An Alternative Method of Specifying Shock Test Criteria

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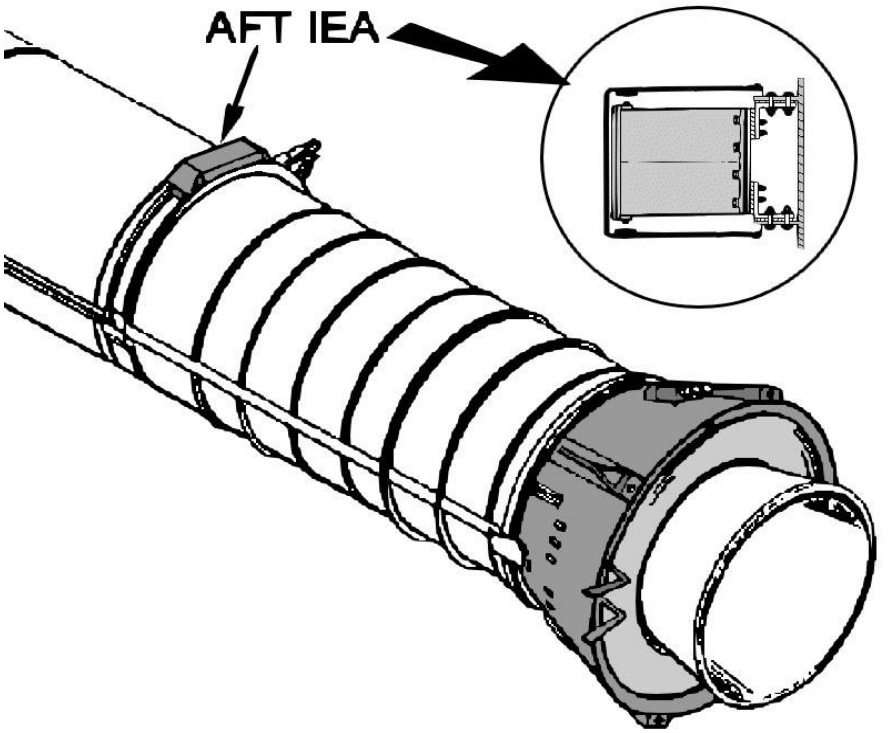
Background

- Space Shuttle Solid Rocket Booster (SRB) water impact shock criteria have presented challenges to component qualification
- Integrated Electronics Assembly (IEA) case was broken while attempting to qualify for water impact shock
  - Shock Response Spectra (SRS) criteria were derived from flight measurements taken at input to the box
  - No margin was added above envelope of data
- Later attempt to test SRB battery also led to structural failure
- The only flight failures on this hardware were due to water pressure from plume impingement rather than impact shock
- bd Systems in Huntsville, AL was contracted to look into alternative means of shock testing

