Empirical Model Development for Predicting Shock Response on Composite Materials Subjected to Pyroshock Loading

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Outline

- Purpose
- Test Setup and Design
- Pyroshock Environment Characterization
- Data Processing Automation
- Processing and Characterization Results
- Post-Processing Data Characterization
- Empirical Model MEFE Prediction Example
- Concluding Remarks
- Forward Work

Purpose

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- Marshall Space Flight Center primarily uses the attenuation methods of the Pyrotechnic Design Guidelines Manual for preliminary pyroshock environment estimation. However, limited information is available for non-metallic structures
- Project Goals:
  - Collect, process, and characterize pyroshock accelerometer data from flat composite panels of a range of parameters
  - Identify the primary composite panel parameters that impact the panel's response to a pyroshock environment
  - Develop empirical distance attenuation models to expand the existing library to include more composite materials
  - Establish guidelines and procedures to allow for continued efforts

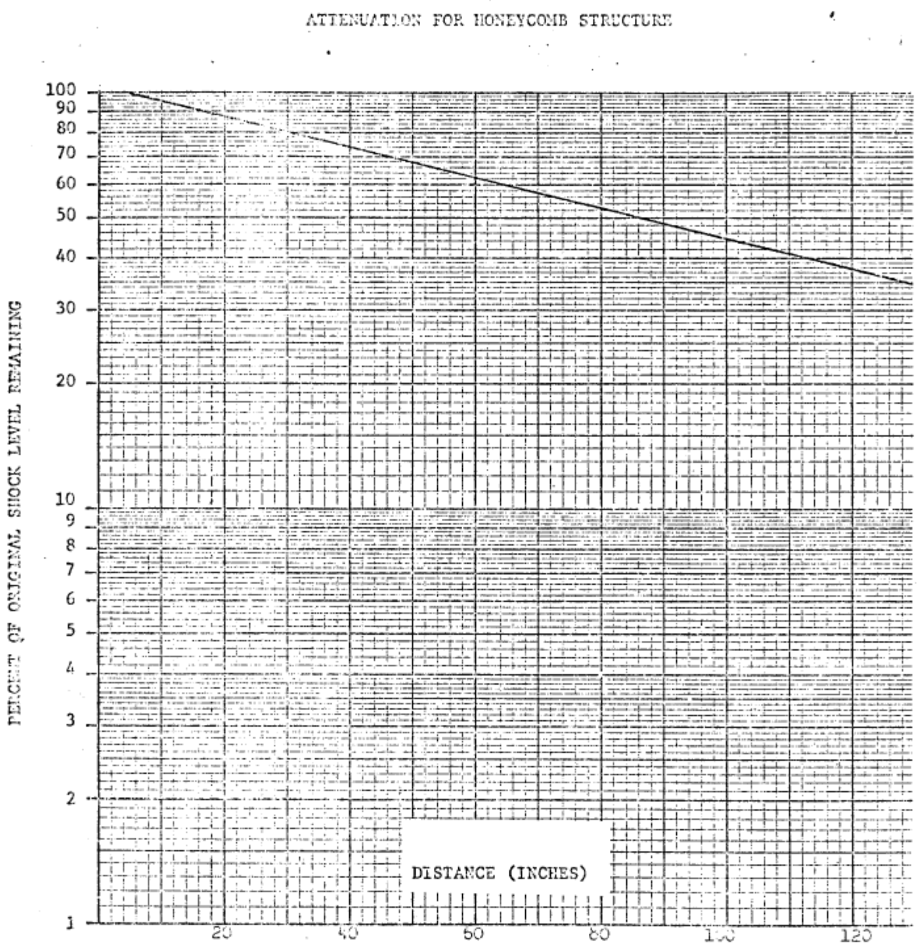


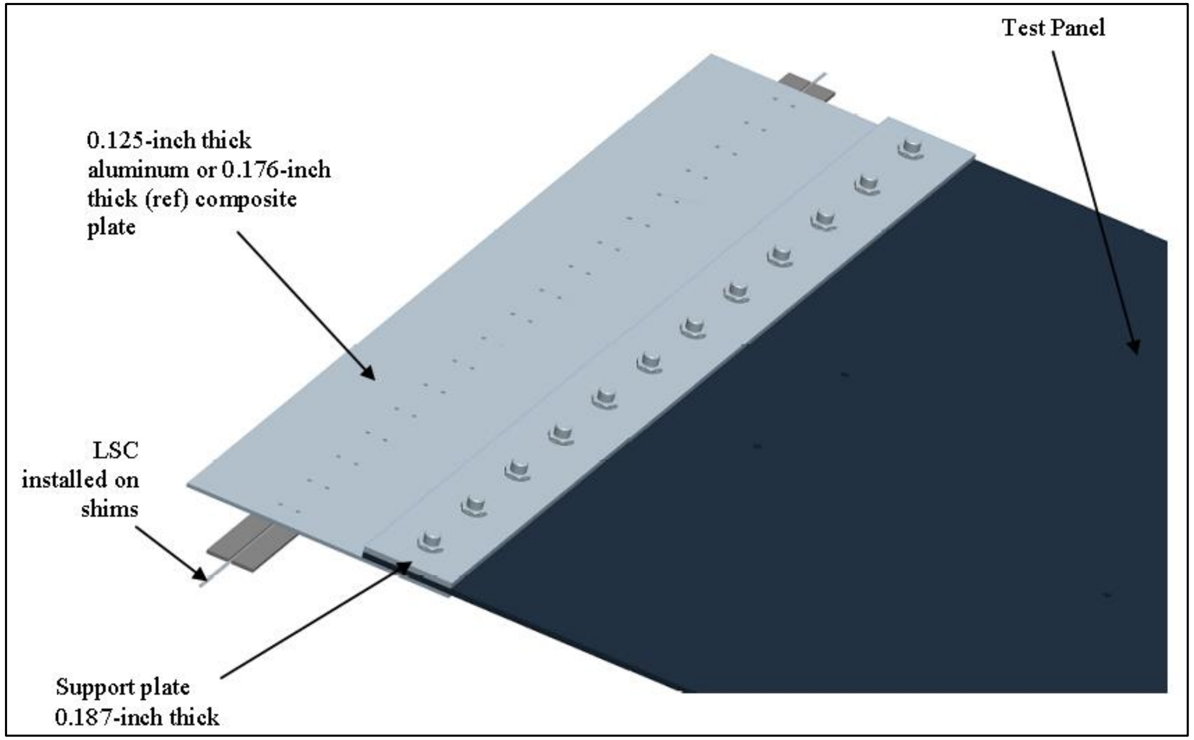
Figure 3.7 Attenuation for Honeycomb

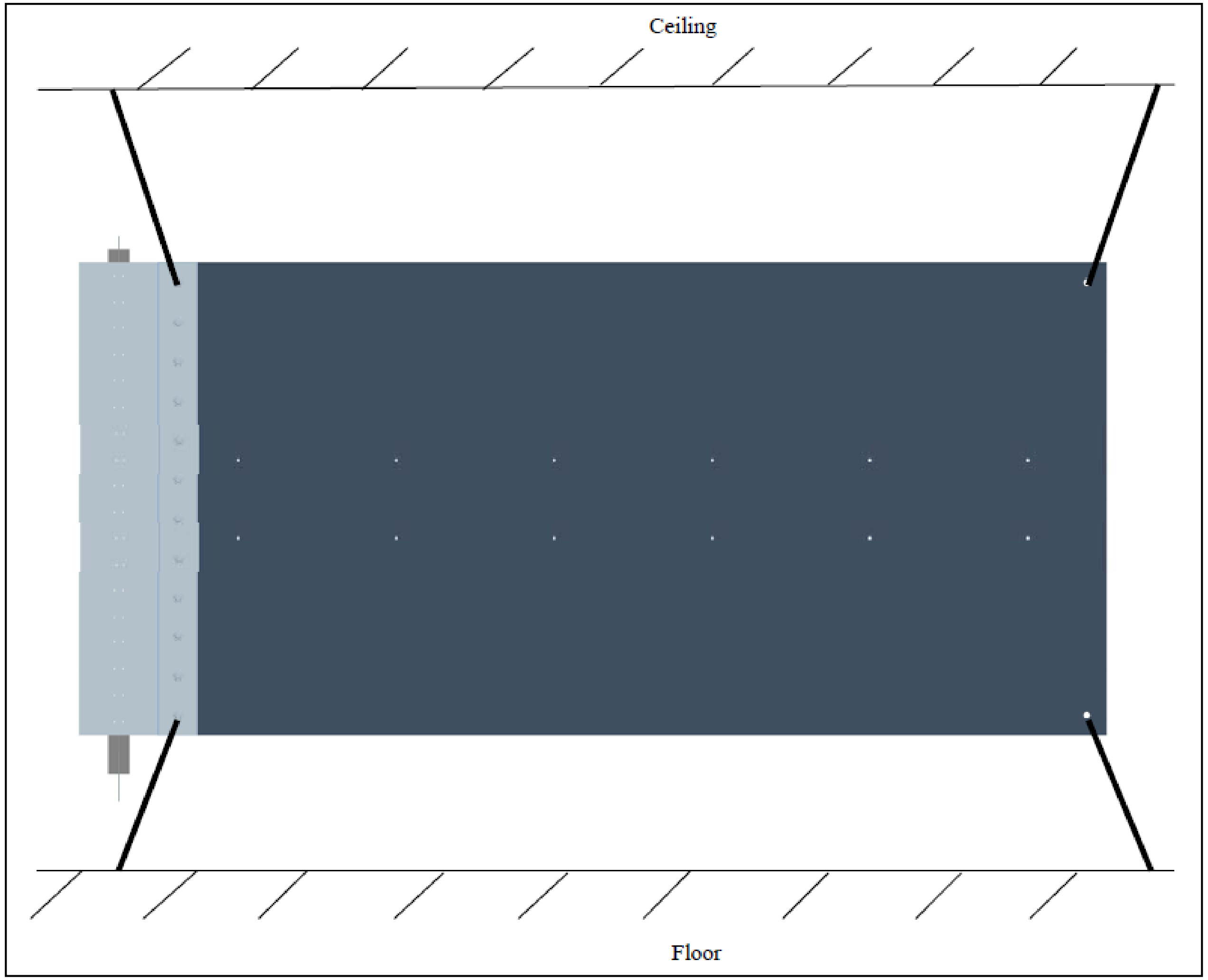
Kacena, W. J., McGrath, M. B., & Rader, W. P. (1970). *Pyrotechnic Shock Design Guidelines Manual.* Denver: NAS5-15208.

Test setup & design

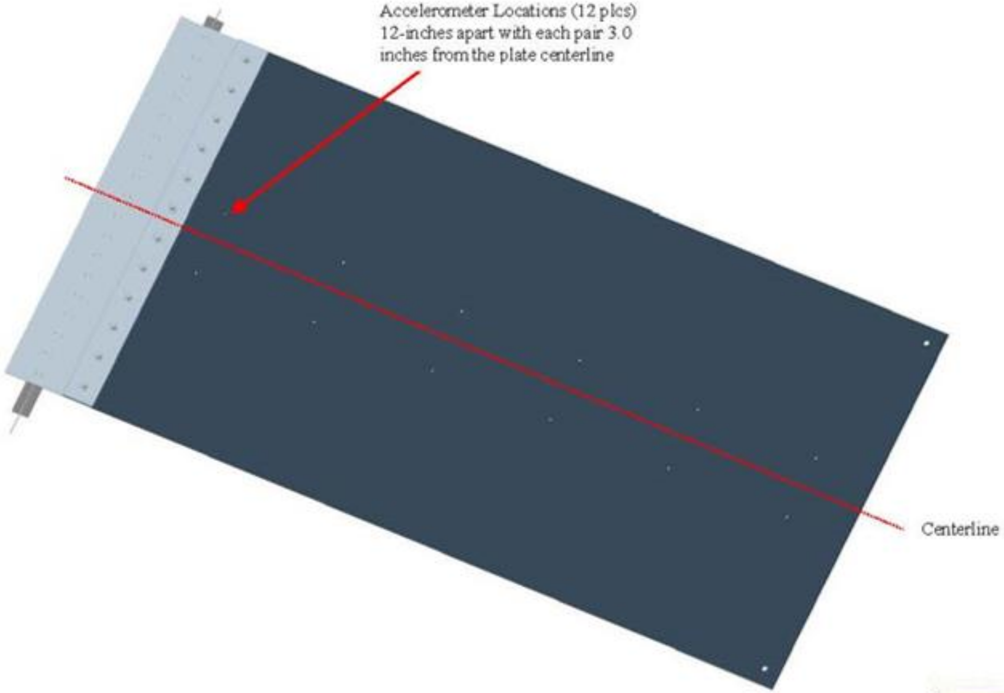
Test Article

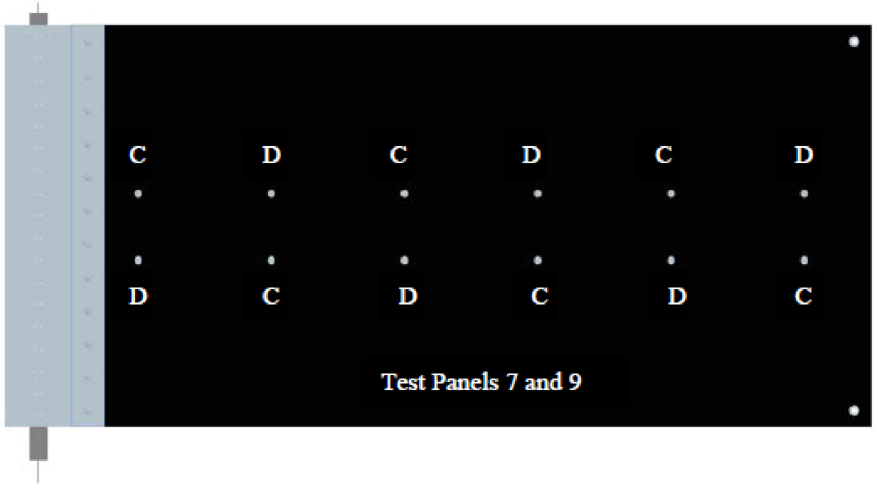
Test Articles are 3ft in height and 6ft in length.



