

Equivalent Bench Handling Shock Response Spectrum Revision A

By Tom Irvine
Email: tomirvine@aol.com

July 25, 2005

Introduction

An electronic component may be subjected to mechanical shock if it is mishandled during assembly, test, or maintenance. A component dropped a few inches onto a hard surface may experience a shock level of several hundred Gs.

MIL-STD-810F specifies a test method for bench handling shock, as shown in Appendix A. The method requires dropping the component onto a hardwood table.

The purpose of this analysis is to determine an equivalent shock response spectrum test for bench handling, as an alternate test method.

The alternative method may be useful for evaluating a component which has been previously tested to some shock response spectrum level, but which has not been subjected to an actual bench test. In some cases, the previous shock response spectrum test may be sufficient to cover the bench test requirement.

Assumptions

1. A sample circuit board is analyzed via a finite element model.
2. The housing is not modeled because it is assumed to be perfectly rigid.
3. The circuit board is fixed at each corner.
4. The dimensions are: 3 in x 3 in x 0.063 in.
5. The mass is uniformly distributed.
6. Three configurations are analyzed, with the mass and stiffness properties shown in Table 1.
7. Three analyses are performed: rigid-body drop, normal modes, & modal transient.
8. The bench shock is treated as an initial velocity problem for the transient analysis.
9. The drop configuration is per the MIL-STD-810F requirement given in Appendix A.
10. The box housing remains fixed to the ground plane after it impacts this plane; the circuit board vibrates freely at its natural frequencies immediately thereafter.
11. The response is linear.
12. The amplification factor is $Q=10$ for all modes.
13. The peak relative displacement is the intermediate metric of interest based on Steinberg's formula in Reference 1 for circuit board shock.

14. The relative displacement is significant when the initial velocity field is normal to the board, but is insignificant otherwise.
15. An assessment of the probability that an avionics component will actually experience the bench shock described in MIL-STD-810F is beyond the scope of this analysis.

Results

Bench shock tests have been performed on certain avionics components in References 2 through 4. Accelerometers were mounted on the housings of the components, but not on any internal circuit boards or battery cells.

An intermediate objective of this analysis is to analyze sample models of circuit boards to determine each board's response to initial velocity shock. The results are briefly compared with the housing measurements in References 2 through 4, in terms of shock response spectra.

Again, the bench shock is treated as an initial velocity problem. The initial velocity is calculated using the method in Appendix B. The initial velocity varies linearly from zero at the hinged end to 68 in/sec at the free end.

The analytical results for the sample circuit boards are given in Table 2.

Table 1. Properties for Each Model				
Model	Model Name	Elastic Modulus (psi)	Total Mass (lbm)	Fundamental Frequency (Hz)
1	Bench5_velox.nas	2.0e+06	0.056	287
2	Bench5b_velox.nas	8.0e+06	0.056	574
3	Bench5c_velox.nas	8.0e+06	0.22	287

The models represent sample circuit boards.

