SVB '86

SUMMARY OF TESTING TECHNIQUES

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I have tried to survey some of the approaches that have been used to simulate pyrotechnic shock over the last 20 years. I have already learned of a few new ones today. I am going to be talking basically about two approaches: (1) the use of flight structures or flight-like structures and (2) general-purpose machines that can be used to simulate a pyrotechnic shock environment that was generated from a wide range of vehicles.

One question is often asked–why don't we just use the device itself to provide the shock? If we use the device itself we are producing a flight environment, not a qualification level that would normally be higher. To compensate for this lower level, we could perform a flight-level test three times to gain confidence. Some people in the past have fired the flight device three times in a flight structure and qualified the hardware that way. If the flight structure and an inexpensive ordnance device, such as a "pin puller" or a separation nut or bolt, are available, this may be a valid approach. However, what happens when you have a stage separation and the structure itself costs $50,000 or $100,000? After you blow it apart, only a flight environment has been produced with no qualification margin. This is part of the problem with using the device itself.

Art Ikola from Lockheed developed a concept many years ago, and he called it the "Barrel Tester." We at McDonnell Douglas read his paper and we designed a different barrel tester. Figure 1 shows the equipment compartment MDAC used. The equipment compartment separated from a Gemini spacecraft with two strips of flexible linear shaped charge cutting 0.09-inch-thick material–the flight separation joint is shown in Figure 2. High-magnitude shock was transmitted into the unpressurized compartment in which all of the electronics were mounted. Figure 3 shows the change we made so the apparatus would be reusable and attain a 6-dB qualification margin. We replaced the flight joint and left the flight-like, unpressurized compartment under it. We used a very rigid backup block, cut a groove in it, and put flexible linear shaped charge of various grain sizes in the groove. We changed the separation sheet thickness and varied that until we attained the needed 6-dB margin on the pressurized compartment. We would then mount the part at its actual flight location and fire the charge.

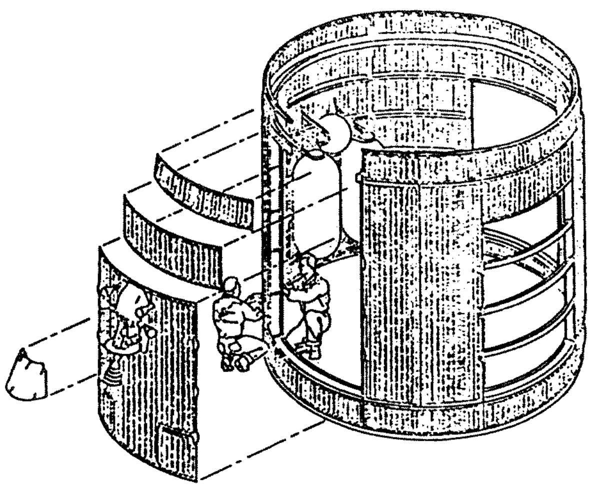
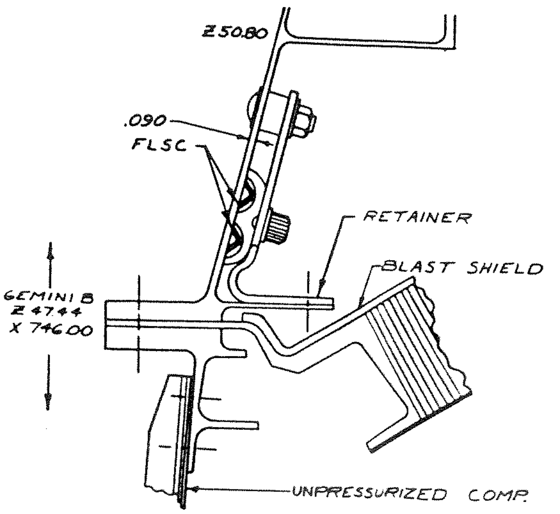
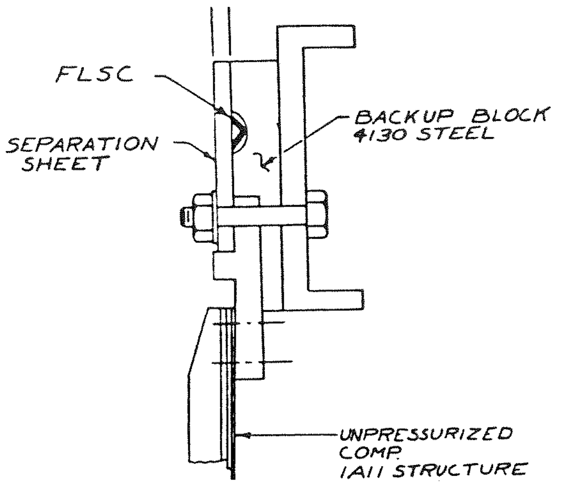