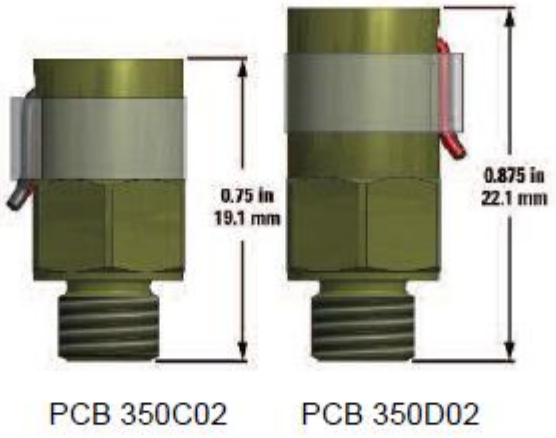


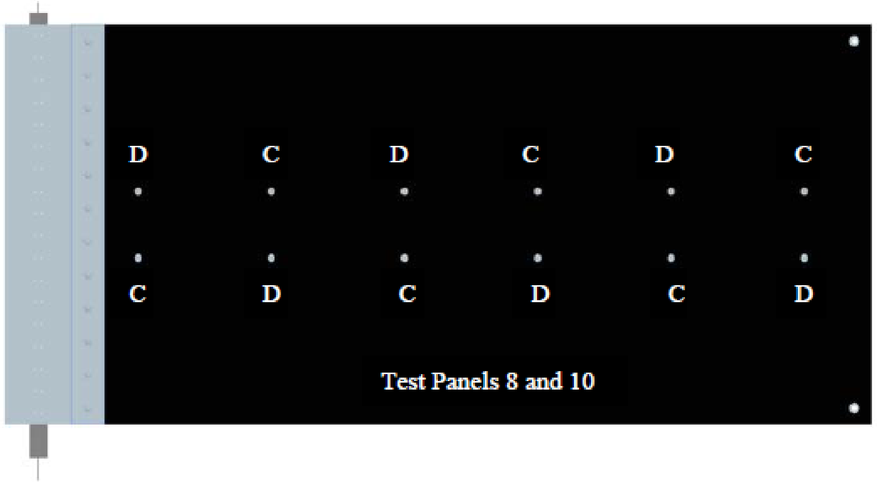
Test Instrumentation





Nearest accelerometer pair located 9 inches from LSC.





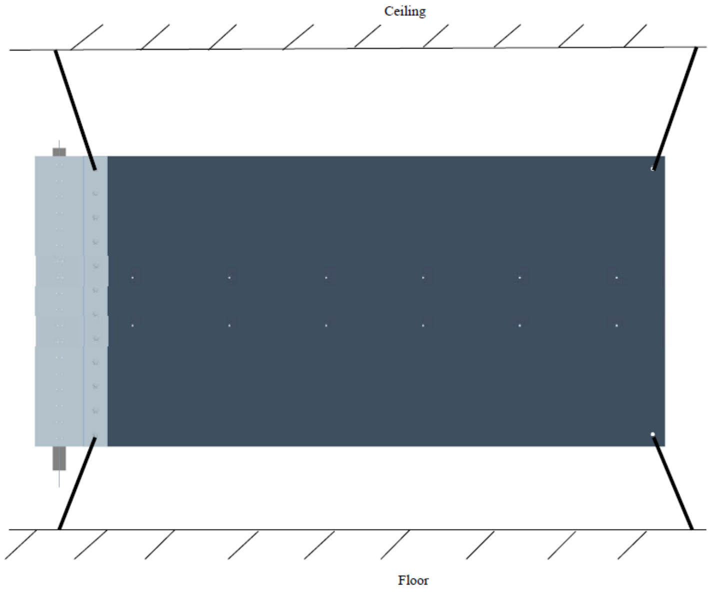
PYROSHOCK ENVIRONMENT CHARACTERIZATION

USING SINGLE-VALUE-INPUTS

Pyroshock Environment Characterization

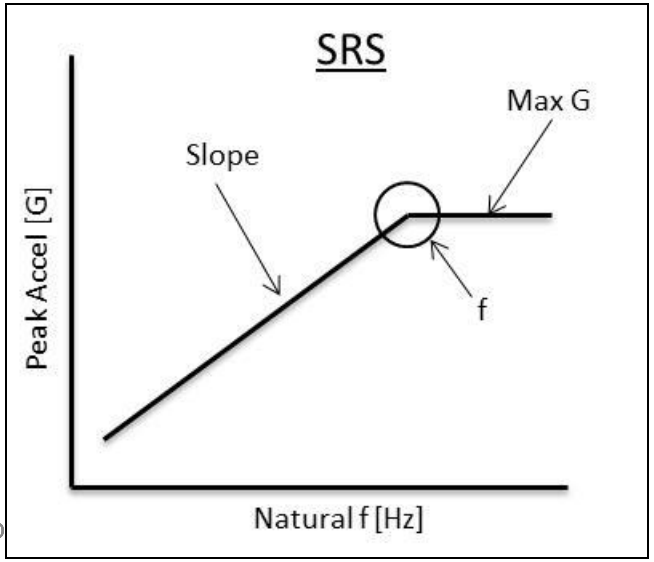
Data Processing and Environment Characterization Goal:

- Develop or utilize procedures, methodologies, and tools to post-process pyroshock acceleration data and characterize the environment for the purpose of developing empirical models to predict the pyroshock environment as it propagates across a composite panel



Challenges:

- Characterizing a pyroshock environment using single-value-inputs for multiple regression analysis
  - Single-value-input defined as a single value or scalar quantity that describes an aspect of the pyroshock environment
- Eliminating or mitigating data noise and subjective decisions (human error/bias) sometimes used in characterizing a pyroshock environment



Single Value Inputs

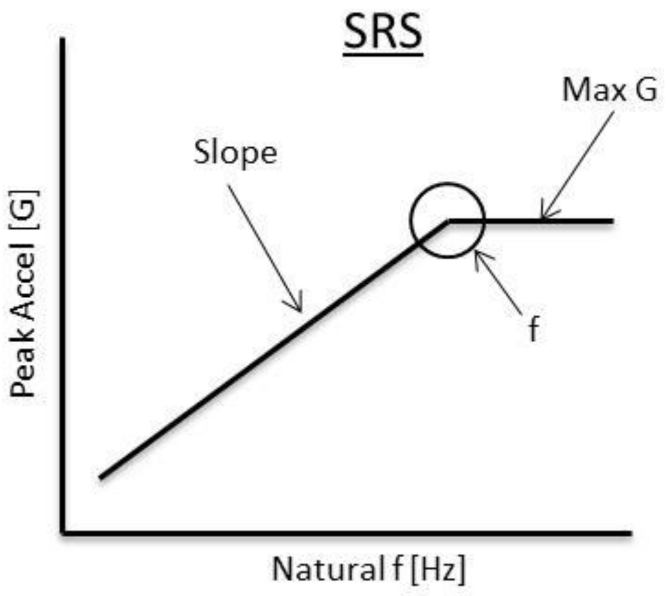
- Shock Response Spectrum:
  - Slope (dB/oct)
  - Frequency break point (Hz)
  - Max Peak Accel or plateau value (G)

- Pseudovelocity Response Spectrum
  - Mean Pseudovelocity (ips)

- Temporal Energy (in^2/s^3)

- Energy Spectral Density (G^2*s/Hz)
  - Frequency and amplitude of the peak ESD value

- Time History: Maximum & Minimum Acceleration (G)



Post-Processing Data Characterization

Post-Processing - Objectives

- Objectives
  - Characterize all the test data by inputting the algorithm output into statistical analysis programs
  - Develop subject matter expert (SME) credible prediction equations using regression-like methods (Taylor series approximations of the physics)
  - For each combination of input factors:
    - Construct a table of predictions for each factor combination
    - Develop prediction equations
    - Develop empirical model for shock prediction based upon predictive equations

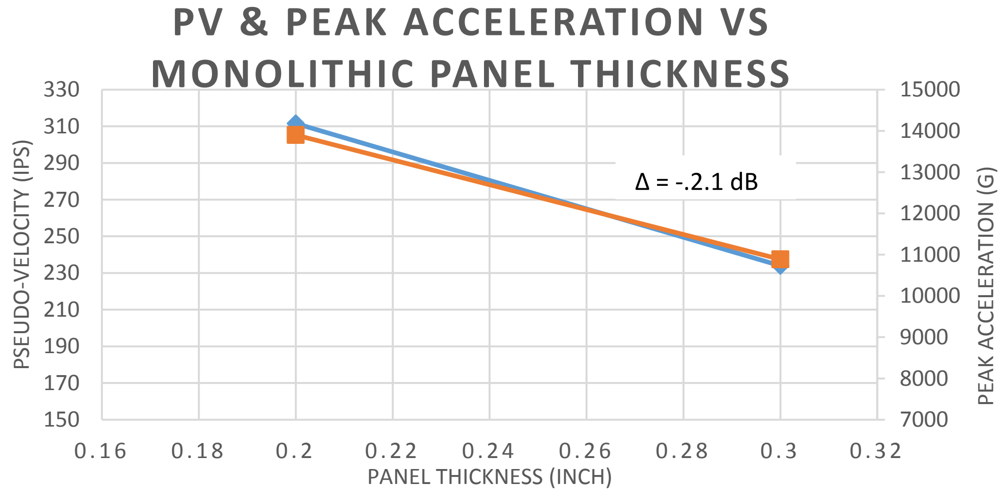
- Analysis was performed using STATGRAPHICS® Centurion™ XVI Version 16.1.8, StatPoint Technologies, Inc., Warrenton, VA, © 1982 – 2012, and JMP® Version 11.1.1 , SAS Institute, Inc., Cary, NC, © 1989 - 2013

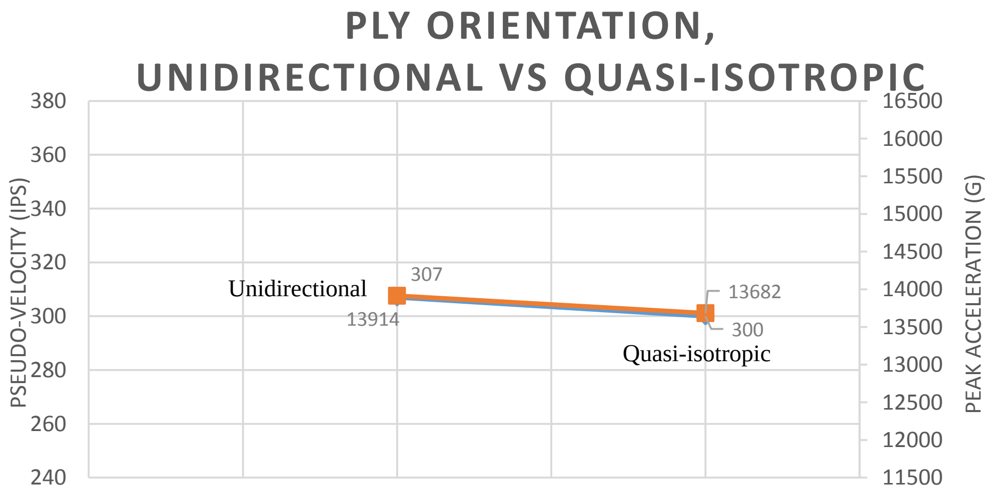
Post-Processing – Factors; Composite Materials and Others

- Thickness of composite material (solid or "monolithic" composite panels, i.e. number of plies)
- Type of ply (tape or fabric) used to fabricate the composite
- Ply layup direction; unidirectional (all 0° versus quasi-isotropic (symmetrical +45°/-45°, 0° (2x), +45°/-45°, 90° (2x))
- Monolithic versus sandwich filled composite
- Type of sandwich fill; aluminum honeycomb and Rohacell® Foam
- Explosive core load of the linear shaped charge (LSC) to induce the shock into the test panel
- Distance from the shock source