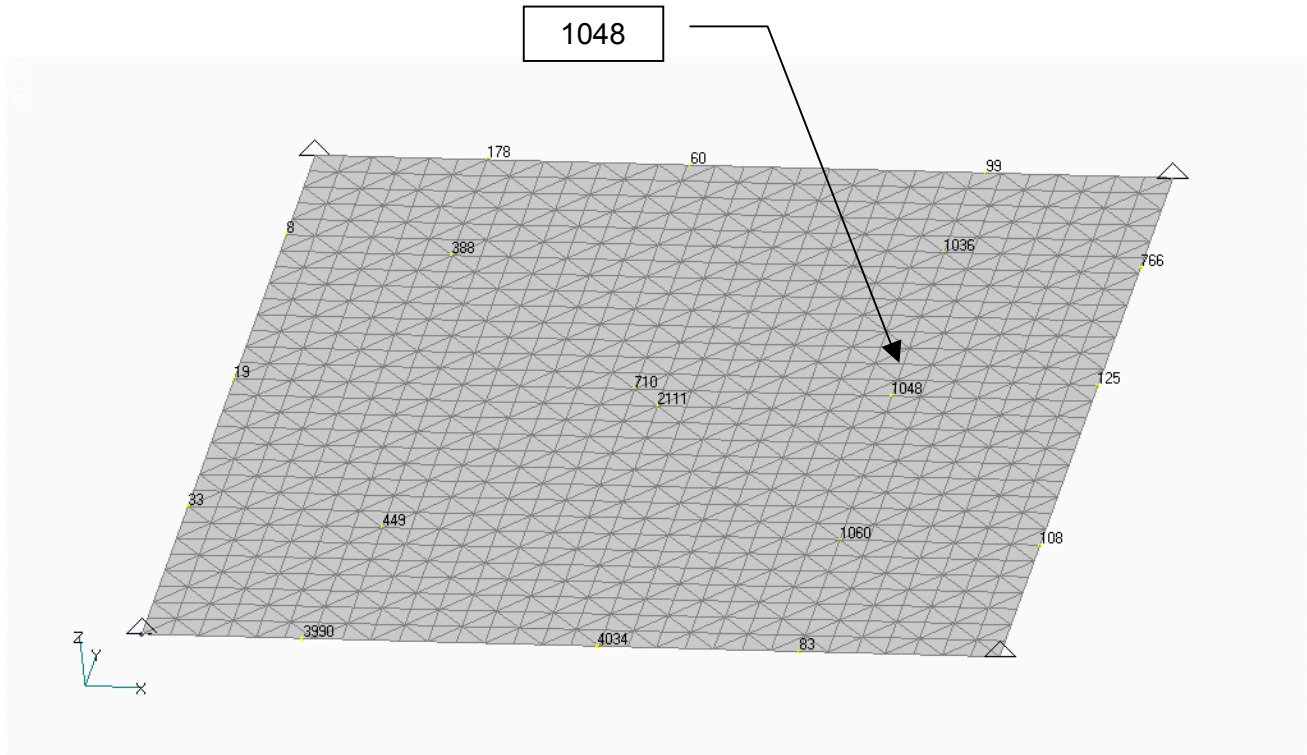


Figure 1. Model 1, Undeformed Model

The rigid-body calculation precedes the modal transient analysis. The rigid-body calculation in Appendix B is used to calculate the initial velocity.

For the rigid-body problem, the left edge is the hinged end. The right edge is the raised, free end.

For the transient analysis, the initial velocity on the left edge was zero. The initial velocity increased from left to right, reaching its maximum of 68 in/sec at the right edge.

The maximum relative displacement occurred at node 1048 for each model.