Figure 1. Equipment Bay Separated From Gemini B



SEPARATION JOINT: 2014 T652 ALUMINUM FORGING .090 THICK CUT WITH TWO PARALLEL FLEXIBLE LINEAR SHAPED CHARGES, SILVER SHEATHED DIPAM, 7 GRAINS/FOOT

Figure 2. Flight Joint



SEPARATION JOINT: 2014 T6 ALUMINUM SHEET .090 THICK CUT WITH FLEXIBLE LINEAR SHAPED CHARGE, LEAD SHEATHED RDX, 10 GRAINS/FOOT

Figure 3. Barrel Tester Joint

Figure 4 shows another concept for using flight-like or flight spacecraft. I took this directly from Stan Barrett's (Martin-Marietta) paper; it shows the appearance of the Viking Lander. The central bay housed all of the electronics. Figure 5 shows the bay that Stan used for the test bed. He listed numerous ordnance devices in his paper and the corresponding shock response spectra. He placed an ordnance charge at the "pyro source" and by varying the quantity could obtain margin over flight devices.

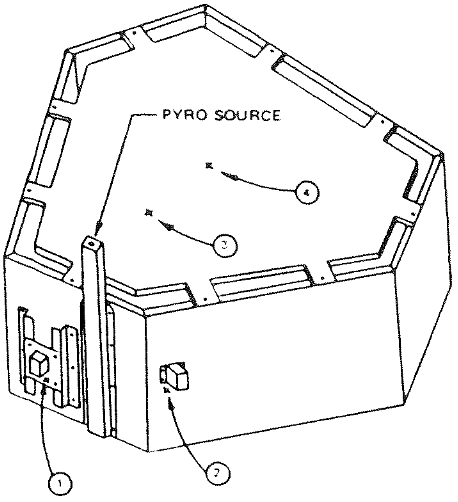


Figure 5. Viking Landing - Electronics Bay

Another group at Martin-Marietta produced a device they called "Flower Pots". The "Flower Pot" was a piece of 3-in.-diameter steel pipe with a 2-in. inside diameter 4 in. long with a 0.5-in. steel base plate welded to the bottom of it. The "Flower Pot" was mounted at the location from which the pyrotechnic shock source came. The desired spectrum was attained by varying the charge size inside the "Flower Pot". As with the Barrel Tester, they mounted the component in the actual flight location and with the increase in charge size it enabled them to get a 6-dB margin. On the same program JPL used pneumatically activated pistons to impact an anvil and generate the required shocks.