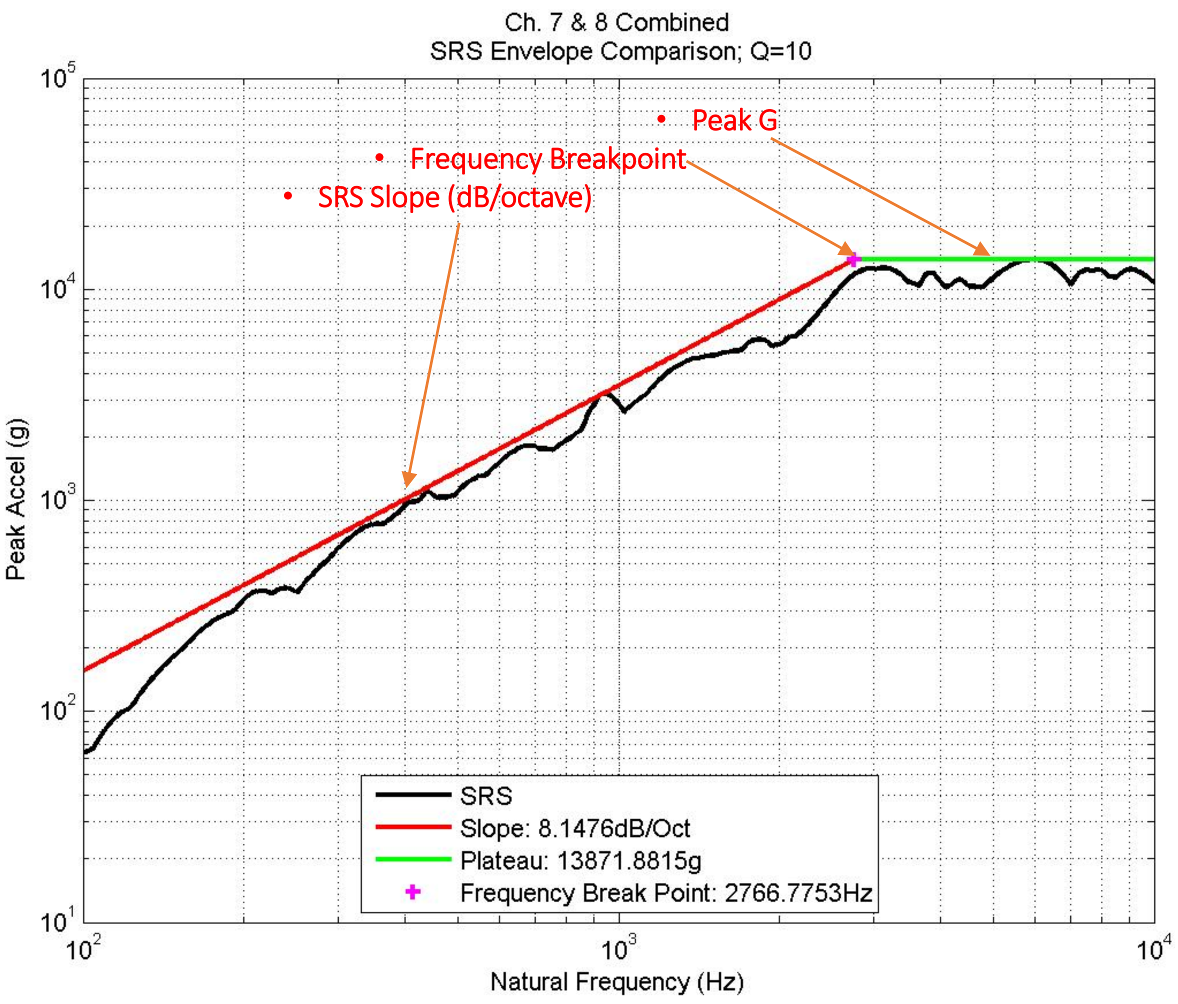
Post-Processing – Factors; Significance

- Post-processing the acceleration time history data determined some factors had no significance on the shock response of the composite material
  - The type of ply (tape or fabric) was not a significant factor
  - The ply orientation (unidirectional or quasi-isotropic lay up) was not a significant factor
  - The thickness of the composite material was not significant with regard to the delta in the attenuation of the shock with distance





Post-Processing – Values Corresponding to SRS



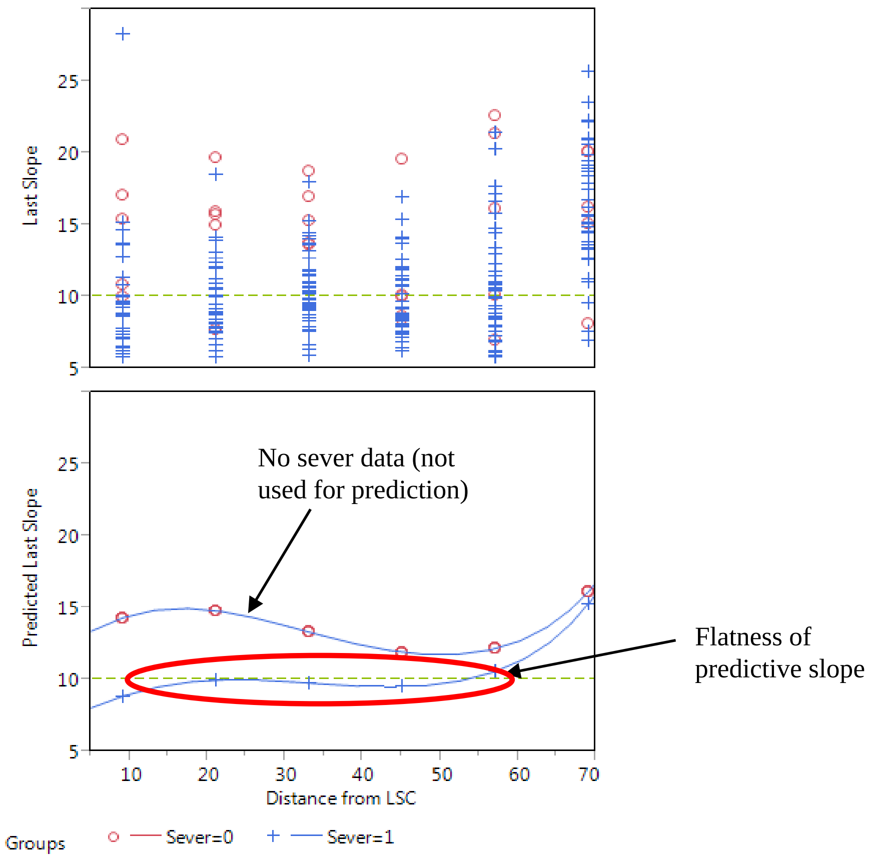
Post-Processing – SRS Slope

- The results from the statistical analysis indicated the significant factors to be:
  - Distance
  - Severance of the LSC panel times distance
- The empirical model prediction for the SRS slope by distance is tabulated in table below, regardless of panel type:

Factor	Predicted Slope by Distance from LSC					
Distance	**9**	**21**	**33**	**45**	**57**	**69**
Slope	8.9	10.0	9.8	9.5	10.6	15.3

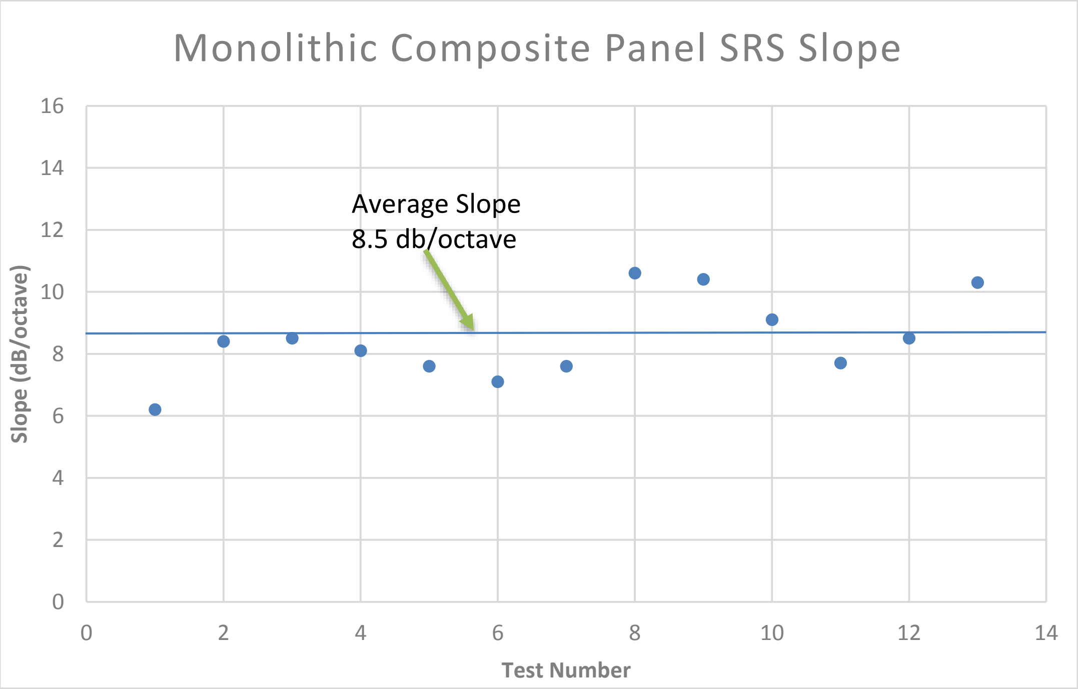
Post-Processing – SRS Slope

- The variance in the slope is fairly flat from 9 inches to 57 inches
- The predicted slope at the 69-inch location is elevated likely due to the reflective shock wave from the boundary condition the end of the panel represents



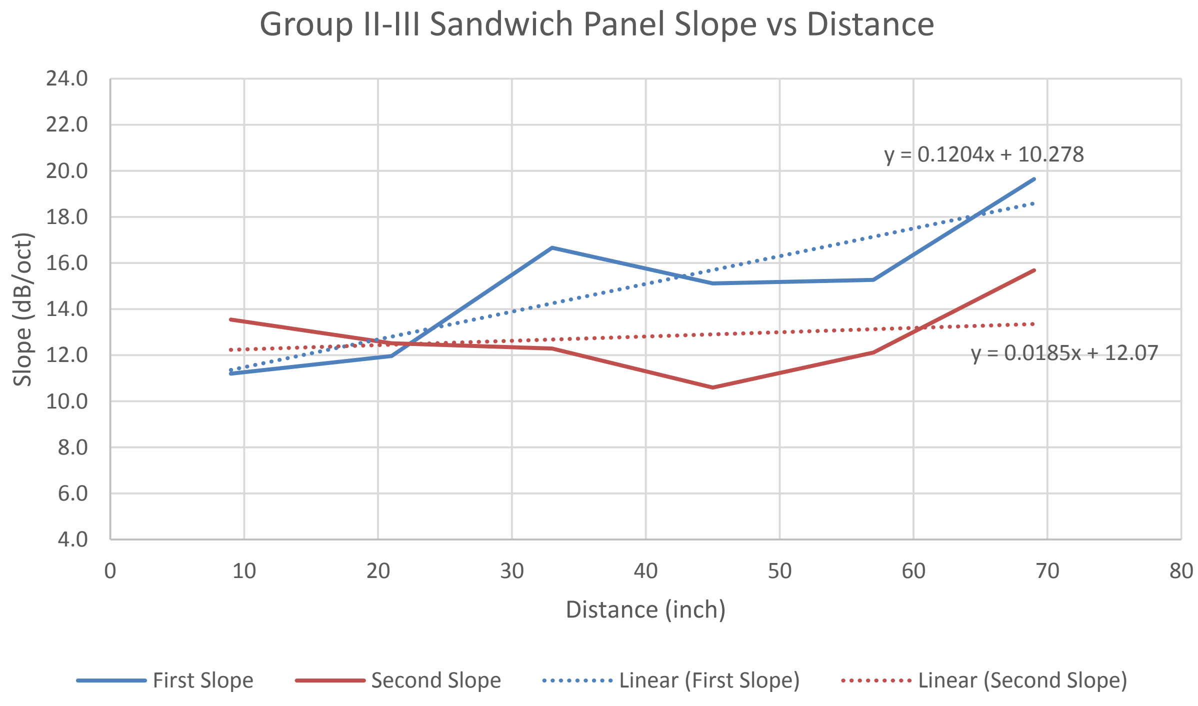
Post-Processing – SRS Slope

- Based on the prediction equation for the SRS predicted slope derived from this flat panel test data the slope can be held constant for calculation of the MEFE, out to a distance of 20 to 60 inches from the source shock, without introducing a large error i.e., the slope of an SRS curve stays constant with distance
- Average SRS slope for monolithic composite panel consistent whether 10 gpf LSC or 22 gpf LSC was used



Post-Processing – SRS Slope

- The sandwich panels were evaluated separately from the monolithic panels due to the predominance of the dual plateau enveloping SRS as computed by the SRS algorithm
- Each of the slopes (low frequency first slope 100 Hz to ~350 Hz and mid-frequency slope ~950 Hz to ~2500 Hz) were evaluated. The evaluation showed the first slope of the SRS to be relatively high (average slope of 15 dB/oct) and the second slope to be also relatively high (13 dB/oct)
- Similarly, as shown for the monolithic composite panel, the delta change for the second slope over distance is minimal
- The reasoning for statistically evaluating only the second slope is it can be directly compared to the Al and monolithic composite panels, with a single plateau and typically have a frequency break point between 2000 and 3000 Hz



Post-Processing – SRS Frequency Breakpoint

- The results from the algorithm were statistically evaluated for sensitivities. There are two significant factors associated with determination of the frequency breakpoint
  - Distance from the shock source
  - The presence of acoustic damping
  - Factors that were determined to be less significant include type of panel (sandwich versus monolithic versus Al) with distance
  - From the statistical analysis the predictive equation for SRS frequency breakpoint was developed for each type of material type (i.e., Al and composite (monolithic and sandwich)).
  - The predictive results for each material type are tabulated