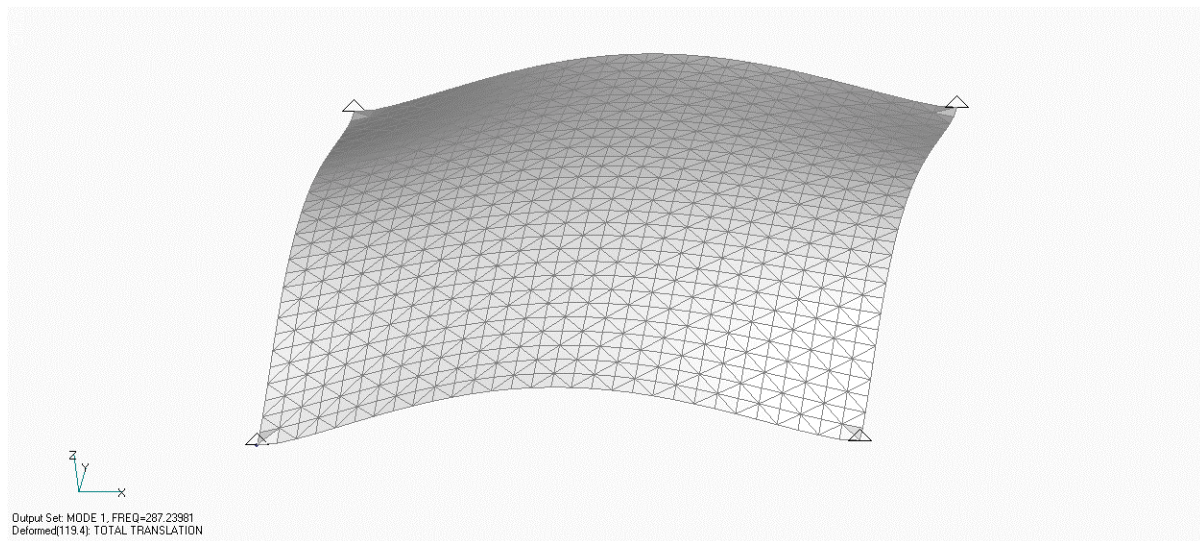


Figure 2. Model 1, Mode 1, Freq = 287 Hz

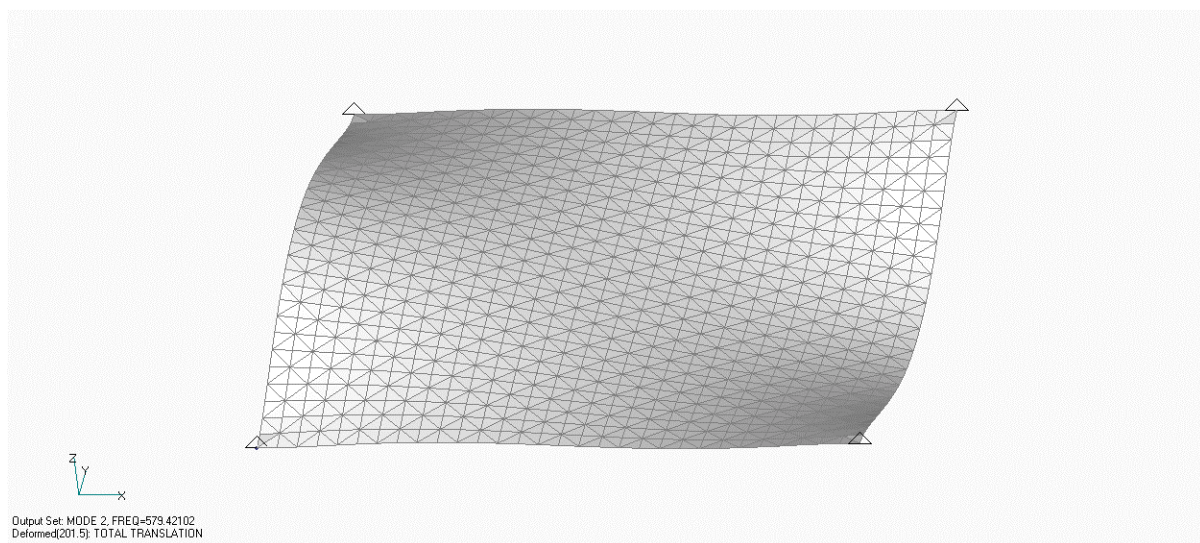


Figure 3. Model 1, Mode 2, Freq = 579 Hz

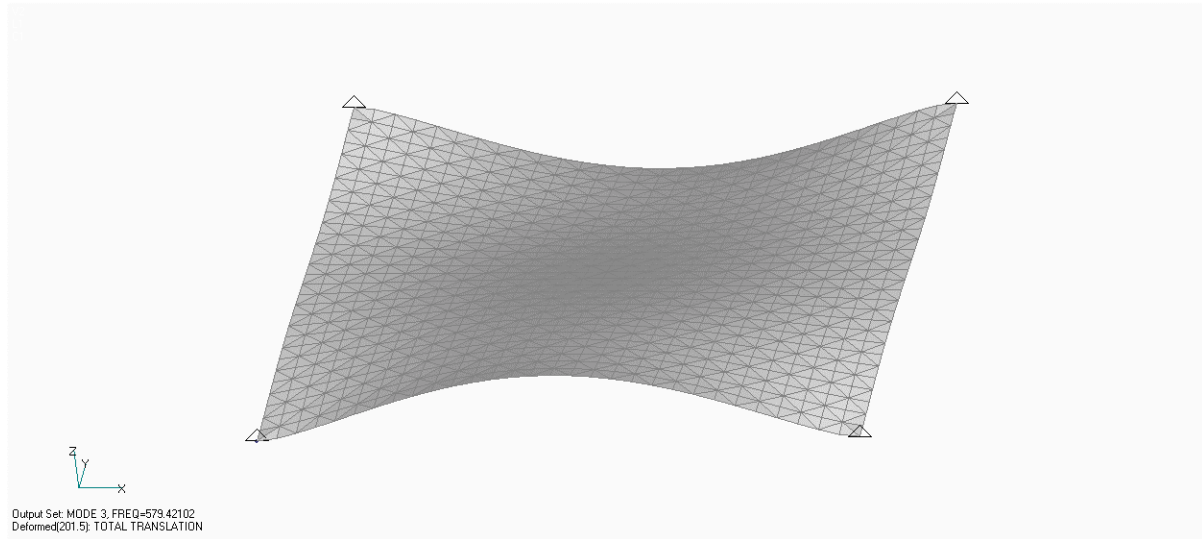


Figure 4. Model 1, Mode 3, Freq = 579 Hz

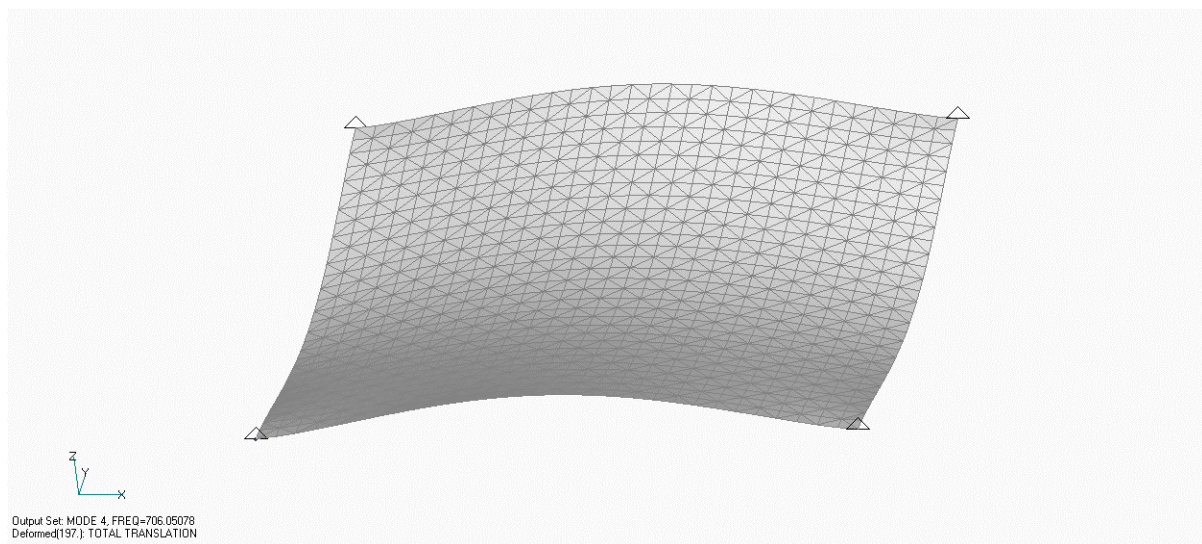


Figure 5. Model 1, Mode 4, Freq = 706 Hz

Note that the mode shapes for each model were qualitatively similar for a given mode number.

Table 2. Transient Response Results			
Model	Natural Frequency (Hz)	Peak Displacement Response (in)	Equivalent Peak Acceleration (G)
1	287	0.024	200
2	574	0.012	397
3	287	0.024	200

Notes:

1. The peak displacement is the maximum for 19 sample locations.
2. The fundamental frequency is the dominant frequency in the displacement response.
3. The absolute and relative displacements are the same.
4. The peak acceleration is equal to the peak relative displacement times ω_n^2 , as an approximation.
5. The displacement response depends on the natural frequency but not directly on either the stiffness or mass alone.
6. The ratio of peak acceleration to frequency is 0.70 G/Hz for each case.

The relative displacement time histories for node 1048 are plotted in Figures 6 through 8 for the three models.

