QUALIFICATION SHOCK TESTING FOR REUSABLE AVIONICS COMPONENTS

By Tom Irvine
Email: tomirvine@aol.com

April 5, 2011

Introduction

A certain launch vehicle avionics component may be subjected to one or more shock events[1] in a given flight. Thereafter the component may be recovered and flown again on another mission.

The purpose of this paper is to recommend a shock test method[2] for reusable components.

The method is based on References 1 and 2 which give methods for random vibration testing. Note that shock is transient vibration.

Assumptions

1. All flight and test shock levels are represented in terms of a shock response spectrum (SRS).
2. The component is only subjected to one flight shock for Method I.
3. The component is subjected to multiple flight shocks for Method II.
4. The qualification shock level is 6 dB greater than the maximum predicted environment (MPE) flight level.
5. The number of qualification shock hits per axis is at least three.
6. Acceptance shock testing is not performed.[3]
7. The number of equivalent flights is conservative because it includes a life factor[4] of 4.
8. The fatigue exponent is 4 which is the conservative recommendation per Reference 1.

---

[1] These events may include pyrotechnic stage and fairing separation.

[2] A literature search has shown that there are no published methods for reusable component shock testing, although such methods are available for random vibration testing.

[3] Component acceptance testing is not usually performed for pyrotechnic-driven shock levels.

[4] The original purpose of this life factor was to assure that the component would still have remaining life for flight after it passed its acceptance testing. This factor is retained in this paper even though acceptance shock testing is not performed.

Method I

The component is only subjected to one flight shock event. The natural frequency is not required.

The equivalent flight number is based on References 1 and 2. This is the maximum number of flights that a component may undergo while still maintaining a life factor of 4.

The recommended number of flights is one-half the equivalent number of flights for additional conservatism, given uncertainties in linearity.[5]

Table 1. Method I, Equivalent Flights and Recommendation for Component Subjected to One Shock per Flight

Qualification Test Shocks/Axis	Equivalent Flights	Recommended Number of Flights
3	12	6
4	16	8
5	20	10
6	24	12
7	28	14
8	32	16
9	36	18
10	40	20

[5] Nonlinearity may occur due to large deflections or to changes in damping ratio.

Method II

The component is subjected to multiple flight shock events. The natural frequency is needed to make best use of this method. The calculation can be repeated for a series of natural frequencies otherwise.

Consider a case where a component is subjected to two shock events per flight. A rigorous approach would be to specify a separate qualification shock test for each event. The common practice, however, is to establish a single qualification shock level which is 6 dB greater than the maximum envelope of the flight shock levels.

Now derive the equivalent flight number as follows, starting with the qualification shock level G_q at the component's natural frequency.