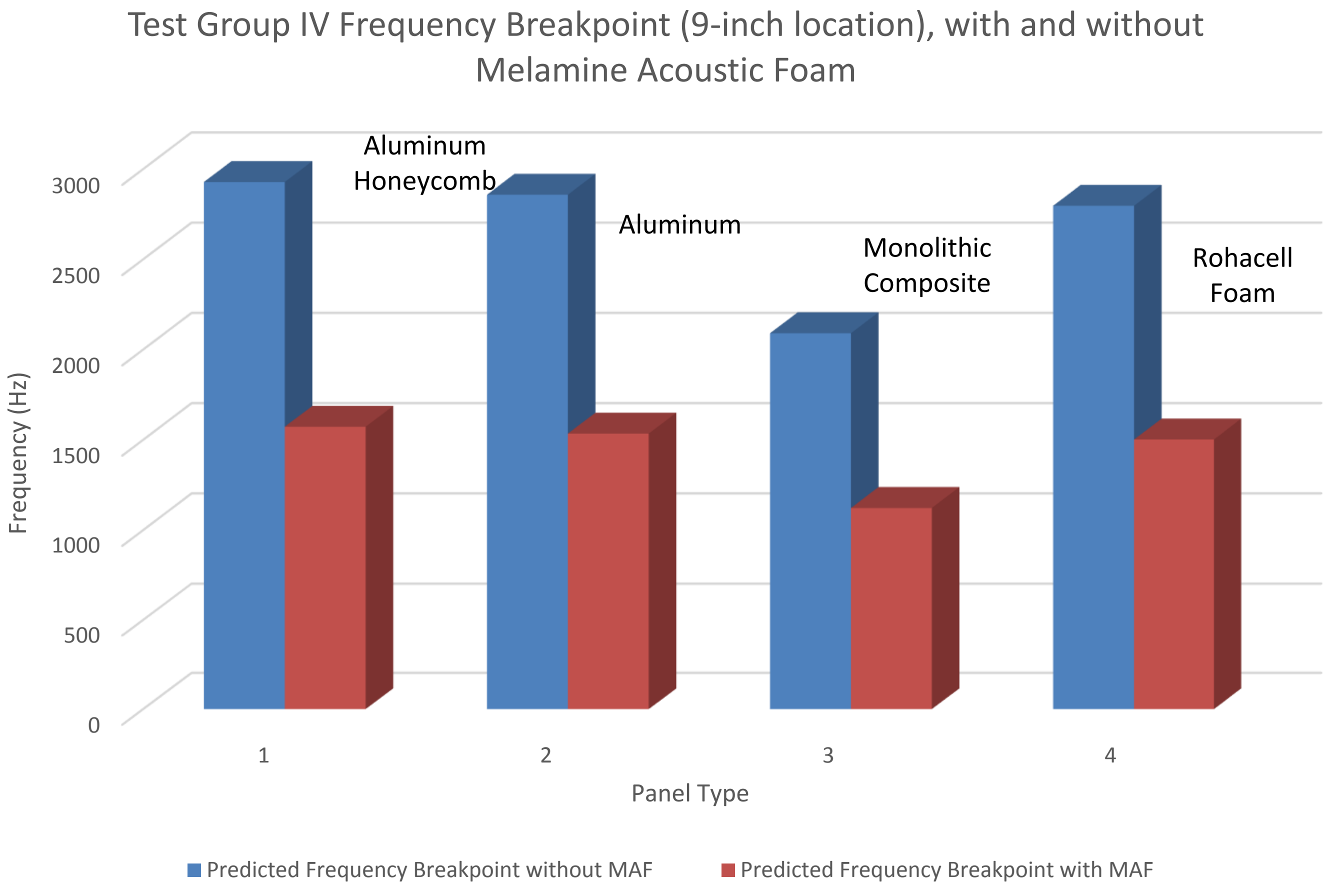
Post-Processing – SRS Frequency Breakpoint

- Tabulation of Predicted Frequency Breakpoint with Distance (by panel type)
- Regardless of panel type the addition of acoustic dampening foam reduced the frequency breakpoint by ~40%
- The frequency breakpoint at 21 to 57 inches from the shock source remains relatively constant

Factors			Predicted Frequency Breakpoint by Distance from LSC, inches					
Type	**Panel Thickness (inch)**	**Acoustic Damped (Yes/No)**	**9**	**21**	**33**	**45**	**57**	**69**
Al Honey	1	No	2927.9	2398.1	2334.9	2422.5	2401.1	2038.2
Al Honey	1	Yes	1572.1	1397.4	1476.4	1662.4	1788.1	1647.2
Homogeneous (Al)	0.187	No	2857.5	2402.7	2401.6	2558.1	2603.0	2268.4
Homogeneous (Al)	0.187	Yes	1534.3	1400.1	1518.6	1755.4	1938.4	1833.2
Monolithic	0.2	No	2199.7	1895.7	1942.0	2120.1	2211.0	1974.8
Monolithic	0.3	No	2090.4	1794.2	1830.6	1990.3	2067.3	1838.9
Monolithic	0.3	Yes	1122.5	1045.5	1157.6	1365.8	1539.5	1486.1
ROHACELL®	1	No	2796.5	2240.8	2134.4	2166.5	2100.9	1744.7
ROHACELL®	1	Yes	1501.6	1305.7	1349.7	1486.7	1564.5	1410.0

Post-Processing – SRS Frequency Breakpoint

- Comparison of frequency breakpoint with and without melamine acoustic foam bonded to the test panel



Post-Processing – SRS Peak Acceleration

- The statistical analysis from the data output of the SRS algorithm indicated the significant factors to be
  - Distance from the shock source
  - The explosive core load of the LSC used to induce the shock
  - The thickness of the monolithic composite panel
  - Type of composite panel (monolithic or sandwich)
- The predictive equations from the SRS algorithm data output statistical analysis by panel type and core load are listed on the following slides

Post-Processing – SRS Peak Acceleration

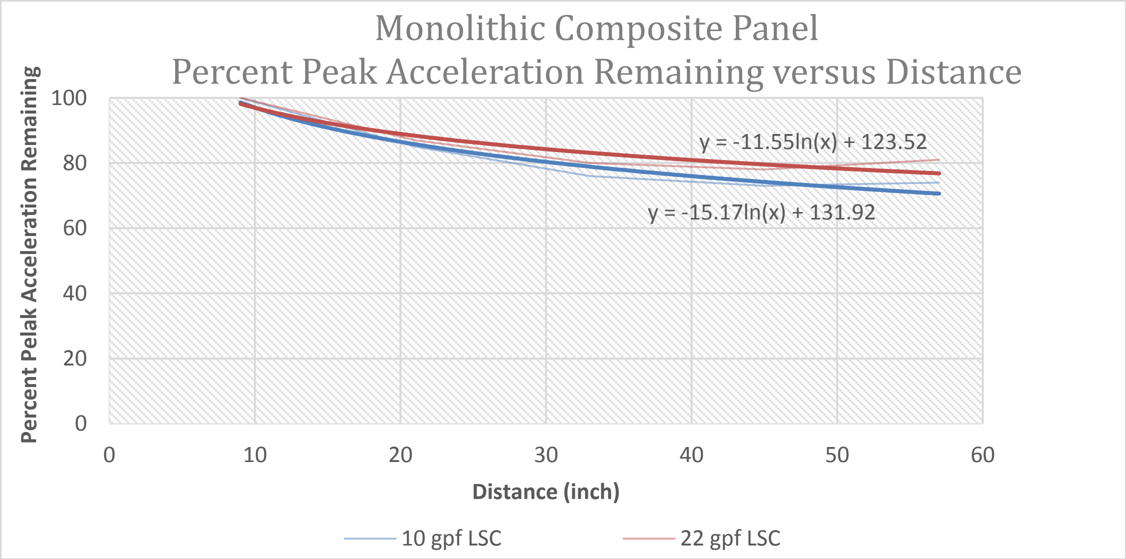
- Predicted Peak Acceleration Values by Panel Material Type

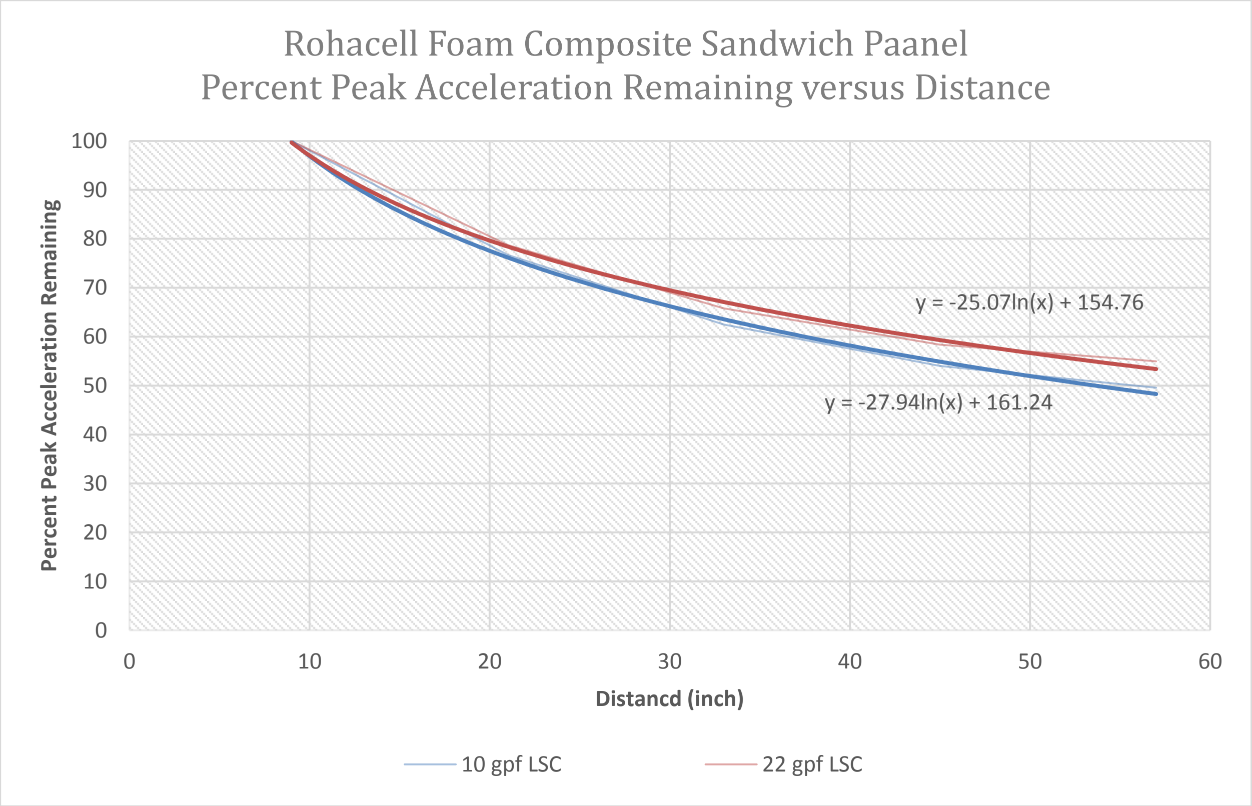
Factor		Predicted Peak Acceleration by Distance from LSC					
Type - Thick	**LSC Core Load**	**9**	**21**	**33**	**45**	**57**	**69**
Al Honey - 1	**10**	12385.2	9754.4	8155.2	7237.9	6819.2	6820.1
Al Honey - 1	**22**	13314.4	10760.9	9232.4	8408.6	8129.7	8343.8
Al - 0.187	**10**	12626.4	10582.4	9415.3	8892.5	8915.6	9489.1
Al - 0.187	**22**	13573.7	11674.4	10659.0	10330.8	10629.1	11609.0
Monolithic - 0.2	**10**	14680.2	12448.4	11205.7	10707.8	10861.9	11696.4
Monolithic - 0.2	**22**	15781.6	13733.0	12685.8	12439.8	12949.4	14309.6
Monolithic - 0.3	**10**	11353.5	9593.5	8605.3	8194.0	8282.7	8887.5
Monolithic - 0.3	**22**	12205.3	10583.5	9742.0	9519.4	9874.4	10873.1
ROHACELL® - 1	**10**	12655.5	9708.9	7906.8	6835.5	6273.1	6111.3
ROHACELL® - 1	**22**	13605.0	10710.7	8951.1	7941.1	7478.6	7476.6

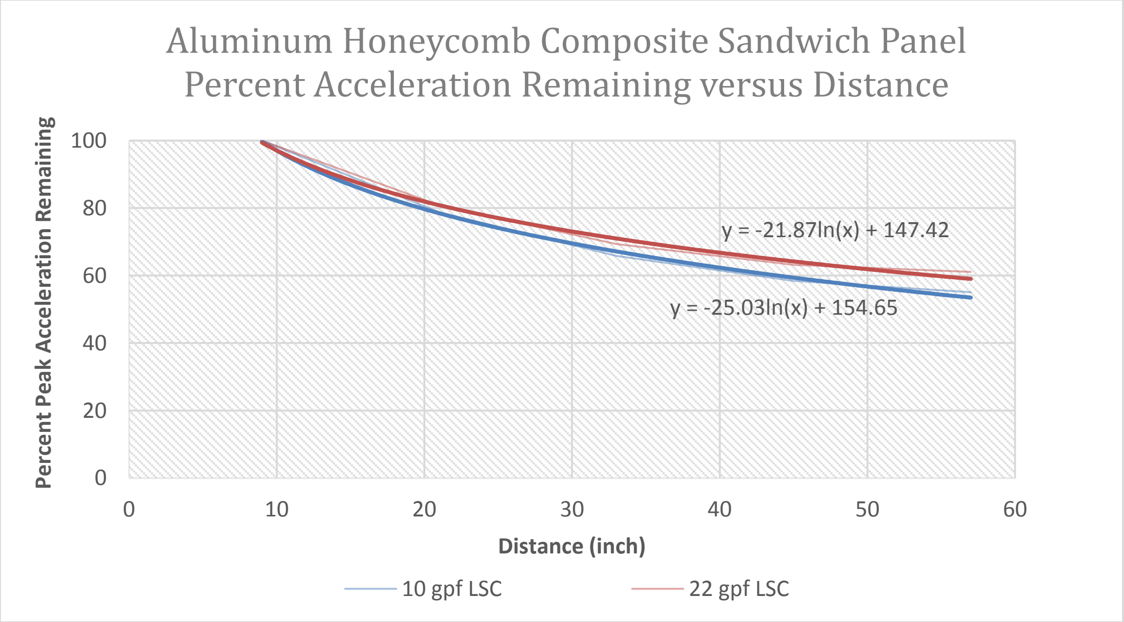
Post-Processing – SRS Peak Acceleration

- Given the limitation of performing the characterization of the composite material for pyroshock using flat panels, the percentile of the remaining shock with distance was evaluated since it is an invaluable tool for predicting the MEFE at a given distance from the shock source
  - The data provided herein are limited to approximately 48 inches from the shock source due to the limited size of the test panels.
- The predicted peak acceleration generated from the statistical analysis from the SRS algorithm output was used to generate graphical representations of the percentile of the shock remaining at a given distance
  - All of the data for this evaluation was normalized for the 9-inch data to be set at 100% and the data at distances further from the shock source shown as a percentile of the 9-inch data.