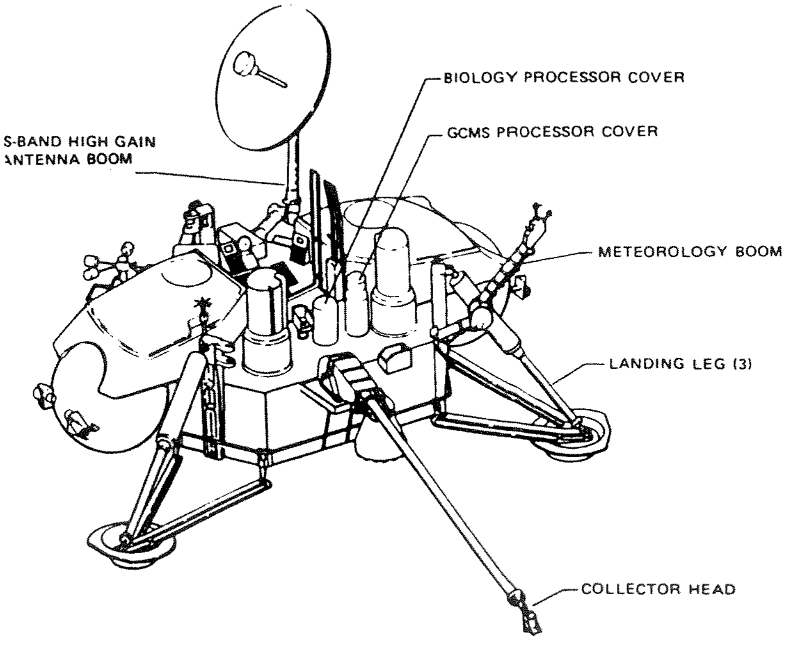


Figure 4. Viking Lander Configuration

Figure 6 shows TRW's approach. It is somewhat like Bob Morse's resonant plate. It is just an anvil on the flight-like structure. A slide hammer is raised to various heights and impacts on a fitting where the flight ordnance device is normally installed. They were able to achieve a 6-dB margin at the various flight locations.

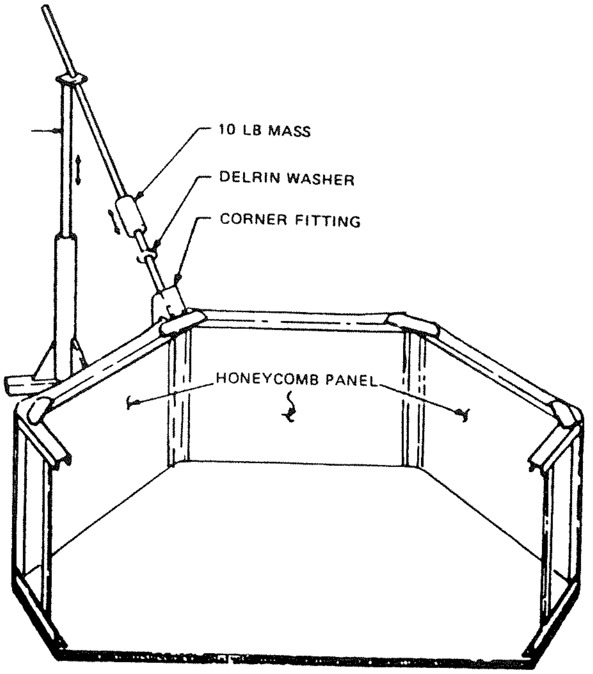


Figure 6. TRW - Shock Simulator

With the previously described apparatus you generate the right shock environment, but you generate it only for a certain vehicle because the flight-like structure responds only for that particular vehicle. It was not practical to build a shock machine for each vehicle. We wanted to build an apparatus that was more generally useful so we utilized the concept of the "Barrel Tester" joint. We took a flat piece of steel, 8 ft long, 0.5 in. thick, and 4 ft wide and put a separation joint on each end. The V joints provided a means to change the flexible linear shaped charge size. In this way we could reach 100 grains per foot on one end and as low as 10 grains per foot on the other end with various thickness sheets. Figure 7 is a photograph of the joint. The flexible linear shaped charge fits in the V-cavity. The separation sheet thickness and charge size is varied to produce the desired spectrum. At that time (1972), we did not have the intelligence to really do what Neil Davie (Sandia) has just presented and the problem as I mentioned earlier, was that we could vary the magnitude of the shock response spectrum, but were restricted to the resonance frequency of the plate, i.e., we could not change the shape of the spectrum, only the amplitude.

Figure 8 shows the test setup for a gyro package. Triaxial blocks were mounted diagonally on opposite corners and an envelope of the maxi-max response spectra was generated. Figure 9 shows that the minimum requirement was met but the 6-dB tolerance was exceeded at the low end. This is really the envelope of the maxi-max shock response spectrum from all three axes.