SRB IEA

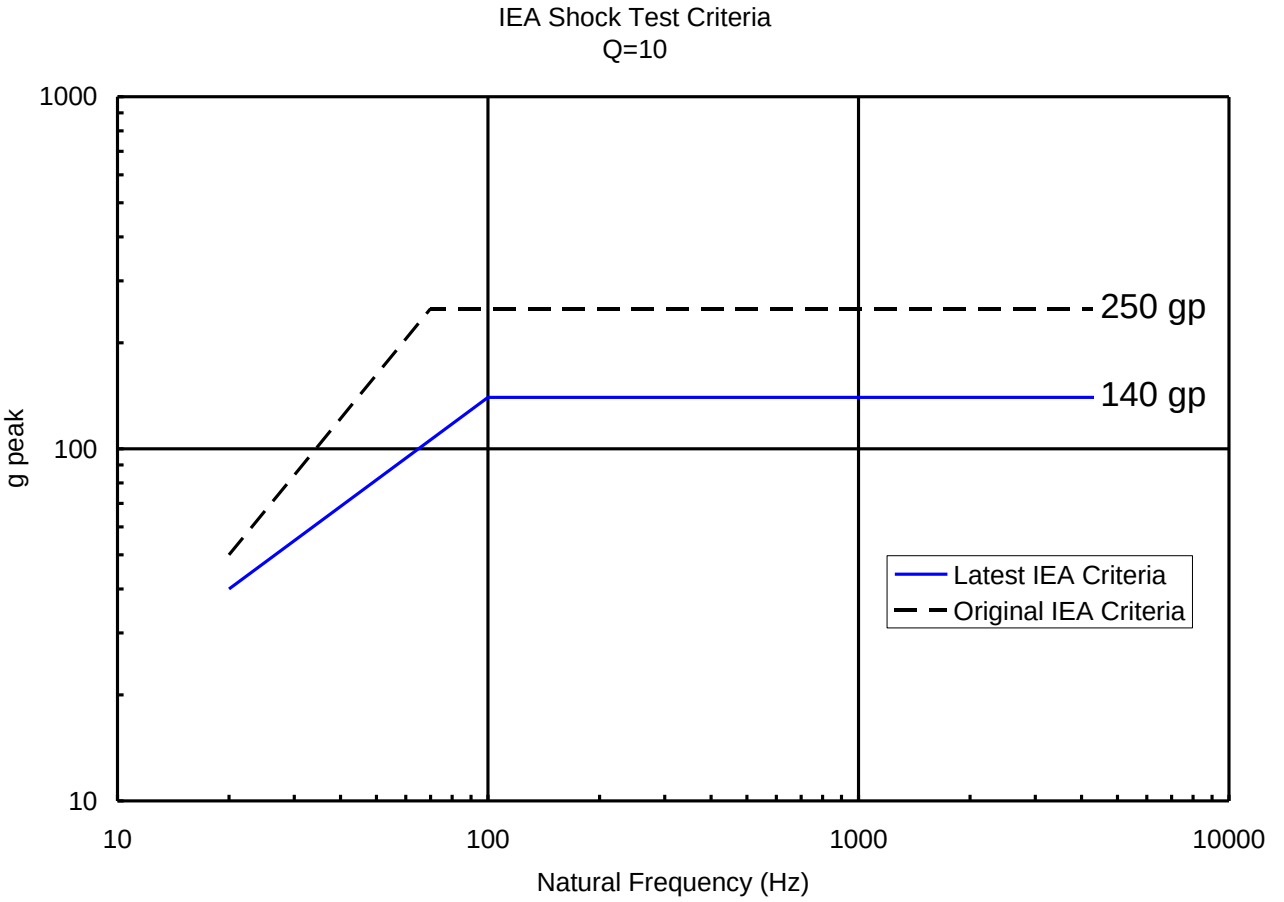
- Two IEAs per SRB
- IEA is four feet long and weighs 200 lb.
- Aft IEA mounted to ET attach ring through rubber isolators
- Forward IEA mounted in forward skirt to ring
- Housing is cast aluminum
- Housing cracked at bracket interface



