Shock Testing

Aircraft, spacecraft, other aerospace structures and all structures in general endure shocks in one form or another throughout their lifetime. These shocks can result from mechanical or natural phenomena causing the excitation. Many things cause shocks in aircraft: catapult take-offs, carrier landings, weapons release, rough transportation and air turbulence to name a few. For these aircraft to survive these harsh events, they need to undergo rigorous testing before flight to ensure the safety of the flight crew and their airplane.

1) Definitions in Shock Testing
2) Types of Shocks
3) Sources of Shocks
4) Shock Testing Methods
5) Example Failures

1) Definitions in Shock Testing

What is shock?
Shock is defined as a non-periodic excitation of a system characterized by sudden and severe relative displacements in the system. Early shock tests called for classical pulses such as half-sine, and these tests could be accomplished via drop methods. Presently, many shock tests require complex, oscillatory pulses that require other methods such as pyrotechnic, impact or shaker induced environments.

How is it defined?
A shock is defined by a transmission of kinetic energy into a system in a short event interval relative to the system's natural period. A steady-state response is not achieved.

How is it measured?
Shock is commonly measured via time histories or shock response spectrum (SRS).

What are Time Histories?
Time histories measure the amplitude and time duration of shock event. They are commonly used for measurement of classical shock pulses (Figure 1), but also are used for transient events as well. Typically, their amplitude is measured in g's and time in

seconds, but one can also measure velocity, displacement, force, pressure, stress or torque.

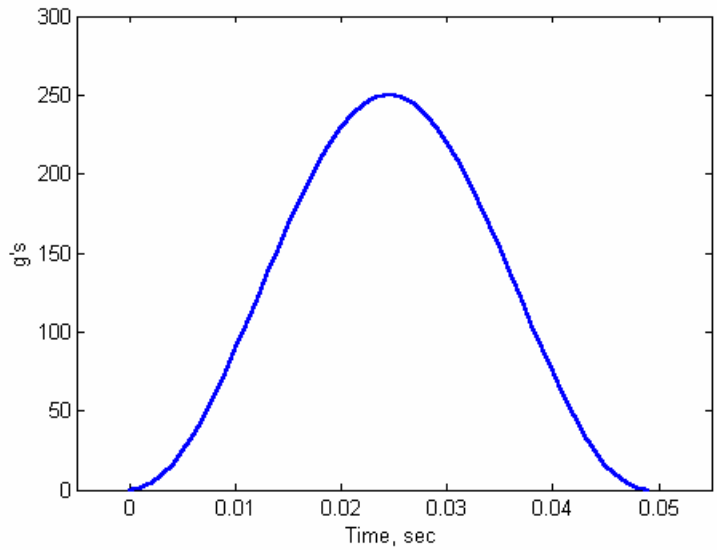

Figure 1 - Classical Shock Pulse

What is the SRS (Shock Response Spectrum)?

A Shock Response Spectrum (SRS) is a plot of the maximum response of a single degree of freedom (SDOF) system, as a function of its natural frequencies, in response to an applied shock input (Figure 2). SRS plots may be expressed in terms of acceleration, velocity or displacement, but commonly are acceleration based. However, a SRS does not uniquely define the shock input, since two different shock pulses can have the same maximum peak response. The maximum of the peaks is only a single point in the time of the response

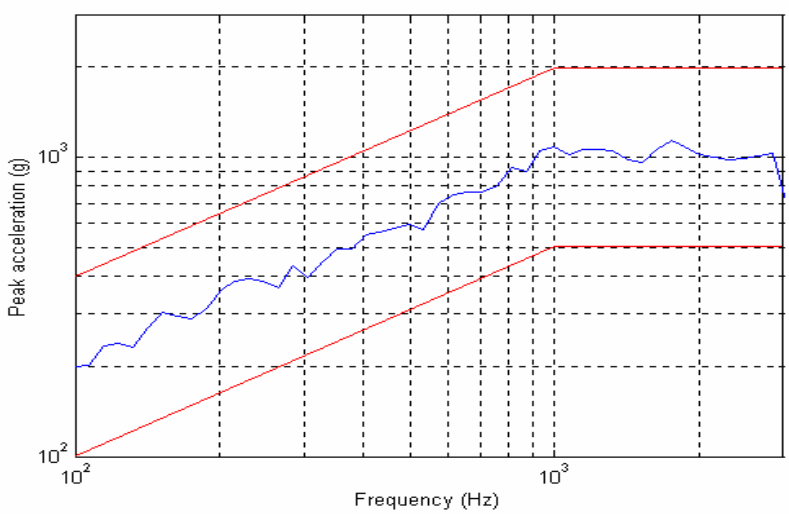

Figure 2 - Shock Response Spectrum (SRS) Plot

The SRS models any complex structure as a set of parallel, SDOF systems as seen in Figure 3.

