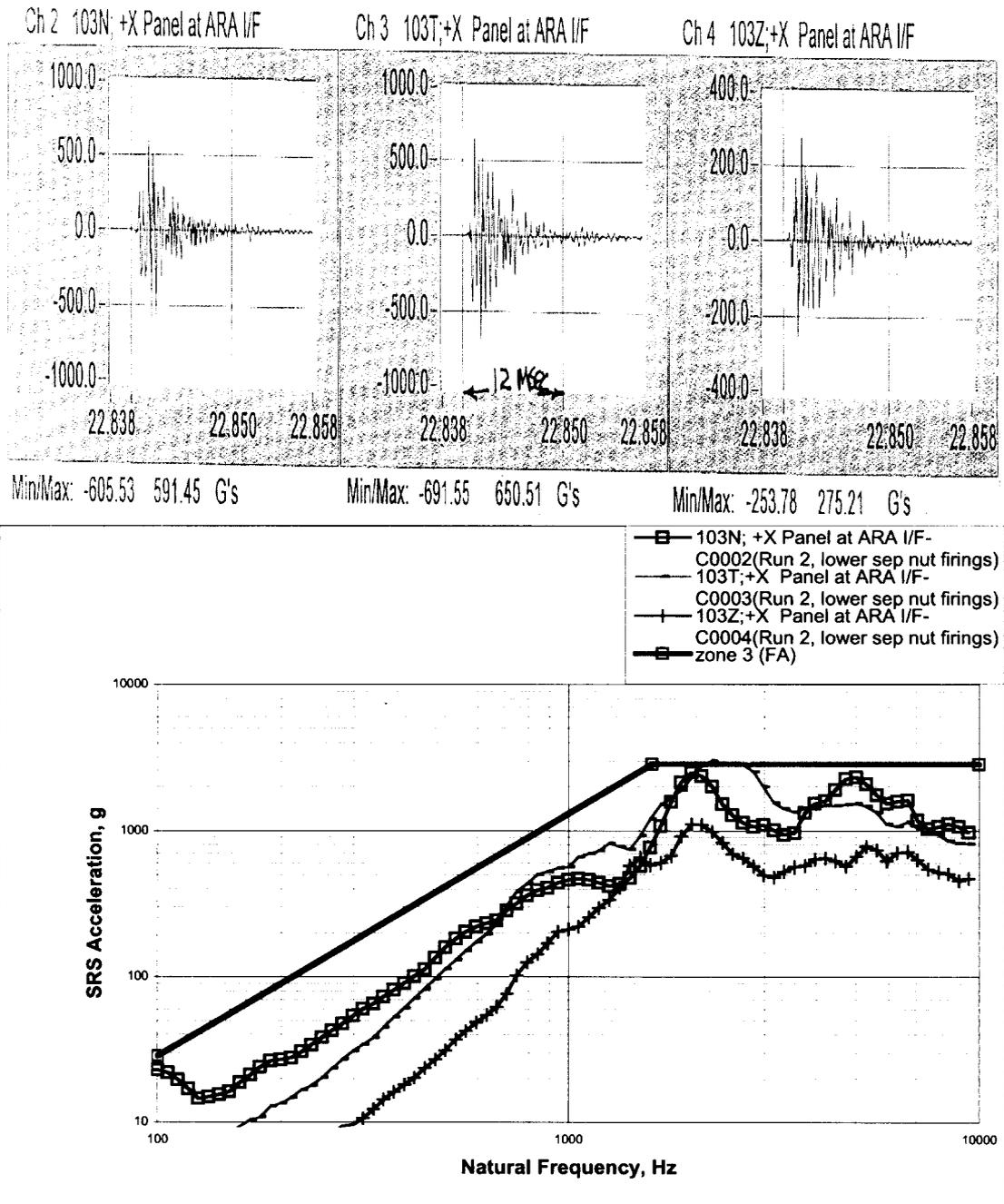


Figure 3. Shock Levels Measured at ARA/Side Petal Interface Due to Lander Latch Release

