Characterizing the Response of Composite Panels to a Pyroshock Induced Environment using Design of Experiments Methodology

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Outline

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The Objective of the Test:

PURPOSE

Purpose

• NASA still depends heavily on the attenuation methods of the Pyrotechnic Design Guidelines Manual for preliminary pyroshock environment estimation.
• Project Goal: Understand and quantify how various composite panel properties impact the composite panel's response to a pyroshock environment.

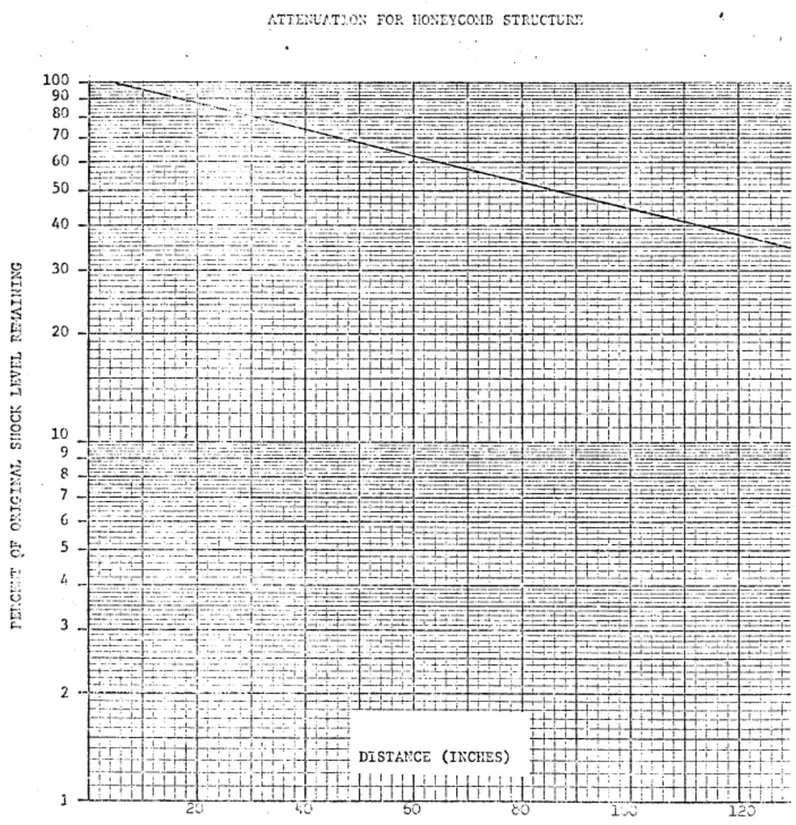


Figure 3.7 Attenuation for Honeycomb

Kacena, W. J., McGrath, M. B., & Rader, W. P. (1970). *Pyrotechnic Shock Design Guidelines Manual.* Denver: NAS5-15208.

Purpose Cont'd…

• Project Process: Use **design of experiments (DOE)** techniques to quantify differences in effects and variability in responses due to changes in input factors.

• **Challenge:**

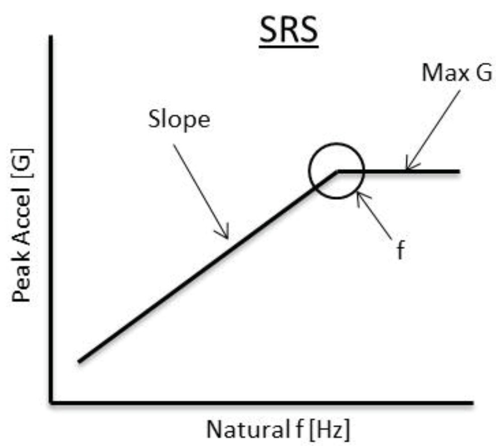
  • Shock environments can be very difficult to quantify. The most common methods are…

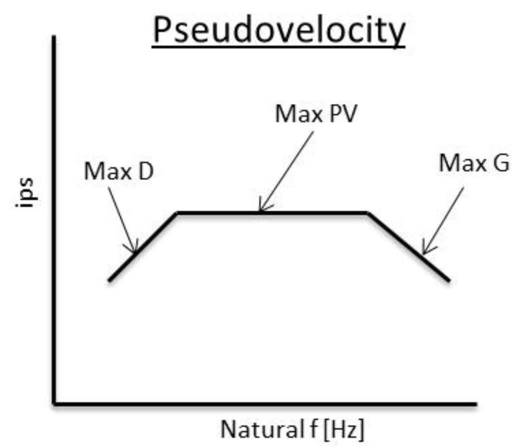
    • Time history based: shock pulses (half-sine pulse, etc.), wavelet reconstruction,…

    • Response spectrums: SRS, pseudovelocity (PV)

  • Analysis methods team starting with **single value inputs**; shock tends to be characterized with a spectrum.

  • Response spectrums for pyroshock tend to show similar trends (slope, frequency break point, plateau), but enveloping response spectrums can be very subjective.





Purpose Cont'd…

- Goal 1: Eliminate human subjectivity by automating
    - Post-Processing of acceleration time history data
        - Use first 20 ms
        - Remove bit-error
        - Detrend
    - Enveloping of Shock Response Spectrum
    - Enveloping of Pseudovelocity
- Goal 2: Determine and calculate single value inputs that can characterize the shock environment
    - SRS Envelope Parameters
    - PV Envelope Parameters
    - Temporal Moments
    - Spectral Moments
- Goal 3: Analyze additional spectrums used for characterizing shock
    - Fourier spectrum
    - Energy Spectral Density
    - Time-Frequency spectrum
- Goal 4: Utilize statistical processes to evaluate the data
    - Isolate non-essential parameters
    - Develop scaling method for composite structures

Collecting the needed data:

TEST SETUP & DESIGN

Test – Parameters

Group I – Monolithic Composite	Thickness (inch)	Ply and Orientation	Fill	LSC Core Load (gpf)	Number of Tests
	Thin	0 degree, unidirectional, tape	N/A, solid	10	4
	Thin	Quasi Isotropic, fabric	N/A, solid	10	4
	Thin	Quasi Isotropic, tape	N/A, solid	22	4
	Thick	Quasi Isotropic, tape	N/A, solid	10	4
	Thick	Quasi Isotropic, fabric	N/A, solid	22	4
Group II – Filled Composite	**Thickness**	**Ply Orientation**	**Fill**	**LSC Core Load**	
	8 Ply Fill	Quasi Isotropic, tape	Al Honeycomb	10	4
	8 Ply Fill	Quasi Isotropic, tape	Rohacell Foam	10	4

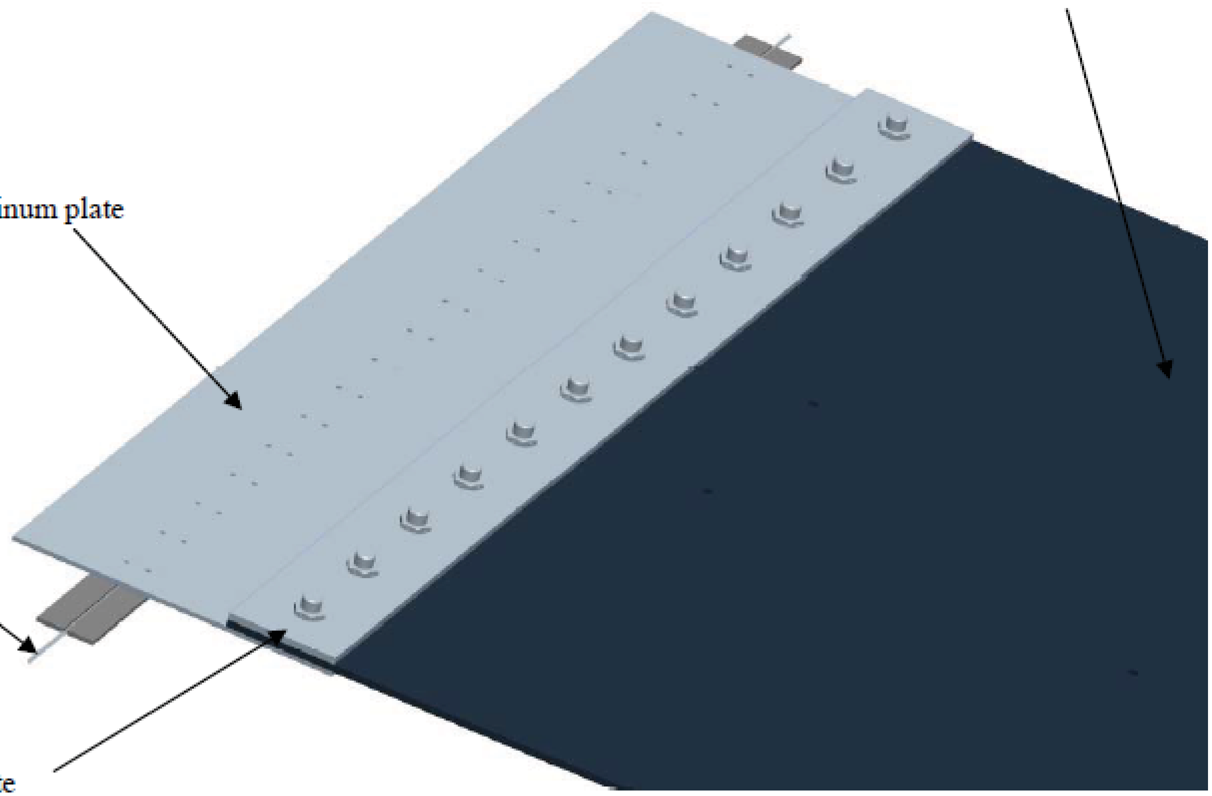
Test Outline

Test Number	Material	Panel Thickness	Ply	Orientation	Type	LSC Core Load
Group I – Solid Composite Panels						
1	Composite, IM7/TC350	Thin	Fabric	0-Deg, 18 ply	Solid	10
2	Composite, IM7/TC350	Thin	Fabric	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 18 ply	Solid	10
3	Composite, IM7/TC350	Thick	Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 54 ply	Solid	10
4	Composite, IM7/TC350	Thick	Fabric	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 27 ply	Solid	22
5	Composite, IM7/TC350	Thin	Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 38 ply	Solid	22
Analyze results from Tests 1-5 and re-plan as necessary						
6	Composite, IM7/TC350	Thin	Fabric	0-Deg, 18 ply	Solid	22
7	Composite, IM7/TC350	Thin	Fabric	+45°/-45°, 0° (2x), +45°/-45°, 90°, 18 ply	Solid	22
8	Composite, IM7/TC350	Thick	Fabric	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 27 ply	Solid	10
9	Composite, IM7/TC350	Thick	Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 54 ply	Solid	22
10	Composite, IM7/TC350	Thin	Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 38 ply	Solid	10

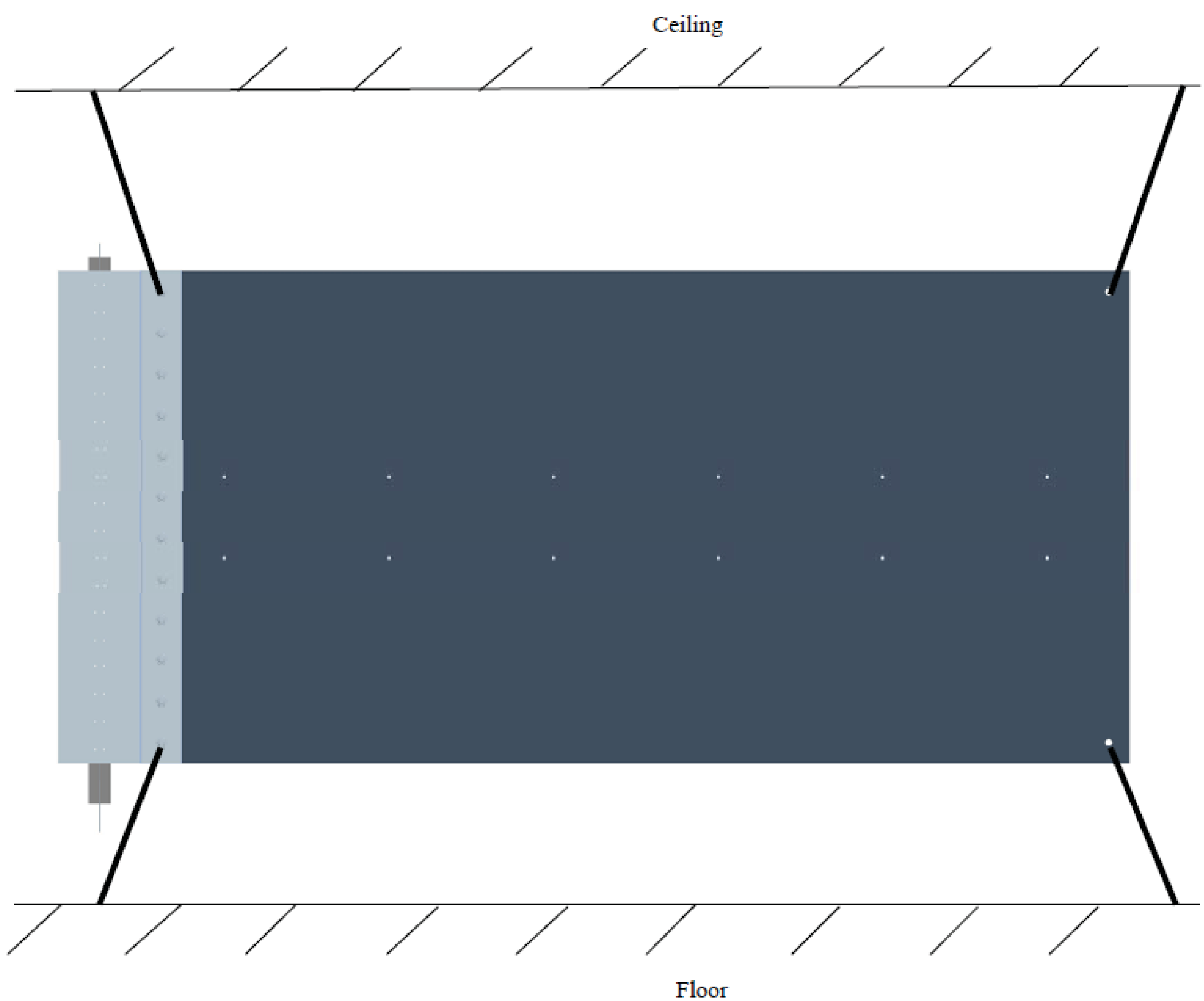
Test Outline Cont'd…

Group II – Sandwich Composite Panels							
Panel Number	Test Order Number	Material	Panel Thickness	Fill/Ply	Orientation	Type	LSC Core Load
11	1	Composite, IM7/TC350	8 Ply Fill	Al Honeycomb & Tape	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	10
12	4	Composite, IM7/TC350	8 Ply Fill	Al Honeycomb & Tape	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	22
13	3	Composite, IM7/TC350	8 Ply Fill	Rohacell Foam &Tape	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	10
14	2	Composite, IM7/TC350	8 Ply Fill	Rohacell Foam &Tape	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	22
15	7	Composite, IM7/TC350	8 Ply Fill	Al Honeycomb & Tape	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	10
16	5	Composite, IM7/TC350	8 Ply Fill	Al Honeycomb & Tape	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	22
17	8	Composite, IM7/TC350	8 Ply Fill	Rohacell Foam &Tape	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	10
18	6	Composite, IM7/TC350	8 Ply Fill	Rohacell Foam &Tape	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	22
	Evaluate results from tests 11-18 and determine test panel configuration for tests 19-28						