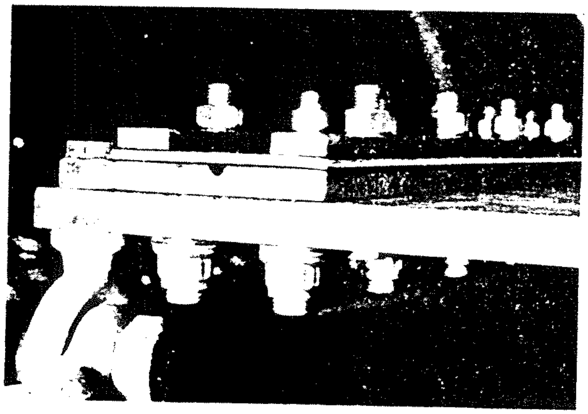


Figure 7. Flat Plate Joint

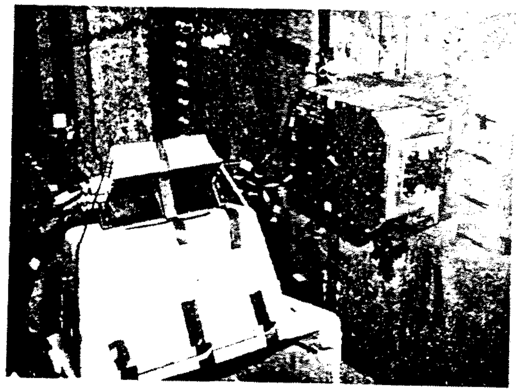


Figure 8. Gyro Package on Flat Plate

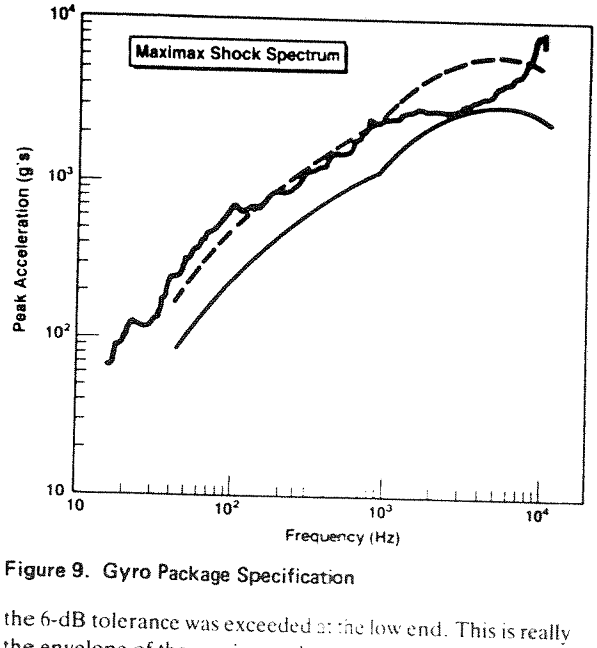


Figure 9. Gyro Package Specification

We found in the past, a compression wave comes through the plate as the explosive charge goes off. This wave was of sufficient magnitude to break off standard 10-32 accelerometer mounting studs. Figure 10 is the approach we use to keep our accelerometers on. We went to a 1/4 - 28 thread and bolted it all the way through the plate and then we mounted the accelerometer directly to that solid stud.

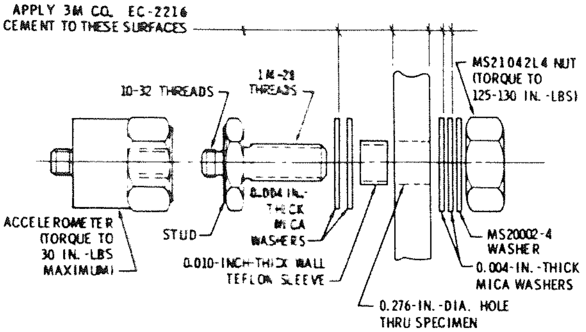


Figure 10. Accelerometer Mounting

Figure 11 shows a concept that TRW uses for simulating pyrotechnic shocks. It is a strain energy machine. The test article is mounted on top of a large block. Damping pads are on the side of the block, and a metal coupon is attached to the block. A hydraulic cylinder is pressurized until the coupon fractures. When the coupon fractures, a large amount of strain energy is released, it travels through the block, the block resonates, and the test article is subjected to a high-level transient. The main problem with this machine is shaping the spectrum.