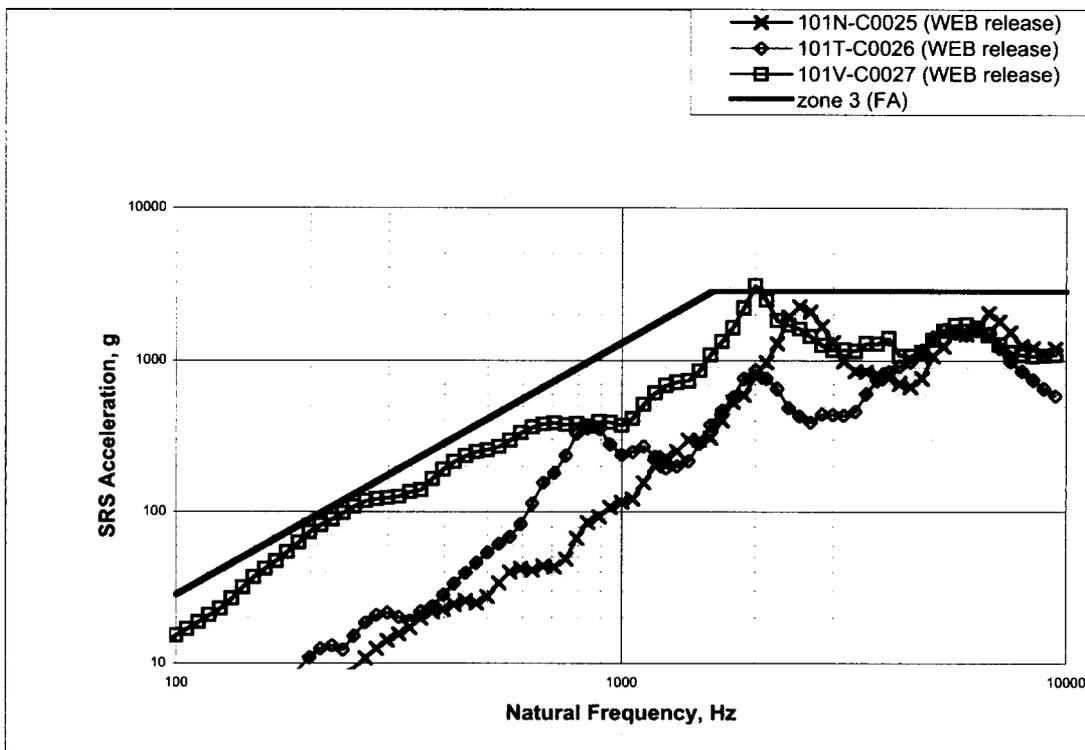


Figure 4. Shock Levels Measured at ARA/Base Petal Interface Due to Rover Stand-up