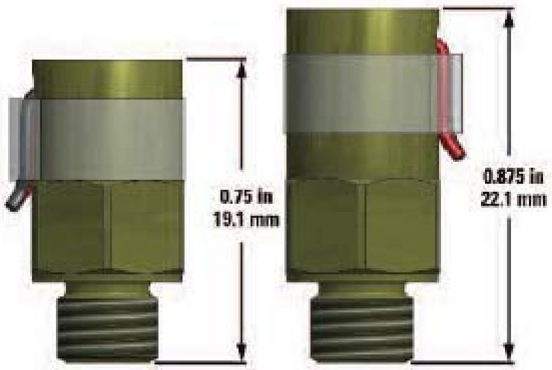
Test Article



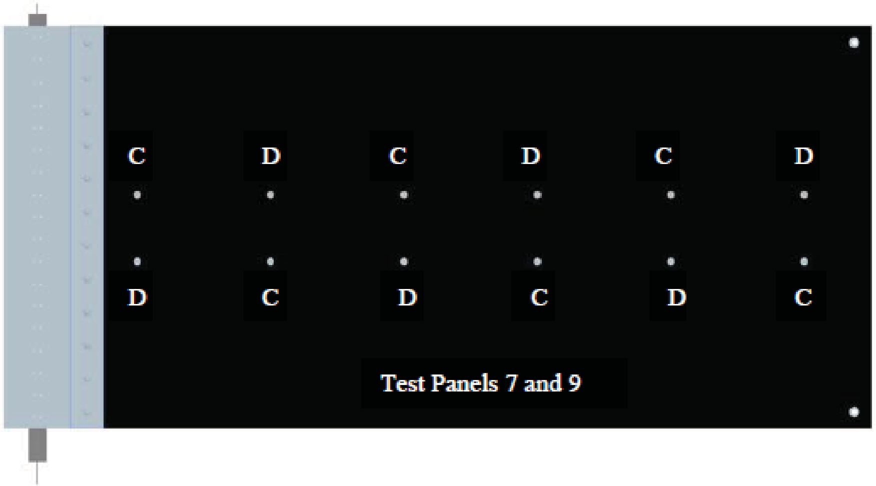
Test Article Cont'd…

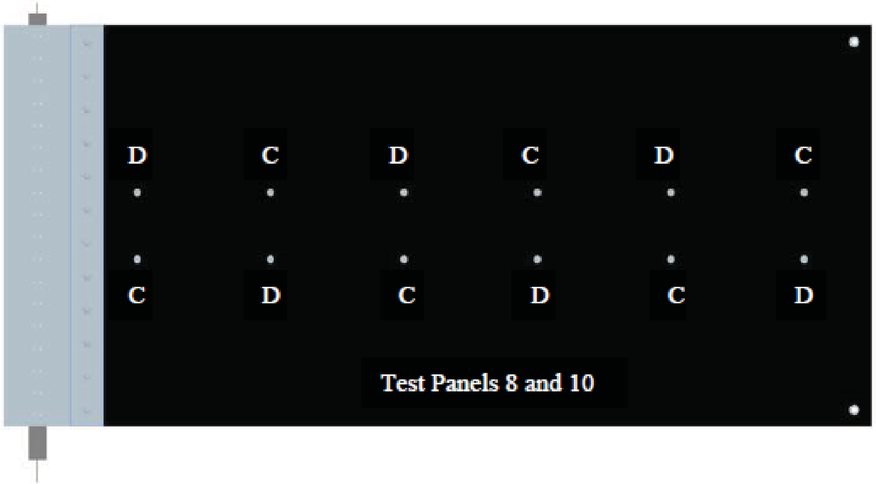


Test Instrumentation



PCB 350C02 PCB 350D02



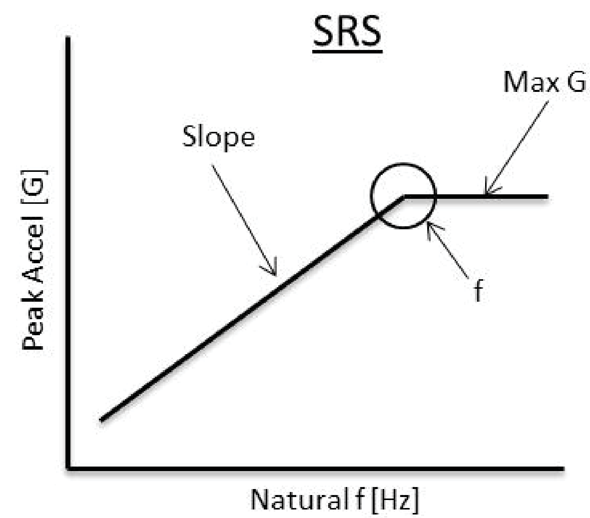


Characterizing the Test Data:

SINGLE VALUE INPUTS

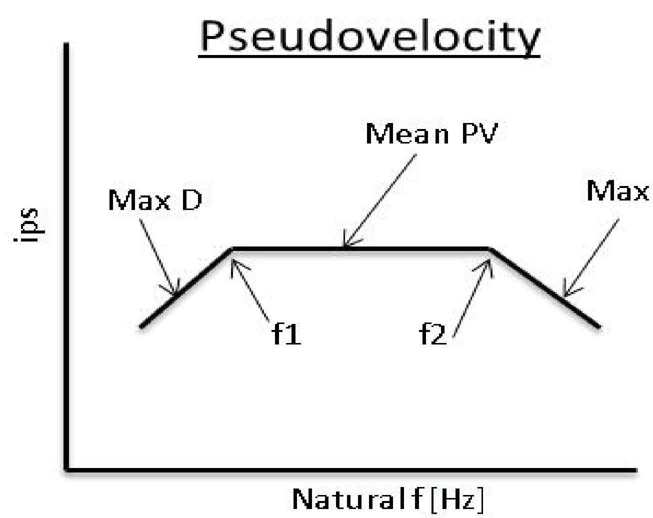
Single Value Inputs – Shock Response

- A shock response spectrum can often be enveloped knowing three parameters (assuming a frequency range of 100 to 10,000 Hz):
  - Frequency break point (Hz)
  - Max Peak Accel or plateau value (G)
  - Slope (dB/oct)



Single Value Inputs - PV

- A pseudovelocity spectrum can be enveloped knowing three parameters (assuming a frequency range of 100 to 10,000 Hz):
    - Mean Pseudovelocity (ips)
    - Max Peak Accel or plateau value (G)
    - Slope (dB/oct)



Single Value Inputs – Temporal & Spectral Moments

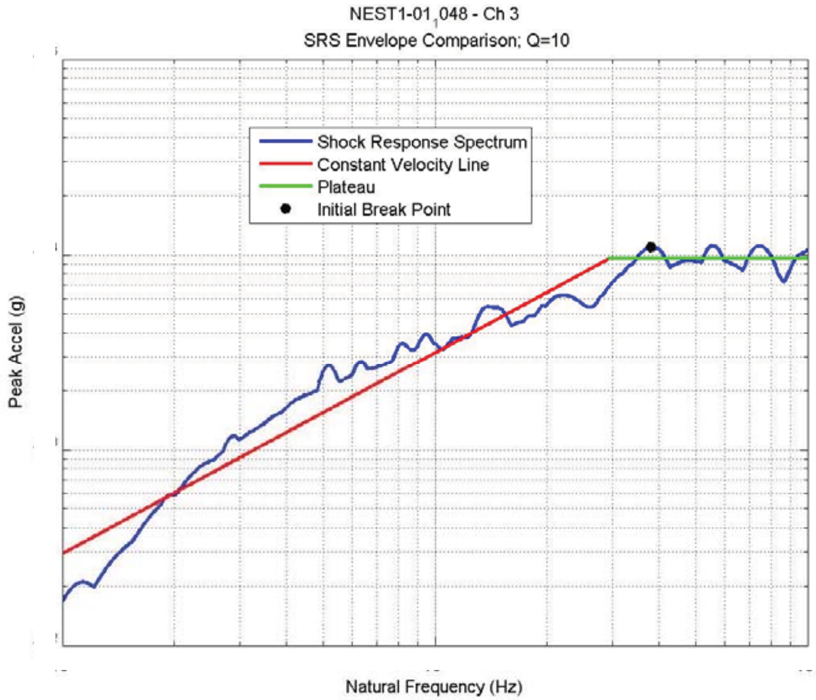
Single Value Inputs: Temporal and Spectral Moments	
Temporal Moment Calculated Values	**Spectral Moment Calculated Values**
Temporal Energy	Spectral Energy
Temporal Mean	One Sided Spectral Mean
Temporal Variance	One Sided Spectral Variance
Root-Mean-Square Duration	One Sided RMS Bandwidth
Variance Normalization	Variance Normalization
Temporal Skewness	One Sided Spectral Skewness
Temporal Kurtosis	One Sided Spectral Kurtosis
Root Energy Amplitude	

Reducing human error:

AUTOMATING THE PROCESS

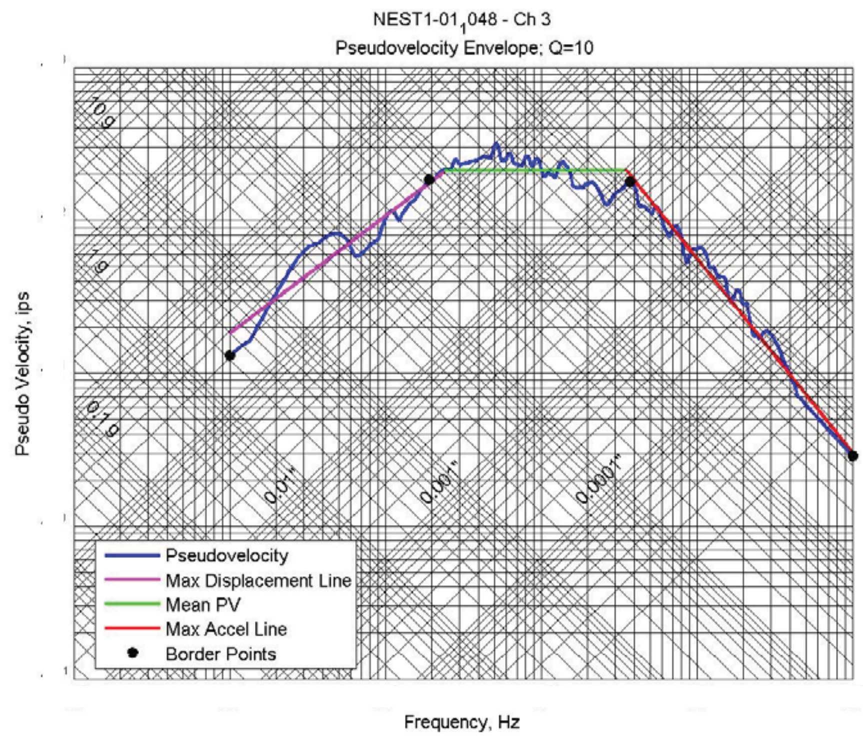
SRS Enveloping - General Algorithm

- Read in SRS plot points.
- Determine a temporary frequency break point (Lowest frequency that is one standard deviation below the highest peak value).
- Calculate the slope of the data points from 100Hz to the temporary frequency break point (Least Squares Fit).
- For the plateau, calculate the mean value of the data points from the temporary frequency break point to 10,000Hz.
- Calculate where the sloped line and the plateau intersect; this is the new frequency break point.
- Create the sloped portion of the curve from 100Hz to the new frequency break point.
- Create the plateau from the new frequency break point to 10,000Hz.
- Output the frequency break point, the slope, and the plateau values.