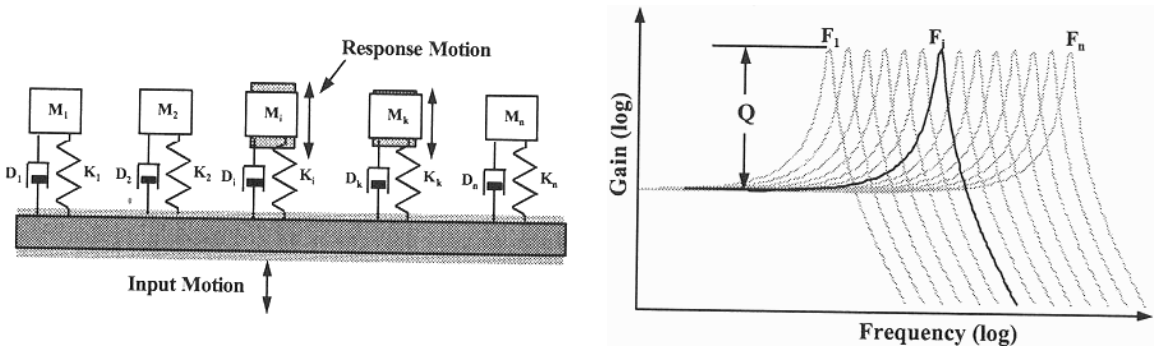

Figure 3 - SRS Representing Multiple SDOF's

The SRS concept has been a very useful tool in engineering design because it provides a consistent way to compare different shock time histories. The assumption inherent in the use of the SRS is that shock events, which have the same response spectra, also have equal damage potential. This allows engineers to perform a shock test in a laboratory before proving the design in a test flight.

What is a Shock Test Specification?

The goal in defining a shock test is to specify a test rationally, with a known level of conservatism that represent a single or composite of measured in service environments. The engineer must determine if the shock test can be modeled as a classical shock or a SRS type shock.

If an SRS is chosen the type of definition must be selected. There are many ways the SRS can be defined. A few are absolute response, relative response, acceleration, velocity, displacement, primary, residual and maxi-max. The 3 most common are:

1) absolute acceleration – Aerospace industry
2) absolute pseudo-velocity – Navy
3) absolute velocity plotted on tripartite paper – Earthquake industry

The maxi-max condition is the envelope of all conditions through the environment. Test tolerances are typically given in ± dB (decibels) value from the nominal test level. The number of test shocks must also be determined. Typically for qualification testing of a product there are three shocks per direction (+/-) per axis (x/y/z) for a total of 18 shocks. For acceptance testing it may be reduced to one shock per direction per axis for a total of only six shocks.

MIL-STD 810 is a good reference for shock testing and definition for both classical and SRS shocks. It is the Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests, which the latest revision being “F”

released January 1, 2000. Other specifications for shocks may come from previous flight or test data, or via analysis.

2) Types of Shocks

There are five classifications of shocks that are described here. They are Classical Shock, Spectrum Shock, Pyroshock, Seismic Shock and Air Blast.

a) Classical Shocks

Classical shocks come in many shapes, and tend to be the most common. They are simple shocks that can be fairly easily reproduced in a test laboratory.

The first is a **half-sine (Haversine)** as seen in Figure 4. It's the most common of all Classical Shocks and resembles a half-sine with rounded beginning and end to make it physically reproducible.

