V-BAND SEPARATION SOURCE SHOCK SCALING

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January 18, 2008

Introduction

V-band Source Energy

A spacecraft is typically mounted to its launch vehicle via V-band, or some similar type of clamp-band. In addition, a V-band may be used to connect two adjacent cylindrical modules.

The V-band consists of two semi-circular halves. These segments are fastened by two bolts, each 180º apart. The V-band and the bolts have initial strain energy. Each bolt is mounted with a pressure cartridge device, which has potential energy in the form of a chemical charge. The charge is initiated by an electrical signal, creating a pressure pulse which drives a chisel blade into the adjacent bolt. Each bolt snaps, resulting in the sudden release of the V-band's strain energy. The V-bands react by flying outward from the vehicle.

These steps do no occur in an ideal thermodynamic manner. At each step, high-frequency pyrotechnic shock energy is release as an unwanted by-product. This high-frequency energy can damage sensitive electronic components. For example, crystal oscillators may shatter and mechanical relays may chatter.

Design and Test Levels

Avionics components must be designed and tested to withstand this pyrotechnic shock energy.

Ground tests must thus be performed to measure the source shock and the resulting shock levels at the avionics mounting locations. The avionics components should be represented by mass simulators.

The ground test levels can later be compared to flight accelerometer data, although the telemetry bandwidth may limit the accelerometer sample rate. This in turn limits the upper frequency of the shock data.

Preliminary Estimates of the V-band Source Shock

Preliminary estimates of the source shock may be needed, however, before any ground test or flight data can be collected. There is some generic data in Reference 1 for "Bolt-Cutters," which presumably represents V-band/bolt-cutter systems, but the data is poorly documented. Furthermore, this data cannot be readily extrapolated for variations in diameter or the preload.

The purpose of this report is to develop a method for estimating the source shock based on published data for V-band systems. This method will account for diameter, although not for preload.

Background Data

Spacecraft separation shock levels are used as a reference, where the separation device is a V-band.

This data is taken from Atlas, Delta and Minotaur launch vehicles. The data is specifically taken from the respective payload user's guides and related documents that are readily available on the Internet.

Note the following for the reference levels:

1. The shock response spectrum (SRS) is given.
2. The V-band diameter is known.
3. The Initial tension load in each V-band is unknown.
4. The amount of safety margin in each level is unknown.
5. The consideration given to the mass-loading or impedance effects of the spacecraft is unknown.

The SRS source levels are given in Appendices A through C. These levels are either acceptance test levels or maximum predicted environment (MPE) levels.

<u>Estimation Method</u>

Knee Frequency

Each of the reference SRS levels has a ramp and a plateau. The knee frequency tends to be nearly the same as the ring frequency.

The ring frequency corresponds to the mode in which all points move radially outward together and then radially inward together. The formula for the ring frequency is given in Appendix D.

The V-band separation certainly has the potential of exciting the ring mode. Ground test data shows that there may be numerous bending modes which have their respective modal frequencies near the ring modal frequency. The response at the knee frequency thus appears to be driven by the combination of the ring mode and bending modes near the ring modal frequency. Note that a similar effect occurs in vibroacoustics.

As a rule-of-thumb, estimate the knee frequency to be the same as the ring frequency.

Plateau Amplitude

Next, estimate the acceleration of the knee frequency based on the pseudo velocity levels at the knee frequencies of the published spacecraft levels. Note that the pseudo velocity is equal to the acceleration divided by the natural frequency in radians per second. This frequency is usually represented as ω_n.