PV Enveloping – General Algorithm

- Read in PV plot points.
- Determine break points (lowest and highest frequencies that correspond to peaks that are two standard deviations below the highest peak.)
- Calculate the slope of the max displacement line.
- Calculate the mean of the max pseudovelocity line.
- Calculate the slope of the max acceleration line.
- Calculate the two break frequencies by calculating where the max displacement and max acceleration line intersect the max pseudovelocity line.
- Create the enveloping curves.
- Output the max displacement value, the pseudovelocity, and the max acceleration value.



Post Processing Automation – General Algorithm

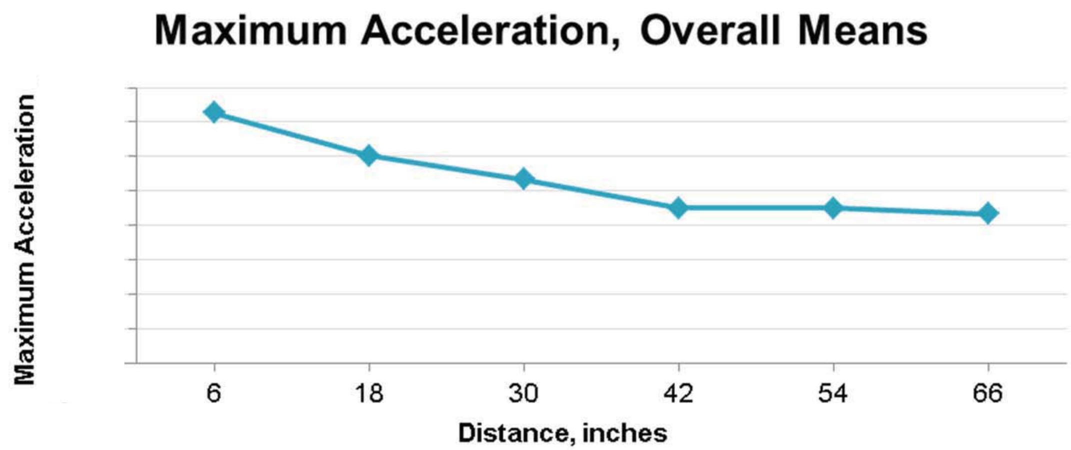
- Import time history data.
- Identify the beginning of the shock pulse in the time history.
- Remove the bit error from the time history.
- Take the first 20msec of the shock pulse.
  - Detrend (linear) the shock pulse.
- Perform calculations on post-processed data.
  - Time history plots
  - Shock Response Spectrum
  - Pseudovelocity Response Spectrum
  - Temporal Moments
  - Spectral Moments
  - Fourier Spectrum
  - Generalized Harmonic Wavelet Transform
- Print and plot results for statistical evaluation.

Searching for Trends:

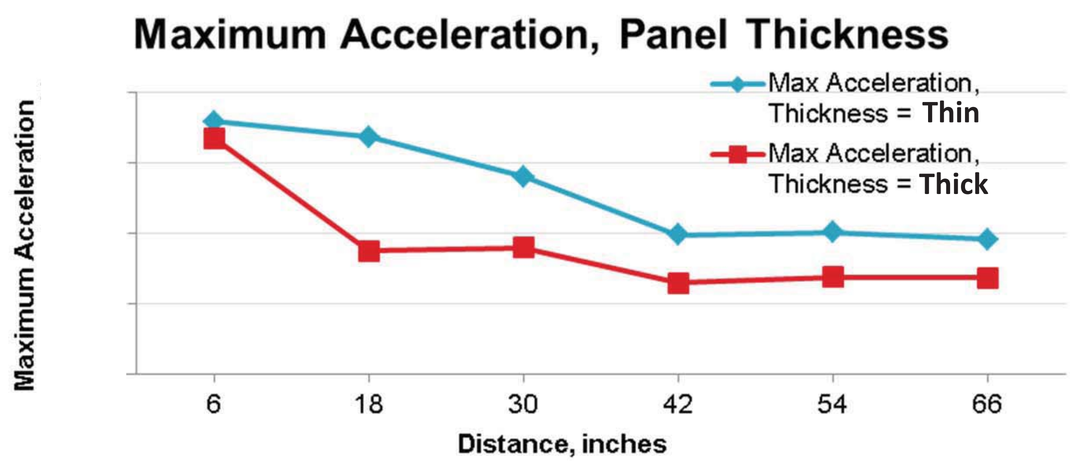
PRELIMINARY STATISTICAL ANALYSIS

Max Acceleration Stats Analysis: Adequate Model Significant Factors

- Distance (top graph) has an **overall** effect of decreasing from 6 to 42 inches, then leveling out

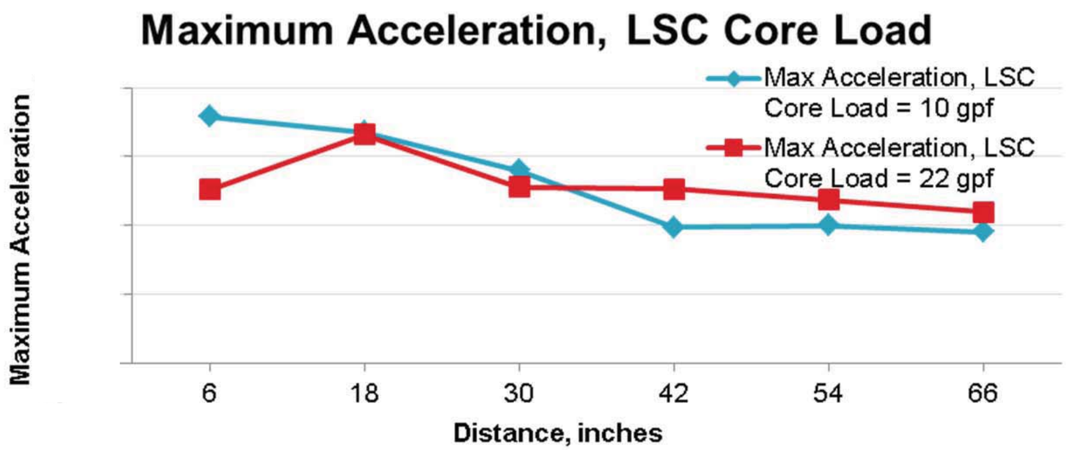


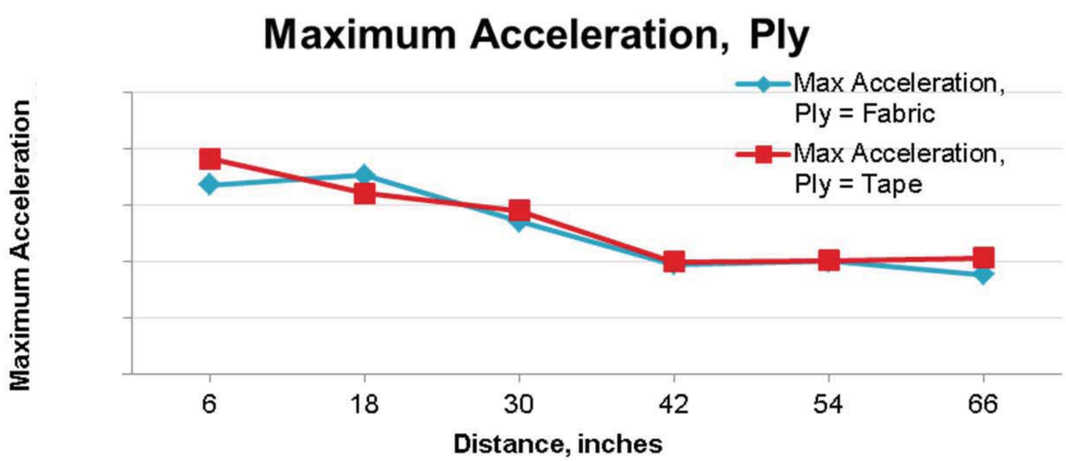
- The attenuation appears steeper and may bottom out at a lower value for Thicker panel than for Thinner (bottom graph)



Max Acceleration Stats Analysis: Adequate Model Significant Factors

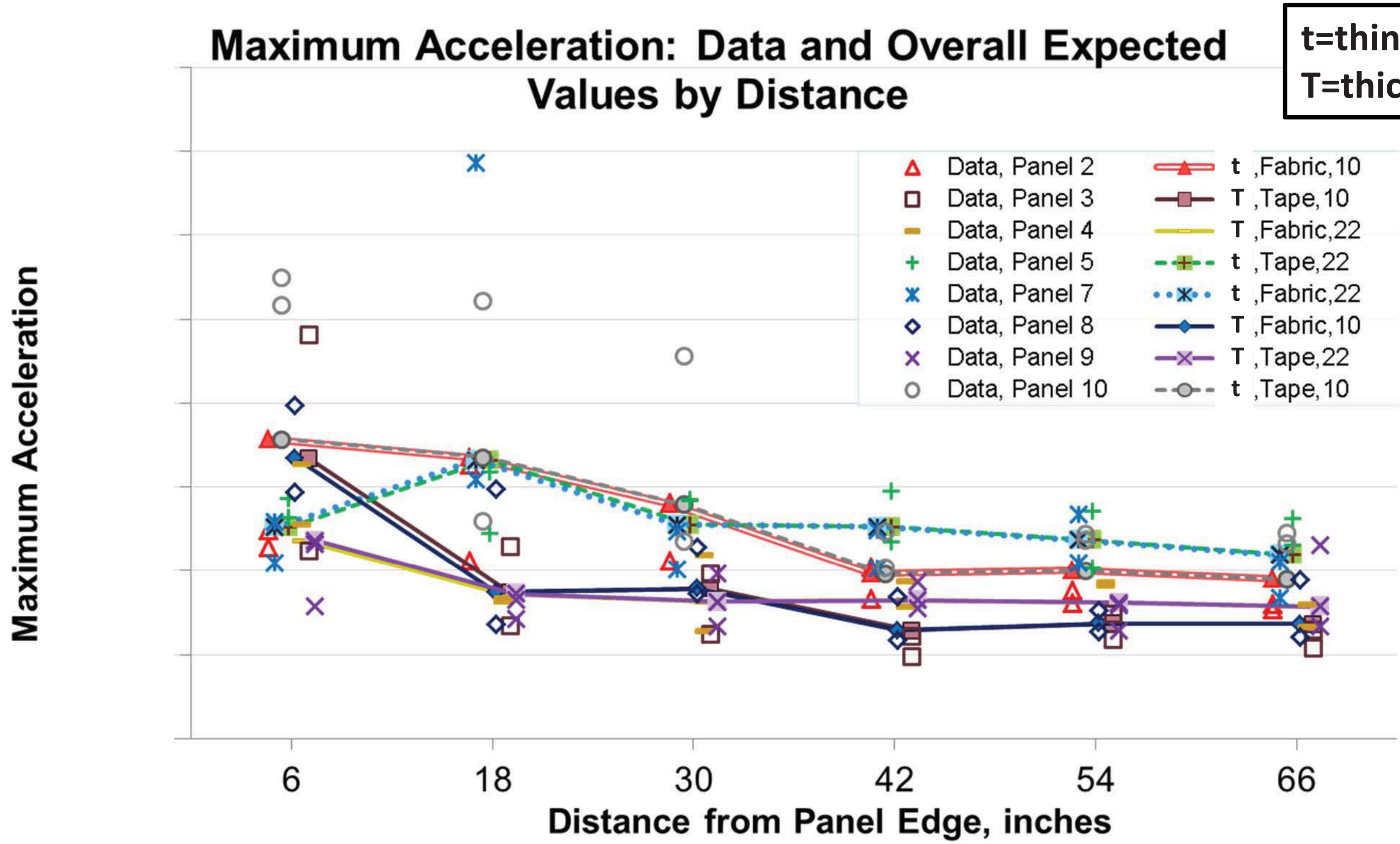
- LSC Core Load may or may not be a significant factor (top)
- Ply does not appear to be a significant driver of Maximum Acceleration, given this model (bottom)