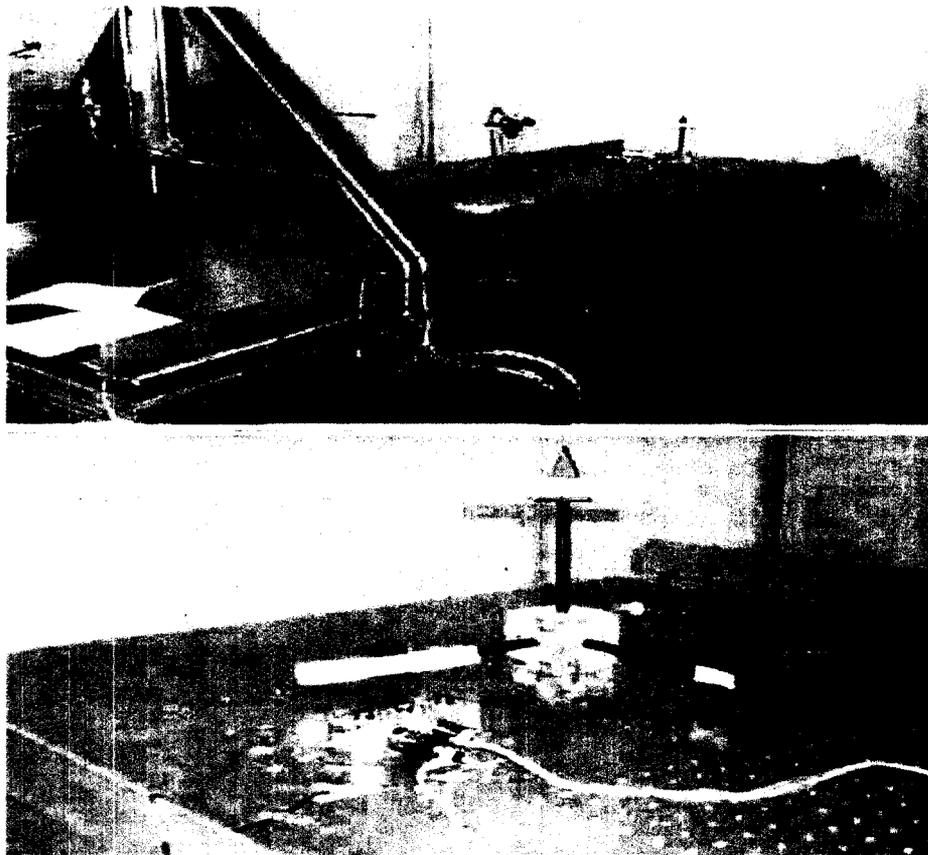


Figure 5. Brush Motors on MIPS Table for pyroscock Test

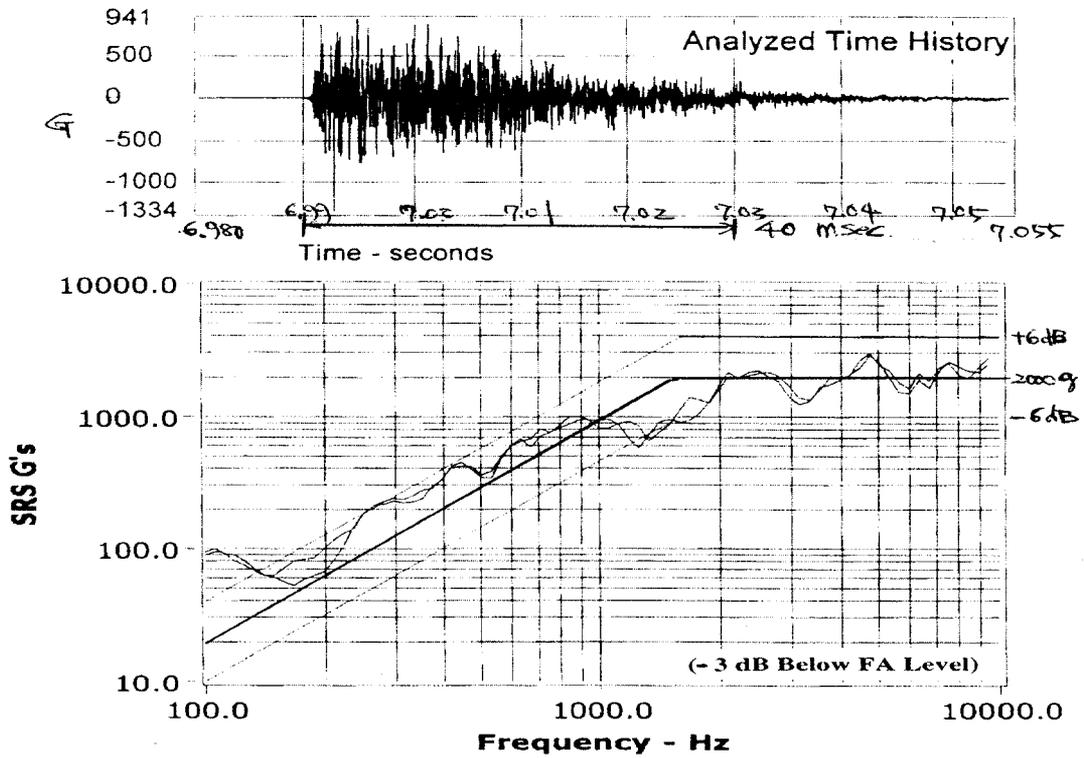


Figure 6. Bush Motor Input Acceleration and Shock Spectrum as controlled by JPL MIPS Table