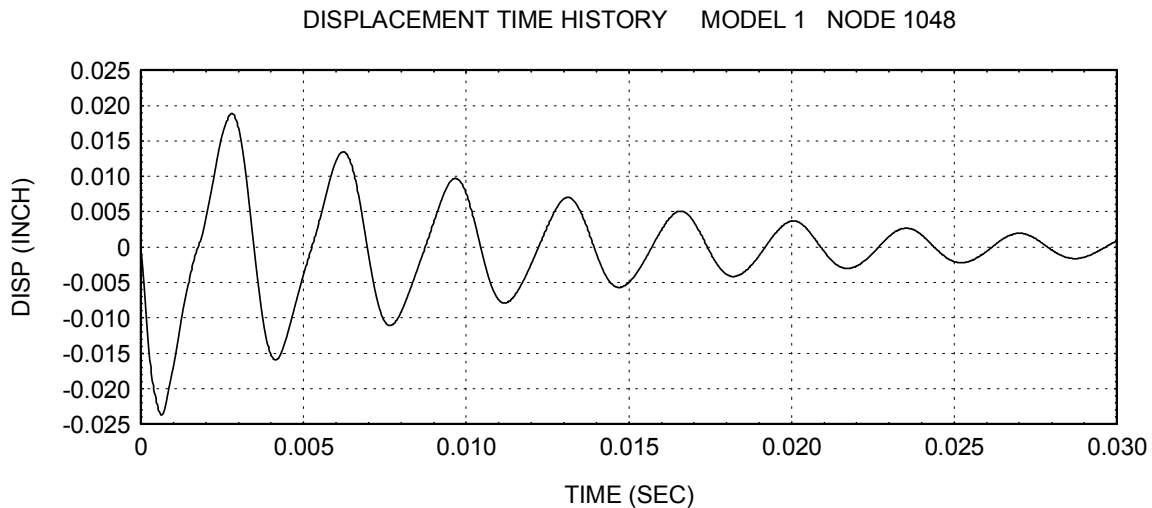


Figure 6.

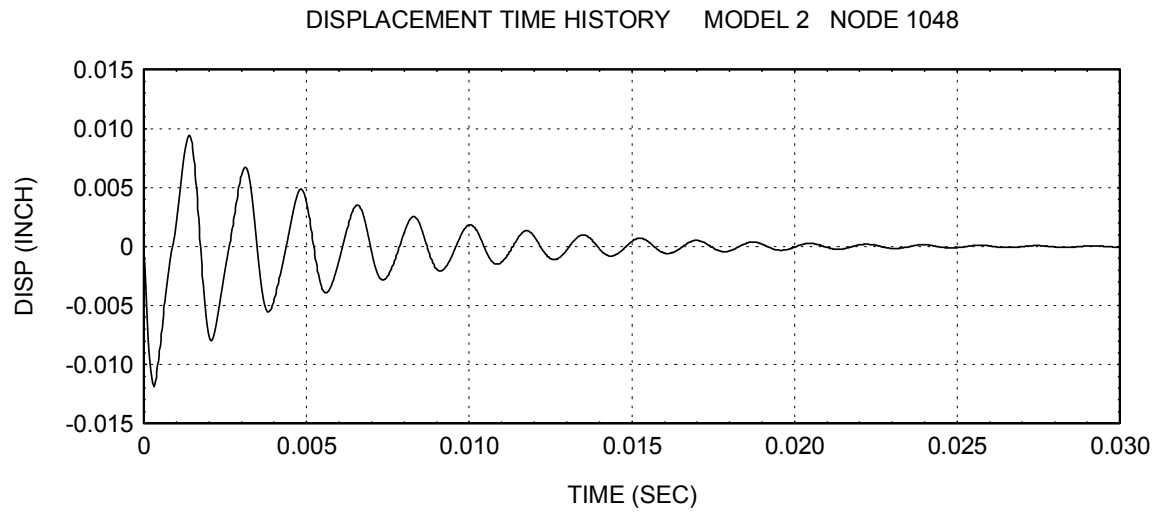


Figure 7.