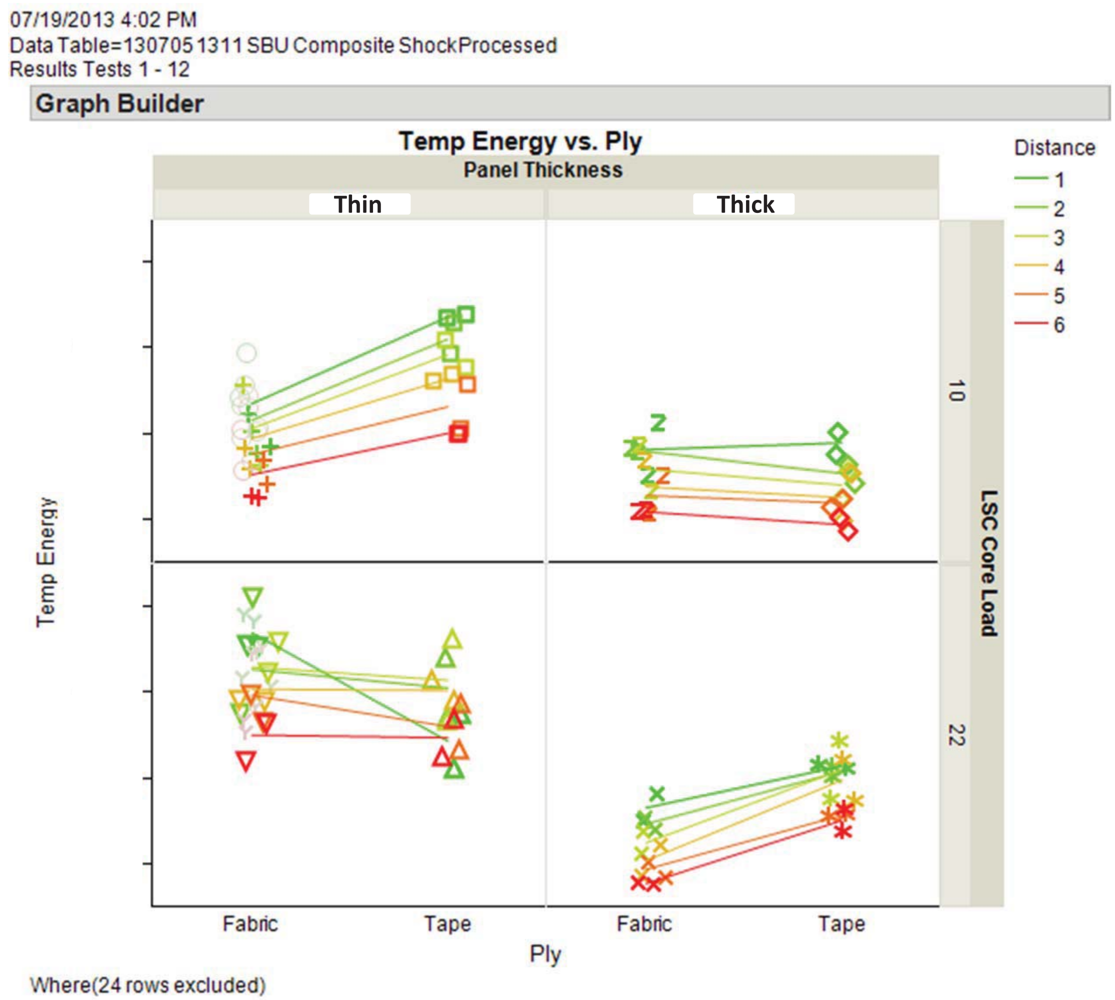
Max Acceleration Stats Analysis: Graph of Data with Full Adequate Model

t=thin
T=thick



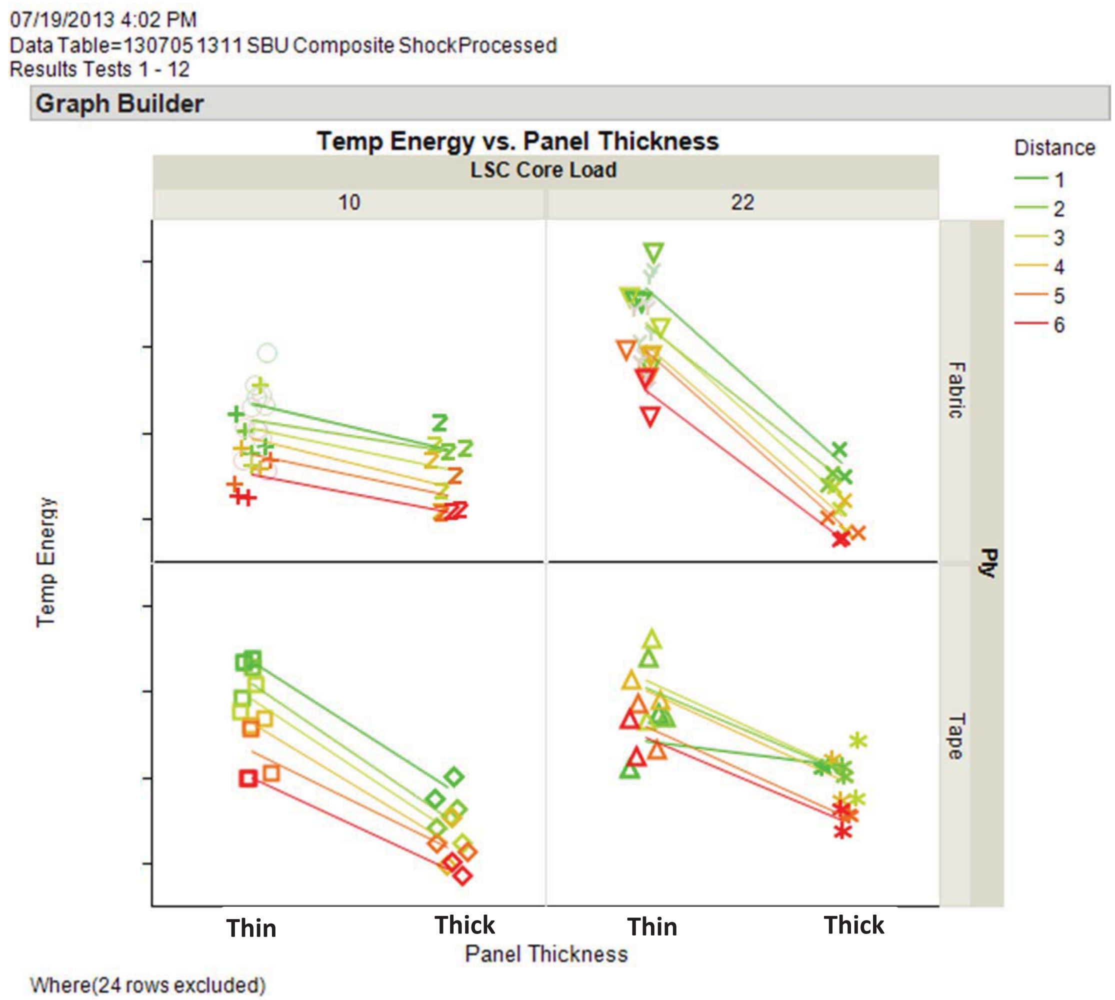
Temporal Energy: Visual Analysis

- In general, there appears to be a decrease in Temp Energy with Distance
- Tape may show a larger response than Fabric – or we may be seeing noise
- Top/ Bottom seem to replicate each other well
- 0 and 45/90 appear to replicate one another



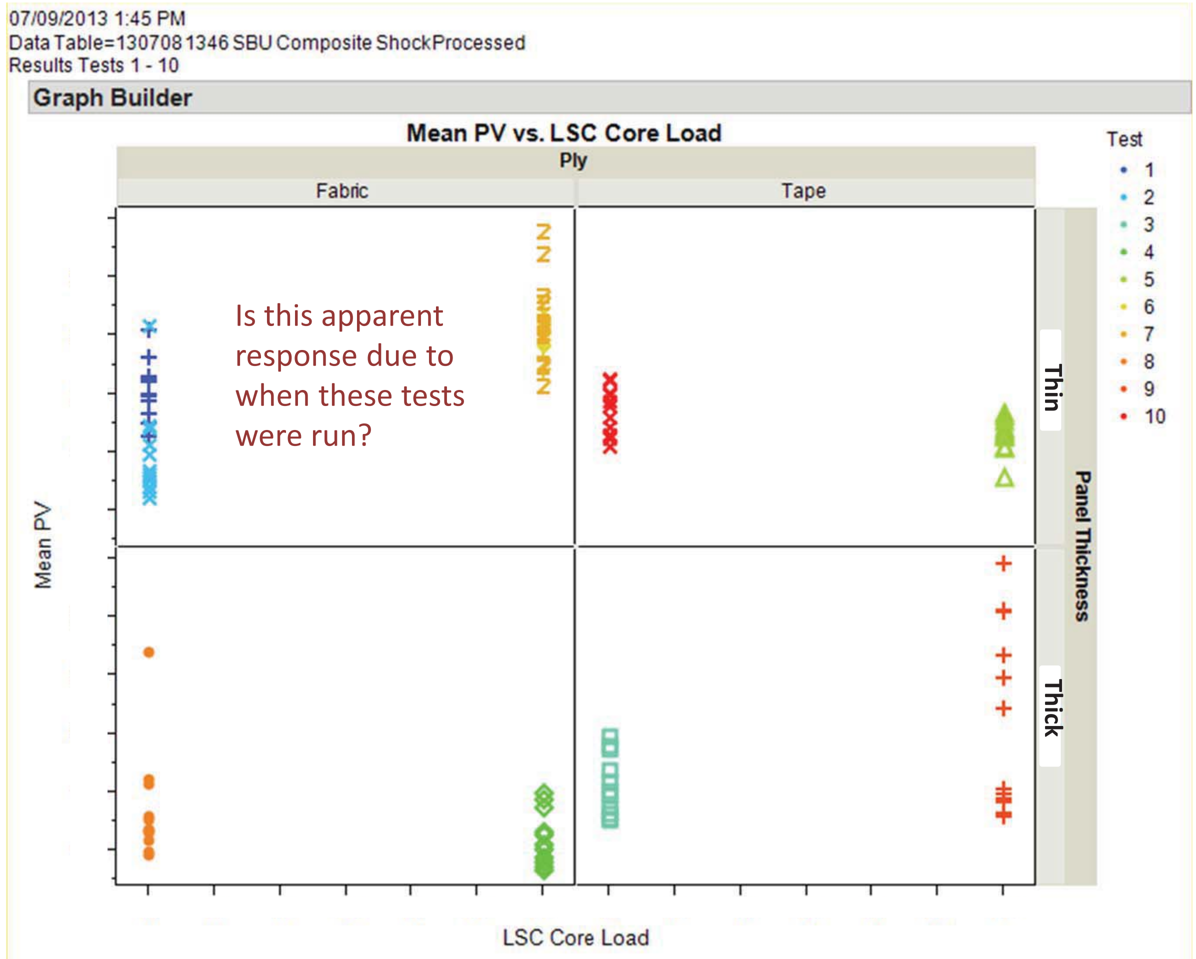
Temporal Energy: Visual Analysis

- Thicker panels appear to have lower Temp Energy than Thin
  - The effect is very noisy – may be difficult to pick out in quantitative analysis OR may not exist
  - Panel 2 (Thinner Fabric 10 gpf) might have given low values – factor combination not on retest list, though Panel 2 is
- Panel 5 (Thin Tape 22 gpf) seems to be noisy close-in
  - Likely not of great concern to analysis, but could be useful to know why



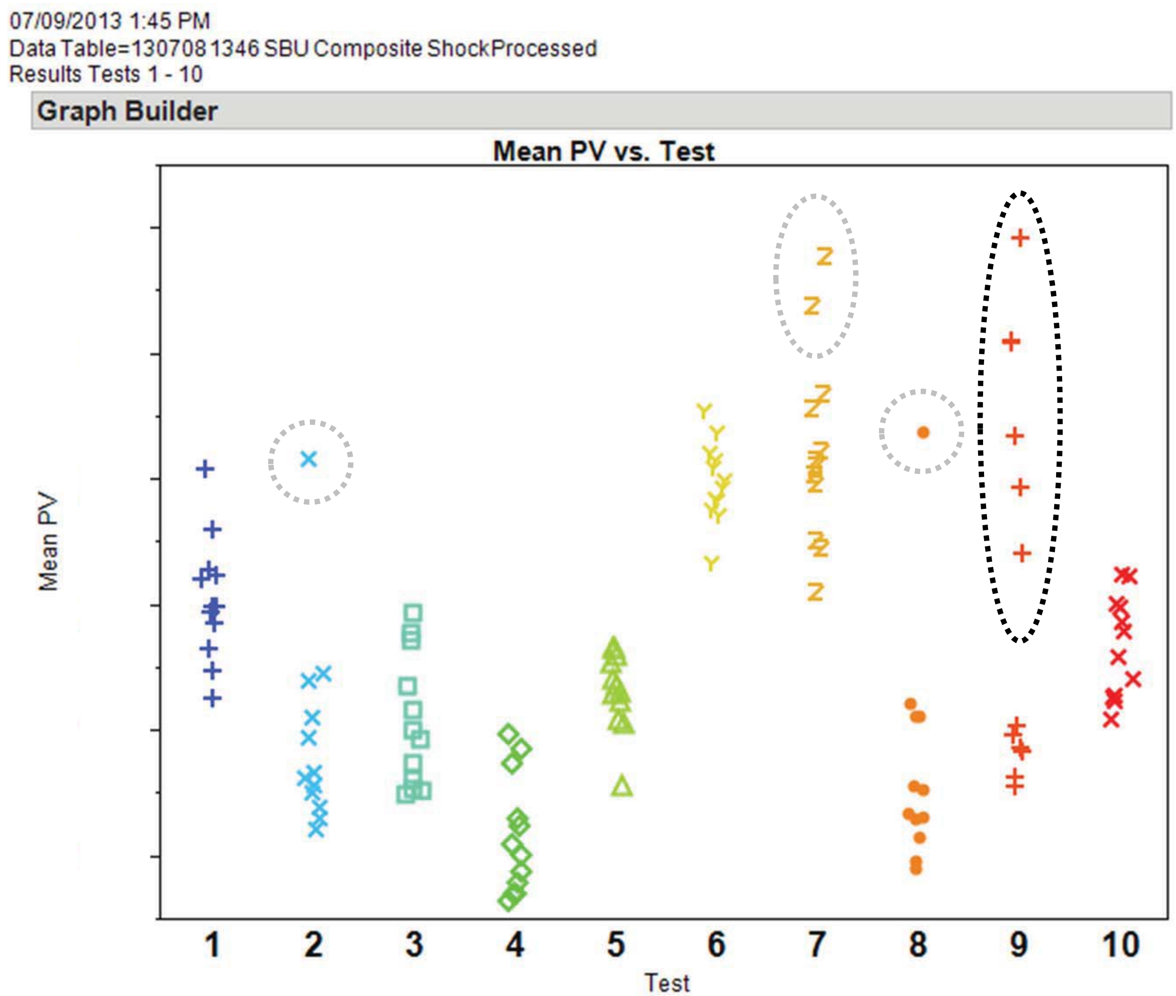
Graphs of Mean PV Data

- Visual analysis:
  - Usually, Core Load doesn't make a difference
  - Usually, Tape gives a higher response than Fabric
  - Usually, Panel Thickness doesn't matter
  - BUT Thin Fabric is quite sensitive to Core Load (3-way interaction)
- BUT data is equivocal



Graphs of Mean PV Data

- Mean PV by Test Number
  - Range of variability – suggests measurement is noisy in particular instances
  - What are the instances?
- In particular, Test 9 has several wild points



Max Acceleration: Bottom Lines

- Max Accel generally decreased with increasing Distance
  - Some panels showed a knee at ~18”, with maximum values there for a few panels
- Little difference seen between Fabric and Tape panels
- Thin panels gave higher Max Accel responses than Thick Panels over a longer distance
  - Thick panels’ Max Accel tended to fall off steeply before 18”
- 22 gpf Core Load tended to result in lower Max Accel values at 6” than 10 gpf
  - Thin panels’ Max Accel values increased to a maximum at 18” Distance

Temporal Energy: Bottom Lines

- Top accelerometer TE values are considerably and fairly repeatably higher than Bottom
- TE generally decreases with decreasing Distance
  - Some panels' curves show a knee at ~30" Distance, with a few even showing a maximum there
- Thinner Thickness results in higher TE than Thicker
- Variability increases with increasing TE
  - Analyzed logarithm of TE – analysis was of little use without this transformation

Mean PV: Bottom Lines

- There are a number of wild points that seriously inhibit quantitative analysis.
  - Recommend looking at these points in the data to see if there is something driving this.
  - Test 9 exhibits particularly high variability.
- In visual analysis, after attempting to identify and disregard these wild points, the following conclusions might be made:
  - Core load and Panel Thickness usually don't make much difference.
  - Fabric usually gives lower Mean PV than Tape.
  - BUT Fabric at Thinner Thickness and 22 gr Core Load appears to have higher Mean PV.
  - 0-degree panels may respond similarly to 45/90 panels.