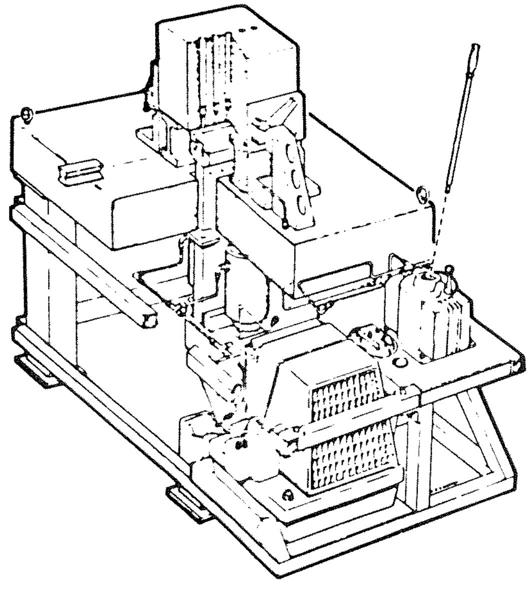


Figure 11. TRW Strain Energy Shock Machine

Figure 12 shows a rather unusual concept for simulating pyrotechnic shock. Richard Snell from McDonnell Douglas has used it in his fracture mechanics work. He has mounted some accelerometers and some strain gages on photoelastic samples. A large capacitive discharge bank can produce 300,000 g's in periods of 2 μsec. It has a Rogowski coil, and when the capacitor bank is discharged, it sends two plates together to generate an extremely short and high force transient that is transmitted to the test article.

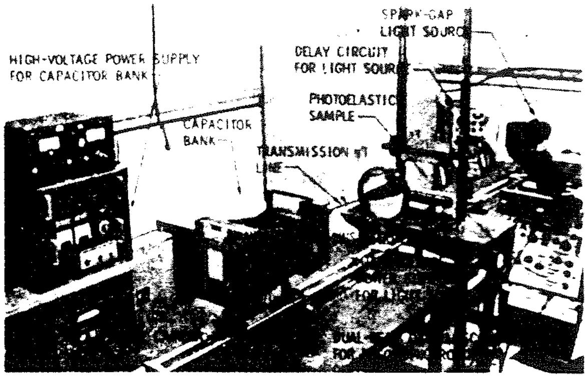


Figure 12. Stress Wave Generator

Figure 13 shows the electrodynamic shaker. The people involved in digital vibration control have new ways of programming to meet a shock spectra, but a skilled technician can still equalize a spectrum faster than any digital system I have yet seen.

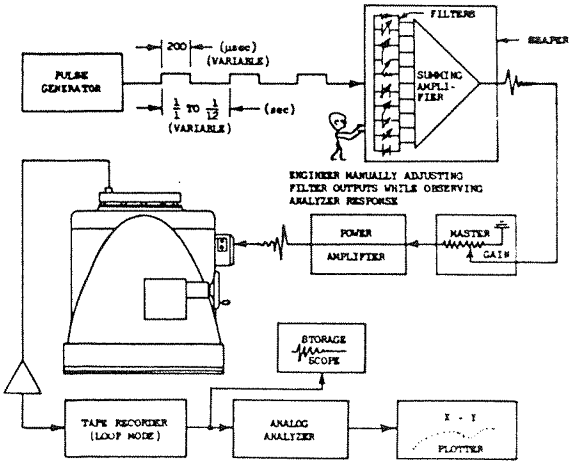


Figure 13. Shaker Shock

Figure 14 lists current problems in simulating pyrotechnic shock. Hank Luhrs (TRW) discussed the differences in the actual pyrotechnic shock environment and why it differs on shakers. Some of the reasons are listed here. The input path to the part is just not the same with the pyrotechnic shock transient as it is on a shaker or a drop tester. As the pyrotechnic shock transients go through a shell, only one foot of a black box is loaded at a time, all four feet are not hit simultaneously. The duration of the input is much shorter, maybe 10 to 15 msec in a pyrotechnic shock and typically 50 to 60 msec on a shaker. The impedance of fight bracketry in flight spacecraft, where equipment is usually mounted on thin panels, is different from the impedance of a shaker where the equipment is mounted on a 100- to 400-lb armature. The velocity content of the pyrotechnic shock is much less that the shock machine. The test item absorbs less kinetic energy. The velocity of crack propagation is lower that the

