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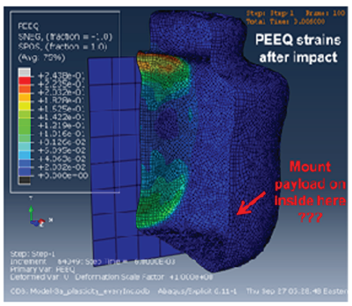
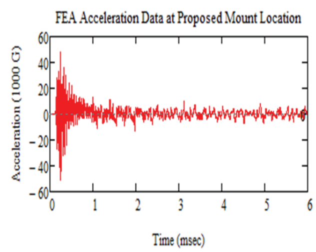
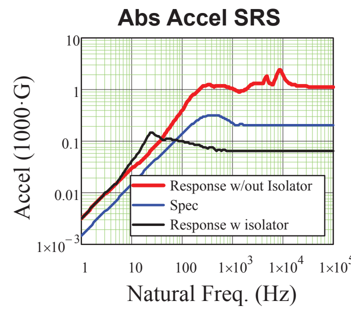
Using Shock Response Spectra Methods (SRS and PVSS) to Enhance Explicit Dynamics FEA Simulations

Ted Diehl, PhD







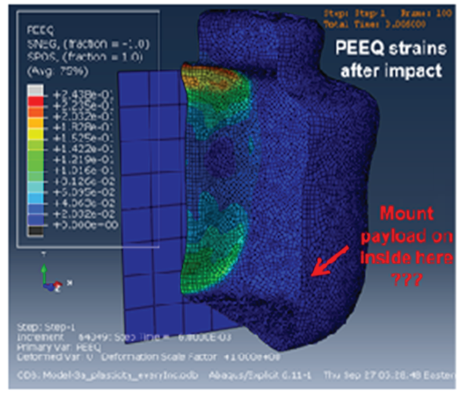
Outline

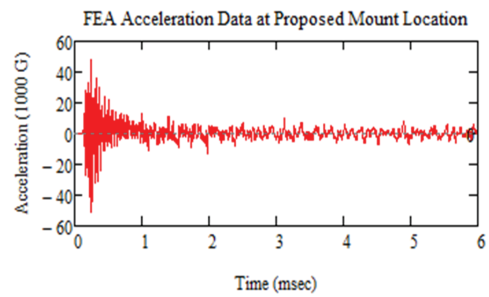
- Problem Set-up Question
  - How to assess typical shock spec (1,000G, 1.0msec) with FEA model?
- Special Issues With Explicit Dynamics FEA Data
  - Increased likelihood of FEA data aliasing
  - Constantly varying time increments
  - Massively oversampled data
- Using Upsampling and Decimation to Cover Large Range of Natural Frequencies in Shock Response Calculation
- Estimating the Influence of Shock Isolation Using 3-Step SRS Calculation
- Mapping Transient FEA Output to Simple Shock Pulses to Drive Historical In-house Codes

Problem Set-up Question

- Explicit Dynamics FEA models predict transient outputs of stress, strain, displacement, velocity, acceleration, …
- Payload too detailed to model explicitly.
  - **Vendor's spec for payload 3000·G and 0.3·msec**

Question: How to use FEA model to determine if payload will survive impact event?



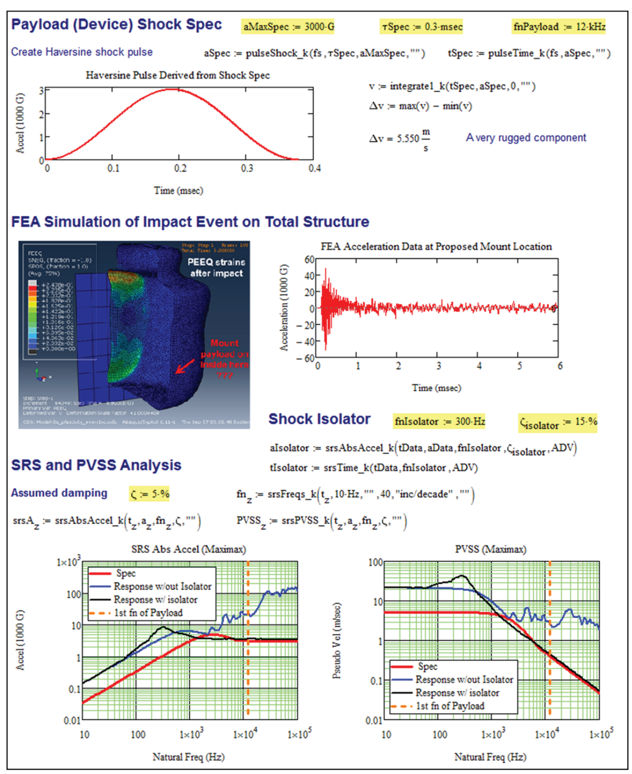


Problem Set-up Question

- Explicit Dynamics FEA models predict transient outputs of stress, strain, displacement, velocity, acceleration, …
- Payload too detailed to model explicitly.
  - **Vendor's spec for payload 3000·G and 0.3·msec**