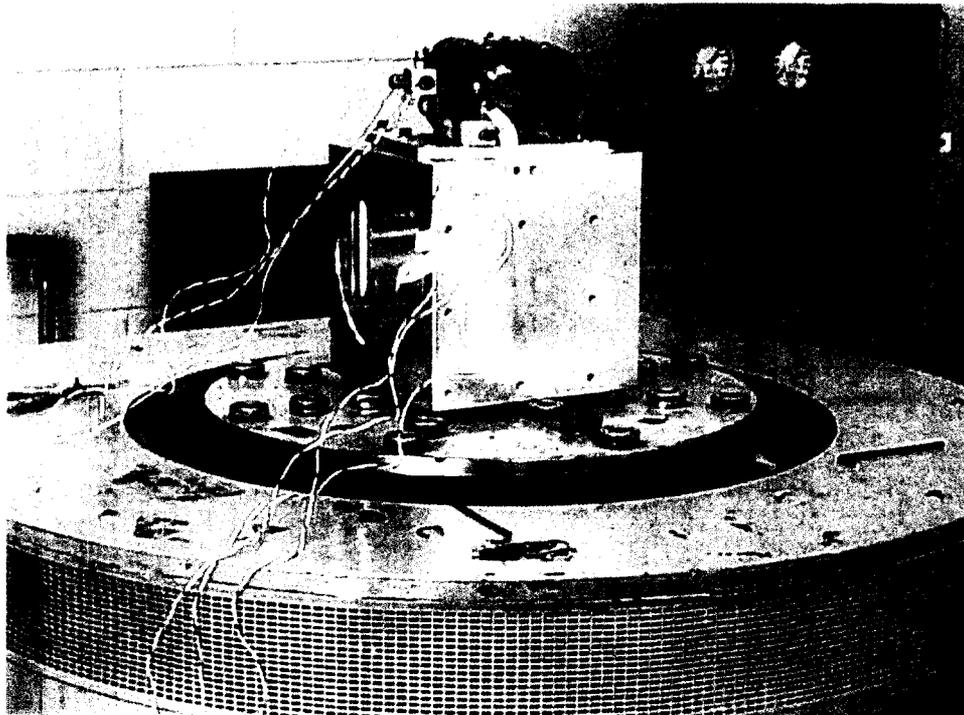


Figure 7. ARA Shaker Simulated Shock Test Set-up (Vertical Excitation)

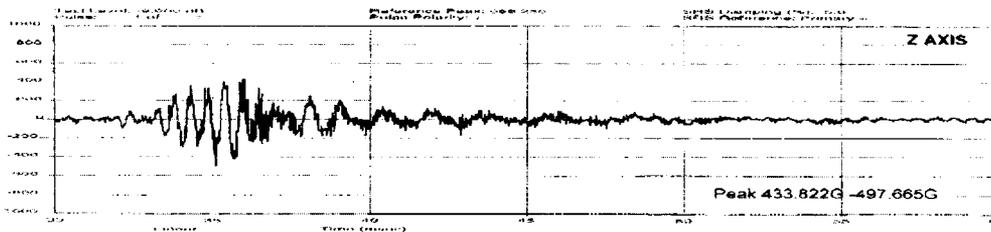


Figure 8a. ARA/Fixture Shock Input control Acceleration from Shaker Test

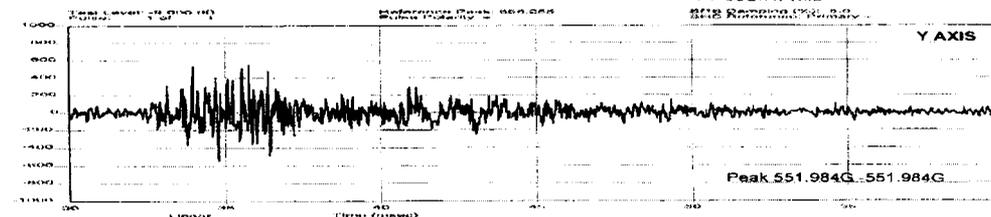
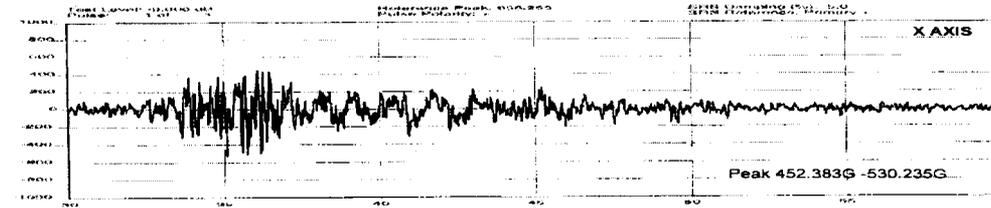
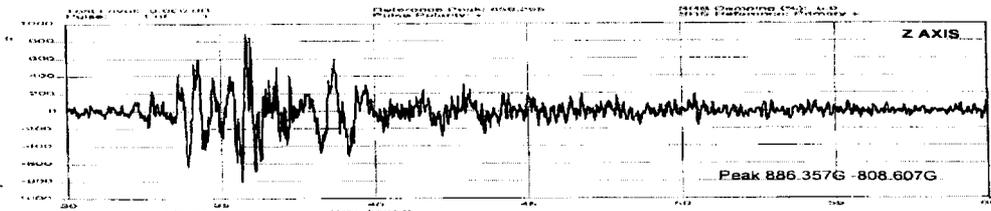