Forward Work

- Evaluate noise in the data.
  - Check if algorithms are too sensitive.
  - Review time histories and any other factors that might explain noise and outliers.
  - Search for trends in data.
- Understand the physical meaning of parameters.
  - Some pseudovelocity results are counter to expectations.
- Consider retesting panels after non-destructive evaluation of panels.
- Complete all test series.
- Develop useful tool for a composite panel's response to a shock environment.
  - Identify non-significant parameters of composite panels.
  - Develop scaling methods for composite panels, if possible.

Questions?

Back up

Single Value Inputs – Temporal Moments

$Accel \equiv AccelerationTimeHistory(\frac{in}{s^2})$

- Temporal Energy, $Tnrg = \sum Accel^2 * \Delta t$
- Normalization, $Anorm = \frac{Accel^2}{Tnrg}$
- Temporal Mean, $Tmean = \sum t * Anorm * \Delta t$
- Standardization, $t0 = t - Tmean$
- Temporal Variance, $T\,\mathrm{var} = \sum t0^2 * Accel^2 * \Delta t$
- RMS Duration, $D = \sqrt{T\,\mathrm{var}}$
- Variance Normalization, $t0 = \frac{t0}{D}$
- Root Energy Amplitude, $Trea = \sqrt{\frac{Tnrg}{D}}$
- Temporal Skewness, $Tskew = \sum t0^3 * Accel^2 * \Delta t$
- Temporal Kurtosis, $Tkurt = \sum t0^4 * Accel^2 * \Delta t$

Hacker, J. (2012, May 30). *Index of ula time-frequency matlab scripts*. Retrieved from ftp://shockwg@drop.aero.org/

Single Value Inputs – Spectral Moments

$$Accel \equiv AccelerationTimeHistory\left(\frac{in}{s^2}\right)$$

$$X(f) = fftshift(fft(Accel)) * \Delta t$$

$$XX(f) = \left|X(f)\right|^2$$

- Spectral Energy, $Fnrg = \sum XX(f) * \Delta f$
- Normalization, $Xnorm = \frac{XX(f)}{Fnrg}$

- One Sided Spectral Mean, $Fmean1 = \sum\left(\left|f\right| * XX(f)\right) * \Delta f$
- Two Sided Spectral Mean, $Fmean2 = \sum\left(f * XX(f)\right) * \Delta f$

- Standardization, $f1 = f - Fmean1$
  $f2 = f$

- One Sided Spectral Variance, $F\text{var}1 = \sum\left(f1^2 * XX(f)\right) * \Delta f$
- Two Sided Spectral Variance, $F\text{var}2 = \sum\left(f2^2 * XX(f)\right) * \Delta f$

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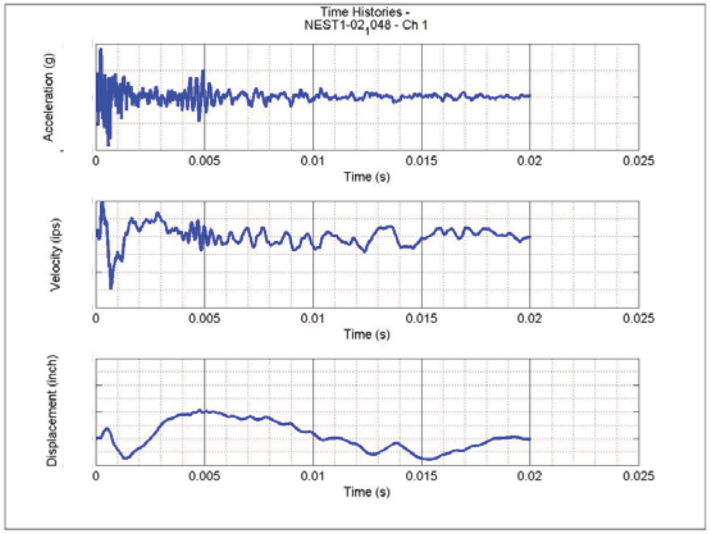
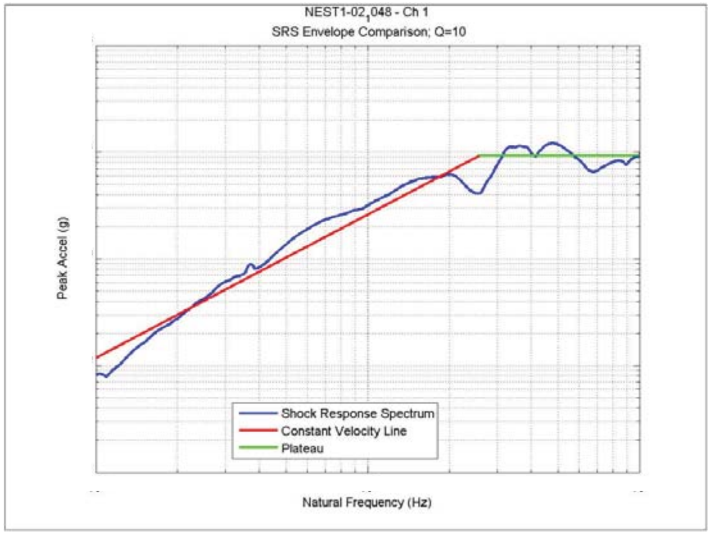
Single Value Inputs – Spectral Moments Cont'd...

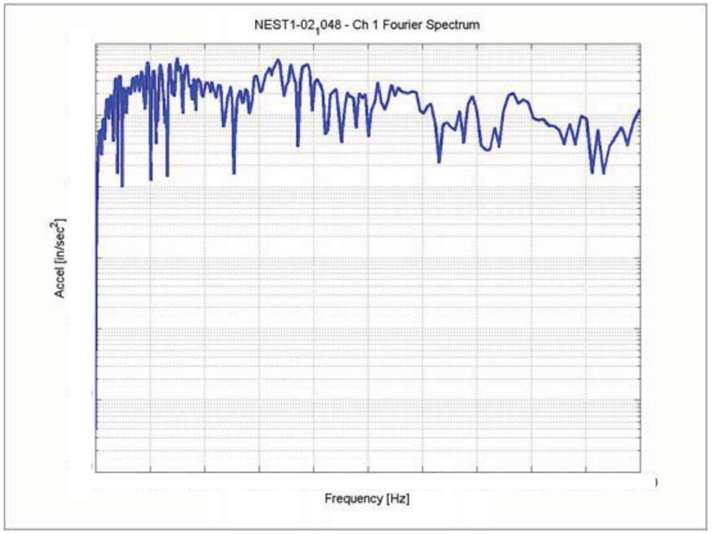
- One Sided RMS Bandwidth, $B1 = \sqrt{F\,\mathrm{var}1}$
- Two Sided RMS Bandwidth, $B2 = \sqrt{F\,\mathrm{var}2}$
- Variance Normalization, $f1 = \frac{f1}{B1}$ $\quad f2 = \frac{f2}{B1}$
- One Sided Spectral Skewness, $Fskew1 = \sum \left(\left| f1 \right|^3 * XX(f) \right) * \Delta f$
- Two Sided Spectral Skewness, $Fskew2 = \sum \left(f2^3 * XX(f) \right) * \Delta f$
- One Sided Spectral Kurtosis, $Fkurt1 = \sum \left(f1^4 * XX(f) \right) * \Delta f$
- Two Sided Spectral Kurtosis, $Fkurt2 = \sum \left(f2^4 * XX(f) \right) * \Delta f$

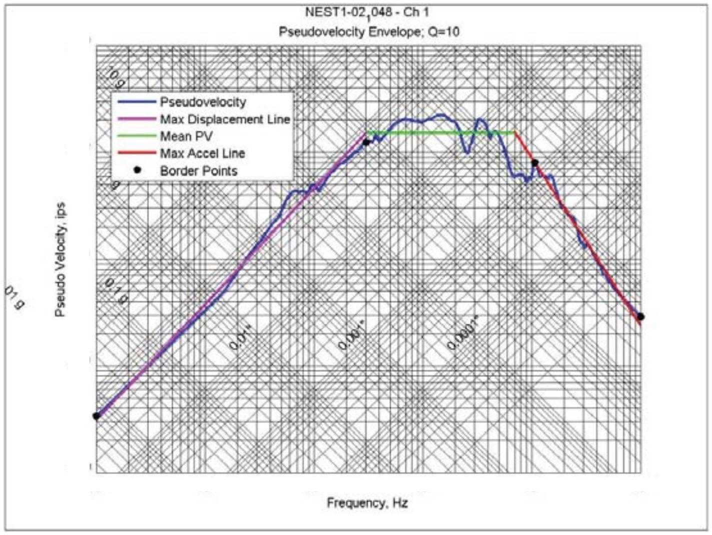
Hacker, J. (2012, May 30). *Index of ula time-frequency matlab scripts*. Retrieved from ftp://shockwg@drop.aero.org/

Results – Output Figures

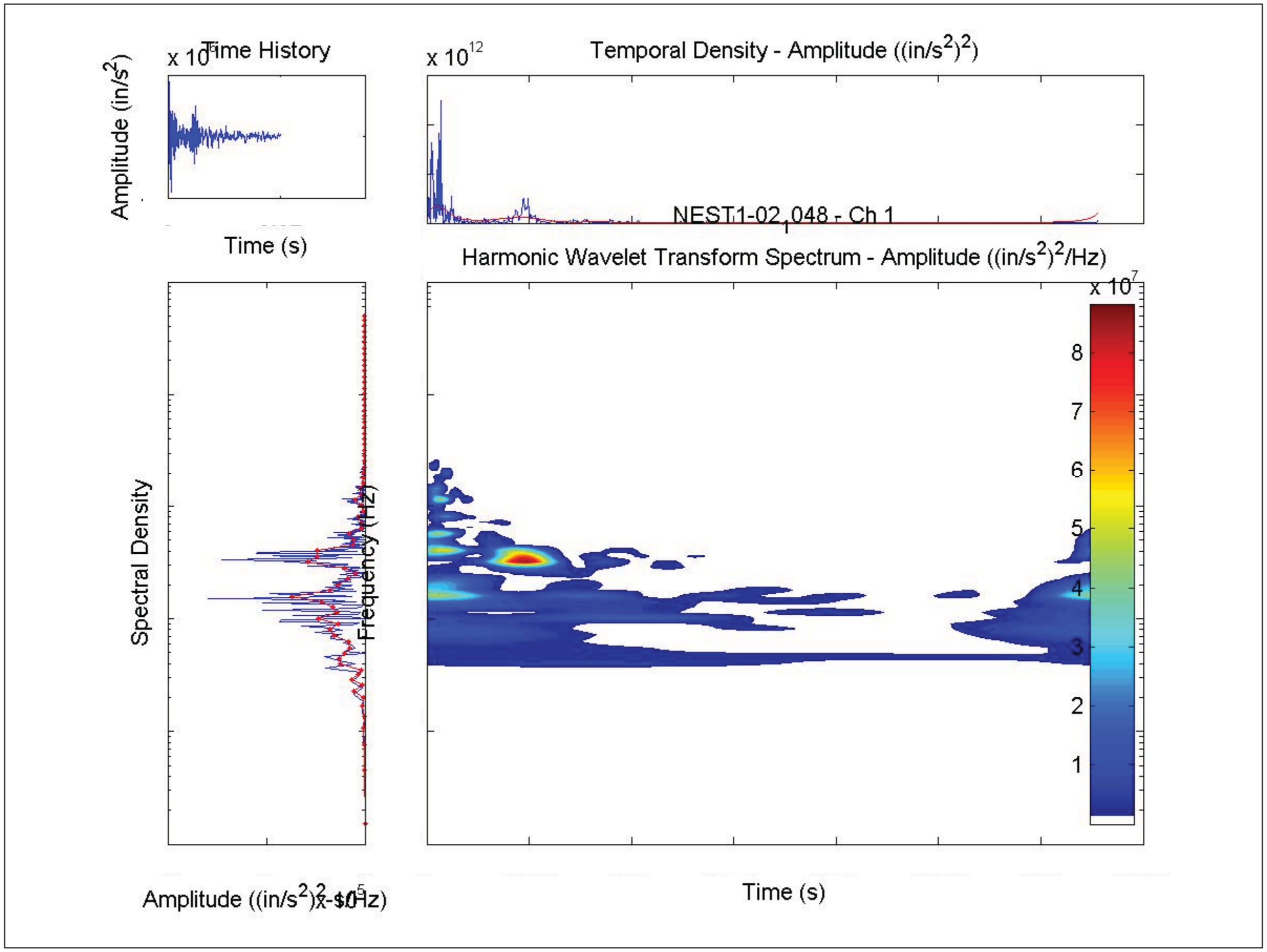








Results – Output Figures Cont'd….