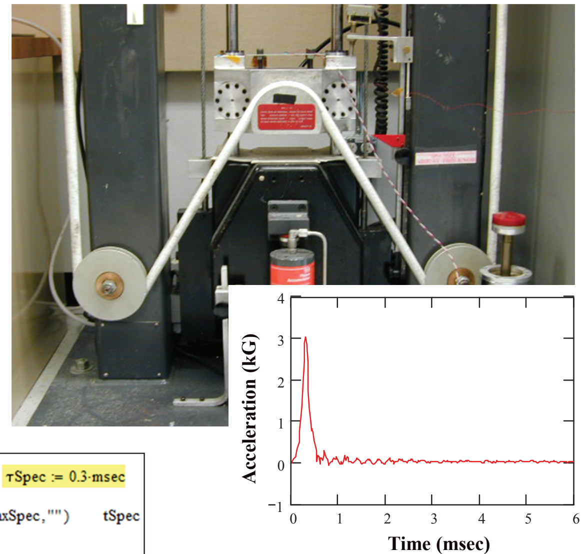
Question: How to use FEA model to determine if payload will survive impact event?

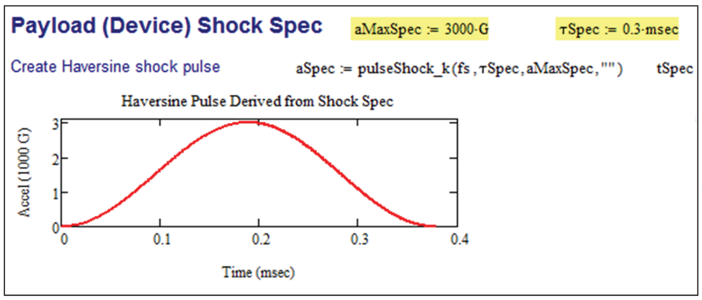
Answer: Convert both the vendor's spec and transient accel output from model to SRS & PVSS domains, then compare.



Approach/Concept

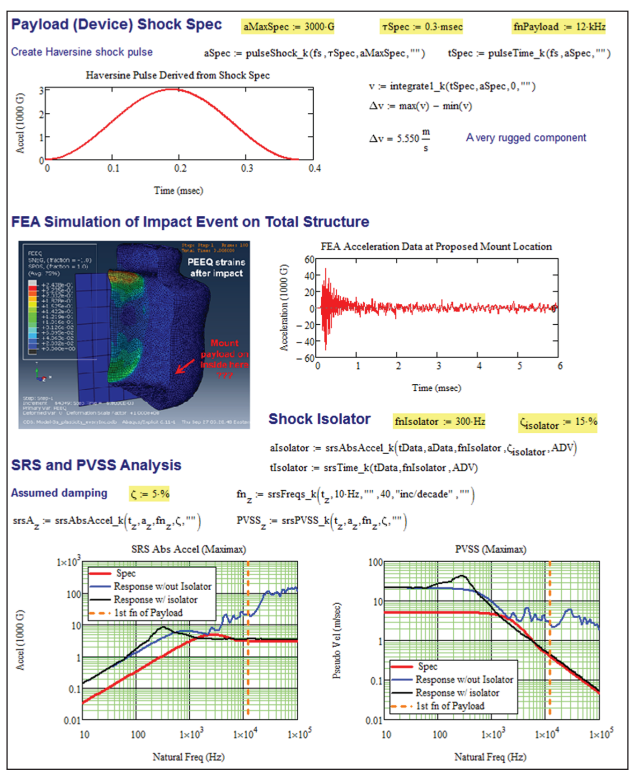
- Vendor's spec.
  - All you get is the spec., no more
  - Spec is likely derived from a shock test which had either a half-sine or haversine shock input (educated guess).
  - Using mean sampling rate of the FEA model, create ideal shock pulse from spec.