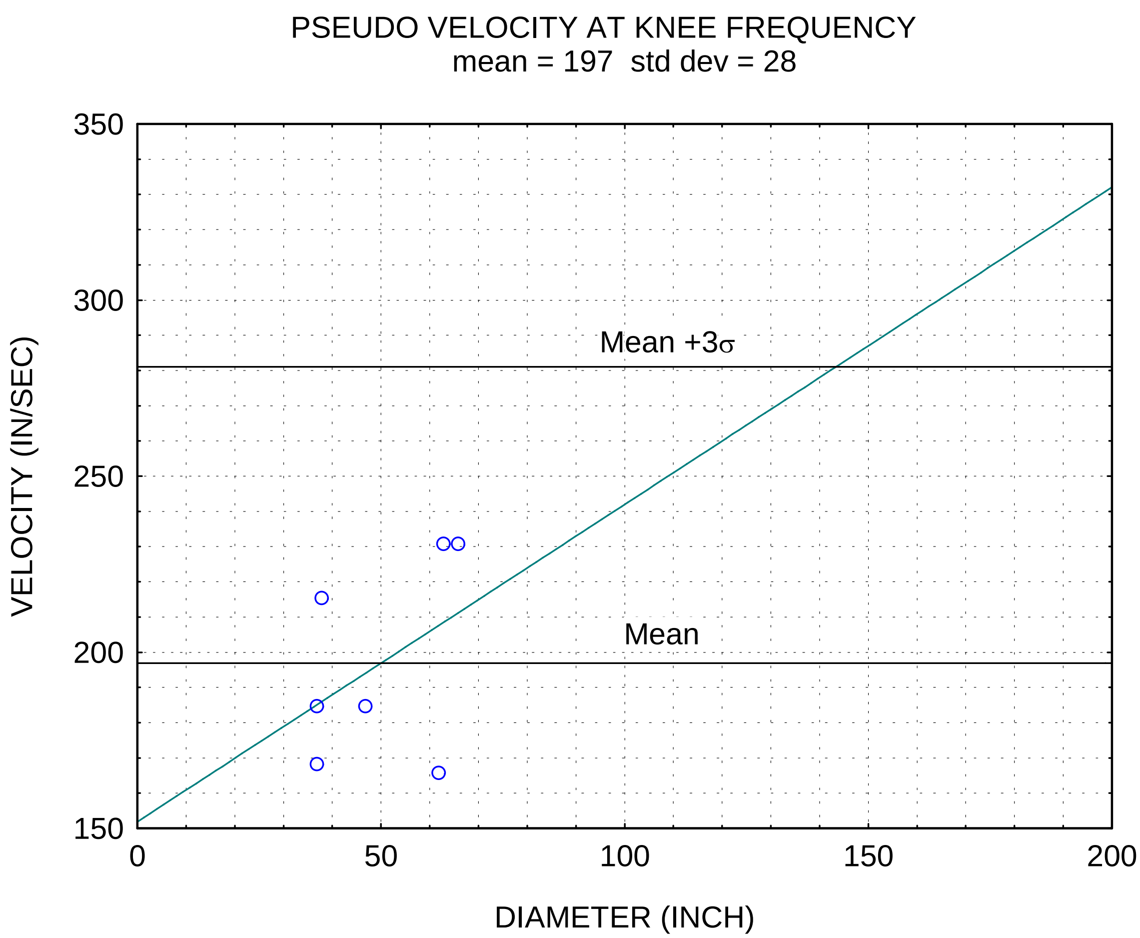

Figure 1.

The pseudo velocity values for the respective knee frequencies are shown as a function of diameter by the circular markers in Figure 1. The values are taken from Appendices A through C.

There is significant variation, perhaps due to differing methodologies in terms of safety factor.

The data seems to indicate that the pseudo velocity tends to increase with diameter, but this may be misleading due to limited data.

The first order trend equation is:

$$\text{pseudo velocity} = (\, 0.901 \,)(\text{diameter}) + 152 \quad \text{(in/sec)}$$

Furthermore, the mean + 3σ value is 281 in/sec.

The next step is thus to estimate the pseudo velocity using the curve in Figure 1.

The pseudo velocity and the knee frequency together determine the acceleration of the plateau.

Note that the acceleration is equal to the pseudo velocity multiplied by ω_n .

Ramp Slope

The final step is to select the slope of the ramp using the reference data in the appendices. The slope values vary from 7 to 11 dB/octave.

<u>Example</u>

A V-band is considered for connecting two cylindrical modules. Each has a diameter of 153 inch. Each module is aluminum. A preliminary estimate of the source SRS is needed for a trade study.

Assume that the spacecraft separation levels in the appendices can be applied to the stage separation of two modules.

The source SRS is estimated as follows:

1. The ring frequency is 421 Hz, as calculated using the formula in Appendix A. Set the knee frequency at this value.

2. Select a pseudo velocity of 292 inch/sec using the trend curve in Figure 1. (This value is slightly higher than the mean +3σ value.) The equivalent acceleration at the knee frequency is 2000 G. Use this acceleration for the plateau.