Figure 8b. Acceleration Responses at ARA Motor Gearbox Interface

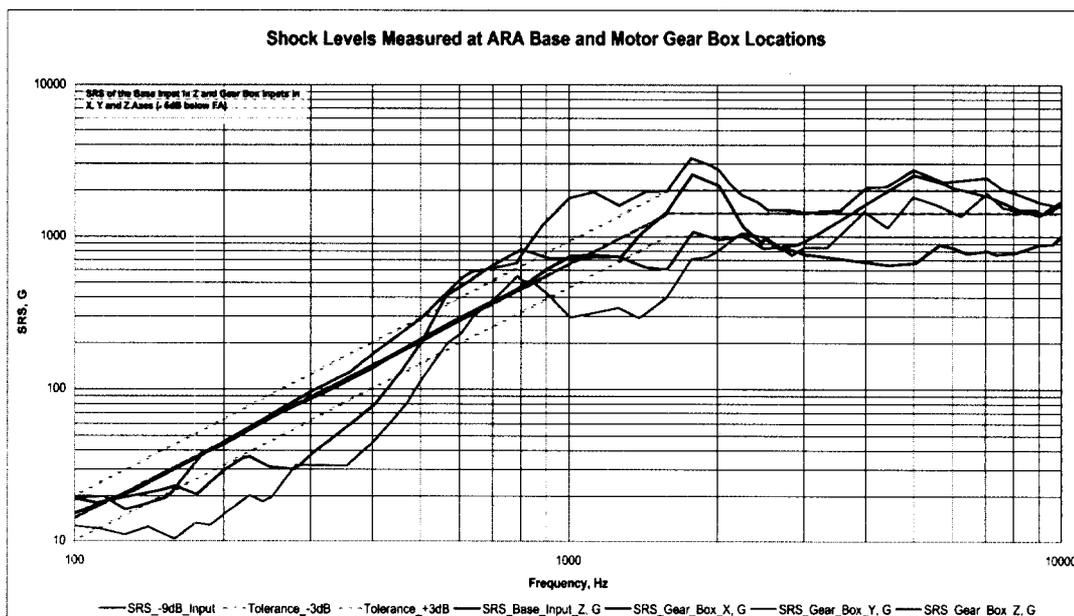


Figure 9. Shock SRS Levels Measured at ARA Base and Motor Gearbox Locations from Shaker Test