Approach/Concept

- Compute Absolute Accel SRS and PVSS for both the Shock Pulse (for the spec) and transient FEA acceleration Output.
  - Compare the results in the Shock Response domain
  - Utilize any knowledge or estimates of natural frequencies you might have for the payload in assessing the Shock Response plots



Special Issues With Explicit Dynamics FEA Data

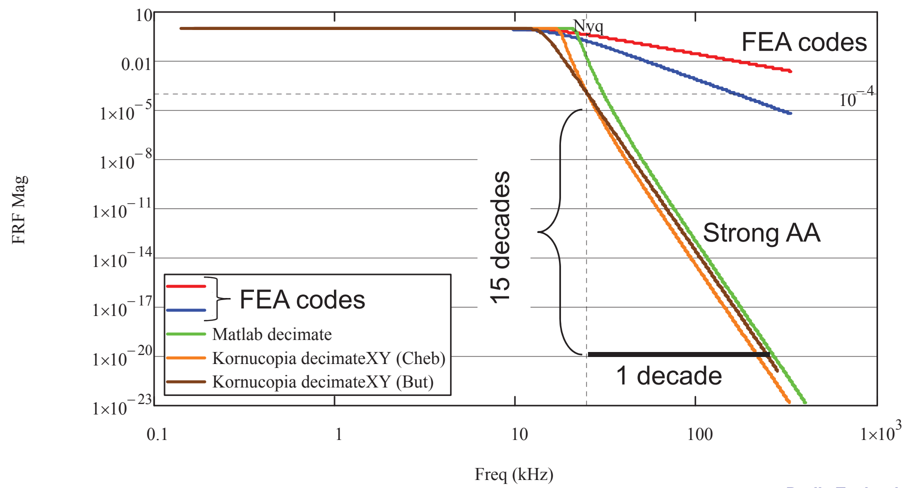
- Data that comes from Explicit Dynamics codes (LS-Dyna, Abaqus/Explicit, Radioss, Sandia codes, …) has several unique challenges that are different from data derived from physical testing.
  - Increased likelihood of FEA data aliasing
  - Constantly varying time increments
  - Massively oversampled data

Increased likelihood of FEA data aliasing

- **Awareness of Aliasing**
  - The need for AA protection in physical test measurements is good**.
    - **There are still people/organizations having aliasing issues!
  - In the FEA world, many analysts are completely unware of the issue!
    - Those who are unware output all kinds of stuff with NO AA filtering.
- **Protecting Against Aliasing**
  - When AA protection is provided in experimental test set-ups, you have a fighting chance it might be "strong"
  - Many simulation codes have NO AA protection what so ever. When the user requests output at anything other than every time increment, they are open to aliasing!
    - For those simulation codes that do have AA protection, it is often very week such as a 2^{nd} order Butterworth.

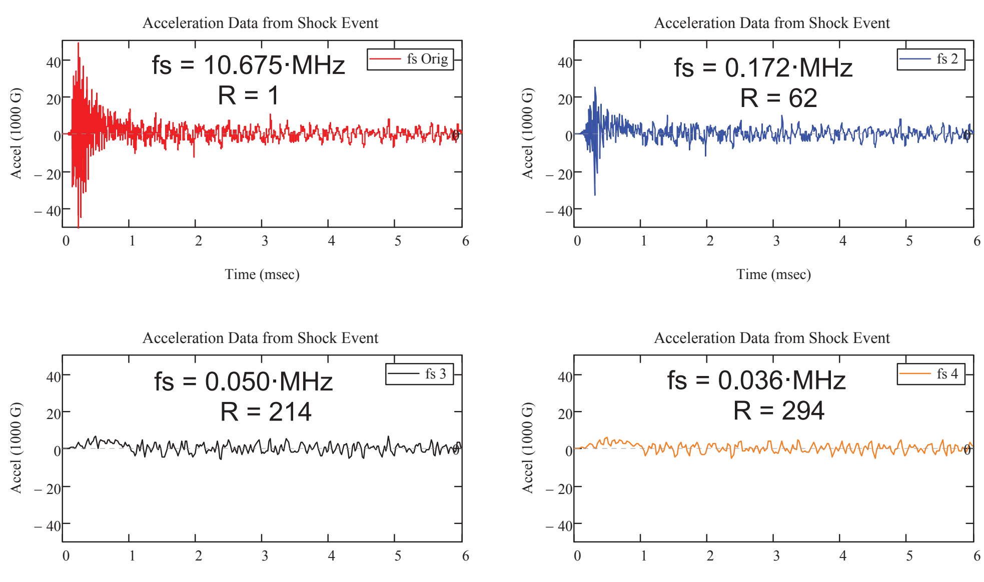
Antialias Filtering

- AA filter attenuation behavior of some FEA software compared with software that provides strong AA protection
  - "Strong" AA protection satisfies guidance from Bateman, V. I., Himelblau, H., Merritt, R., Validation of Pyroshock Data, Sound & Vibration, March 2012.