Forward IEA Installation

Shock Test Criteria

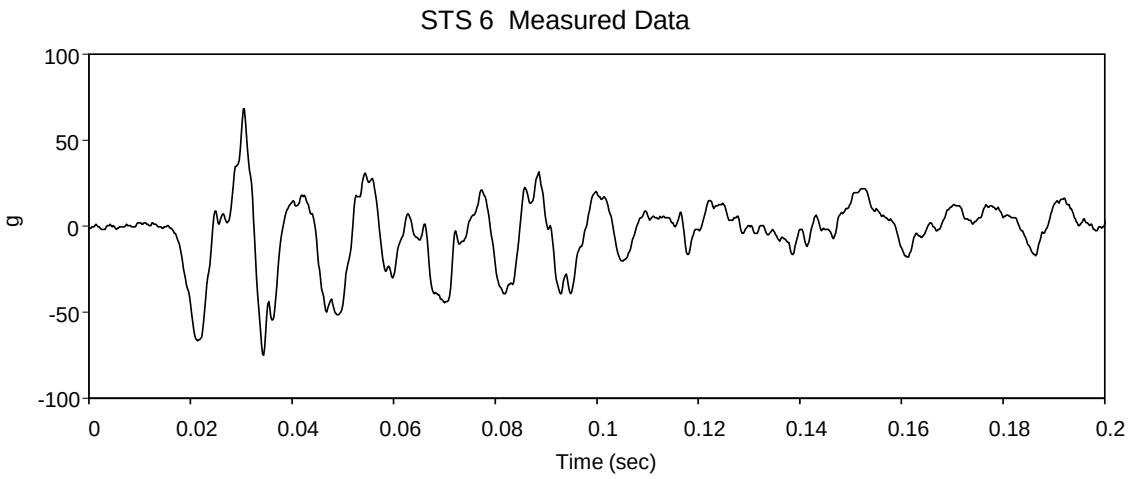
- Water impact shock criteria based on measurements taken on five Shuttle flights

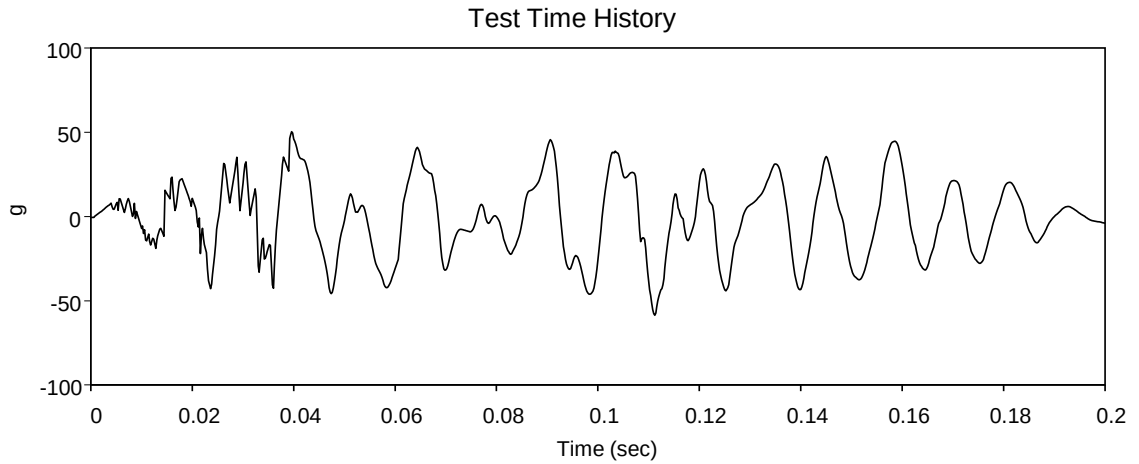


Background

- Two primary reasons why the IEA broke in test
  - Compliance of support hardware not accounted for
  - Time history of test shock input did not match actual measured data
    - Any number of time histories can produce the desired SRS
    - We suspected that the test time history was somehow inducing severe forces into the test article
    - We also questioned whether the internal component response was different with the different time histories
- First attempted fix was to use force-limiting for shock testing
  - Short duration of test precludes normal application of force-limiting, although that may be a future direction
- Joe Clayton suggested using wavelets to more precisely simulate the actual acceleration time history
  - Wavelets have the advantage of yielding zero net displacement and velocity