$$G_q{}^4 = 4n\left[G_1{}^4 + G_2{}^4\right] \tag{1}$$

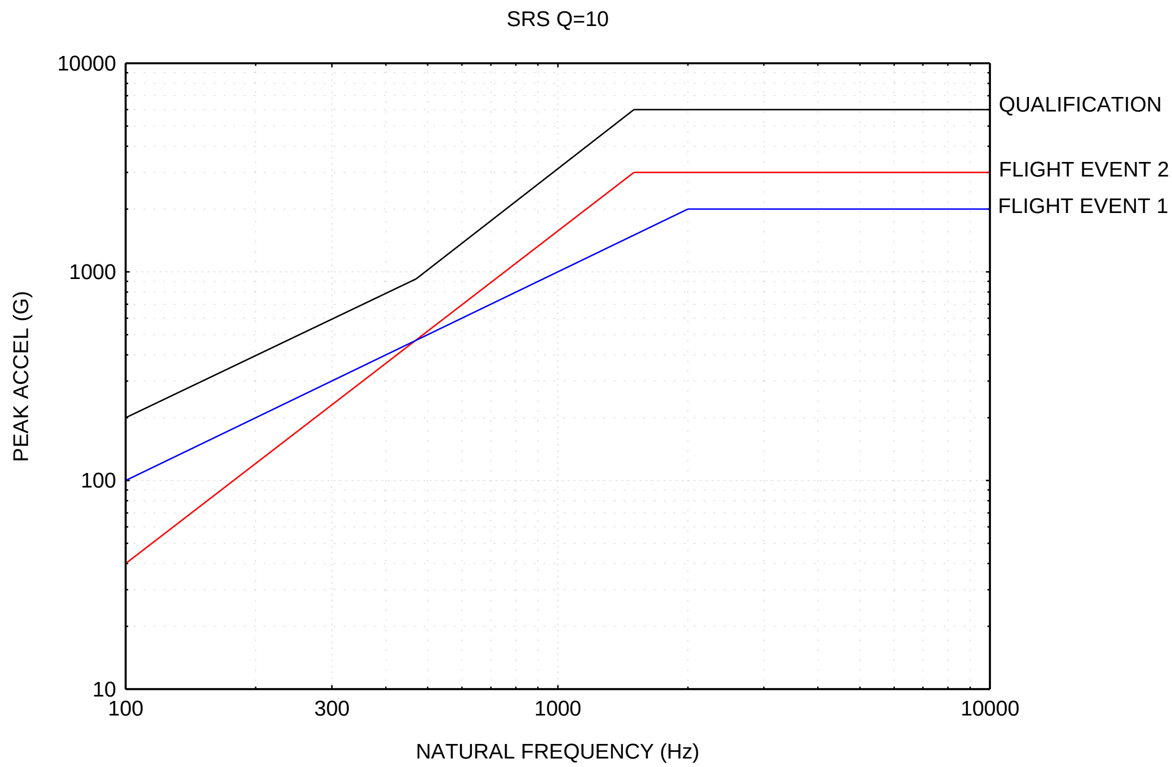
where

n	is the number of equivalent fights per shock test hit
G_1	is the MPE for the first flight shock event at the component's natural frequency
G_2	is the MPE for the second flight shock event at the component's natural frequency

The number of equivalent fights per shock test hit is thus

$$n = \frac{G_q{}^4}{4\,[\,G_1{}^4 + G_2{}^4\,]} \tag{2}$$

As an example, consider that a component is subjected to the two shock MPE levels in Figure 1. The qualification shock level is also shown.



Flight Event 1	
Fn(Hz)	Peak(G)
100	100
2000	2000
10000	2000

Flight Event 2	
Fn(Hz)	Peak(G)
100	40
1500	3000
10000	3000

Figure 1.

Now assume that the component has a natural frequency of 300 Hz. The levels for this frequency are:

Level	Peak Accel (G)
Flight 1	300
Flight 2	230
Qualification	600

The number of equivalent fights per shock test hit is thus

$$n = \frac{(600)^4}{4\left[\,(300)^4 + (230)^4\,\right]} = 2.97 \tag{3}$$

The results are shown in Table 2.

Table 2. Method II, Equivalent Flights and Recommendation for Component Subjected to Two Shocks per Flight for the Example in Figure 1		
Qualification Test Shocks/Axis	Equivalent Flights	Recommended Number of Flights
3	8.9	4.5
4	11.9	5.9
5	14.9	7.4
6	17.8	8.9
7	20.8	10.4
8	23.8	11.9

Conclusion

This paper has established conservative methods for determining the number of equivalent flights per a shock qualification test. The recommended number of flights is one-half the equivalent flight number for further conservatism.

Additional consideration should be given to random vibration qualification and acceptance testing, as well as a random vibration test to be performed between flights.

References

1. E. Perl, editor, Test Requirements for Launch, Upper-Stage, and Space Vehicles, Aerospace Report No. TR-2004(8583)-1 Rev. A, 2006.

2. NASA-SSP 41172, Qualification and Acceptance Environmental Test Requirement, National Aeronautics and Space Administration, International Space Station Program, Johnson Space Center Houston, Texas, International Space Station Program, Revision U, 28 March 2003.

APPENDIX A

Aerospace Report No. TR-2004(8583)-1 Rev. A

10.2.2 Acceleration of Acceptance Life for Acoustic and Random Vibration Tests

Spacecraft and many launch vehicle components are exposed to acoustics and random vibration during the liftoff and ascent segments of flight for a nominal period of 15 seconds. Some components maybe exposed to these environments in excess of 15 seconds, such as those located on or near engines.