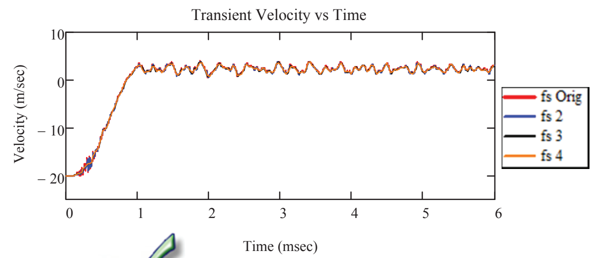
How SRS and PVSS Analysis can be Distorted by Aliasing

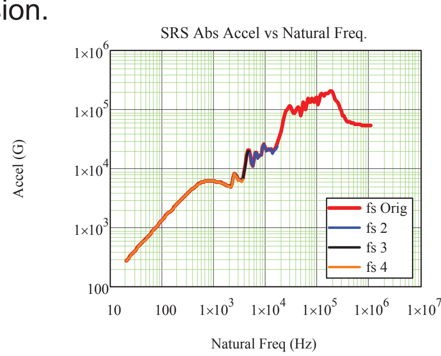
- Plots show the data from previous page plus three further decimated versions, <u>all using good AA decimating filters</u>. Note, R is the decimation factor relative to top left dataset.

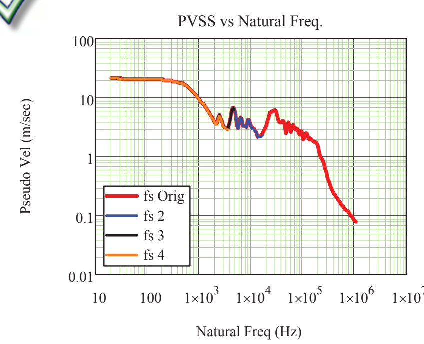


How SRS and PVSS Analysis can be Distorted by Aliasing

- Velocity integration assessment shows all four acceleration versions integrate to essentially the same velocity signal.
- The SRS and PVSS plots also show excellent agreement.
  - See next slide for more discussion.

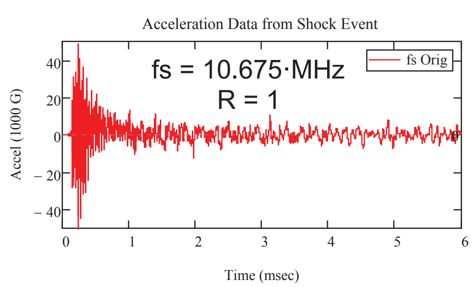


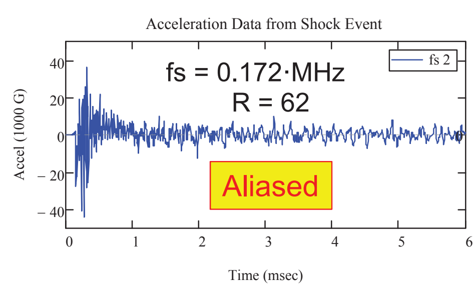


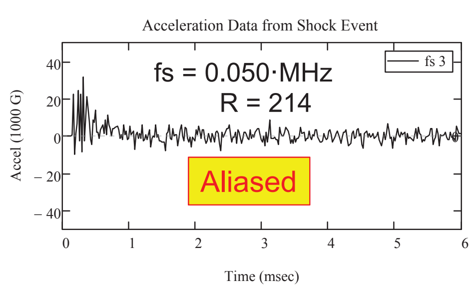


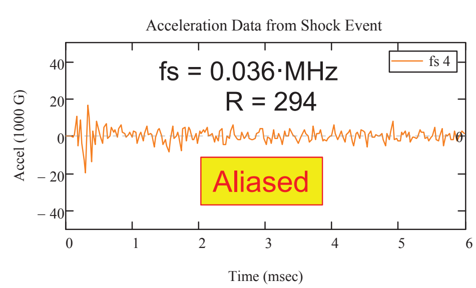
How SRS and PVSS Analysis can be Distorted by Aliasing

- We now repeat the analysis, but this time no AA filter is used during decimation to obtain signals fs2 thru fs4. Signals fs2 thru fs4 come from improper sampling.



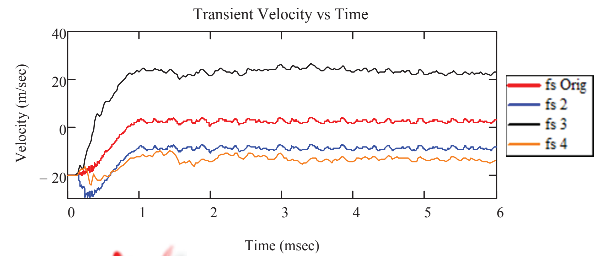




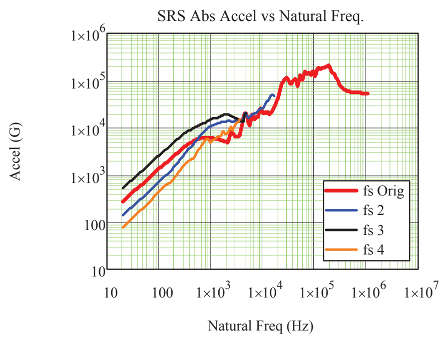


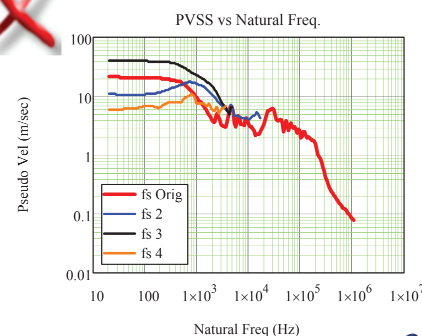
How SRS and PVSS Analysis can be Distorted by Aliasing