Post-Processing – SRS Peak Acceleration







Empirical Model MEFE Prediction Example – SRS

- The SRS predominate shock spectrum used within the aerospace industry for shock test requirements and is used herein for the example of a MEFE shock prediction
- Using the guidelines developed from the data evaluation within this report, a hypothetical shock that is characterized as having a peak shock of 8,000 g at 10,000 Hz (similar to a source shock from a 10-gpf linear explosive induced into a 0.19-inch metallic structure) is used as an example for the prediction of the MEFE at a distance of 48 inches from the shock source
  - Note: The hypothetical source shock is assumed to have been predicted through a bolted interface
- The first example will be for the monolithic composite material followed by the Al honeycomb sandwich composite material and then the ROHACELL® foam sandwich composite material
- The first step for the prediction is to generate an SRS for source shock.
- The peak acceleration is given so the two attributes that need to be included are the slope (in dB/oct) and the frequency breakpoint (in Hz).
  - For this exercise the tabulated listing for the predictive slope is used at the 9-inch location, which is 8.9 dB/oct (for all panel types).
  - The second step is to determine the frequency breakpoint.
  - The predicted frequency breakpoint for both the 0.2-inch-thick monolithic composite and the 0.3-inch monolithic composite materials is tabulated in the table for predicted frequency break point
- Another potential use of the normalized curves is scaling an existing SRS at a certain distance of one composite type to another composite type

Empirical Model MEFE Prediction Example – SRS

- Monolithic composite MEFE prediction
  - Predicted slope by distance table

Value used for initial source shock prediction

Factor	Predicted Slope by Distance from LSC					
Distance	9	21	33	45	57	69
Slope	8.9	10.0	9.8	9.5	10.6	15.3

  - Predicted frequency breakpoint by distance table

Factors			Predicted Frequency Breakpoint by Distance from LSC, inches					
Type	Panel Thickness (inch)	Acoustic Damped (Yes/No)	9	21	33	45	57	69
Al Honey	1	No	2927.9	2398.1	2334.9	2422.5	2401.1	2038.2
Al Honey	1	Yes	1572.1	1397.4	1476.4	1662.4	1788.1	1647.2
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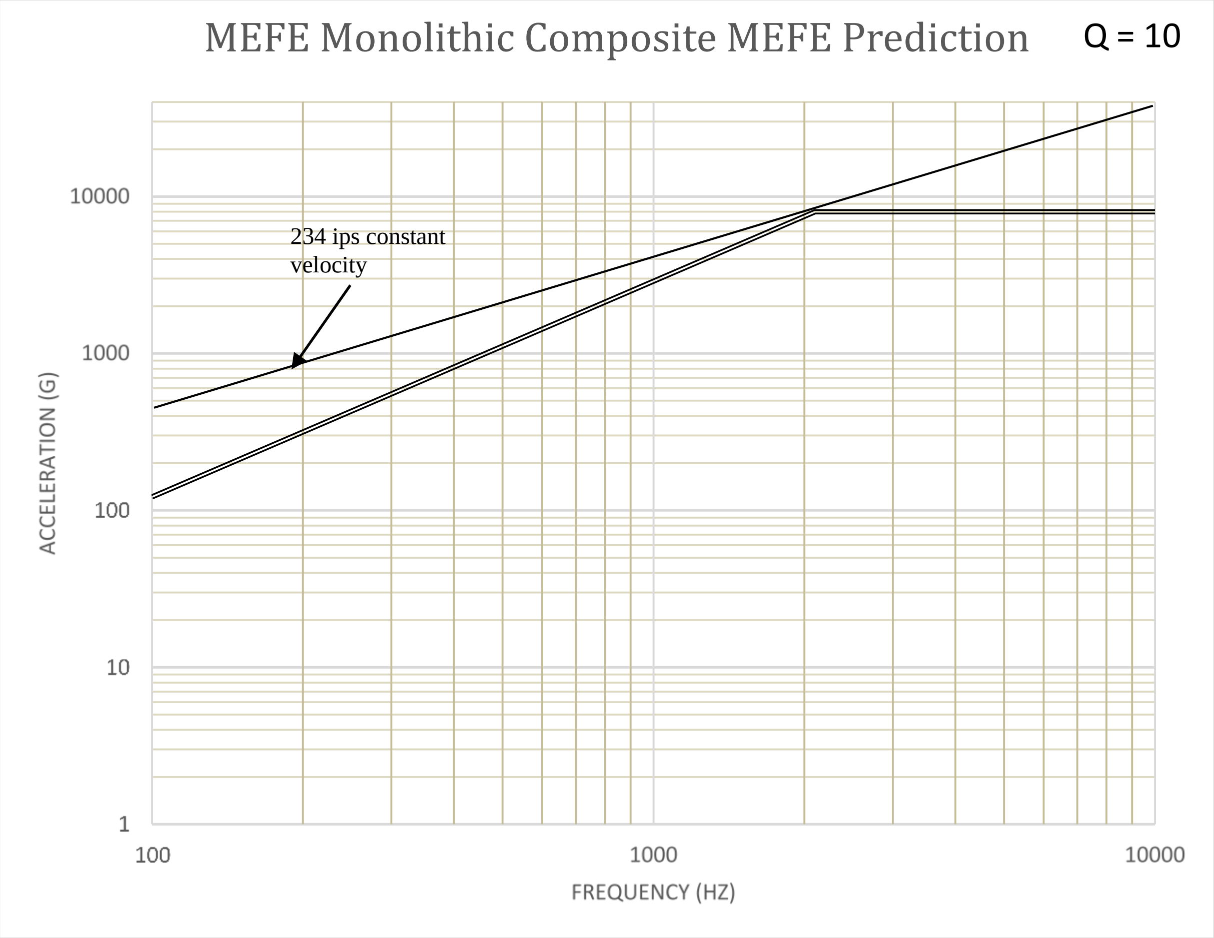
Value used for initial source shock prediction

Empirical Model MEFE Prediction Example – SRS

- Monolithic composite MEFE prediction
  - Predicted source shock



Frequency (Hz)	Acceleration (g)
100	122
2100	8000
10000	8000

Empirical Model MEFE Prediction Example – SRS

- To predict the shock for a component mounted 48 inches away from the 9-inch location given for the shock source, the 10-gpf LSC is used from the predicted peak acceleration table
- At a distance of 48 inches (from the 9-inch location), the percent peak acceleration remaining is approximately 70%, which would be 5,600 g based upon the initial 8,000 g hypothetical shock
- Given the SRS slope the slope is held constant for prediction of the attenuated shock spectrum and using the table for the frequency breakpoint for the monolithic composite at 57 inches is 2067 Hz a new SRS can be generated for an attenuated shock at a distance of 48 inches

Factor		**Predicted Peak Acceleration by Distance from LSC**					
Type - Thick	**LSC Core Load**	**9**	**21**	**33**	**45**	**57**	**69**
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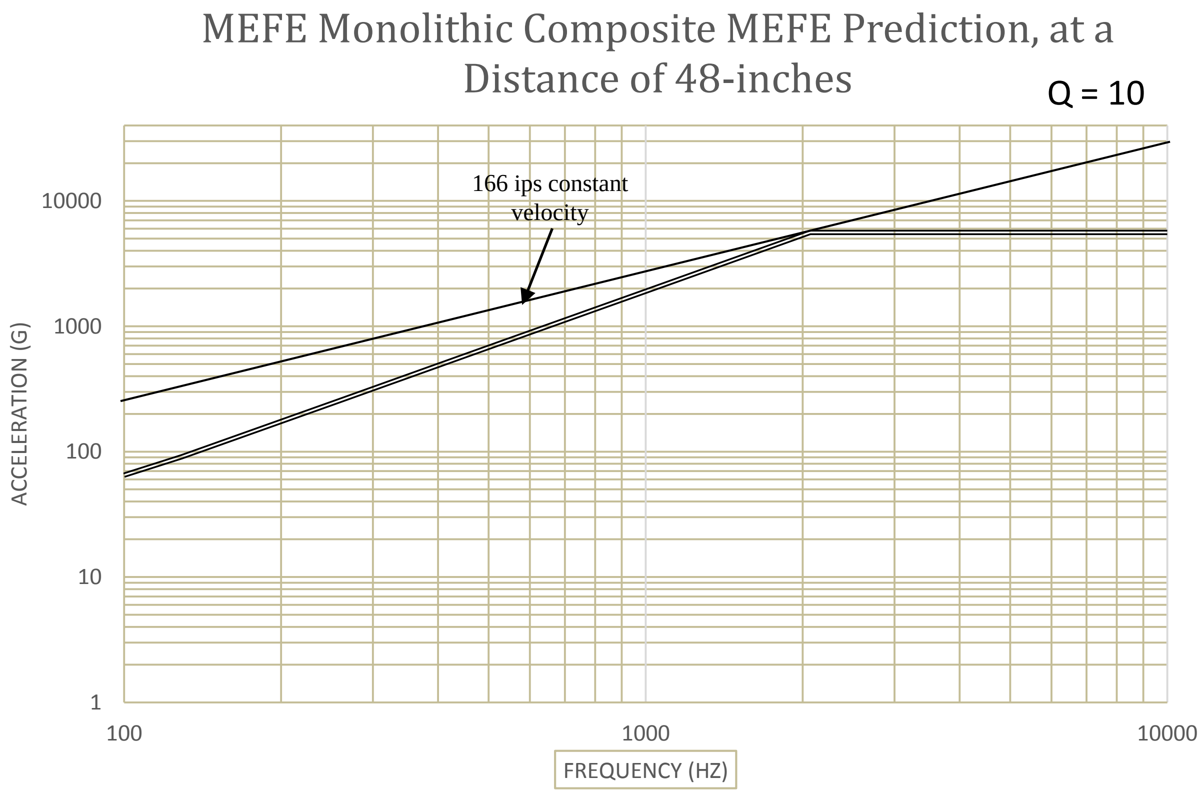
ROHACELL® - 1	**22**	13605.0	10710.7	8951.1	7941.1	7478.6	7476.6

Empirical Model MEFE Prediction Example – SRS

- Monolithic composite MEFE prediction
  - Predicted shock at 48 inches



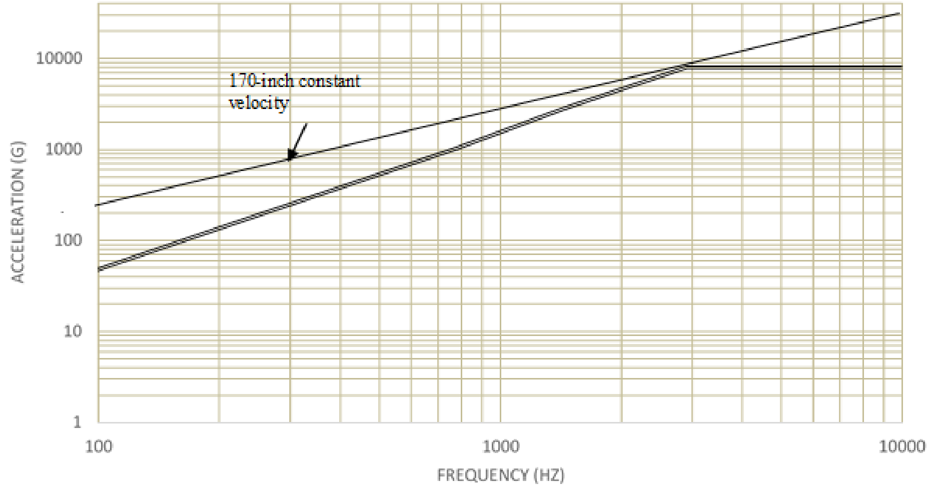
Frequency (Hz)	Acceleration (g)
100	65
2067	5600
10000	5600