1. **The input path** to the part is not the same with the pyrotechnic transient as it is with a shaker or drop tester.
2. **The duration of the input** is much shorter with the pyrotechnic transient
3. **The impedance** of the in-flight bracketry is much less than it is on any of the shock machines.
4. **The velocity content** of pyroshock is much less than that of shock machines and consequently the part absorbs less kinetic energy in a pyrotechnic shock.
5. **The velocity of crack propagation** is lower than the velocity of the extensional wave through the material; consequently, cracks that are formed do not have time to grow before the wave has passed on and the stress has been removed.
6. **For very short pulses,** fractures may occur in one area completely independent of what's happening in the rest of the part and complete failure will not occur.
7. **The ultimate strength of materials** increases significantly with increases in strain rates. It is the job of the test engineer to choose a method that will produce the same failure that would occur in the field.

Figure 14. Reasons Why Shock Simulation May Produce Different Failures Than the Actual Pyrotechnic Event

extensional wave through the material, consequently the cracks which form do not have time to grow. I showed the slide on the output of a strain gage that was located very near the source. The rate of change of strain was 2400 μin./in./sec. In Kolsky's book on solids, he shows the ultimate strength of a material can go from 50,000 to 80,000 psi when subjected to strain rates of 1000 μin./in./sec. When we are talking about pyrotechnic shock, we are definitely in this region. Now I will ask the audience to add to the list anything they think I may have missed.

Discussion

Mr. Moening (The Aerospace Corporation): Are there any advantages that you see of using an explosively driven plate over a hammer excited plate?

Mr. Powers: Let me answer that with another question. Why do transducers fail when I put them on my explosively driven plate, and why don't they fail when hit with a hammer?

Mr. Moening: I suspect the reason is that the explosively driven plate has much more of the ultra high frequency.

Mr. Powers: This is correct, actually the same thing happens, in an actual stage separation. That high frequency is there.

Mr. Moening: You are reinforcing a feeling that I had that for some limited applications that is where you have a component mounted very near the ordnance device.

Mr. Powers: That is right. If you are in area I (Neil Davie's presentation), then you have to realize that it is a different phenomenon than if you are 174 in. away and sitting on a single-degree-of-freedom system. I am talking about levels of 20,000 or 30,000 thousand g's not something 12 or 13 hundred g's. But there is a difference. If you are smart enough, you do not put electronic equipment in a 20,000-g environment even though we have qualified items to 20,000 g's.

Figures 15 and 16 show an acceleration history and its associated shock spectra near a flight separation joint. Figure 17 and 18 show comparable plots on mounting bracketry 174 in. away. The transient shown in Figure 17 certainly does not look like a pyrotechnic transient but it is. The difference is that the accelerometer is mounted far enough away from the source that it responds to the "classical" structural modes and not to the longitudinal compression and tension waves.