- Now the crime of improper decimation is clearly evident!
  - Both Velocity and Shock Response Spectra assessments are highly dependent on decimation factor.



Also note there is not even a trend in whether the aliasing makes a given quantity larger or smaller.



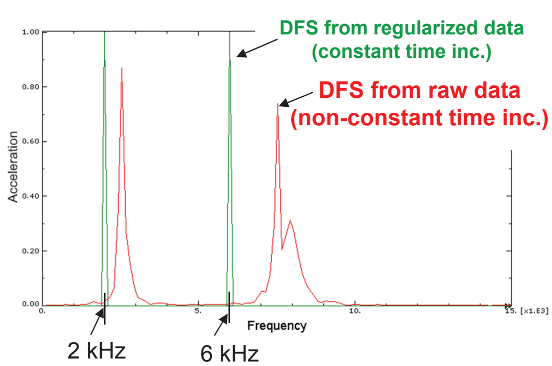


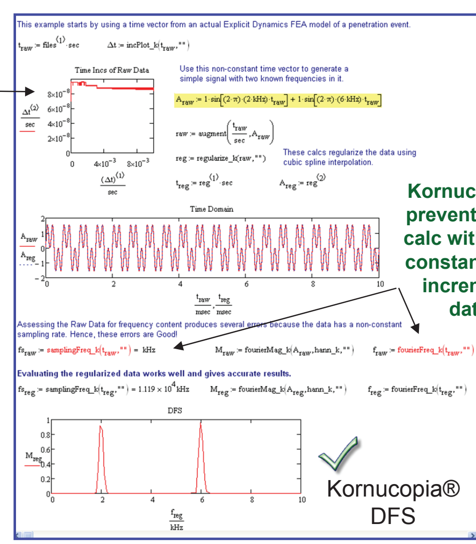
Problems with Processing Data with Ever-Changing Δt

- When data has ever-changing time increments, the data should FIRST be regularized to a constant time increment.
  - This can be done with spline or linear interpolation if the increment spread is not too crazy.

$$A_{raw} := 1 \cdot \sin\left[(2\cdot\pi)\cdot(2\cdot kHz)\cdot t_{raw}\right] + 1 \cdot \sin\left[(2\cdot\pi)\cdot(6\cdot kHz)\cdot t_{raw}\right]$$

Non-constant time increments

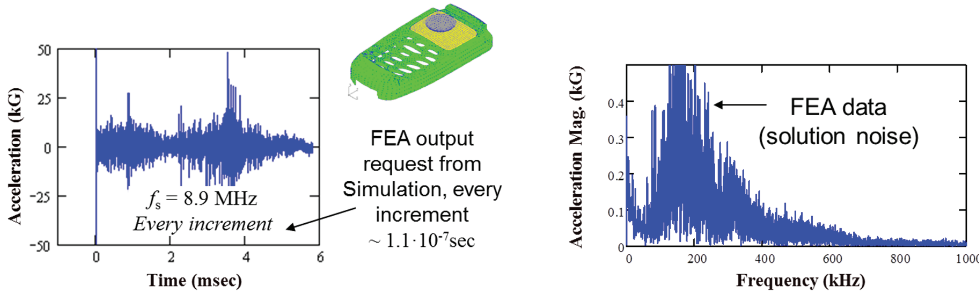




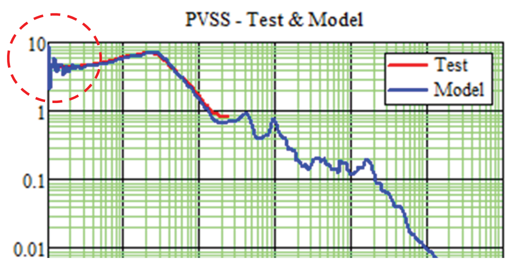
Kornucopia® prevents DFS calc with non-constant time increment data