3. Select a ramp slope of 10 dB/octave.

The resulting SRS is shown in Figure 2.

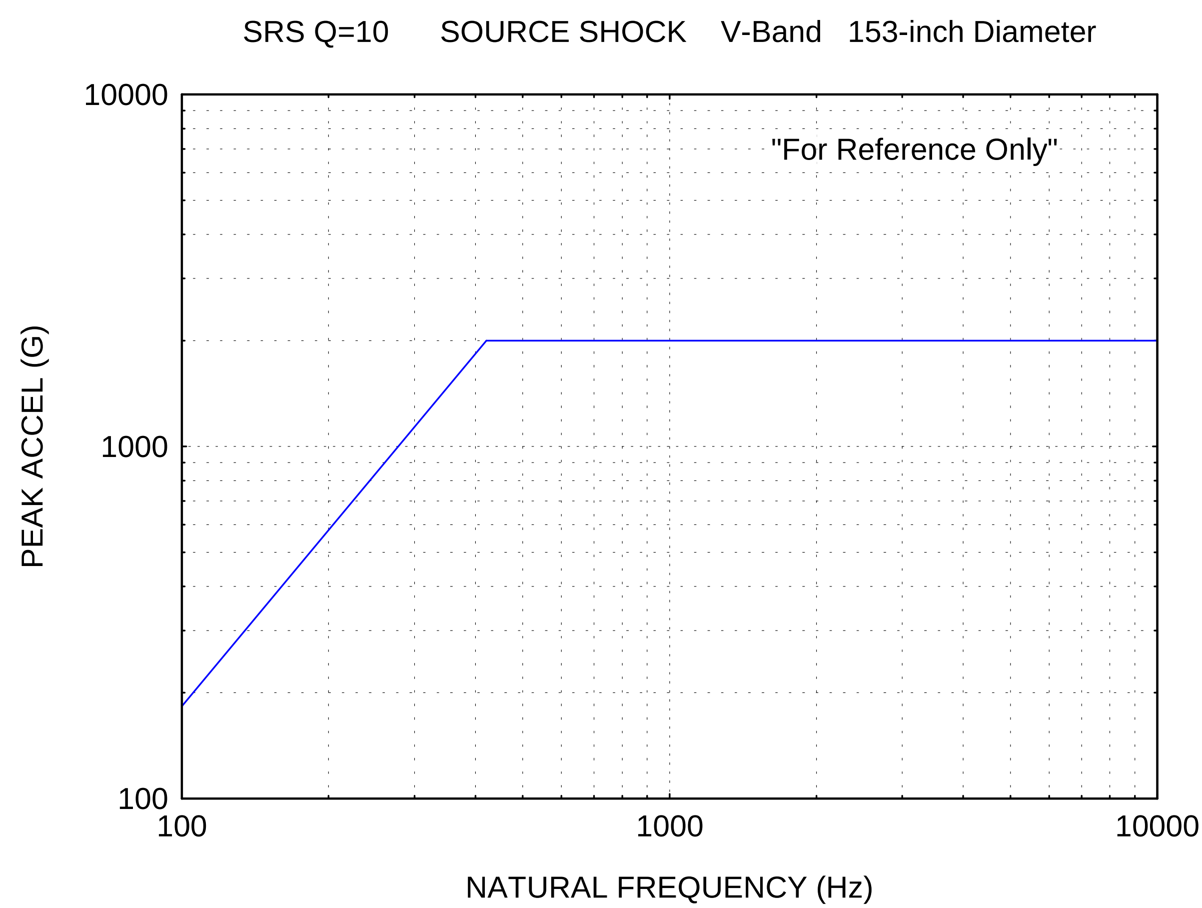

Figure 2.

Table 1. SRS Q=10, Source Shock, V-Band, 153-inch Diameter	
Natural Frequency (Hz)	Peak Accel (G)
100	183
421	2000
10000	2000

References

1. W. Kacena, M. McGrath, A. Rader; Aerospace Systems Pyrotechnic Shock Data, Vol. VI, NASA CR 116406, Goddard Space Flight Center, 1970.