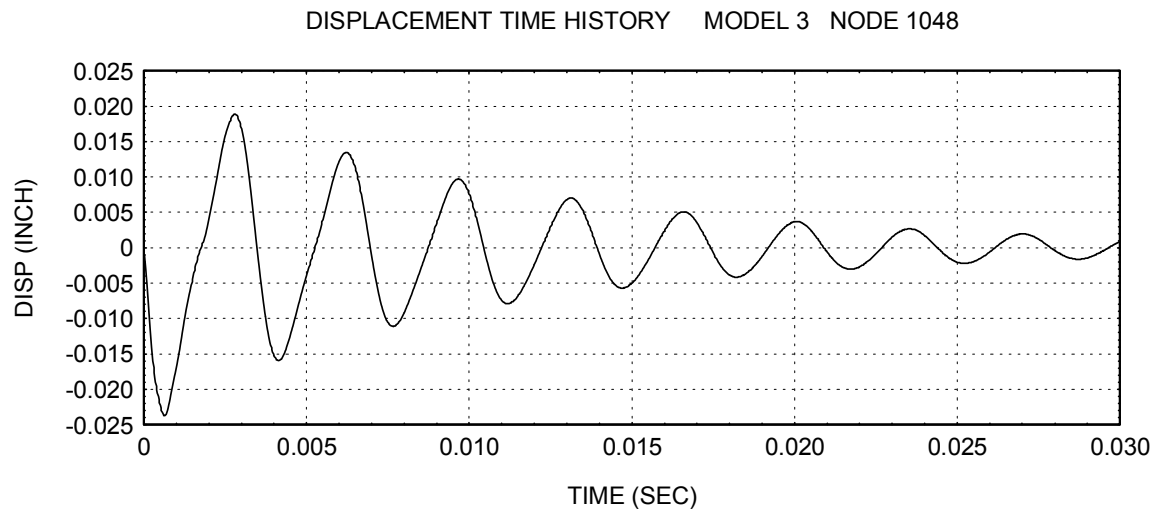


Figure 8.

Sample Equivalent Shock Specification

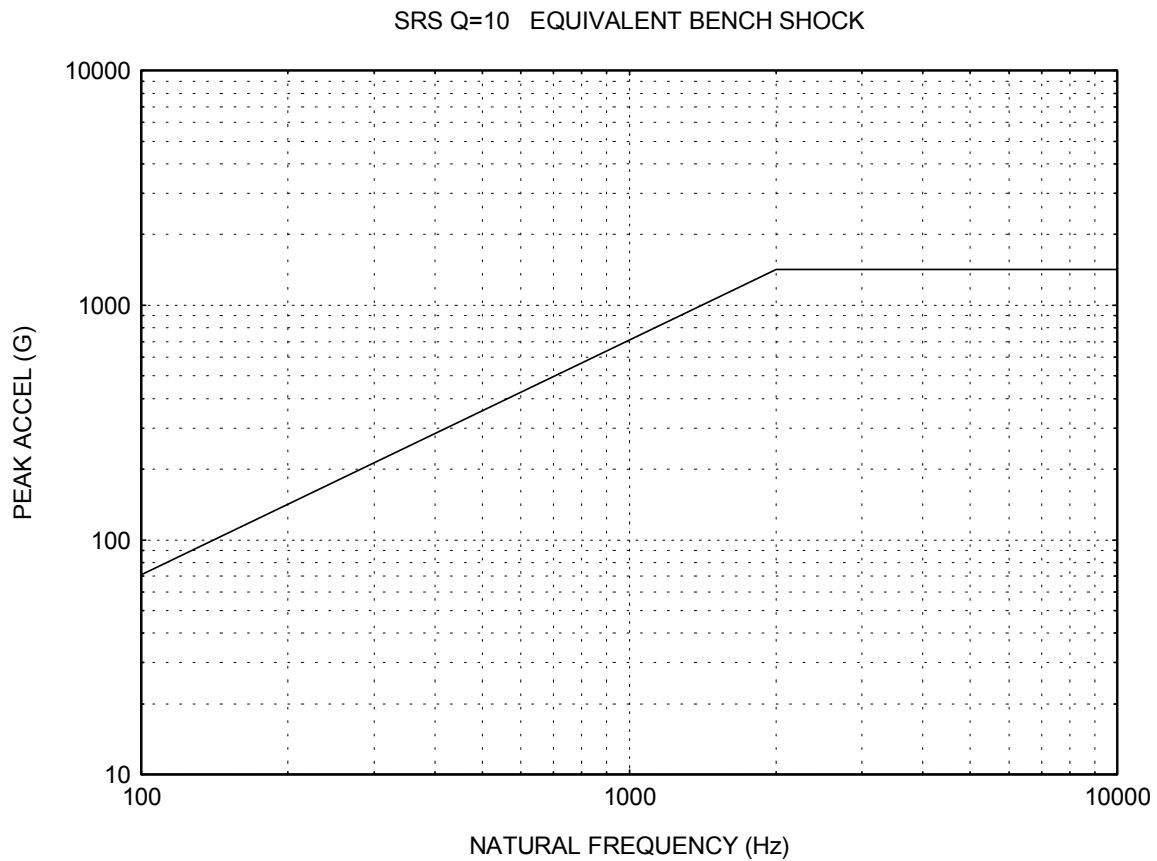


Figure 9.