Kornucopia® DFS

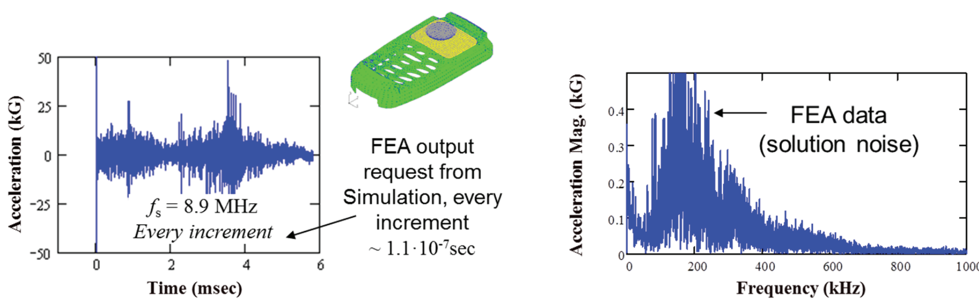
Massively Oversampled Data Causes Numerical Issues



- Compared to physical test data, Explicit Dynamics FEA data have smaller mean time increments, often several orders of magnitude smaller!
  - This can cause numerical problems with PVSS at lower natural frequencies



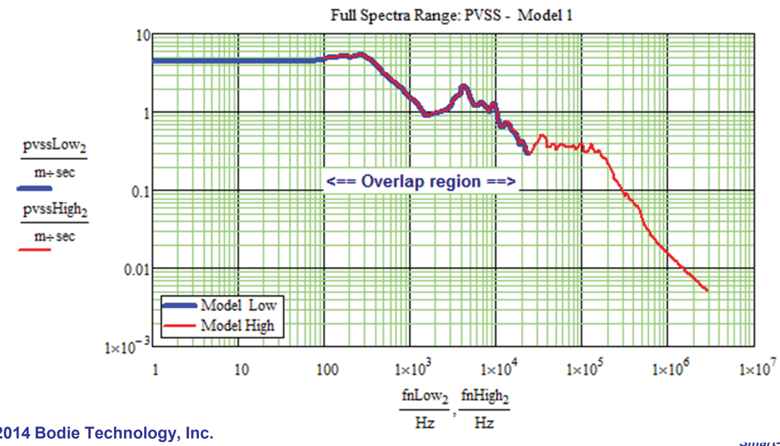
Massively Oversampled Data Causes Numerical Issues



- Explicit Dynamics FEA models are integrated to satisfy Courant Stability, which means that the low frequency response portion of the output signal can be quite accurate BUT it is polluted by high frequency solution noise that also has high magnitude.
  - This can cause Shock Response Spectra to show unusually large magnitudes at the high natural frequencies.
    - Decimation or lowpass filtering will be needed to address this, but the user needs to ensure they do not filter with too low of cutoff as to remove the physical response too!

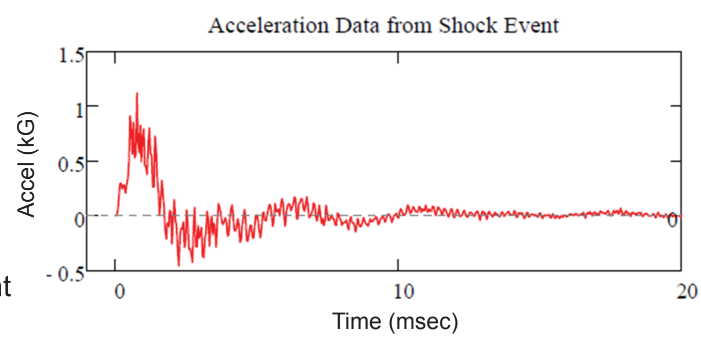
Using Upsampling and Decimation For Broad Range

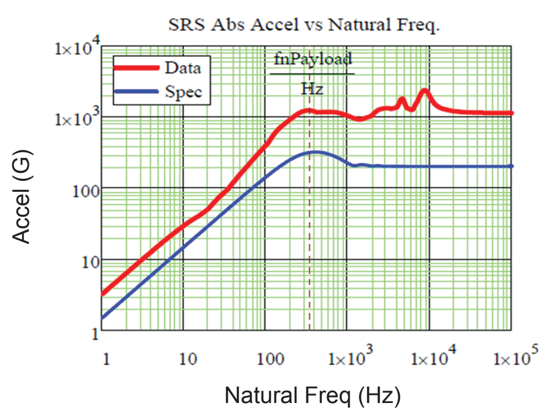
- When you need to compute a large spread of natural frequencies that exceed the suggested limits (to avoid numerical issues), use a combination of upsampling and decimation as described below.
  - To achieve higher natural frequency maximum, upsample original data and then compute SRS with the upsampled data.
  - To achieve lower natural frequency minimum, decimate original data and then compute SRS with the decimated data.