Empirical Model MEFE Prediction Example – SRS

- Aluminum honeycomb sandwich composite MEFE prediction

MEFE Aluminum Honeycomb Sandwich Composite

Q = 10

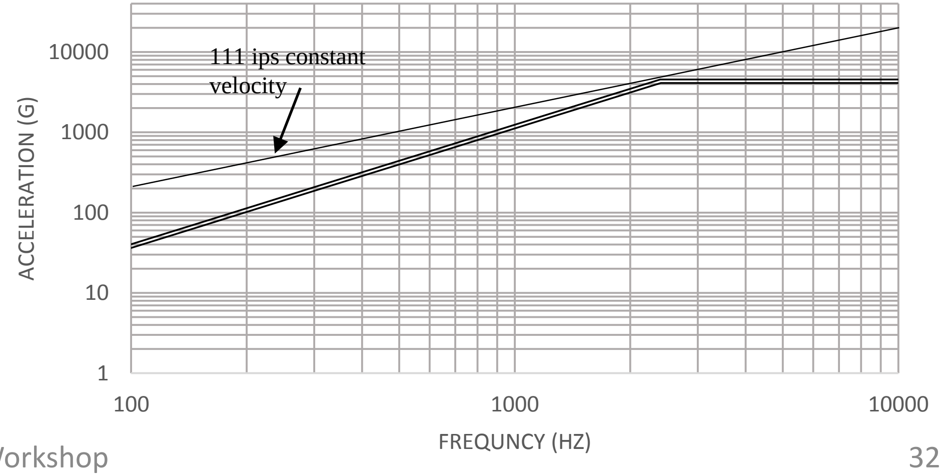


- Predicted source shock

Frequency (Hz)	Acceleration (g)
100	46
2900	8000
10000	8000

MEFE Auminum Honeycomb Sandwich Composite
MEFE Prediction, at a Distance of 48-inches

Q = 10



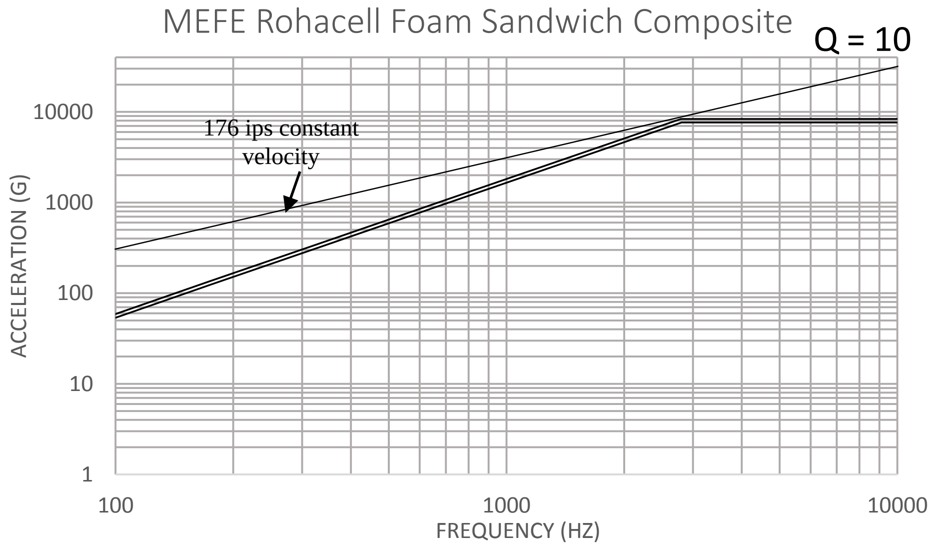
- Predicted shock at 48 inches

Frequency (Hz)	Acceleration (g)
100	33
2400	4320
10000	4320

Empirical Model MEFE Prediction Example – SRS

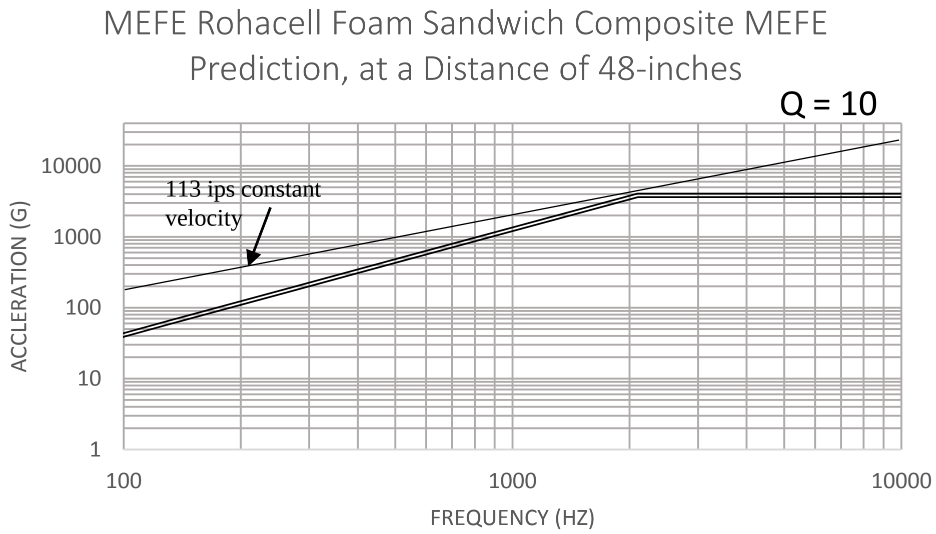
- Rohacell® foam sandwich composite MEFE prediction
  - Predicted source shock

Frequency (Hz)	Acceleration (g)
100	52
2800	8000
10000	8000



- Predicted shock at 48 inches

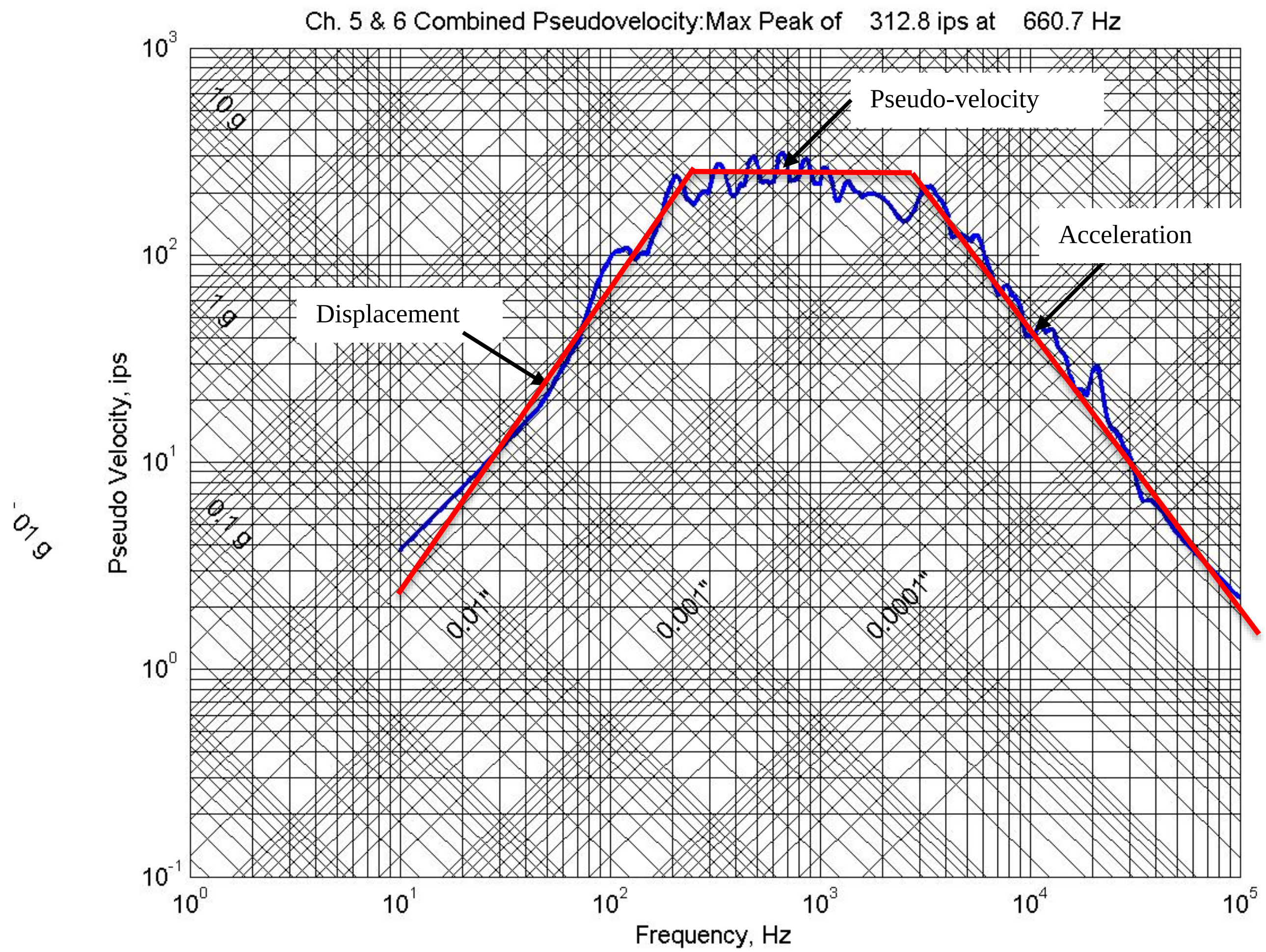
Frequency (Hz)	Acceleration (g)
100	33
2100	3840
10000	3840



Post-Processing – PVRS

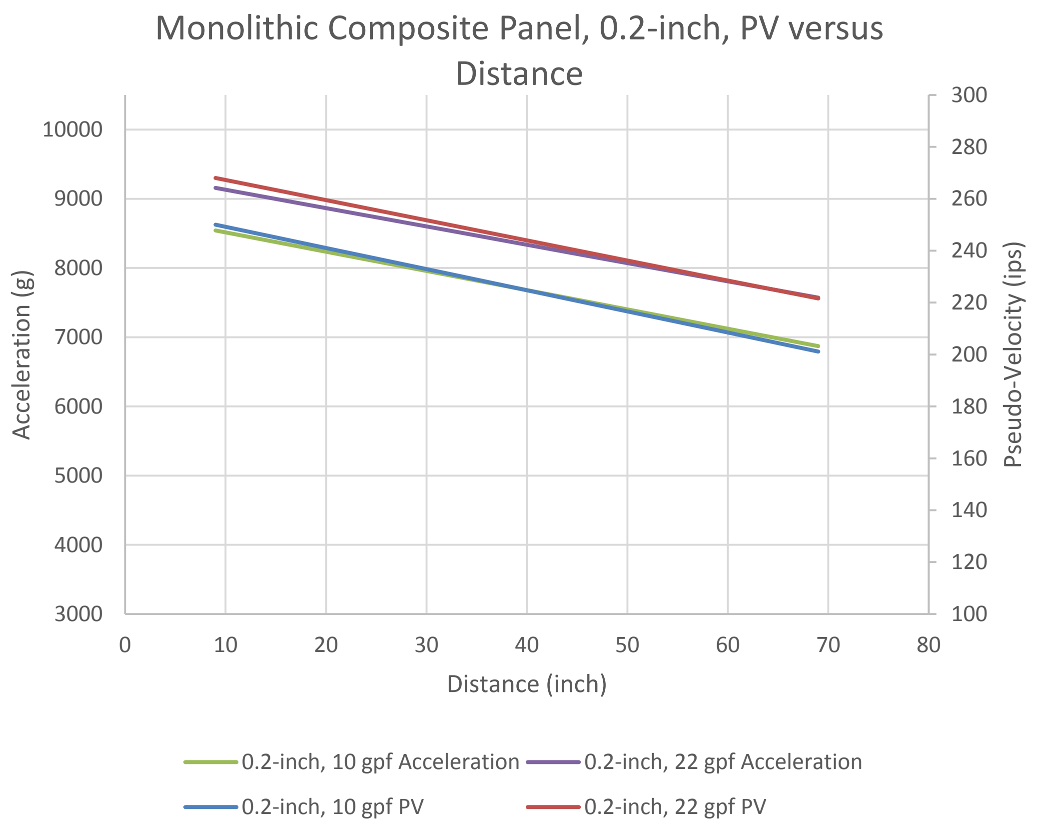
- The PVRS may be regarded as the second most common method for characterizing the shock environment in the aerospace industry
- ANSI/ASA S2.62-20098, *Shock Test Requirements for Equipment in a Rugged Shock Environment*, specifies shock severity levels according to the plateau level on the PVRS plotted on 4CP or displayed as a four coordinate plot
- The maximum PV may be calculated directly from the PV curve without further algorithm processing
- The data output from the maximum PV was not empirically modeled since no factors were determined, which correlated meaningfully from the statistical analysis
  - To evaluate the mean PV the data from the algorithm was imported to Excel® and a graph of each test data set was generated
  - From the graph the frequency band was chosen for the PV plateau, the values averaged and new plots generated for the mean PV at each of the accelerometer distances from the shock source
  - The data were normalized from the 9-inch data set to produce plots of the percentile PV remaining with distance in a similar manner to the evaluation of the SRS peak acceleration data