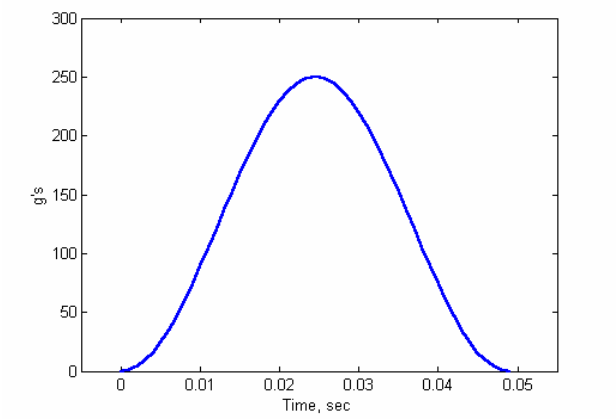

Figure 4 - Half-Sine (Haversine)

Next is the **sawtooth shock** (Figure 5)**,** which resembles a tooth on saw blade. It has a rising slope followed by a sharp drop off. The shock is also specified in MIL-STD-810F. A Sawtooth shock is obtained by dropping a shock table on cylindrical lead pellet with conical top.

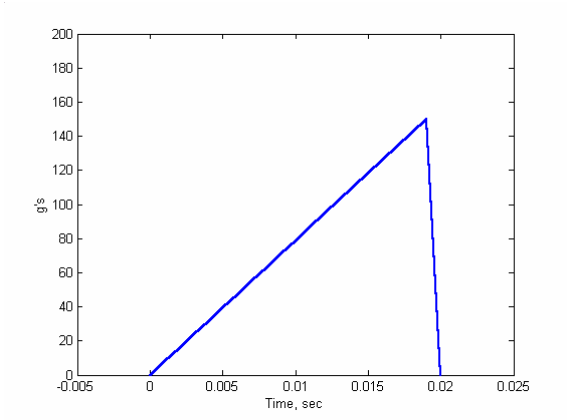

Figure 5 - Sawtooth Shock

Another classical shock is the **triangle shock** (Figure 6). It is similar to a sawtooth; however the drop is not quite as severe. The triangle shock is infrequently used in shock testing.

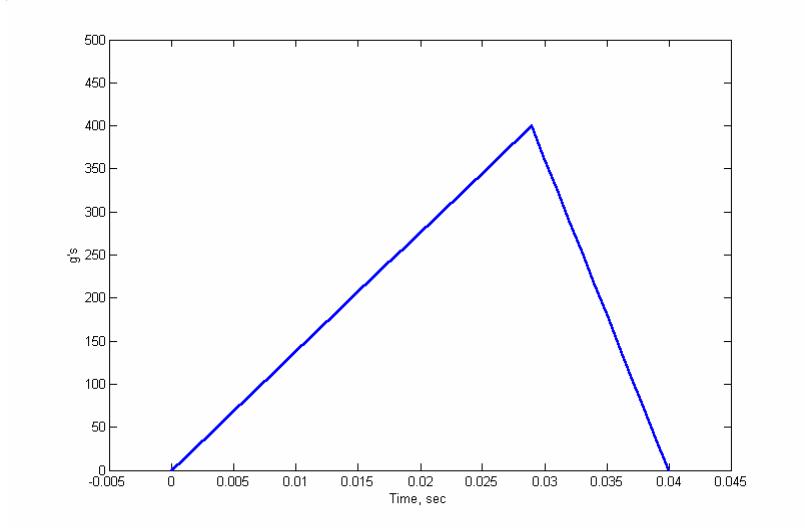

Figure 6 - Triangle Shock

b) Spectrum Shock

A shock response spectrum defined by frequency and acceleration level pairs and uses the SRS for measurement. (Figure 7)