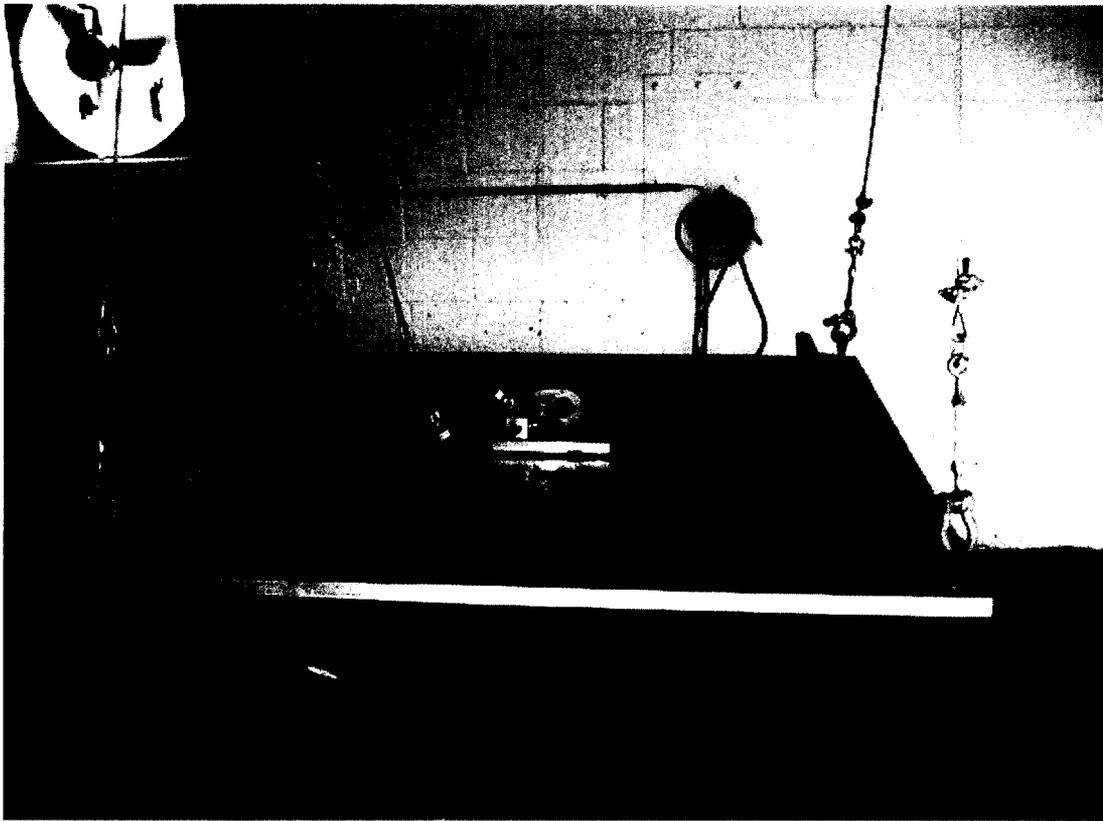
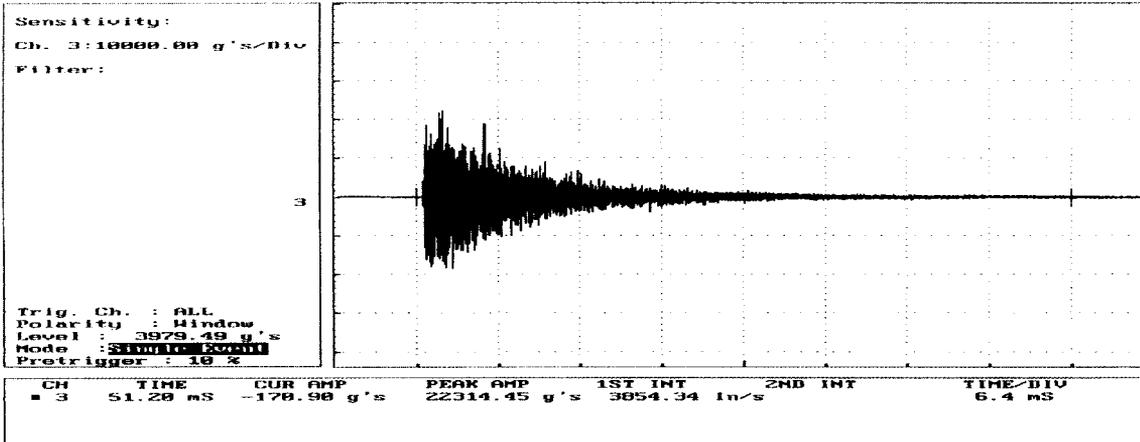


Figure 10. ARA Ordnance Simulated Shock Test Configuration and Instrumentation

Waveform Test Report
GDI SYSTEMS, INC. CAT SYSTEM

DATE / TIME : Mar 14 2004 13:18 TEST PROCEDURE: SOW & EMAIL
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 MJO NO. : 141-0258-14 SHOCK TITLE : ORDNANCE SHOCK



Remarks:

TEST ITEM: MER AIRBAG RETRACTION ACTUATOR P/N: 10158945-1 TRIAX #1 ON FIXTURE: Z PLOT NO: 53	TEST TEMP: AMBIENT S/N: 020 SHOCK NO: 2 @ 4000
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Figure 11a. Input Acceleration in Vertical Direction of ARA Ordnance Shock Test