Example Shock Waveforms

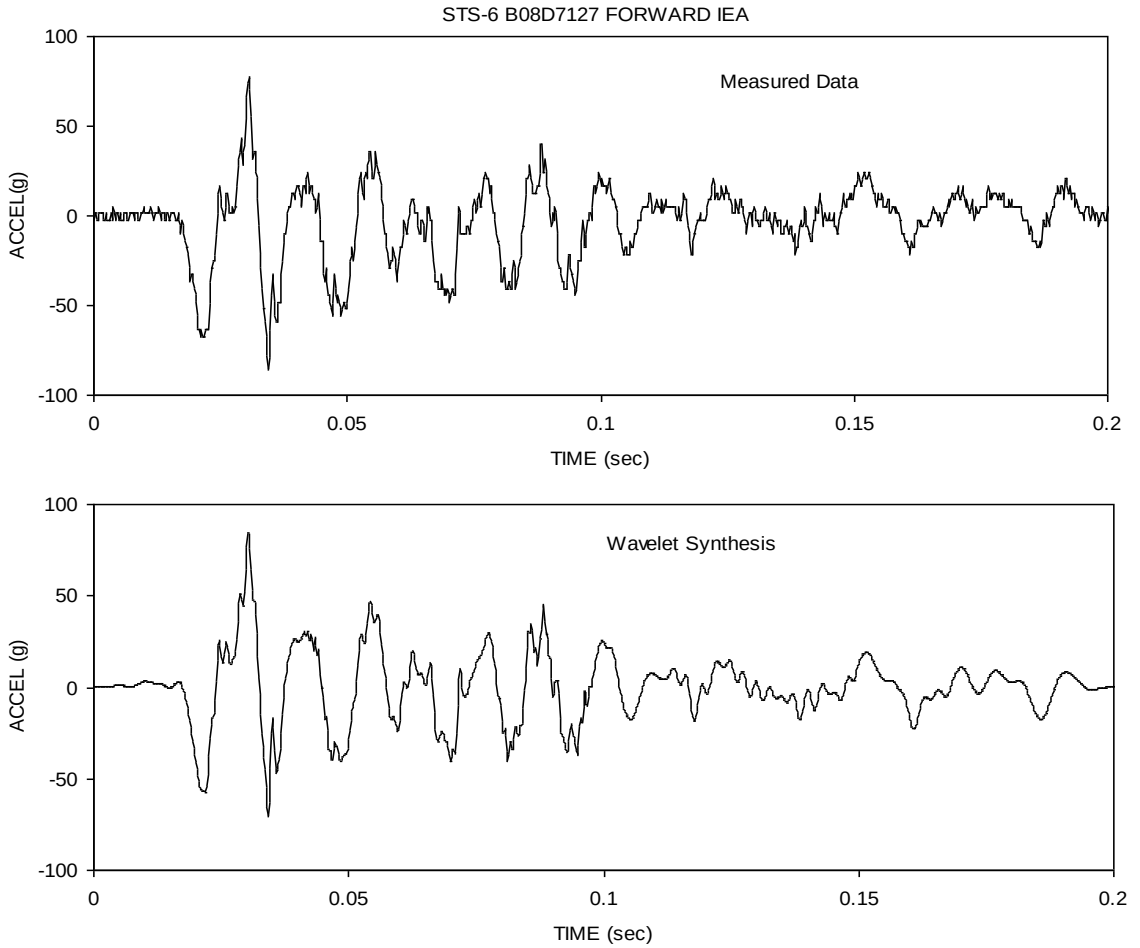




Synthesizing a Single Time History

- An iterative approach, developed by Tom Irvine, was used to construct a synthesized time history composed of wavelets
- Using the well-documented wavelet equation, the following four parameters were iteratively adjusted to yield the lowest error
  - wavelet acceleration amplitude
  - wavelet frequency
  - number of half-sines
  - wavelet time delay
- The number of wavelets used will determine the accuracy of the final result
- The following synthesis is composed of 60 wavelets