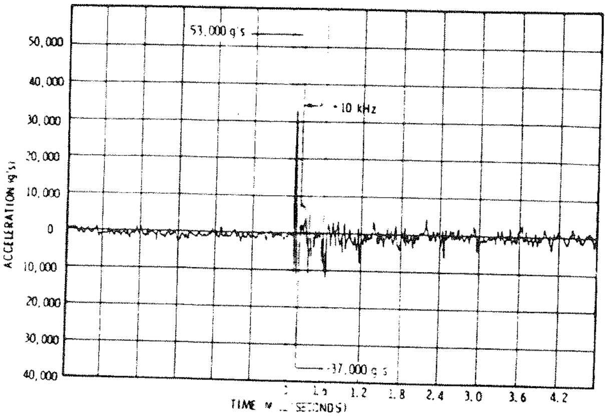


Figure 15. Acceleration History 3 Inches From Sepration Joint

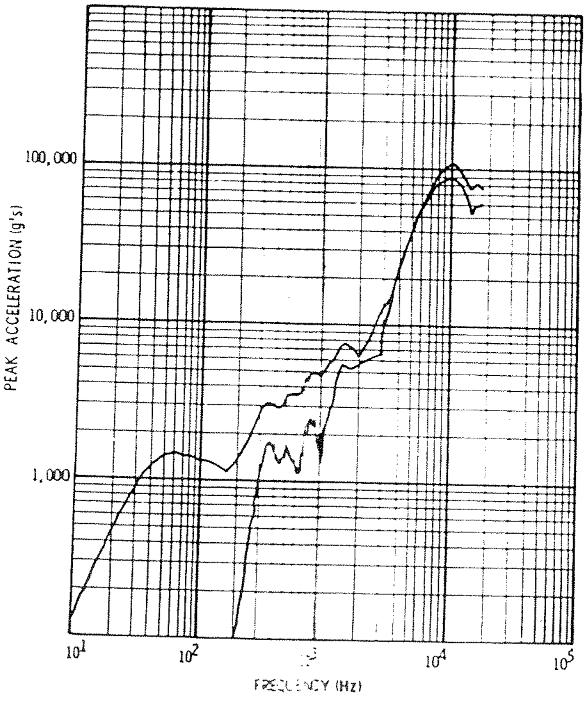


Figure 16. Shock Response Spectra Near the Separation Plane (100,000 g's at 10 kHz)

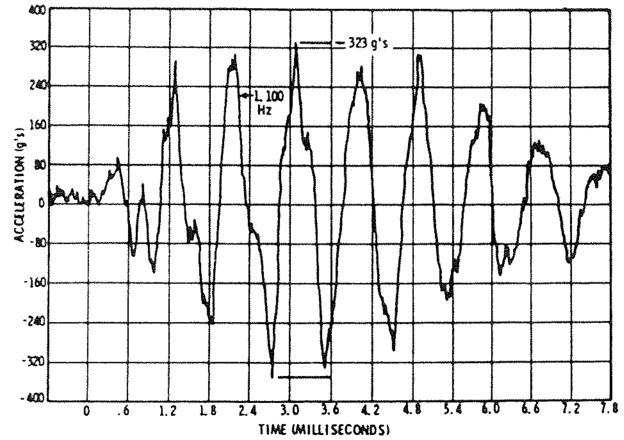


Figure 17. Acceleration History 174 Inches From Sepration Joint

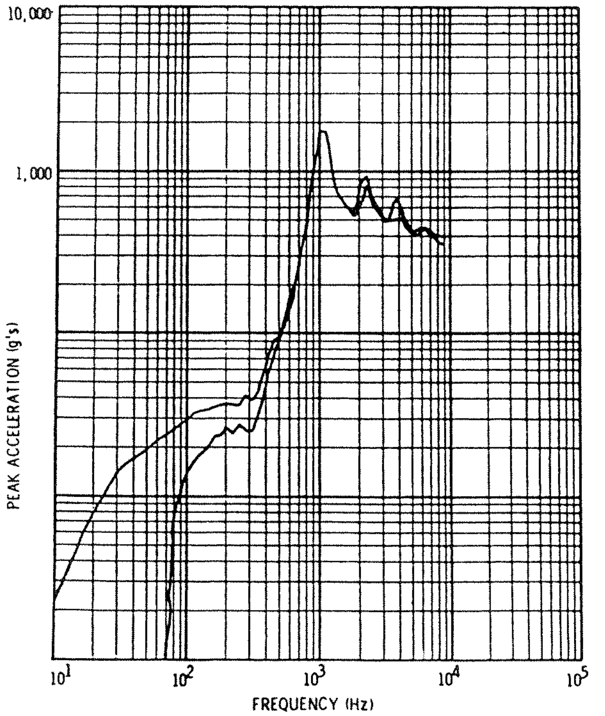


Figure 18. Shock Response Spectra 175 Inches From the Separation Plane (1800 g's at 1100 Hz)

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