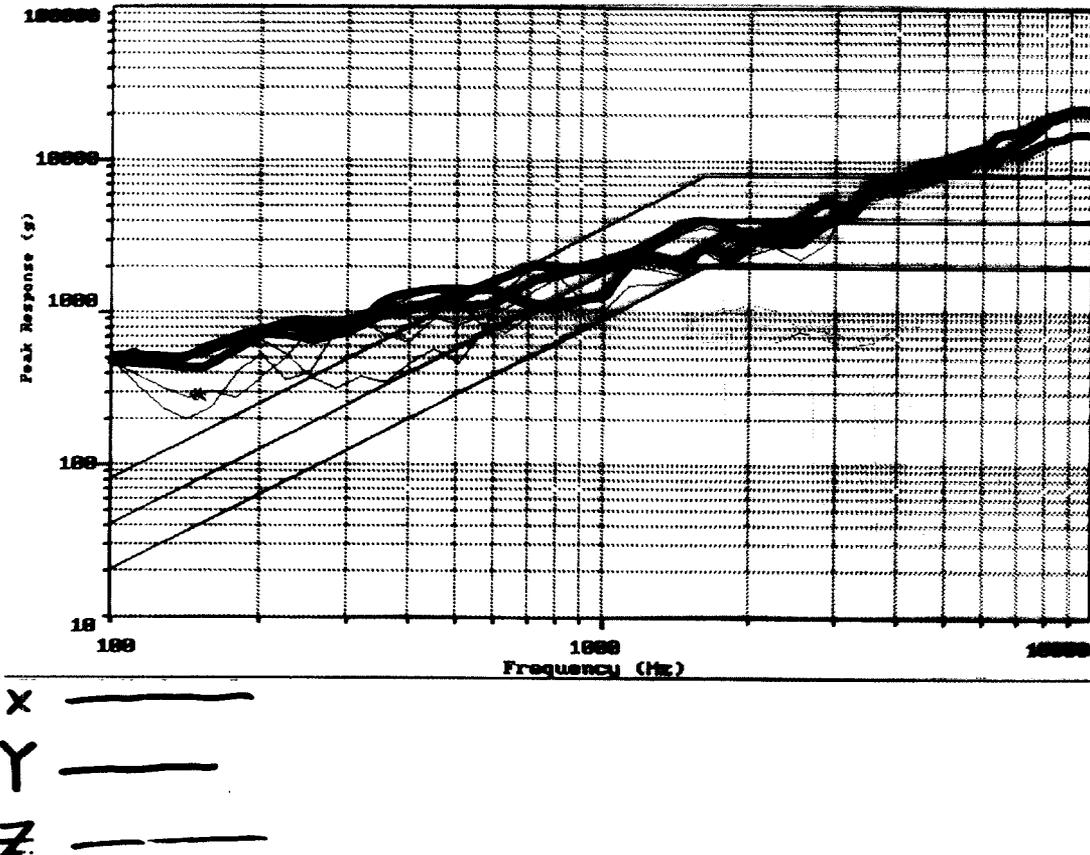
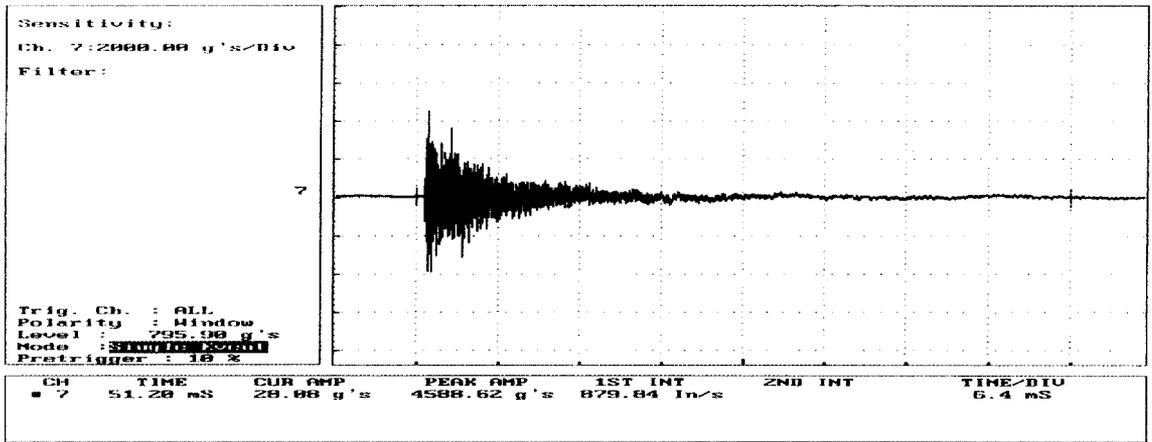