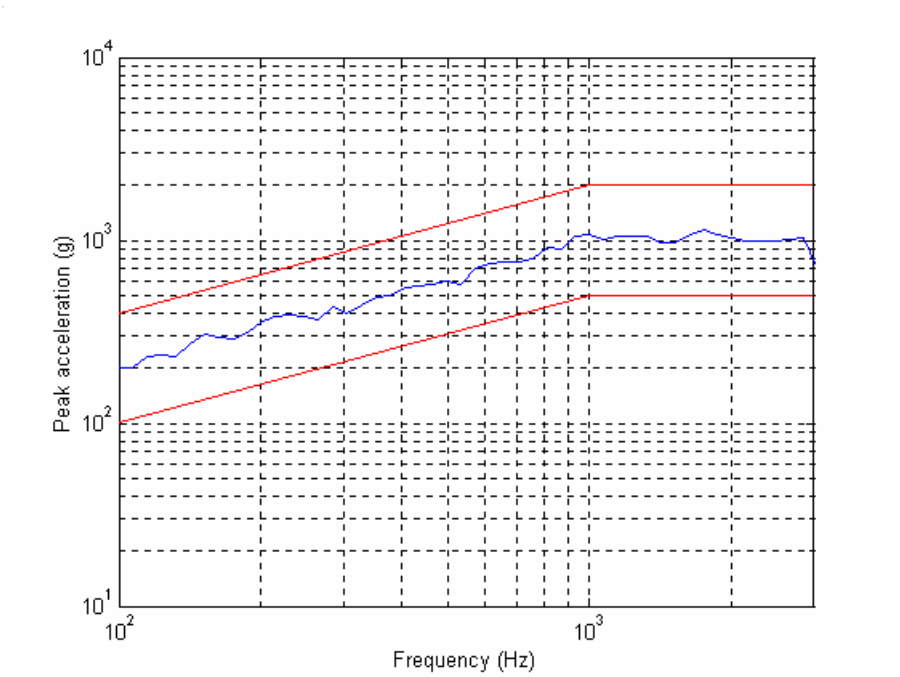

Figure 7 - Shock Spectrum

c) Pyroshock

Pyroshock (Figure 8) is characterized by a high acceleration, short duration shock pulse. This shock oscillates somewhat symmetrically around a zero baseline value, and typically decays in a very short time of less than 20 milli-seconds. Pyroshocks are measured using the SRS (Figure 9).