Table 3. SRS Q=10, Equivalent Bench Shock Qualification, 3 shock per axis	
Natural Frequency (Hz)	Peak Accel (G)
100	70
2000	1400
10000	1400

The equivalent bench qualification shock level is shown in Figure 9. The ramp is taken from the response acceleration levels in Figure 2. It is given a flat plateau beginning at 2000 Hz with the assumption that any natural frequencies above 2000 Hz make only a minor contribution to the relative displacement.

Only three shocks per axis are specified because avionics components are used for a single flight. On the other hand, MIL-STD-810F requires additional shocks because it is intended for components that require periodic maintenance.

Comparison with Measured Data

The specification in Figure 9 tends to envelop the measured levels in Reference 2 except that the measured levels have some excursions at frequencies above 2000 Hz.

The specification in Figure 9 has good agreement with the measured levels in Reference 3.

The specification was not necessarily intended to fully envelop the measured data. Among other reasons, a single base measurement does not account for the spatial distribution of initial velocity.

The intent was to develop a reasonable specification.

Conclusions

The preferred bench shock qualification method is MIL-STD-810F, METHOD 516.5, Procedure VI, which is given in Appendix A.

An alternative base excitation shock level is given in Figure 9. The alternative assumes that a base excitation shock can be substituted for an initial velocity shock. The alternative level is generic. An individual component's response to actual bench shock could differ significantly from the level implied in Figure 9.

References

1. Dave S. Steinberg, Vibration Analysis for Wiley-Interscience, New York, 1988.
2. ME File: T042-012, FTLU (9000-5510) Transportation & Bench Handling Drop Shock (Release is pending).
3. ME File: T042-011, Characterizing Transportation Shock, Transportation Random Vibration, and Bench Handling Shock for the 9000-4950 Battery (Release is pending).
4. TD-2681Rev A, Taurus Launch Vehicle FTS Component Environments Derivation Document.

APPENDIX A

MIL-STD-810F, METHOD 516.5, Excerpts

2.2.2 Difference among procedures.

f. Procedure VI - Bench Handling. Procedure VI is intended for materiel that may typically experience bench handling, bench maintenance, or packaging. It is used to determine the ability of the materiel to withstand representative levels of shock encountered during typical bench handling, bench maintenance, or packaging. Such shocks might occur during materiel repair. This procedure may include testing for materiel with protrusions that may be easily damaged without regard to gross shock on the total materiel. The nature of such testing is highly specialized and must be performed on a case-by-case basis, noting the configuration of the materiel protrusions and the case scenarios for damage during such activities as bench handling, maintenance, and packaging. This procedure is appropriate for medium-to-large test materiel out of its transit or combination case that has a maximum dimension greater than approximately 23 cm (9 inches). Small materiel systems, in general, will be tested to higher levels during Procedure IV, Transit Drop.

4.5.7 Procedure VI - Bench handling.

The intent of this test is to determine the ability of materiel to withstand the usual level of shock associated with typical bench maintenance or repair. Use this test for any materiel that may experience bench or bench-type maintenance. This test considers both the structural and functional integrity of the materiel.

4.5.7.3 Procedure VI.

Step 1. Following a functional and physical checkout, configure the item as it would be for servicing, e.g., with the chassis and front panel assembly removed from its enclosure. Position the test item as it would be for servicing. Generally, the test item will be non-operational during the test.

Step 2. Using one edge as a pivot, lift the opposite edge of the chassis until one of the following conditions occurs (whichever occurs first).

- a. The lifted edge of the chassis has been raised 100 mm (4 in) above the horizontal bench top.
- b. The chassis forms an angle of 45° with the horizontal bench top.
- c. The lifted edge of the chassis is just below the point of perfect balance. Let the chassis drop back freely to the horizontal bench top. Repeat using other practical edges of the same horizontal face as pivot points, for a total of four drops.

Step 3. Repeat Step 2 with the test item resting on other faces until it has been dropped for a total of four times on each face on which the test item could be placed practically during servicing.

Step 4. Visually inspect the test item.

Step 5. Document the results.