Figure 11b. Input Shock Response Spectra at ARA Mounting Interface

Waveform Test Report
GILL SYSTEMS, INC. GAE SYSTEM

DATE / TIME : Mar 14 2003 13:18 TEST PROCEDURE: SOW & EMAIL
 CUSTOMER : JPL TEST LAB/SITE : NTS/SANTA CLARITA
 MJO NO. : 141-0258-14 SHOCK TITLE : ORDNANCE SHOCK



Remarks:
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 P/N: 10158945-1 S/N: 020
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 PLOT NO: 59

Figure 12a. Response Acceleration in Vertical Direction of ARA/Gearbox Location

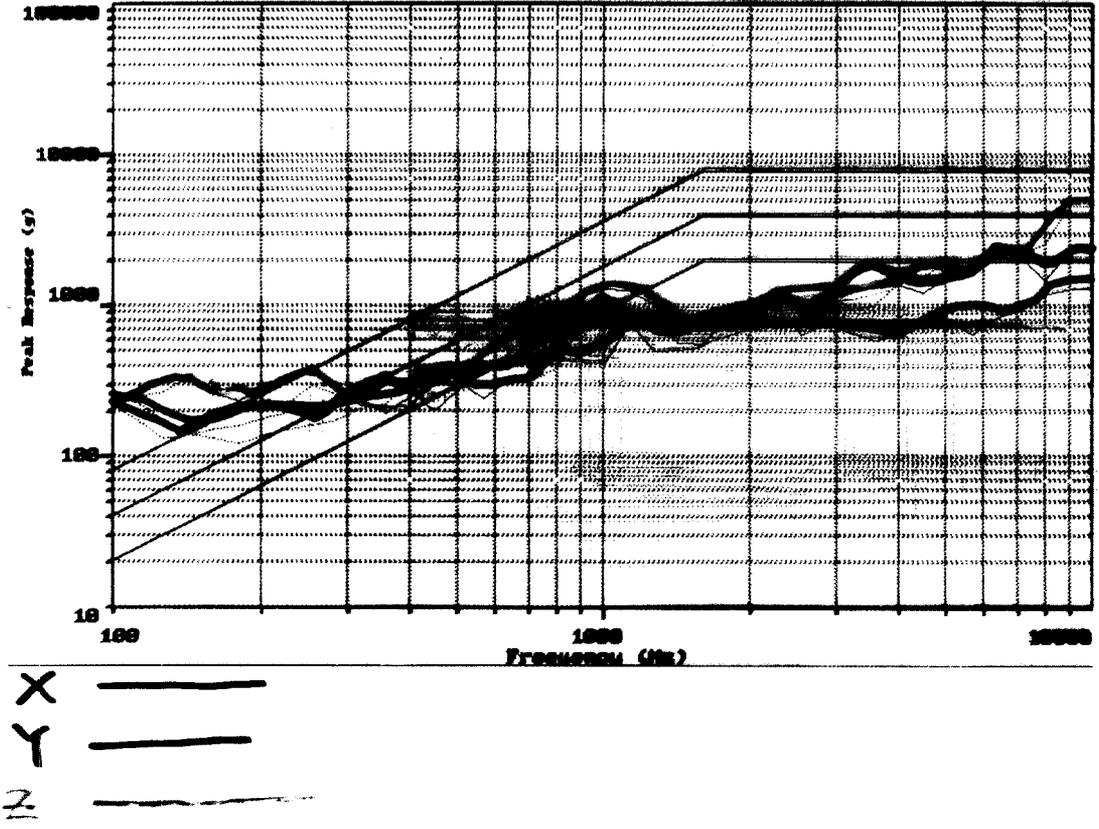


Figure 12b. Response Shock Spectra at ARA Motor Gearbox Location