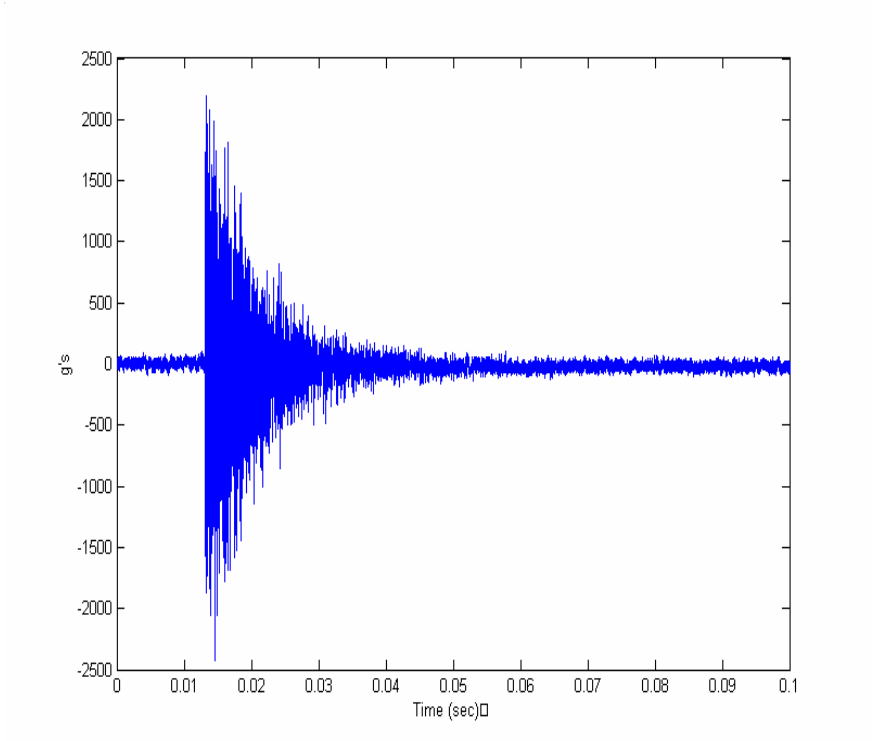

Figure 8 - Pyroshock Pulse Time History

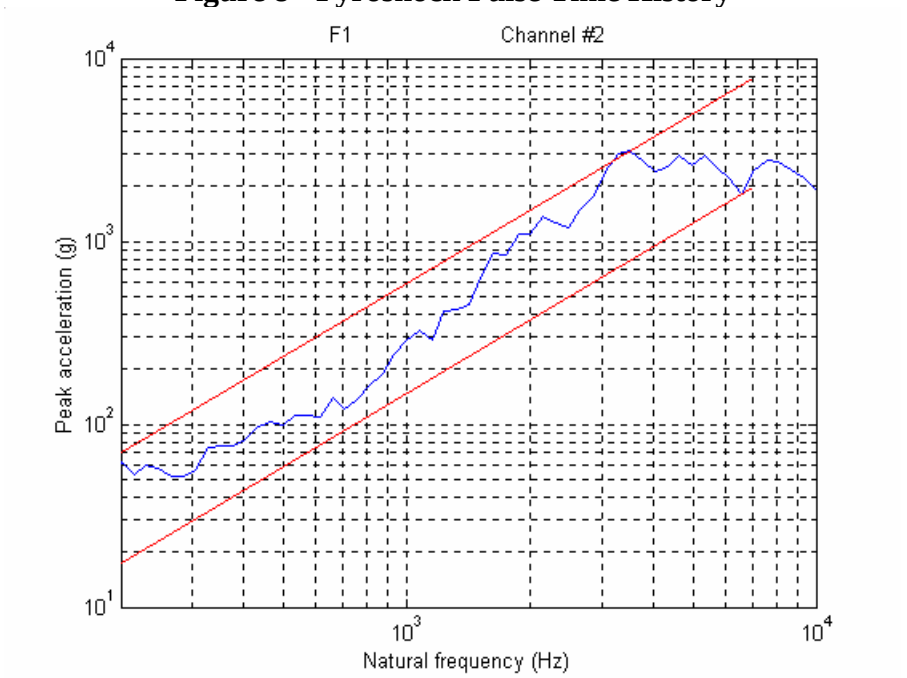

Figure 9 - Pyroshock Shock Response Spectrum

d) Seismic Shock

Seismic shock (Figure 10) is characterized by low acceleration, high displacement, and long time duration.

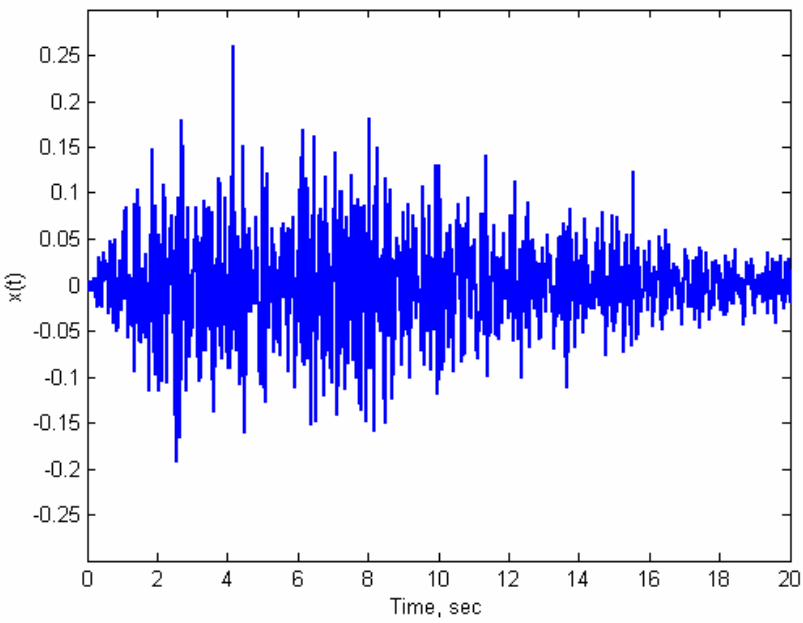

Figure 9 - Seismic Shock Time History

e) Air Blast

Air blast (Figure 11) is characterized by sharp rise and longer decay than a pyroshock. A photo of an airblast shock wave is seen in Figure 12.

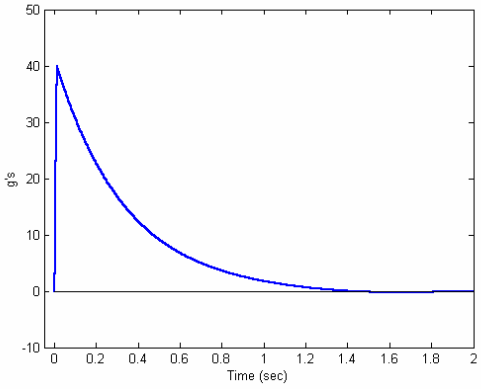

Figure 10 – Air blast

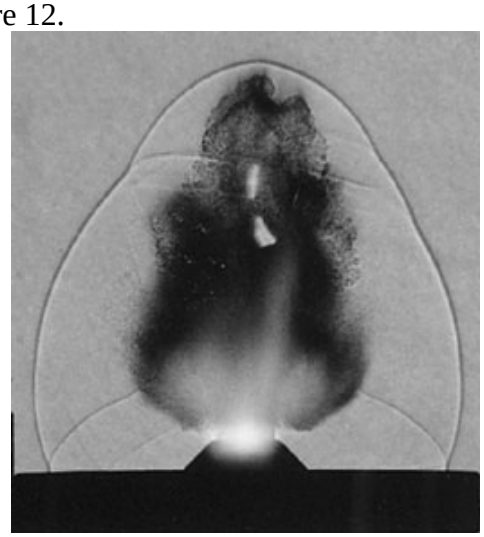

Figure 11 - Photo of Air Blast Shock Waves

3) Sources of Shocks

There are three main sources for shock events. They are pyrotechnic excitation, mechanical excitation and natural phenomena. All of these shock events commonly occur in the aerospace applications as well as the rest of the world.