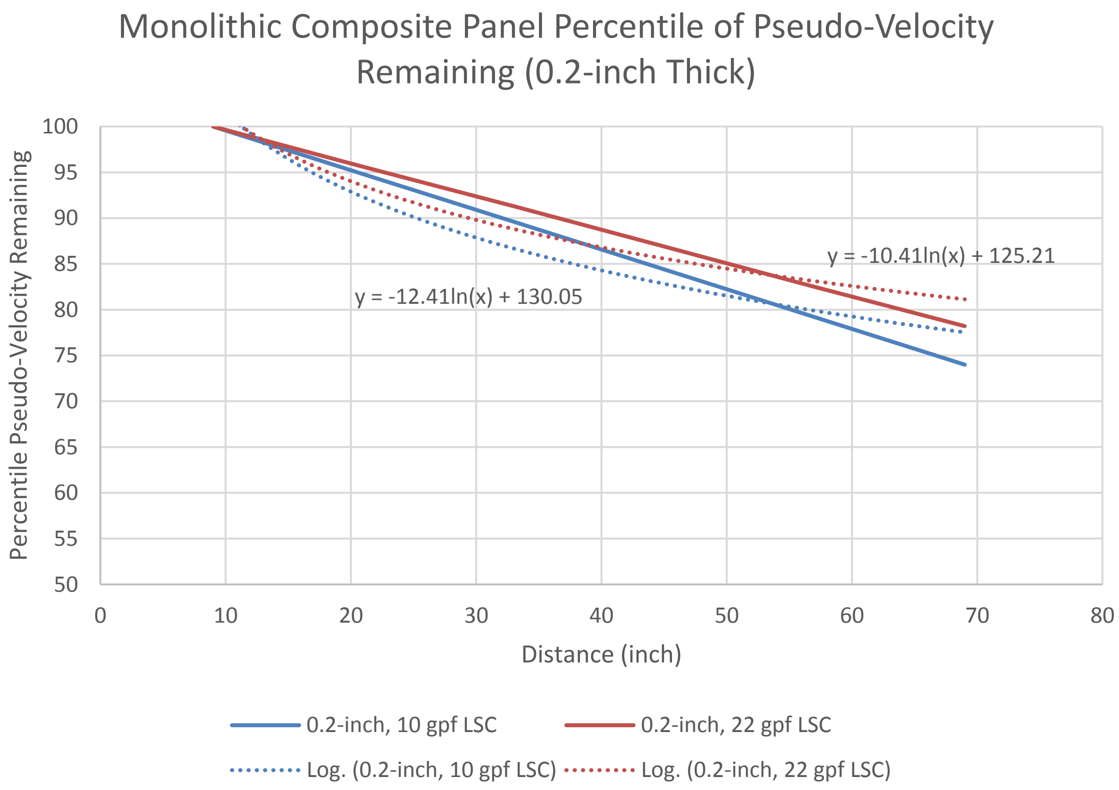
Post-Processing – Values Corresponding to PVRS



Post-Processing – PVRS Attenuation with Distance

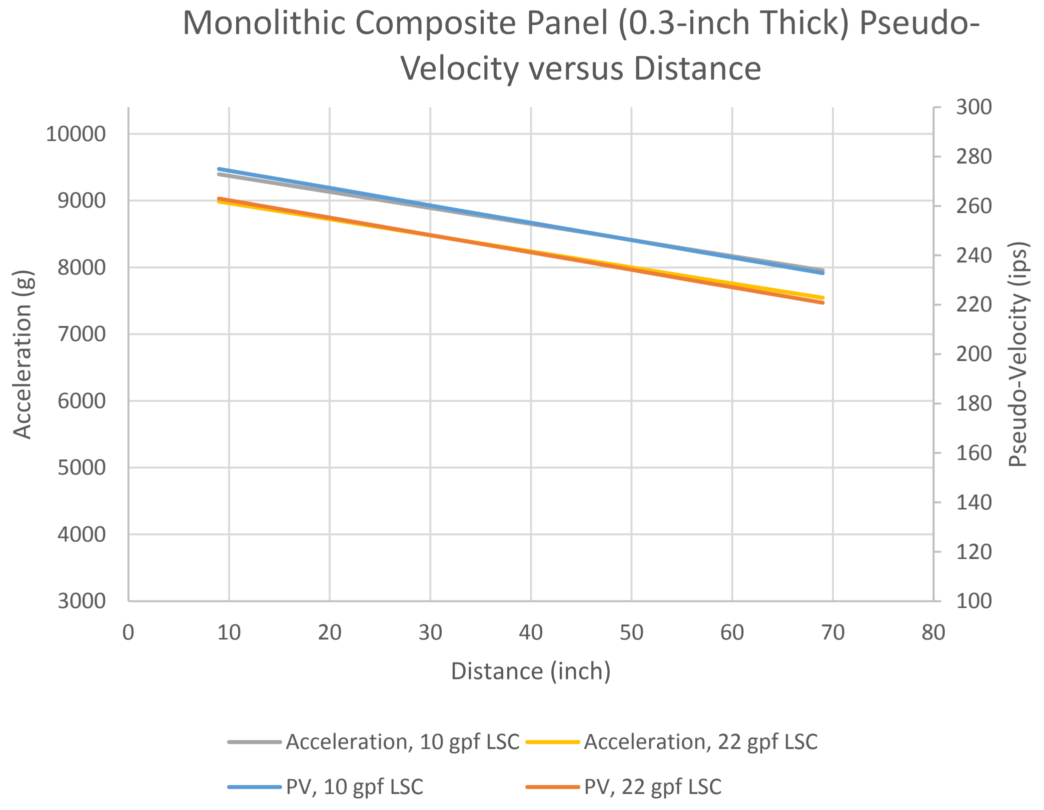
- Mean PV versus Distance, 0.2-inch-thick Monolithic Composite Panel

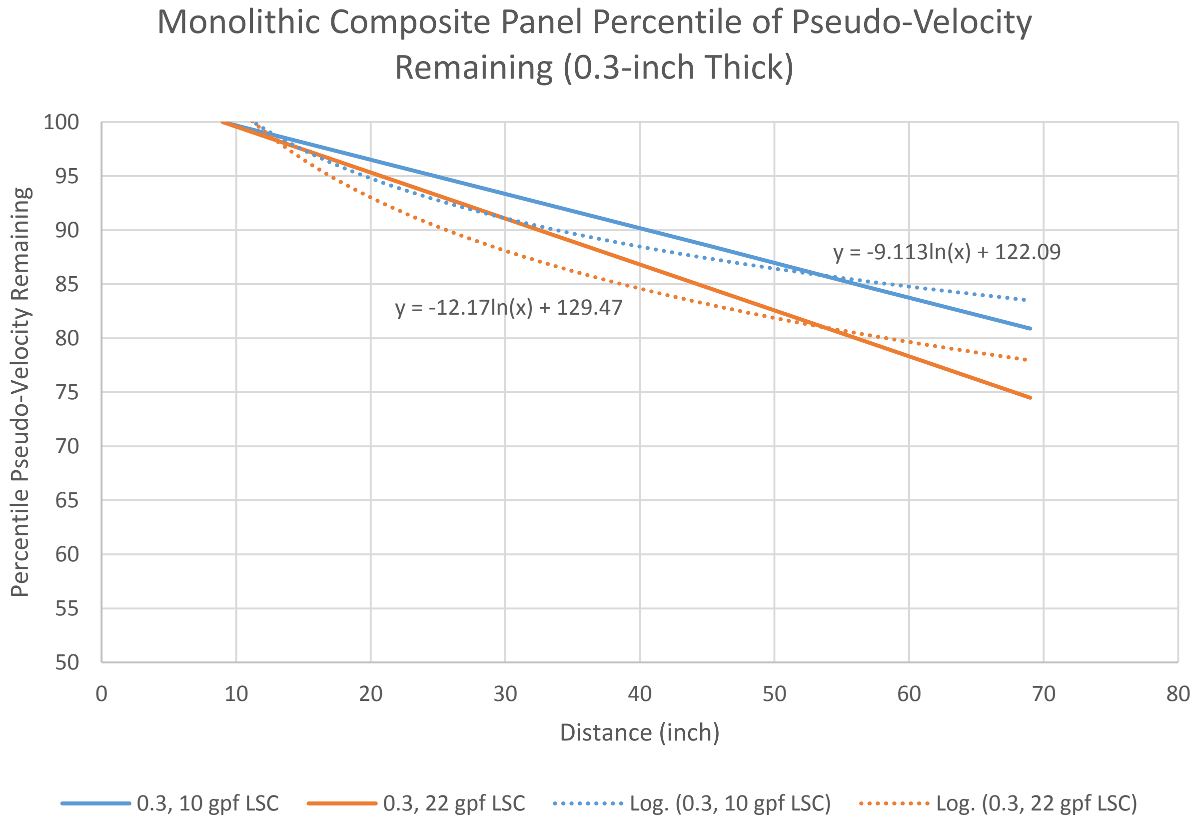




Post-Processing – PVRS Attenuation with Distance

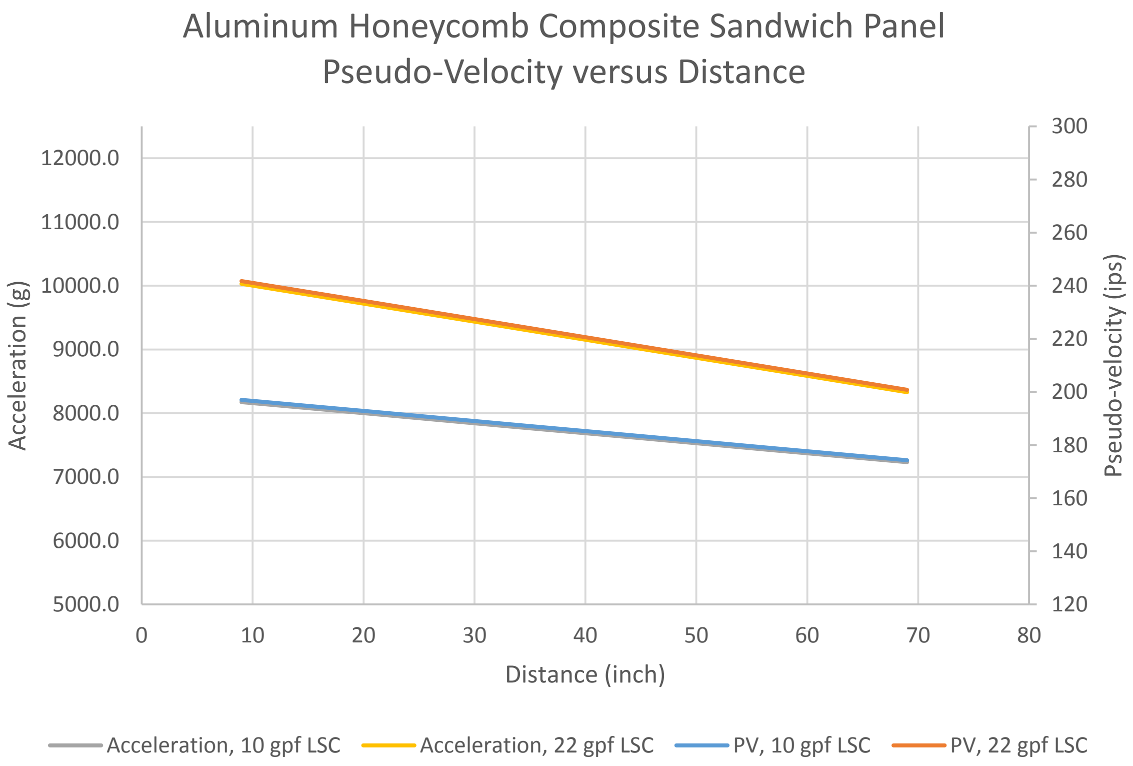
- Mean PV versus Distance, 0.3-inch-thick Monolithic Composite Panel