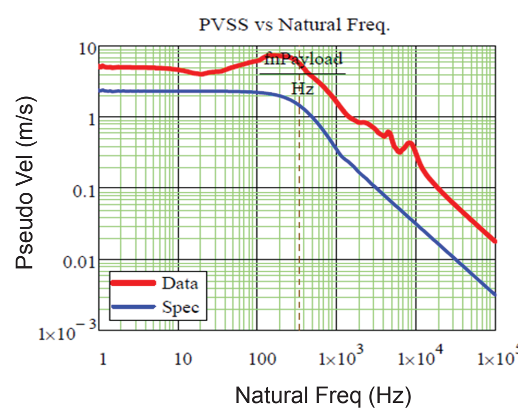


Estimating Influence of Shock Isolation

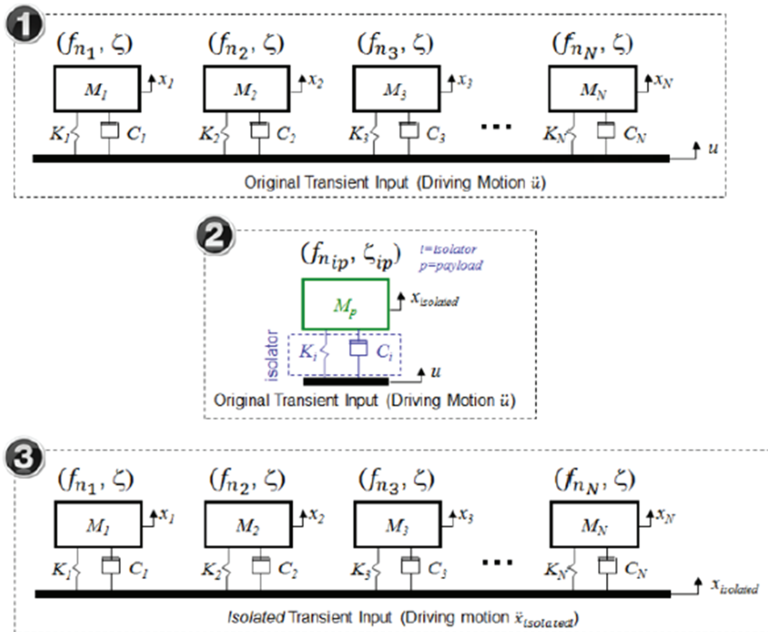
- Payload spec: 200·G, 2·msec
- Both SRS Abs Accel and PVSS show that shock event too severe for payload







Estimating the Influence of Shock Isolation Using 3-Step SRS Calculation



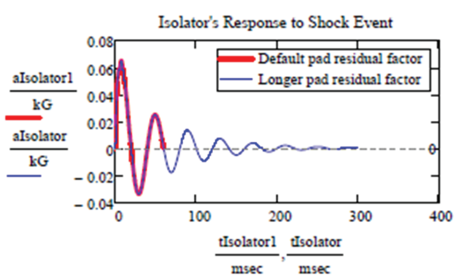
Re-Calculating the shock isolator response with a longer residual component.

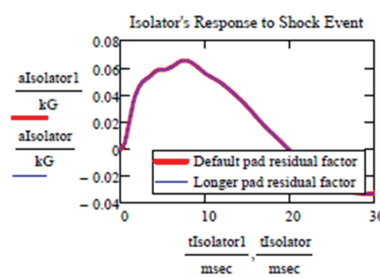
ADV := ("return : time domain" ; "pad residual factor : 7")

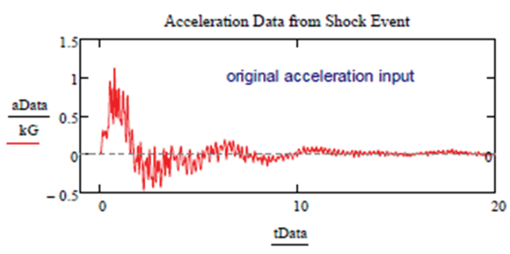
aIsolator := srsAbsAccel_k(tData, aData, fnIsolator, dampIsolator, ADV)

tIsolator := srsTime_k(tData, fnIsolator, ADV)

The plot below is zoomed to the early portion of time record to show the transient portion due directly to the aData input