Hacker, J. (2012, May 30). *Index of ula time-frequency matlab scripts*. Retrieved from ftp://shockwg@drop.aero.org/

SRS Enveloping - Code

Contents


```
function [ env ] = srs_envelope2( srs, varargin )
```

```
%srs_envelope Envelopes an SRS. Creates a plot and returns the values of
%the break point, slope, and plateau value
%   SRS is a two-column matrix of frequency and G values

f=srs(:,1);
g=srs(:,2);
```

```
Error using srs_envelope2 (line 6)
Not enough input arguments.
```

Determine the intermediate frequency break point of the slope and plateau

```
[pks,locs]=findpeaks(srs(:,2));
s=std(pks);

pl=zeros(length(pks),1);
jj=1;
for ii=1:length(pks)
    if pks(ii)>=(max(pks)-1*s)
        pl(jj)=locs(ii);
        jj=jj+1;
    end
end
% remove zeros from pl
pl(pl==0)=[];
% now use the first point as the initial frequency break point
fbi=pl(1);
```

SRS Enveloping - Code

Find envelope line properties

find line properties from 0Hz to the initial breakpoint

```
mdl=LinearModel.fit(log10(f(1:fbi)),log10(g(1:fbi)));

% y=b*x^N
N=mdl.Coefficients{2,1}; %intercept
b=10^mdl.Coefficients{1,1}; %slope for exponent

% Find mean value for the plateau
% Note: mean was chosen rather than max because it will take into account
% all of the values in the plateau range.
yp=mean(g(fbi:end));

% Calculate break point
fb=(yp/b)^(1/N);
```

Create envelope curve

Determine counter for envelopes

```
ss=1;
while f(ss)<fb
    ss=ss+1;
    if ss>length(f)
        break
    end
end
ss=ss-1;

% Sloped part of line
fslope=zeros(ss,1);
yslope=zeros(ss,1);
for gg=1:ss;
    fslope(gg)=f(gg);
    yslope(gg)=b*f(gg)^N;
end
% Remove excess zeros
fslope(fslope==0)=[];
yslope(yslope==0)=[];
% Calculate the slope in dB/Oct
dbOct=2*log10(20)*log10(yslope(end)/yslope(1))/log10(fslope(end)/fslope(1));
% Plateau
cc=1;
fplateau=zeros(length(f)-ss,1);
yplateau=zeros(length(f)-ss,1);
for hh=ss:length(f)
    fplateau(cc)=f(hh);
    yplateau(cc)=yp;
    cc=cc+1;
end
% Remove excess zeros
fplateau(fplateau==0)=[];
yplateau(yplateau==0)=[];
```

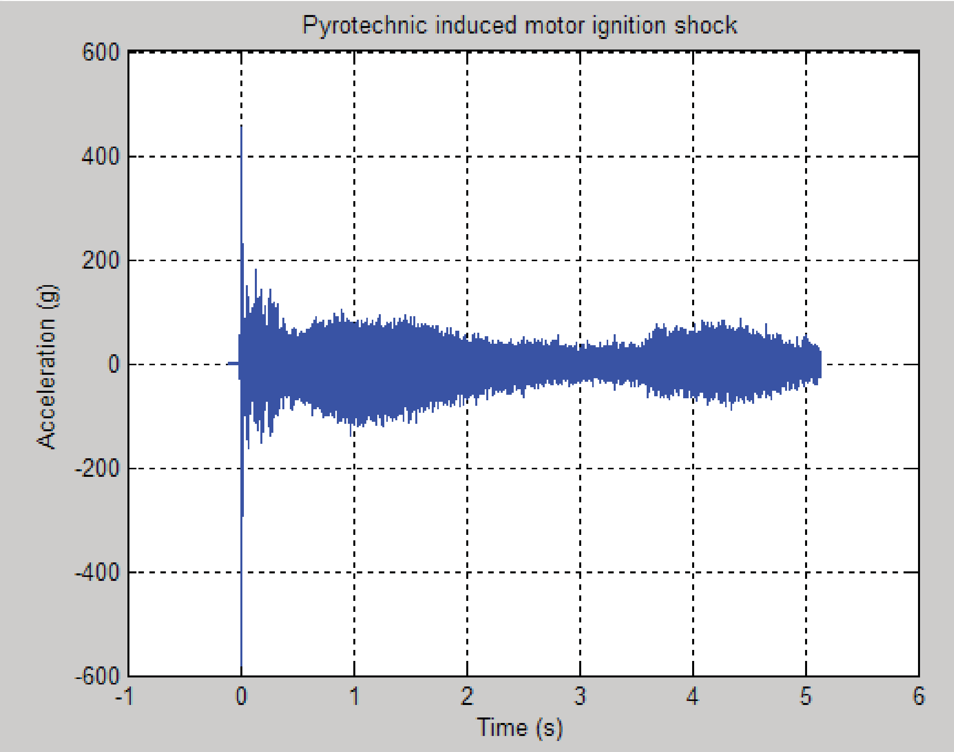
SRS Enveloping - Code

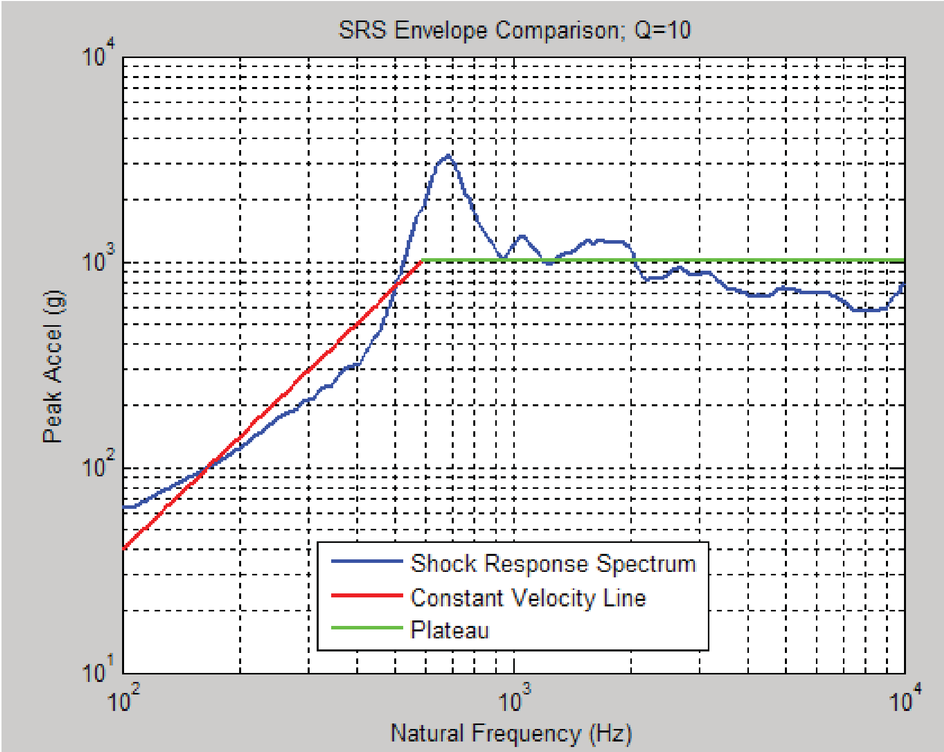
Plot results

```
loglog(f,g,'LineWidth',2)
hold on
loglog(fslope,yslope,'r','LineWidth',2)
loglog(fplateau,yplateau,'g','LineWidth',2)
grid on
title([varargin,' SRS Envelope Comparison; Q=10']);
legend('Shock Response Spectrum','Constant Velocity Line','Plateau','Location','Best');
xlabel('Natural Frequency (Hz)')
ylabel('Peak Accel (g)')
hold off

% Output envelope properties
env=[fb,dbOct,yp];
```

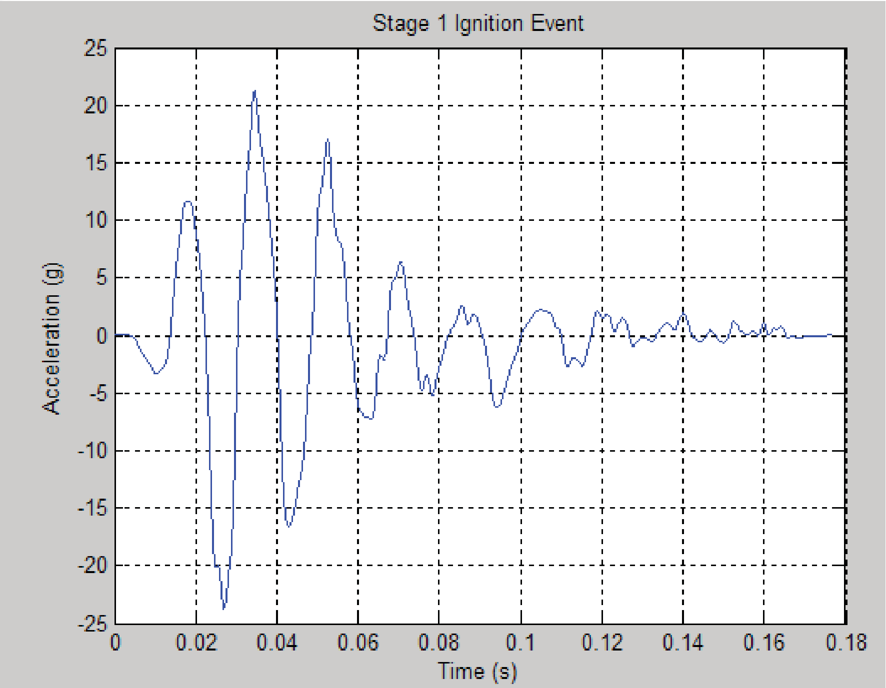
```
end
```

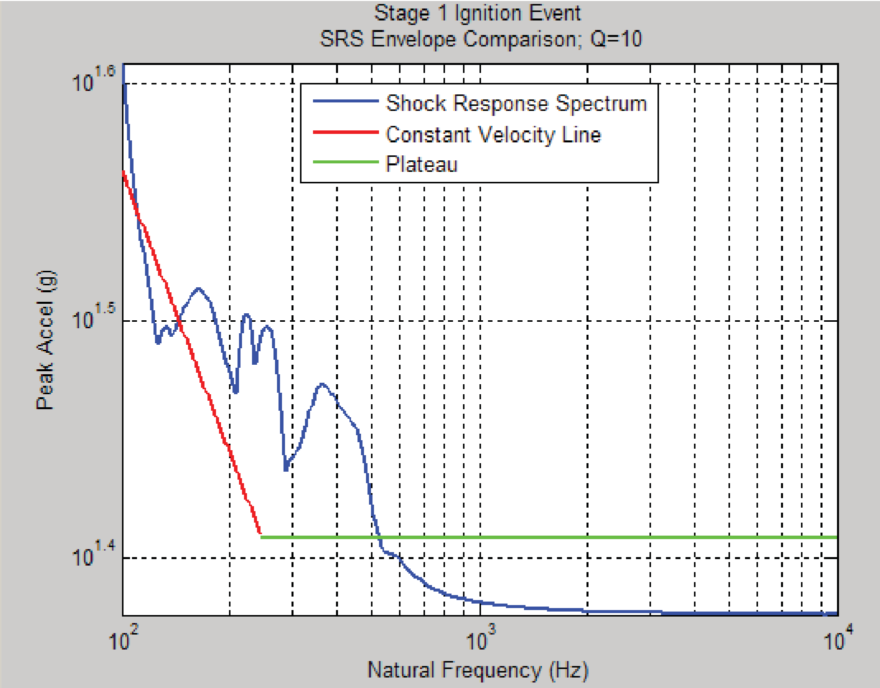
SRS Enveloping Algorithm Limitations





SRS Enveloping Algorithm Limitations





PV Enveloping - Code

Contents


```
function [ env ] = pv_envelope2( pseudo, varargin )
```

```
%pv_envelope2 Envelopes a pseudovelocity plot and outputs a figure of the
%enveloped curve and the primary properties of the curve.
```

Determine the frequency break points

```
[pks,locs]=findpeaks(pseudo(:,2));
s=std(pks);

pl=zeros(length(pks),1);
jj=1;
for ii=1:length(pks)
    if pks(ii)>=(max(pks)-2*s)
        pl(jj)=locs(ii);
        jj=jj+1;
    end
end
% Remove zeros from pl
pl(pl==0)=[];
% Now use the first and last points for your bounds
k=[1,pl(1),pl(end),length(pseudo(:,1))];

% Find max displacement line properties
mdl_1=LinearModel.fit(log10(pseudo(k(1):k(2),1)),log10(pseudo(k(1):k(2),2)));

% y=b*x^N
N_1=mdl_1.Coefficients{2,1}; %intercept
b_1=10^mdl_1.Coefficients{1,1}; %slope for exponent

% Find mean value max pseudovelocity plateau
% Note: mean was chosen rather than max because it will take into account
% all of the values in the plateau range.
yp=mean(pseudo(k(2):k(3),2));

% Calculate first break point
fb_1=(yp/b_1)^(1/N_1);

% Find max acceleration line properties
mdl_2=LinearModel.fit(log10(pseudo(k(3):k(4),1)),log10(pseudo(k(3):k(4),2)));

% y=b*x^N
N_2=mdl_2.Coefficients{2,1}; %intercept
b_2=10^mdl_2.Coefficients{1,1}; %slope for exponent

% Calculate second break point
fb_2=(yp/b_2)^(1/N_2);
```