Comparison of Time Histories

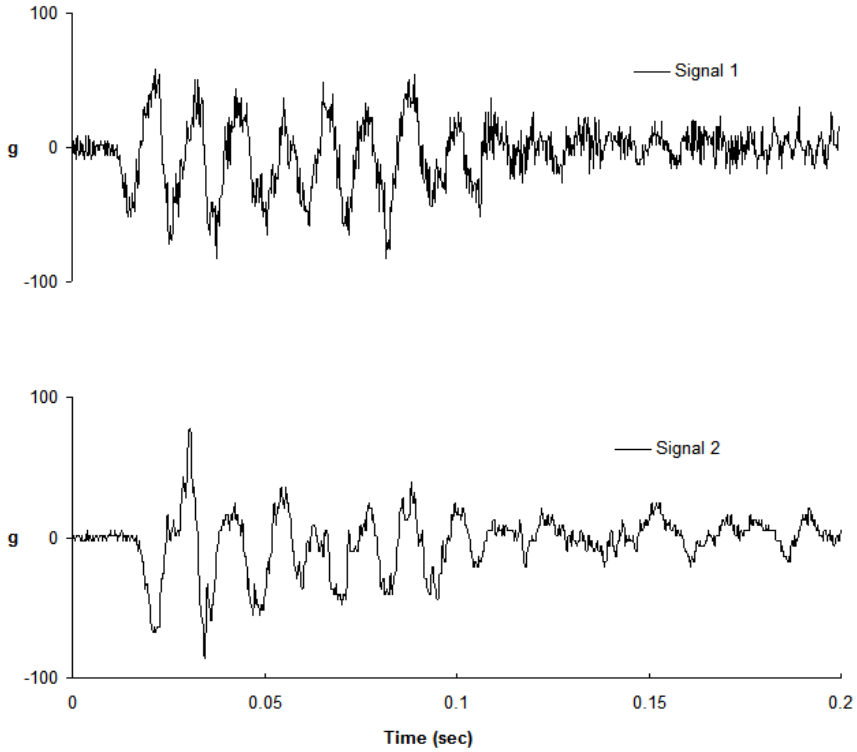


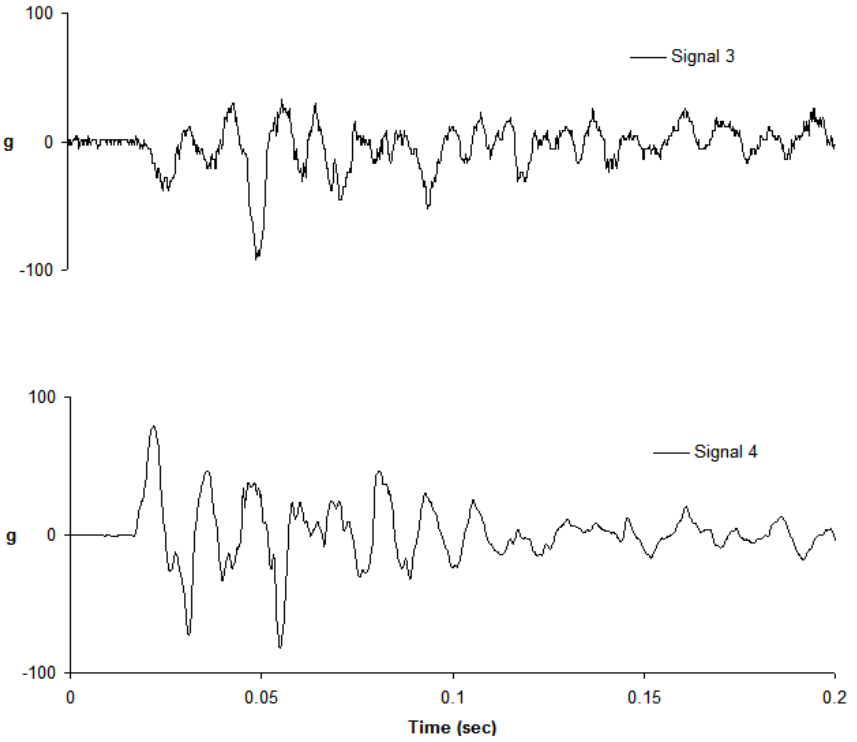
Maximum Expected Environment

- With SRS approach the maximum expected environment can be estimated by calculating the P95%/50% probability level of the spectra from different measurement locations, directions, and flights
  - This can't be done easily with time histories
- Tom Irvine developed a technique to calculate a composite waveform that "resembles" the desired time history
  - Each waveform is randomly multiplied by +1 or -1 and delayed by a random percentage of time
  - Waveforms are summed and mean-square value calculated
  - Optimum waveform has the highest mean-square value
- The composite pulse SRS is then scaled to the measured P95% SRS by trial and error