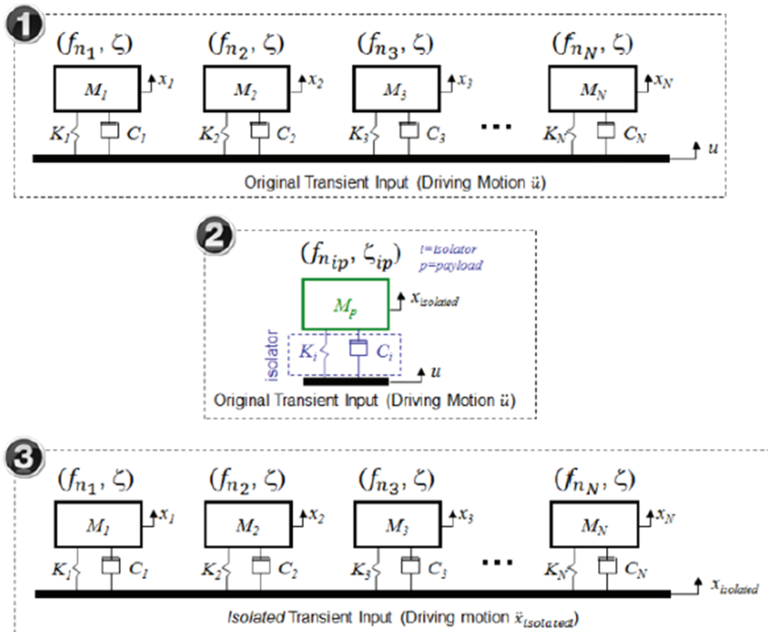






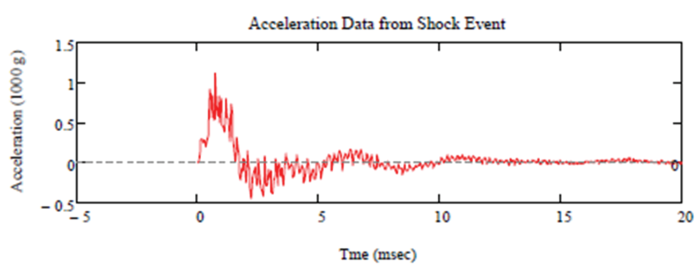
Comparing the shock isolator's response (above left) to the original acceleration input (left) shows that the transient time-domain acceleration levels that are driving the payload have reduced significantly and the time duration of the transient event has been elongated tremendously.

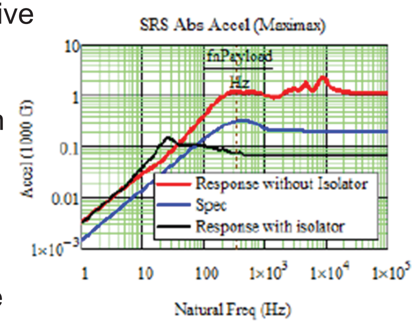
Estimating the Influence of Shock Isolation Using 3-Step SRS Calculation

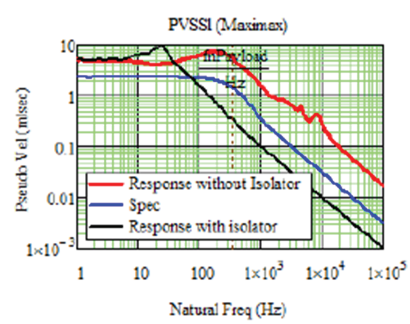


Final Results Without and With Shock Isolation

- Isolation hurts low frequency but helps at higher frequencies, as expected.
- Prediction is made without the need to re-run expensive FEA model.
- Once a design is found, then re-run FEA w/ isolation included for more accurate final simulation.

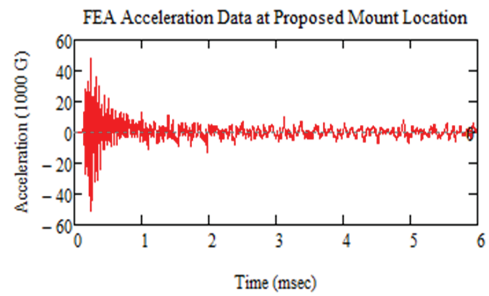






Mapping Transient FEA Output to Simple Shock Pulses to Drive Historical In-house Codes

- **Issue:**
  - Historical (legacy) analysis technique for component fragility uses a software that requires a simple shock pulse as input.
    - Pulse can be half-sine, haversine, sawtooth, …
  - FEA Analyst has only transient acceleration outputs from simulation



- **Solution:**
  1. Compute Shock Response for FEA data.
  2. Find simple pulse parameters that produce similar or enveloping Shock Response.
     - A small parameter study can find this fairly readily.
  - NOTE: This is a plausible solution approach, but it does not create a unique solution.

Conclusions

- Aliasing with FEA data is still a large problem for many analysts and organizations.
  - Aliasing can significantly distort results.
- Explicit Dynamics data has several other numerical challenges that are different than what occurs with physical testing data.
- If aliasing is avoided and numerical issues are handled properly, good Shock Response calculations can be derived from transient FEA simulations.
- A simple and quick 3-step process can be used to estimate the influence of adding shock isolation to an analysis.
  - The method itself uses the transient output of a single SDOF Shock Response "component" to derive the isolated shock input.
- Shock Response (SRS Absolute Accel and PVSS) are great approaches to use with FEA when analyzing transient shock results and when needing to assess a component based on simple shock specs.

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