1) Pyrotechnic Excitation

a. Point Sources (explosive bolts, pin pullers)
b. Line Sources (linear shape charges, detonating chords)

Figure 13 is a sequence of photos of a **launch vehicle stage separation** test. The pyrotechnic excitation source is a linear shape charge.

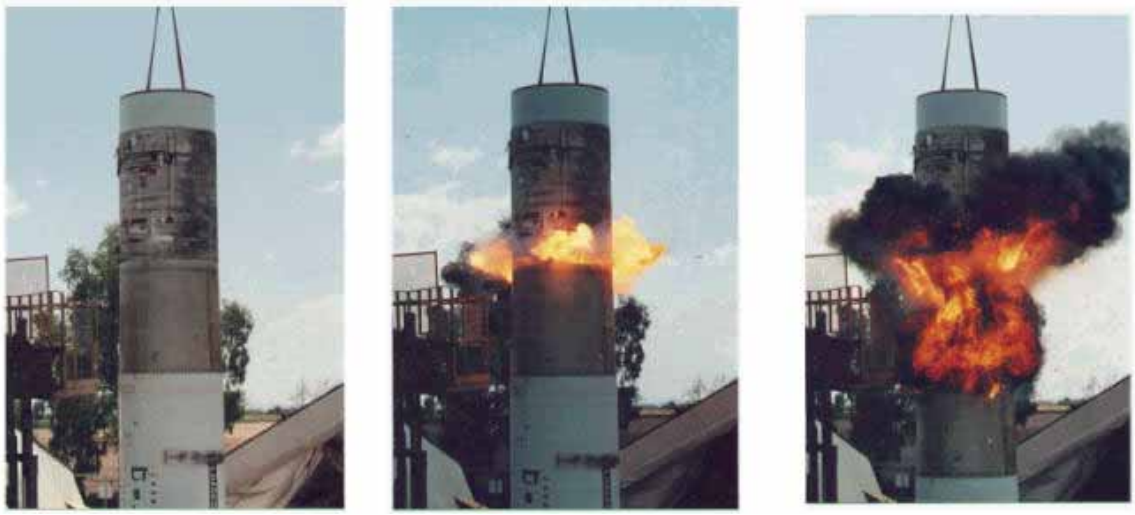

Figure 12 - Launch Vehicle Stage Separation (Photo from Vibrationdata.com)

2) Mechanical Excitation

a. Collision impact
b. Handling / drop
c. Evasive maneuvers in aircraft or missiles (gust loading)
d. Ballistic impact
e. Aircraft landing
f. Braking
g. Missile / Rocket launching
h. Gunfire
i. High-speed fluid entry
j. Transportation, uneven surfaces, rough terrain

3) Natural Phenomenon

a. Earthquake
b. Wind gust
c. Air blast
d. Ocean waves
e. Ice impact

4) Shock Testing Methods

Shock testing is commonly performed via the following methods. Each method imparts the kinetic energy to the system in a different manner.

- Drop
- Hammer / Impact
- Shaker (Electrodynamic / Hydraulic)
- Pyroshock
- Hopkinson Bar

In drop testing $\Delta V \neq 0$ (change in velocity) and $\Delta d \neq 0$ (change in displacement), while others maintain zero overall change in velocity and displacement

a) Drop Shock

During drop shock the test item is moving towards an impact surface. It is usually free-fall or an assisted (pulled by a bungee-cord) fall. There is a massive target surface and a shock programmer (target surface) that determines the pulse shape, peak acceleration and duration. The drop height and assist method determine the impact velocity. Typically, there is very little energy outside the pulse bandwidth. Drop shock is performed by general-purpose machines (Figure 14). They are capable of large ΔV (changes in velocity) and large Δd (changes in displacement). A drop shock machine is typically used for producing simple (Classical) pulses shapes.