PV Enveloping - Code

Create curve envelope

Determine counters for envelopes

```
ss_1=1;
while pseudo(ss_1,1)<fb_1
    ss_1=ss_1+1;
    if ss_1>length(pseudo(:,1))
        break
    end
end
ss_1=ss_1-1;

ss_2=1;
while pseudo(ss_2,1)<fb_2
    ss_2=ss_2+1;
    if ss_2>length(pseudo(:,1))
        break
    end
end
ss_2=ss_2-1;

% Sloped part of max displacement line
mdispl=zeros(ss_1,2);
for gg_1=1:ss_1;
    mdispl(gg_1,1)=pseudo(gg_1,1);%frequency
    mdispl(gg_1,2)=b_1*pseudo(gg_1,1)^N_1;%pseudovelocity
end

% Pseudovelocity plateau
cc=1;
pvplateau=zeros(ss_2-ss_2,2);
for hh=ss_1:ss_2
    pvplateau(cc,1)=pseudo(hh,1); %frequency
    pvplateau(cc,2)=yp; %pseudovelocity
    cc=cc+1;
end

% Sloped part of max acceleration line
maccel=zeros(length(pseudo(:,1))-ss_2,2);
for gg_2=ss_2:length(pseudo(:,1));
    maccel(gg_2,1)=pseudo(gg_2,1); %frequency
    maccel(gg_2,2)=b_2*pseudo(gg_2,1)^N_2; %pseudovelocity
end
```

PV Enveloping - Code

Create figure

```
loglog(pseudo(:,1),pseudo(:,2),'b','LineWidth',2)
hold on
loglog(mdispl(:,1),mdispl(:,2),'m','LineWidth',2)
loglog(pvplateau(:,1),pvplateau(:,2),'g','LineWidth',2)
loglog(maccel(:,1),maccel(:,2),'r','LineWidth',2)
loglog(pseudo(k,1),pseudo(k,2),'k*','LineWidth',2)
hold on
FourcpDP
hold off
title([varargin,' Pseudovelocity Envelope; Q=10'])
legend('Pseudovelocity','Max Displacement Line','Mean PV','Max Accel Line','Border Points','Location','Best');
```

Calculate PV parameters

Max value of max displacement line

```
maxdisp=max(mdispl(:,2)./(2*pi()*mdispl(:,1)));
% Max value of max acceleration line
maxg=max(maccel(:,2).*maccel(:,1)*2*pi()/386.1);

env=[maxdisp,yp,maxg];
```

```
end
```

Post Processing Automation

```
% Choose a name that the data and outputs will be saved under.
test_set='Group-1_Test-2';
```

Prepare Accel Time Data for Post Processing or load existing processed data

First, check to see if the data has already been saved in a .mat file of the name test_set.

```
check=dir([test_set,'.mat']);
if isempty(check)==1
    check=([]);
    check.name='false';
end
if strcmpi(check.name,[test_set,'.mat'])==1
    load(check.name)
else % If data has not already been saved, import the data
    % Import .csv file information
    info=dir('*.csv');
    test=struct([]);
    for ff=1:length(info)
        test(ff).name=regexprep(info(ff,1).name,' - Time Data.csv','');
        test(ff).data=csvread(info(ff,1).name,5,0);
    end
    clear info ff

    % Find where shock pulse begins by locating the first data point that is
    % Greater than the bit error (assume first 10,000 data points).
    counter=ones(1,length(test));
    if length(test(1,1).data(:,1))>=100000;
        for ff=1:length(test)
            for jj=1:length(test(1,ff).data(:,1))
                biterror=max(abs(test(1,ff).data(1:10000,2)));
                if test(1,ff).data(jj,2)<=biterror
                    counter(ff)=counter(ff)+1;
                else
                    break
                end
            end
            if counter(ff)>=100000
                counter(ff)=60000;
            end
        end
        % Remove bit error from data then take detrended 20ms after pulse
        for ff=1:length(test)
            test(1,ff).data=[test(1,ff).data(:,1),test(1,ff).data(:,2)-mean(test(1,ff).data(1:counter(ff),2))];
            test(1,ff).data=[test(1,ff).data(counter(ff):counter(ff)+20000,1),detrend(test(1,ff).data(counter(ff):counter(ff)+20000,2))];
            % Shift time so that it starts at zero
            dt=test(1,ff).data(2,1)-test(1,ff).data(1,1);
            N=length(test(1,ff).data(:,1));
            test(1,ff).data=[(0:N-1)'*dt,test(1,ff).data(:,2)];
        end
```

Post Processing Automation Cont'd…

Data is now ready to be post processed.

Save figure of time histories (accel, veloc, disp)

```
for ff=1:length(test)
    timehistplot(test(1,ff).data,test(1,ff).name);
    set(gcf,'Units','normalized','OuterPosition',[0 0 1 1]);
    saveas(gcf,[test(1,ff).name,'_time'],'jpeg');
    close;
end
clear ff
clf

% Calculate SRS and SRS envelop and save figures
for ff=1:length(test)
    test(ff).srs=srsfunc(test(1,ff).data);
    test(ff).srs_env_prop=srs_envelope2(test(1,ff).srs,test(1,ff).name);
    set(gcf,'Units','normalized','OuterPosition',[0 0 1 1]);
    saveas(gcf,[test(1,ff).name,'_srs_envelop'],'jpeg');
    close
end
clear ff
clf
close

% Calculate PV
for ff=1:length(test)
    test(ff).pv=pvssmax(test(1,ff).data);
    test(ff).pv_env_prop=pv_envelope2(test(1,ff).pv,test(1,ff).name);
    set(gcf,'Units','normalized','OuterPosition',[0 0 1 1]);
    saveas(gcf,[test(1,ff).name,'_PV'],'jpeg');
    close
end
clf
close
```

Post Processing Automation Cont'd…

```
% Calculate fourier spectrum
for ff=1:length(test)
    test(ff).fr=fouriergab(test(1,ff).data);
    semilogy(test(1,ff).fr(:,1),test(1,ff).fr(:,2),'LineWidth',2);
    grid on
    title([test(1,ff).name,' Fourier Spectrum']);
    xlabel('Frequency [Hz]')
    ylabel('Accel [in/sec^2]')
    set(gcf,'Units','normalized','OuterPosition',[0 0 1 1]);
    saveas(gcf,[test(1,ff).name,'_Fourier'],'jpeg');
    close
end
clf
close

% Calculate Temporal Moments
for ff=1:length(test)
    test(ff).tm=tmoment_DP(test(1,ff).data(:,1),test(1,ff).data(:,2));
end

% Calculate Spectral Moments
for ff=1:length(test)
    test(ff).sm=smoment_DP(test(1,ff).data(:,1),test(1,ff).data(:,2));
end

% Calculate Generalized Harmonic wavelet transform
for ff=1:length(test)
    [test(ff).S,test(ff).F,test(ff).H]=ghwt_DP(test(1,ff).data,test(1,ff).name);
    set(gcf,'Units','normalized','OuterPosition',[0 0 1 1]);
    saveas(gcf,[test(1,ff).name,'_ghwt'],'jpeg');
    close
end
clf
close
```

Post Processing Automation Cont'd…

Write parameters to a text file.

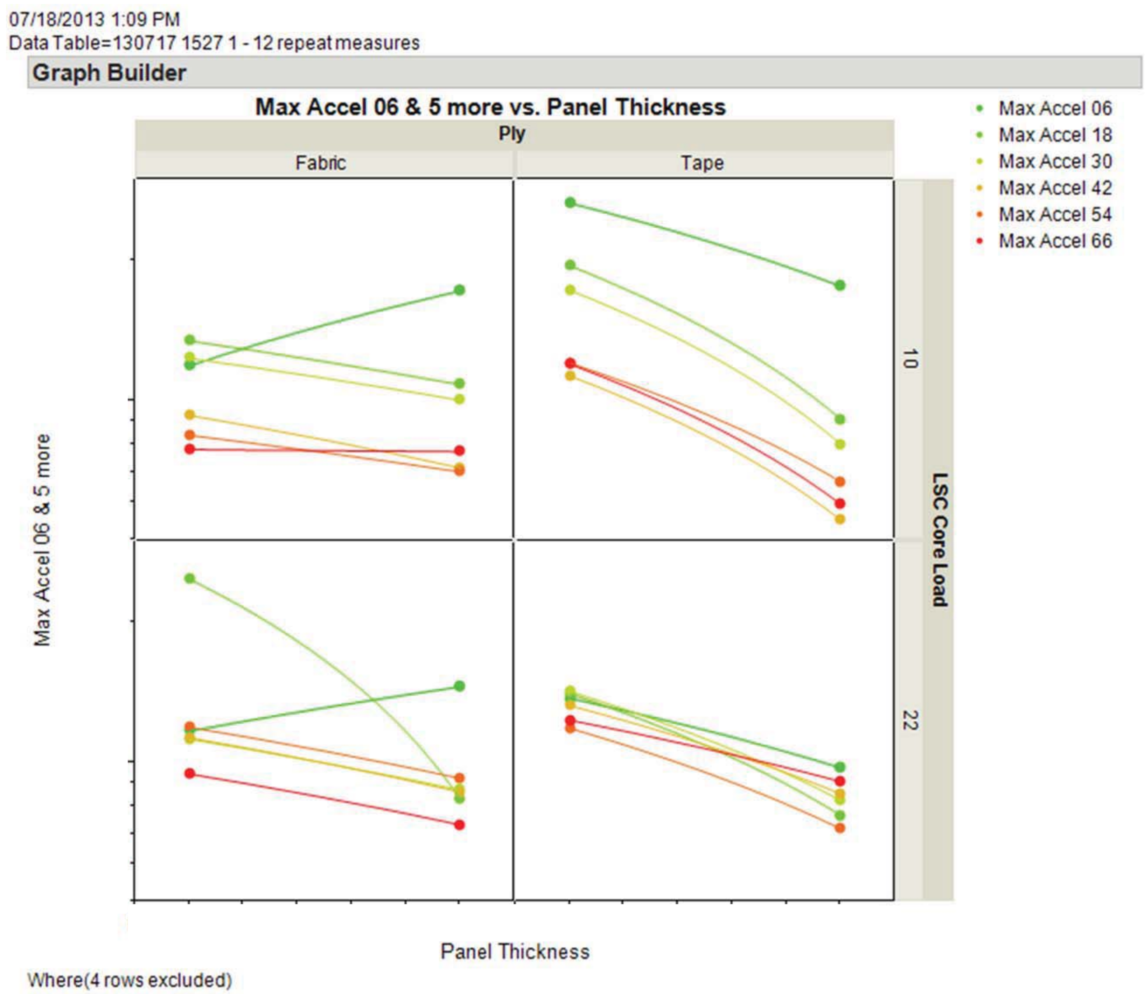
```
fid=fopen([test_set,'_Parameters.txt'],'w');
fprintf(fid,'%s\n',test_set);
fprintf(fid,'Shock Response Spectrum Parameters\n');
fprintf(fid,'Output Name\t\t\t\t\t\t\t\t\t\t\tFrequency Break Point-(Hz)\t\tSlope-(dB/Oct)\t\tPeak-(g)\n');
for ff=1:length(test)
    fprintf(fid,'%s\t\t\t\t\t\t\t\t\t\t\t%6.2f\t\t\t\t\t\t\t\t%6.2f\t\t\t\t\t\t%6.2f\n',test(1,ff).name,test(1,ff).srs_env_prop);
end
fprintf(fid,'\nPseudovelocity Spectrum Parameters\n');
fprintf(fid,'Output Name\t\t\t\t\t\t\t\t\t\t\tMax Displacement-(in)\t\tMean Pseudovelocity-(ips)\t\tMax Accel-(g)\n');
for ff=1:length(test)
    fprintf(fid,'%s\t\t\t\t\t\t\t\t\t\t\t%5.3f\t\t\t\t\t\t\t\t\t%6.2f\t\t\t\t\t\t\t%6.2f\n',test(1,ff).name,test(1,ff).pv_env_prop);
end
fprintf(fid,'\nTemporal Moments\n');
fprintf(fid,'Output Name\t\t\t\t\t\t\t\t\t\t\tTemporal Energy\t\t\tTemporal Mean\t\t\tTemporal Variance\t\t\tTemporal Skewness\t\t\tTemporal Kurtosis\t\t\tRMS Duration\t\t\tRoot Energy Amplitude\n');
for ff=1:length(test)
fprintf(fid,'%s\t\t\t\t\t\t%2.5e\t\t\t\t%2.5e\t\t\t\t\t%2.5e\t\t\t\t\t\t%2.5f\t\t\t\t\t\t\t%2.5f\t\t\t\t\t\t\t%2.5e\t\t\t\t\t%2.5e\n',test(1,ff).name,test(1,ff).tm(1,:));
end
fprintf(fid,'\nSpectral Moments\n');
fprintf(fid,'Output Name\t\t\t\t\t\t\t\t\t\t\tSpectral Energy\t\t\tOne Sided Spectral Mean\t\t\tTwo Sided Spectral Mean\t\t\tOne Sided Spectral Variance\t\t\tTwo Sided Spectral Variance\t\t\tOne Sided Sp
for ff=1:length(test)
fprintf(fid,'%s\t\t\t\t\t\t%2.5e\t\t\t\t\t\t%2.5e\t\t\t\t\t\t\t%3.4f\t\t\t\t\t\t\t\t%2.5e\t\t\t\t\t\t\t\t\t\t%2.5e\t\t\t\t\t\t\t\t\t\t\t%3.5f\t\t\t\t\t\t\t\t\t\t\t\t%3.5f\t\t\t\t\t\t\t\t\t\t\t\
end
fclose(fid);

save(test_set,'test');
clearvars -except test
```

Analysis Procedure

- Procedure
  - Look for potential model(s) using ANOVA on columnized dataset.
  - Examine model using repeated measures analysis.
    - Obtain model parameters.
  - Reanalyze using ANOVA on columnized dataset with model parameters from repeated measures analysis.