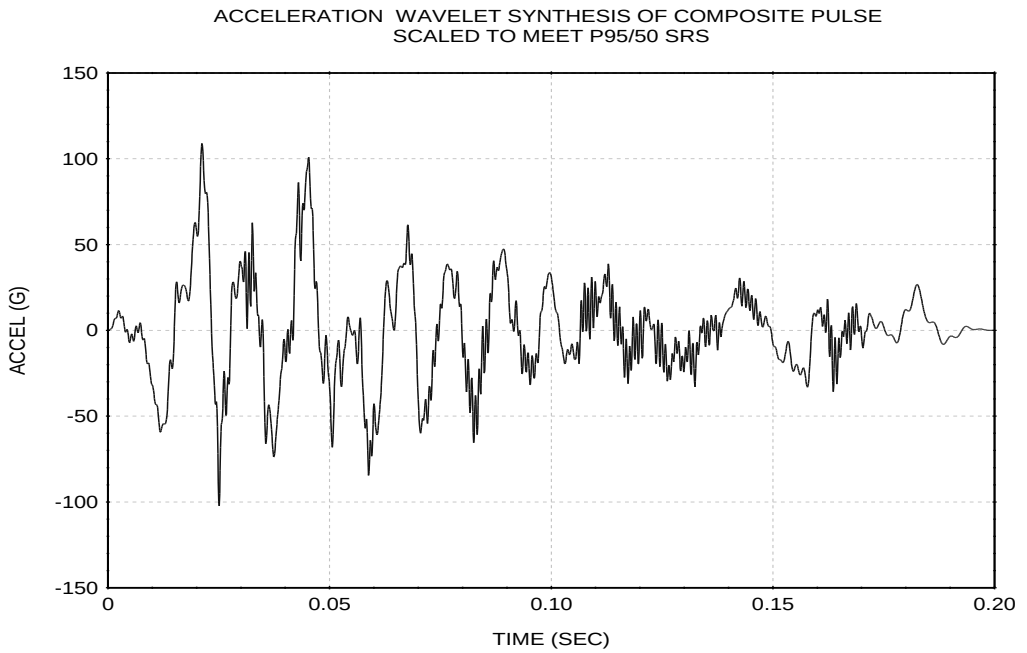
Measured Acceleration Time Histories

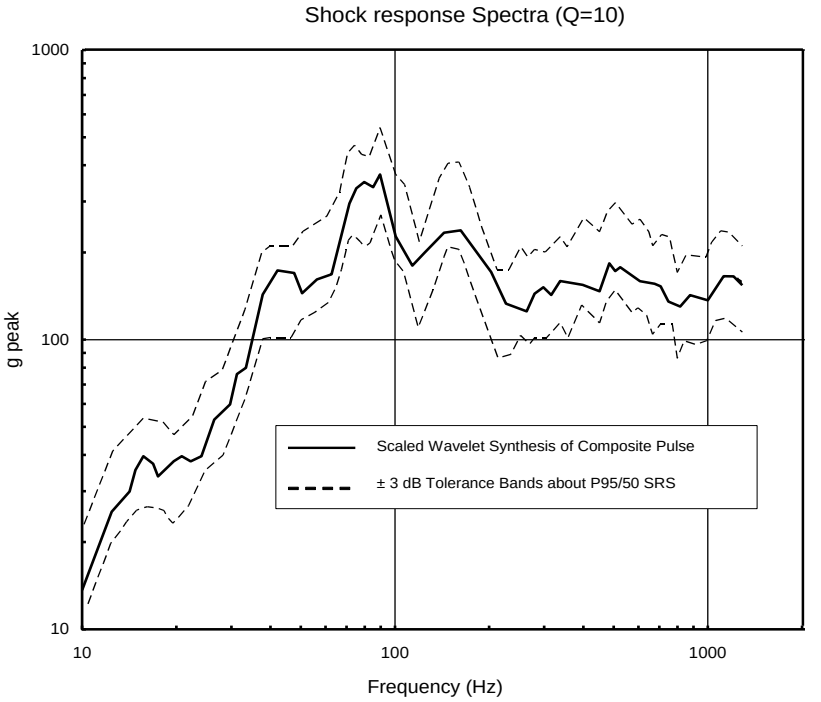
These four measurements were made at the same location in the same direction on different flights