2. T. Irvine, Ring Vibration Modes, Revision A, Vibrationdata, 2004.

3. T. Irvine, The Pseudo Velocity Shock Response Spectrum, Vibrationdata, 2007.

4. General Environmental Verification Specification for STS & ELV Payloads, Subsystems, and Components Rev A, NASA Goddard Space Flight Center, June 1996. See Appendix C.

5. Delta II Payload Planners Guide, Boeing, July 2006. See Figures 4-25 & 4-26.

6. Minotaur User's Guide, Release 2.0, Orbital Sciences Corporation, October 2004.

7. Minotaur IV User's Guide, Release 1.1, Orbital Sciences Corporation, October 2006.

APPENDIX A

ATLAS Spacecraft V-band Separation

66 inch Diameter

The pseudo velocity at the knee frequency is 230.5 inch/sec.

The initial slope is 7.1 dB/octave.

Table A-1. SRS Q=10, Atlas, 66 in Diameter	
Natural Frequency (Hz)	Peak Accel (G)
100	150
800	3000
3000	3000

47 inch Diameter

The pseudo velocity at the knee frequency is 184.4 inch/sec.

The initial slope is 8.5 dB/octave.

Table A-2. SRS Q=10, Atlas, 47 in Diameter	
Natural Frequency (Hz)	Peak Accel (G)
100	100
1500	4500
3000	4500

37 inch Diameter

The pseudo velocity at the knee frequency is 184.4 inch/sec.

The initial slope is 10 dB/octave.

Table A-3. SRS Q=10, Atlas, 37 in Diameter	
Natural Frequency (Hz)	Peak Accel (G)
100	50
1500	4500
3000	4500

APPENDIX B

DELTA Spacecraft V-band Separation

63 inch Diameter

The pseudo velocity at the knee frequency is 230.5 inch/sec.

The initial slope is 9.9 dB/octave.

Table B-1. SRS Q=10, Delta, 63 inch Diameter	
Natural Frequency (Hz)	Peak Accel (G)
100	100
800	3000
3000	3000

37 inch Diameter

The pseudo velocity at the knee frequency is 168 inch/sec.

The initial slope is 10.8 dB/octave.

Table B-2. SRS Q=10, Delta, 37 inch Diameter	
Natural Frequency (Hz)	Peak Accel (G)
100	40
1500	4100
3000	4100

APPENDIX C

MINOTAUR Spacecraft V-band Separation

38 inch Diameter

The pseudo velocity at the knee frequency is 215.1 inch/sec.

The initial slope is 10.9 dB/octave.

Table C-1. SRS Q=10, Minotaur 1, 38 inch Diameter	
Natural Frequency (Hz)	Peak Accel (G)
100	55
1000	3500
10000	3500

62 inch Diameter

The pseudo velocity at the knee frequency is 165.5 inch/sec.

The initial slope is 10 dB/octave.

Table C-2. SRS Q=10, Minotaur 4, 62 inch Diameter	
Natural Frequency (Hz)	Peak Accel (G)
100	50
1300	3500
10000	3500

APPENDIX D

Ring Frequency

Consider a ring with a rectangular cross section and with completely free boundary conditions.

The ring frequency corresponds to the mode in which all points move radially outward together and then radially inward together. This is the first extension mode. It is analogous to a longitudinal mode in a rod.

The ring frequency f_r is the frequency at which the longitudinal wavelength in the skin material is equal to the vehicle circumference.

$$f_r = \frac{C_L}{\pi d} \tag{D-1}$$

where

C_L is the longitudinal wave speed in the skin material

d is the diameter

Note that the wave speed can be calculated from the elastic modulus E and mass density μ.

$$C_L = \sqrt{\frac{E}{\mu}} \tag{D-2}$$

The longitudinal wave speed in aluminum is approximately 16,700 feet per second.

Thus the ring frequency for aluminum is

$$f_r = \frac{5316 \ \text{ft Hz}}{d} \tag{D-3}$$

$$f_r = \frac{63{,}790 \ \text{in Hz}}{d} \tag{D-4}$$

Note that the ring frequency mode is a higher mode. It occurs at a much higher frequency than the first few bending modes.