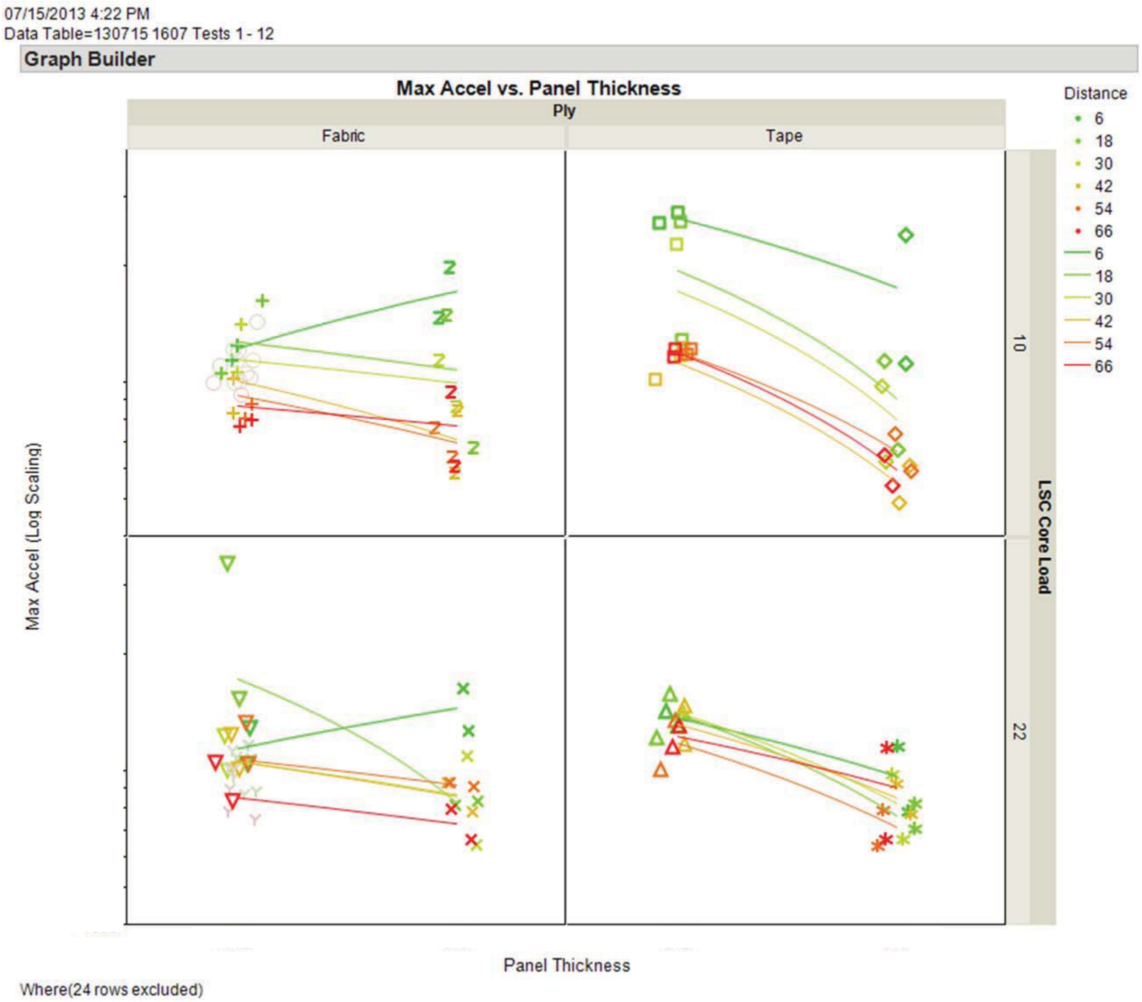
Max Accel: Visual Analysis

- Graph of 45/90 data
  - By input factor combination
  - Distance indicated by color
  - Log-scaled Max Accel
- There appears to be decrease in Max Accel with increase in Panel Thickness
  - Decrease may be more pronounced with Tape than Fabric, but Tape may have a larger Max Accel at 0.2 Panel Thickness than Fabric
- There *appears* to be greater variability:
  - Closer-in Distances
  - 10 gpf Core load



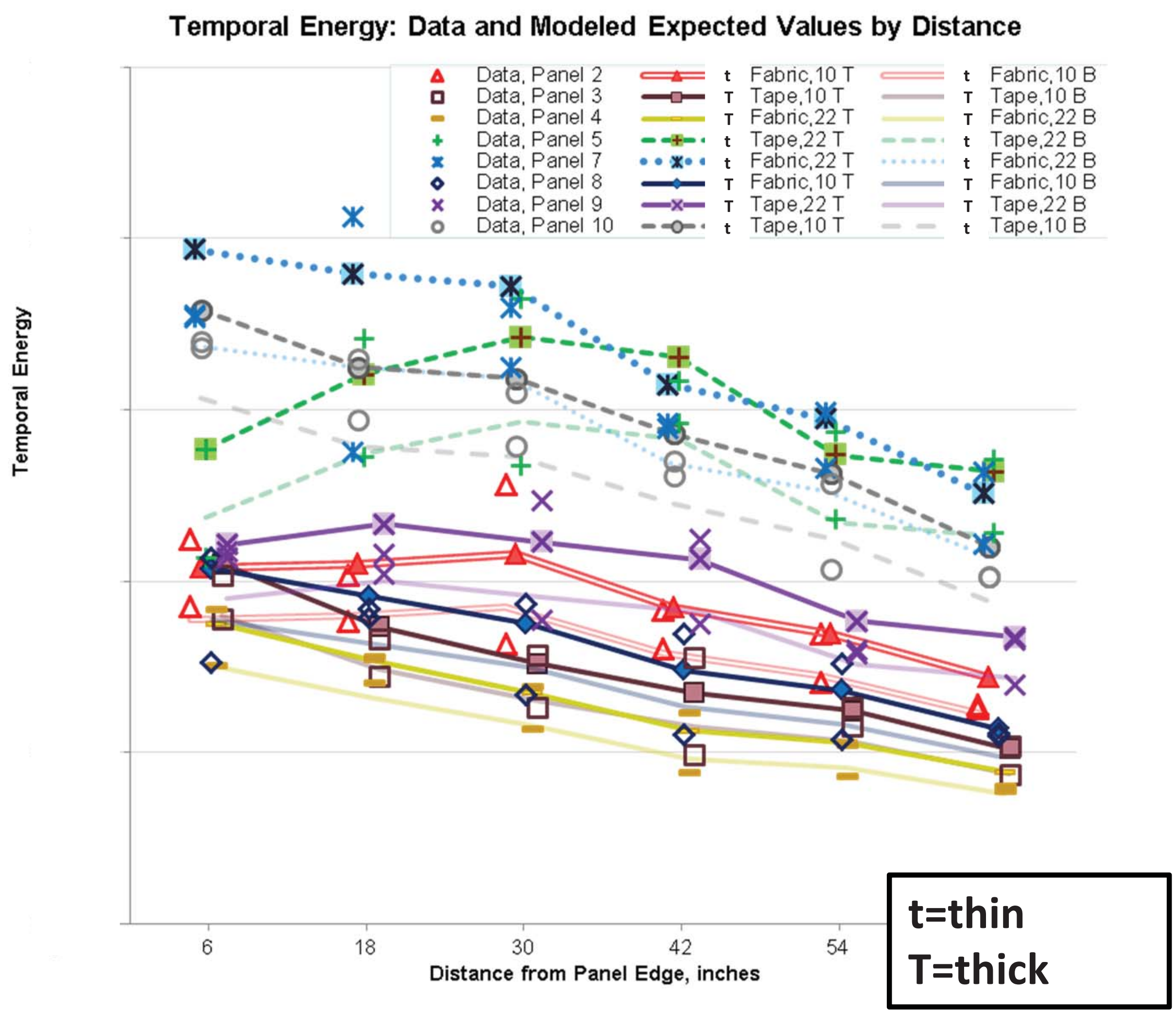
Max Accel: Visual Analysis

- Similar to previous graph, but showing individual points
- Variability in Tape 22 gpf now seems especially small compared to other factor settings
- 0 degree appears to track 45/90 degree data



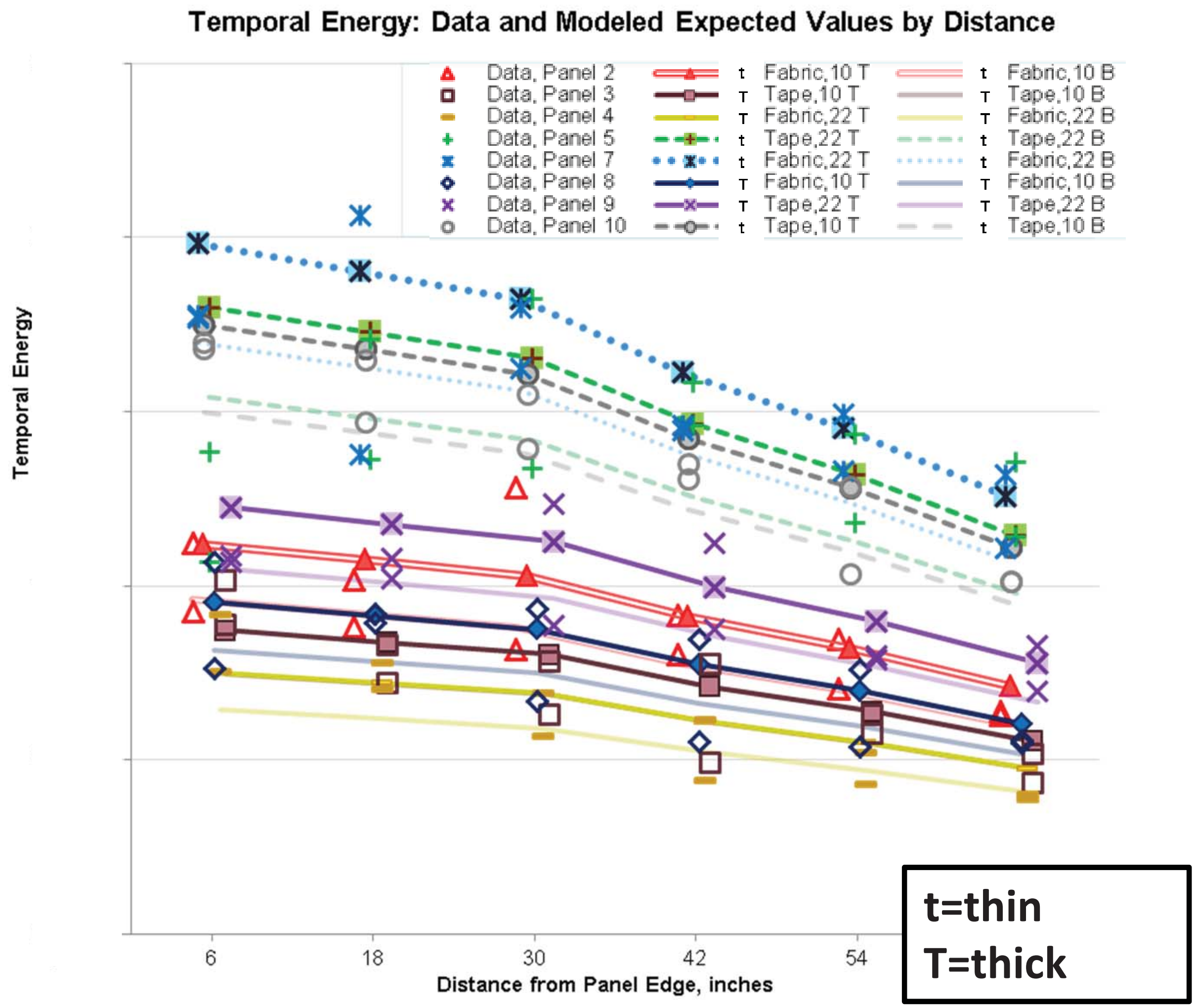
Stats Analysis, Temporal Energy: Unconstrained Model

- Model with main effects and a number of interactions is adequate fit to data
  - Log TE modeled: says variability increases with increasing TE
- Significant, persistent difference between Top (darker lines) and Bottom (lighter)
- In general, Thinner thick panels give higher TE response than Thicker
- Panel 5 (green crosses, 0.2, Tape, 22) shows odd low values at close distance(s)
  - Max at 30" also seen in Panel 9 (violet X's), possibly 2 (red triangles) and 7 (blue asterisks)



Stats Analysis, Temporal Energy: Reduced Model

- Constraining the model results in some ill fits, but on the whole it is probably still useful
  - Knee at 30” may not represent some panels’ data – see Panels 4 (yellow dashes) and 8 (indigo diamonds)
- Largest responses now clearly result from Thinner Thickness



Graphs of Mean PV Data

- Colored by Distance
  - Distance appears to have little effect in this measure