Baseline acoustic and random vibration qualification and protoqualification tests include a 1-minute duration for the liftoff and ascent flight environment with a margin added to the acceptance spectrum.

A longer than the baseline 15-second duration of the maximum predicted environment (**3.11**) leads to an increased test time for flight of 4 times that of the MPE, where 4 is the duration factor for fatigue life demonstration by test. To insure that flight capability is maintained after the acceptance program on production hardware, the test duration is increased beyond the time required for flight to serve as a life test for a maximum duration acceptance testing.

The assumptions are that fatigue is the life limiting mechanism, that Miner's Rule for fatigue accumulation applies, and that induced stress is proportional to the applied acceleration. Miner's Rule (Reference 4 in **10.2.7**) states that the summation of the product of the number of cycles times their stress amplitude raised to an exponent "b" is proportional to the fraction of life exhausted. Therefore, if T_A denotes the upper limit on the duration of acceptance testing, $4T_A$ becomes the duration of the life test for acceptance required if performed with the acceptance spectrum.

Since the qualification and protoqualification testing are performed at higher than the acceptance level beyond the duration required for flight, the added testing becomes an accelerated acceptance life test. The time acceleration factor is given by the amplitude factor on the acceptance excitation raised to the fatigue exponent "b". The amplitude factor equals $10^{M/20}$, where M is the margin in dB. So the time acceleration factor is $10^{Mb/20}$.

Let t_A be the duration of an acceptance test (baseline 1 minute), T_A be the limit on the duration of acceptance testing, and 4 be the life factor, then

$$T_A / t_A = (1/4)\, 10^{\,Mb/20} \tag{10.3}$$

For conservatism, the exponent on stress is taken to be 4, a conservative value for this purpose. For example, Reference 2 in **10.2.7** recommends b=4 for solder.

$$T_A / t_A = (1/4)\, 10^{\,M/5} \tag{10.4}$$

A table of the acceptance duration limit versus the test margin M follows:

Test margin, M (dB)	3	4	5	6
Acceptance limit, T_A / t_A	1.0	1.6	2.5	4.0

As seen above, 1 minute of 6-dB margin testing demonstrates life for 4 acceptance tests of 1 minute each. Since baseline qualification uses a 6-dB margin and a 3-minute test (2 minutes beyond the 1 minute for flight), adequate remaining life for flight life is demonstrated for up to eight 1-minute acceptance tests. Note that each minute with a 3-dB margin demonstrates life for a single acceptance test. So, for protoqualification (3 dB margin for 2 minutes, 1 of which is for flight), a limit of only 1 acceptance test is demonstrated. Therefore, under nominal assumptions, there is no demonstrated life remaining to accommodate any retesting.

APPENDIX B

NASA-SSP 41172, 8.2.2 METHOD II

Step 1:

Convert one flight exposure to equivalent time at the acceptance test level by the following relationship:

$$t_{ae} = t_f \left(\frac{G_f}{G_a} \right)^b$$

where [8.4]

t_{ae}	is the equivalent acceptance test time for one flight
t_f	is the exposure time of one flight (30 seconds)
G_f	is the root mean square (rms) acceleration level (grms) of the maximum predicted flight environment
G_a	is the rms acceleration level (grms) of the acceptance test environment in each axis

Step 2:

Establish the total acceptance test duration (per axis) for which the equipment has been qualified:

$$t_a = \frac{t_q}{4} \left(\frac{G_q}{G_a} \right)^b$$

where [8.5]

t_a	is the qualified time in each axis for acceptance vibration testing
t_q	is the time of the qualification random vibration test in each axis
G_q	is the rms acceleration level (grms) of the qualification random vibration test environment

Step 3:

Compute remaining allowable acceptance random vibration test time in each axis:

$$t_{ar} = t_a - [(t_{ae})(F) + t_{au}] \quad \text{where,} \qquad [8.6]$$

t_{ar}	is the acceptance test time remaining in each axis
t_a	is the qualified total acceptance test time in each axis from equation [8.5]
t_{ae}	is the total equivalent acceptance test time for all service environments in each axis from equation [8.4]
F	is the number of required flights for the equipment
t_{au}	is the acceptance test time in each axis already expended