Step 6. Operate the test item in accordance with the approved test plan.

Step 7. Document the results for comparison with data obtained in step 1, above.

APPENDIX B

Rigid-body Problem for Initial Velocity Calculation

Consider a thin plate released from rest as shown in Figure B-1. Point A remains effectively hinged at the ground. Solve for the velocity of the plate as it impacts the ground plane. The change in height Δh is referenced to the center of gravity.

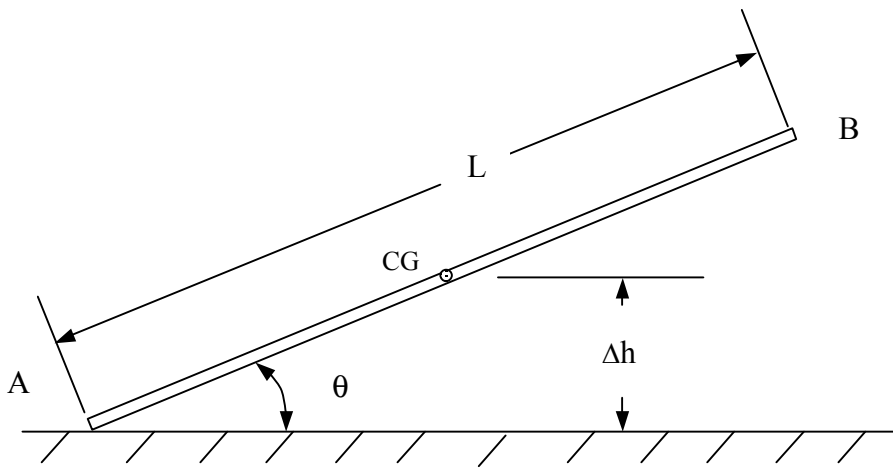


Figure B-1.

$$\frac{1}{2} J_A \dot{\theta}^2 = mg \Delta h \quad (\text{B-1})$$

$$J_A = \frac{1}{3} mL^2 \quad (\text{B-2})$$

$$\frac{1}{6} mL^2 \dot{\theta}^2 = mg \Delta h \quad (\text{B-3})$$

$$\dot{\theta}^2 = \frac{6g \Delta h}{L^2} \quad (\text{B-4})$$

$$\dot{\theta} = \frac{1}{L} \sqrt{6g \Delta h} \quad (\text{B-5})$$

The tangential velocity varies linearly along the length of the plate. It is zero at point A. The velocity at point B is

$$V_B = \sqrt{6g \Delta h} \quad (\text{B-6})$$

Now consider that the initial distance of Point B above the ground is 4 inches. The CG is thus 2 inches above the ground.

$$V_B = \sqrt{6(386 \text{ in/sec}^2)(2 \text{ in})} \quad (\text{B-7})$$

$$V_B = 68 \text{ in/sec} \quad (\text{B-8})$$

The tangential velocity varies linearly from zero at point A to 68 in/sec at point B.

APPENDIX C

Steinberg Calculation

This section is an aside. The purpose is to assess the severity of the displacement responses. Steinberg gives the following empirical formula for the maximum allowable relative displacement limit for a shock environment.

$$Z_{\text{peak}} = \frac{0.00132 B}{C h r \sqrt{L}} \text{ inches} \quad (\text{C-1})$$

where

B = length of the circuit board edge parallel to the component, inches

L = length of the electronic component, inches

h = circuit board thickness, inches

r = relative position factor for the component mounted on the board

C = Constant for different types of electronic components, $0.75 < C < 2.25$

Consider a standard DIP mounted at the center of each board. The DIP is 0.75 inches long. For a standard DIP, $C = 1.0$. For the center of the board, $r = 1.0$.

The shock limit in terms of relative displacement is

$$Z_{\text{peak}} = \frac{0.00132 (3)}{(1)(0.063)(1) \sqrt{0.75}} \text{ inch} = 0.073 \text{ inch} \quad (\text{C-2})$$

The expected peak response is thus less than the limit for each of the three models as shown in Table C-1.

Table C-1. Relative Displacement Comparison.			
Model	Natural Frequency (Hz)	Peak Displacement Response (in)	Limit (in)
1	287	0.024	0.073
2	574	0.012	0.073
3	287	0.024	0.073