Figure 13 - Large Drop Shock Machine (Courtesy of Wyle Labs)

b) Hammer / Impact Testing

The US Navy prescribes testing to simulate severe but non-lethal, non-contact underwater explosions. These shock tests are categorized by light-weight, medium-weight and heavy-weight machines depending on the size of the test article.

The light-weight machine (Figure 15) is a pendulum hammer that strikes an anvil plate to which specimen is attached. The medium-weight machine is pendulum hammer that strikes a group of steel channels that are attached to an anvil plate. The anvil plate is allowed to move up to 3" before being stopped by a retaining ring. The heavy-weight machines are floating barges where the specimen is located and explosive charges are set off underwater at prescribed distances away from the barge

Figure 14 – Light-Weight Shock Machine (Courtesy of Wyle Labs)

c) Shaker Testing

An electrodynamic shaker is also used for shock testing (Figure 16). These shakers are capable of performing both classical and SRS shocks. However, they are limited to shaker velocity, force and displacement capabilities. Shaker shock is used for shock pulses less than 3000 Hz, typically. These shock pulses can be controlled within test tolerances better than other methods due to control system and shaker setup of allowing pre-test levels

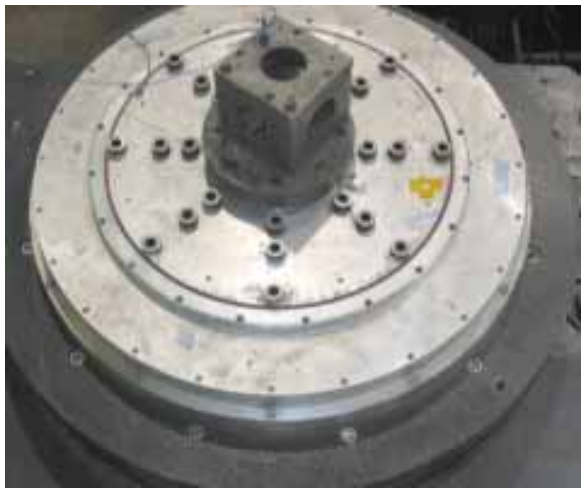

Figure 15 - Shaker Setup for Shock Testing (Courtesy of Wyle Labs)

d) Pyroshock

Pyroshocks are caused by explosive devices or propellant-activated devices releasing stored strain energy. The input is highly localized and has a short time duration of less than 20 milli-seconds (0.002 seconds). They typically have high acceleration levels (100~200,000 g) and high frequency content (100Hz~1MHz) while being very lightly damped. Characteristics of pyroshock vary greatly with distance from shock event (near-field, mid-field and far-field pyroshock)

- Near-field
  - within 6 inches of source
  - materials stress waves dominate response
  - peak accelerations greater than 5000 g's and contains frequency content up to and above 1 MHz
  - very difficult to measure due to instrumentation limitations
- Mid-field
  - 6–24 inches from source
  - peak accelerations greater than 1000 g's and contains frequency content up to and above 10 KHz
- Far-field
  - greater than 24 inches from source
  - low g levels and frequencies usually less than 10KHz

During pyroshock testing, energy is imparted in all directions. There is also very little rigid body motion of a structure in response to pyroshock. The analysis of the shock is measured using a SRS, not the time history of shock. Damping of the SRS model is held at 5% or Q=10 and the results are plotted on log-log paper and typically is terms of acceleration vs. frequency. Pyroshock testing rarely causes structural failure, more frequently is causes failure in electronic components (eg. relay chatter, short circuits, and circuit board failures).

e) Hopkinson Bar

A Hopkinson Bar utilizes controlled projectile impacts on the end of a metallic bar and a stress wave of know magnitude then propagates through the bar. This provides extremely high g levels. The unit under test is at the end of the bar and experiences high accelerations and rapid rise time stress when the shock wave arrives. This method is also used in calibration of accelerometers.

5) Example Failures

Following is a list of some examples of various types of failures that can occur from shocks during the service life of an aerospace component.

a) Broken electronics

- shattering of crystals
- solder joints break
- relay chatter / transfer
- computer hard drives lock up
- broken wires or leads
- cracked glass
- blown fuses

b) Contamination

- broken material lodging in valve
- seal failure

c) Structural failures

- cracked housings
- fatigue cracks and failures
- deformation of structural elements

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