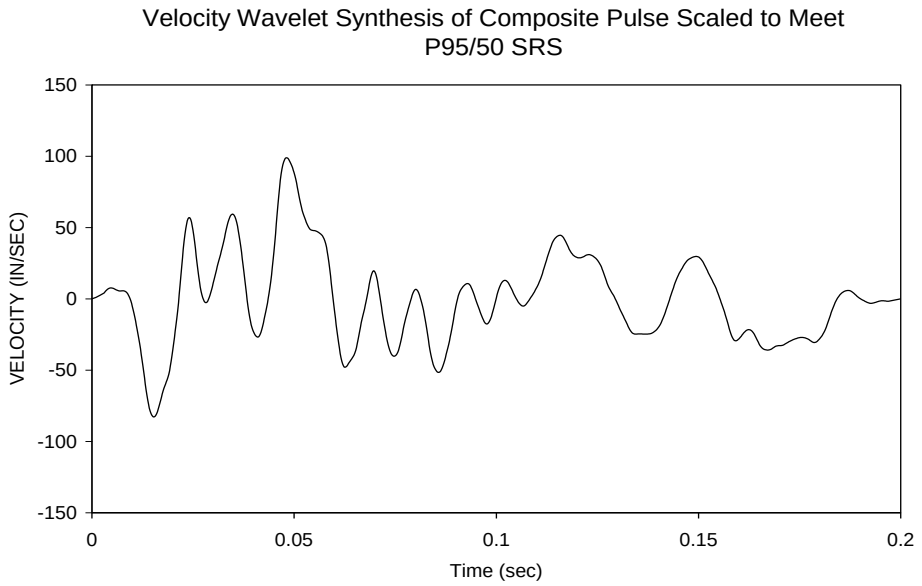


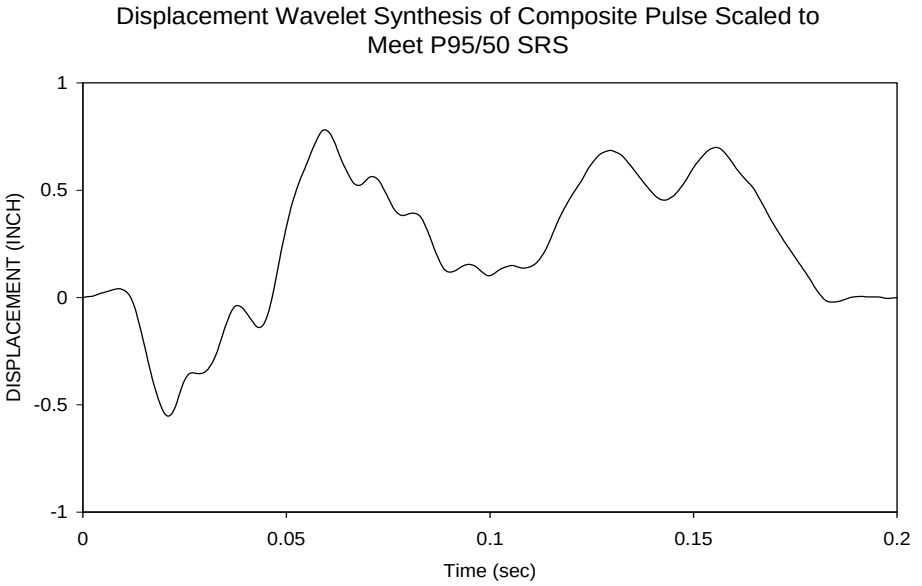
Scaled Composite SRS





Velocity and Displacement of Scaled Composite Waveform





Result

- Result meets criteria
  - Falls within P95%/50% bounds
  - Resembles original time history
  - Net zero velocity
  - Net zero displacement
    - If the peak displacement is too high the wavelet synthesis program can be adjusted to start at a higher frequency
- Test specification would consist of a table of wavelets rather than an SRS

Shock Criteria Specified as Wavelet Table

Accel(G)	Freq(Hz)	NHS	Delay(sec)	Accel(G)	Freq(Hz)	NHS	Delay(sec)	Accel(G)	Freq(Hz)	NHS	Delay(sec)
-3.79	16.36	5	0.0048	-9.02	98.88	5	0.0902	8.85	345.89	7	0.1126
-1.89	19.78	5	0.001	-4.29	102.91	3	0.1354	-9.35	360.3	19	0.0777
-1.58	26.43	9	0.0166	-3.38	113.53	9	0.1584	-5.7	379.76	5	0.0934
2.33	35.77	3	0.1567	-10.55	124.46	19	0.0242	5.38	383.49	11	0.1214
-4.04	38.95	13	0.0125	-2.2	133.06	21	0.0495	-12.66	426.15	3	0.0332
-14.22	41.27	7	0.1072	-3.78	135.14	7	0.0046	7.24	434.76	13	0.0253
-23.19	44.74	3	0.0128	6.51	146.43	3	0.0478	3.37	469.06	21	0.043
2.99	45.05	3	0.0003	20.38	149.91	7	0.0159	4.87	532.84	23	0.0563
1.48	49.99	17	0.0166	-4.88	153.39	15	0.0776	4.64	593.45	27	0.0418
4.24	55.43	13	0.0789	6.99	153.87	11	0.0163	-10.63	609.62	13	0.0257
9.76	55.67	3	0.0086	-6.34	157.05	17	0.1399	8.64	627.99	9	0.0209
-4	57.68	5	0.016	10.44	168.46	7	0.0591	5.85	698.73	13	0.0862
-19.5	63.18	5	0.0285	5.93	230.17	17	0.025	7.61	765.69	7	0.0688
2.08	63.73	5	0.1576	2.29	263.19	13	0.0081	-5.34	865.48	13	0.0306
6.28	73.98	9	0.1353	-8.86	273.93	5	0.0826	5.74	992.92	11	0.0784
31.42	74.59	9	0.0119	2.83	282.84	11	0.0664	-6.43	1034.55	9	0.0936
24.41	80.76	17	0.0232	-4.42	290.23	7	0.1564	4.54	1334.48	27	0.0827
-5.6	83.75	19	0.0306	-6.26	312.02	3	0.1454	-4.39	1343.2	21	0.0406
-2.75	91.92	9	0.1496	-5.22	314.89	15	0.0263				
-4.06	93.69	7	0.056	12.22	325.26	9	0.062				
-3.96	97.17	9	0.152	-7.81	335.76	7	0.1347				

Conclusion

- Technique was developed to synthesize shock test criteria as a wavelet table
  - Synthesized shock meets maximum expected levels of flight measurements and resembles time histories so that forces generated are comparable to flight
    - Does not address mounting structure compliance
- Future Work
  - Address mounting structure compliance (Force-limiting?)
  - Brute-force synthesis method can be more efficient through convergence algorithms
  - Optimization of waveform to reduce peak displacement
  - Perform tests on dummy hardware to measure force differences between SRS and wavelet techniques

References

- Ferebee, et al. “An Alternative Method of Specifying Shock Test Criteria”. NASA/TM-2008-215253, April 2008.
- The code used to generate the waveforms is available at Tom Irvine’s web site (vibrationdata.com).