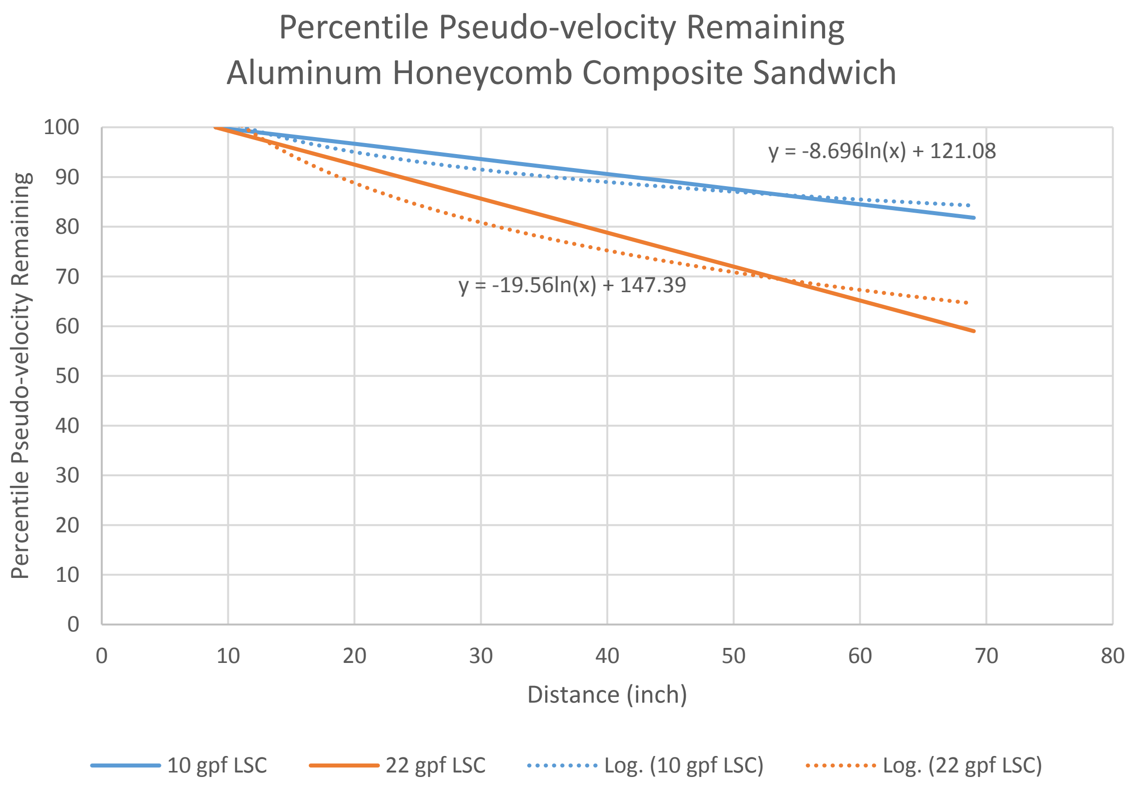




Post-Processing – PVRS Attenuation with Distance

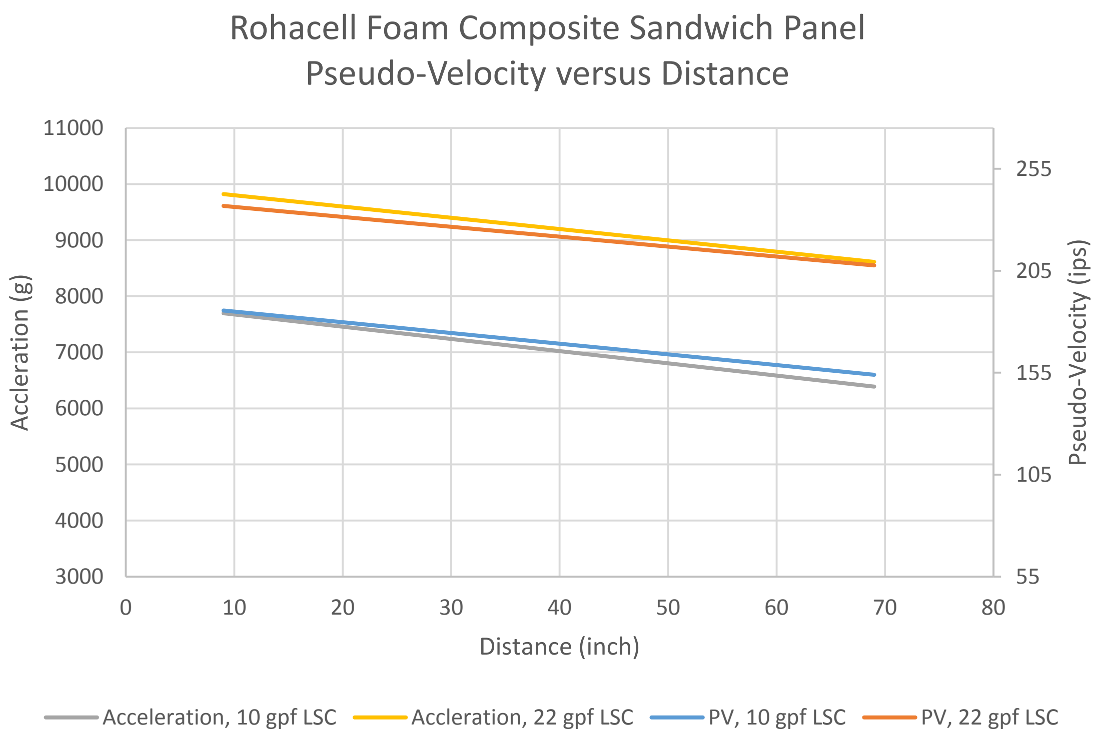
- Mean PV versus Distance, Al Honeycomb Composite Sandwich Panel

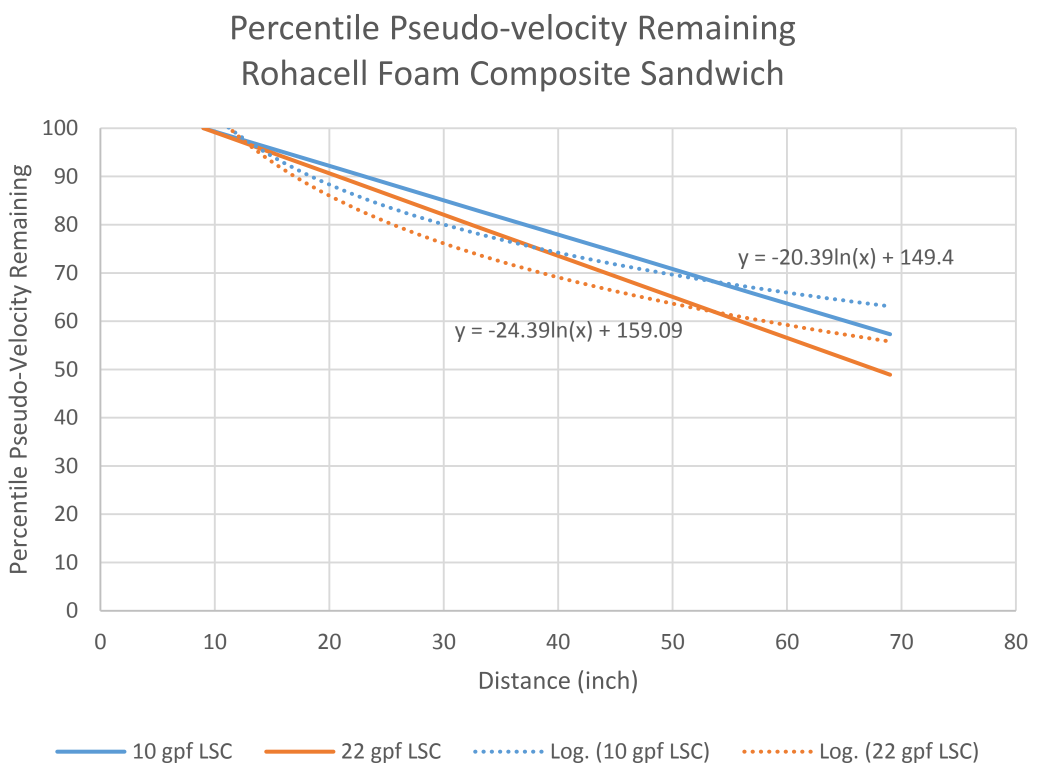




Post-Processing – PVRS Attenuation with Distance

- Mean PV versus Distance, ROHACELL® Foam Composite Sandwich Panel

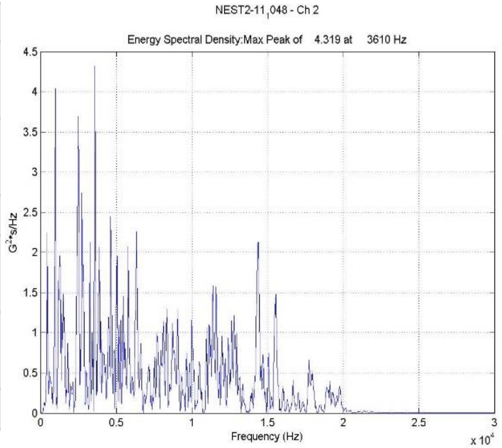


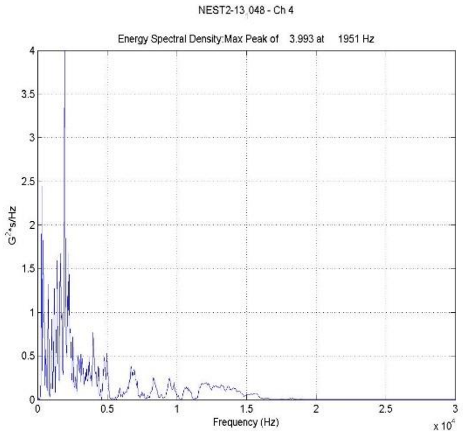


Post-Processing – Energy Spectral Density (ESD)

- ESD energy spectrum was statistically evaluated and the following significant factors were determined:
  - If an Al or composite LSC, plate was used (Note: Composite LSC panels (0.2-inch thick) were fabricated from both tape and fabric plies and used in the second group of sandwich panel tests in lieu of the aluminum LSC plate)
  - The location of the accelerometers (top row versus bottom row)
    - The Al was more efficient in coupling the shock energy through the bolted joint to the composite panel than a composite-to-composite interface
    - The top row of accelerometers rather consistently showed higher maximum energies, at a given location down the test panel, than the lower row of accelerometers, which was likely an artifact of the test setup
    - The LSC was always initiated from below the test panel; therefore, the detonation wave was traveling from the bottom of the test panel to the top of the test panel, hence the higher maximum energies calculated from the top row of accelerometers
  - Statistical analysis results for the maximum energy within the ESD is tabulated below

Factors			**Prediction at Distance from LSC**					
LSC Core Load	**Al LSC Plate**	***LSC Plate***	**9**	**21**	**33**	**45**	**57**	**69**
10	0	*Fabric Composite*	2.465	2.649	2.704	2.623	2.418	2.117
10	1	*Al*	7.405	7.958	8.124	7.881	7.264	6.361
22	0	*Fabric Composite*	3.938	4.057	3.972	3.695	3.266	2.743
22	0	*Tape Composite*	3.938	4.057	3.972	3.695	3.266	2.743
22	1	*Al*	11.830	12.190	11.935	11.102	9.813	8.240



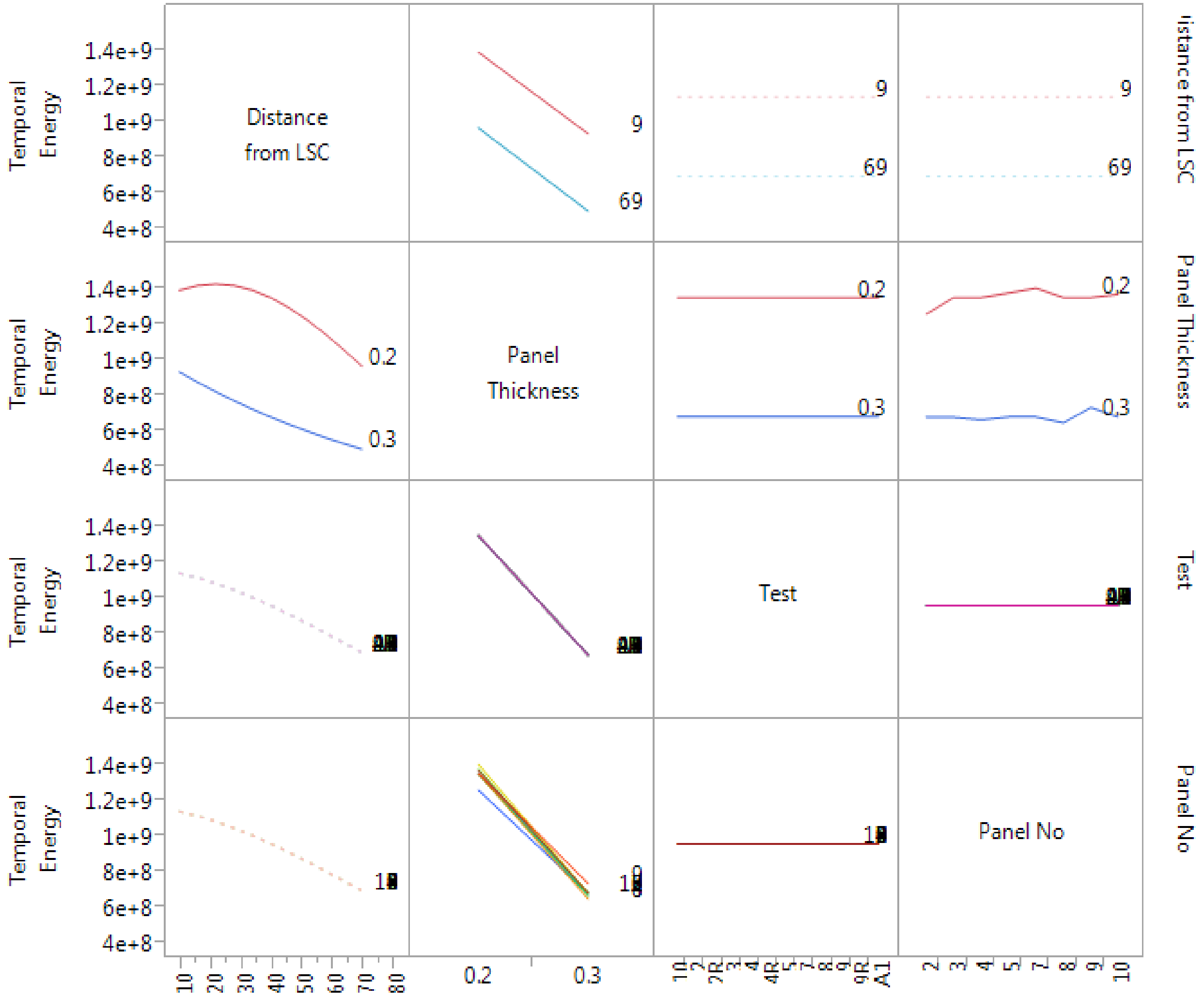


Post-Processing – Temporal Moments

- Temporal moments is basically the square root of the energy normalized by the root mean square (RMS) duration
  - Referred to as the root energy amplitude
  - Convenient way to describe the energy of the shock transient
- For this task, the temporal energy (TE) was calculated and statistically evaluated for the monolithic composite panel test results *only*
  - The results from the evaluation indicated the following significant factors:
    - The panel thickness
    - The distance from the shock source.
    - Factors determined not to be significant
    - The explosive core load used for inducing the shock
    - The type and orientation of the ply used in fabrication of the monolithic composite panel.
    - General conclusions that may be drawn are:
    - Thin panels had higher TE
    - TE decreased with increasing distance from the shock source

Post-Processing – Temporal Moments

- Monolithic composite panel statistical analysis results



Concluding Remarks

Concluding Remarks

- At total of 48 pyroshock tests were conducted using either aluminum, monolithic composite, or sandwich filled composite panels
  - Shock data was collected at six different locations for each of the 48 pyroshock tests
  - The accelerometer data was processed using MATLAB® algorithms developed to mitigate data noise and subjective decisions (human error/bias), to the greatest plausible extent, for characterizing a pyroshock environment
  - The processed data from the algorithm was statistically analyzed to determine the significance of the factors related to composite materials
  - The post-processed data was characterized for usage in an empirical predictive methodology for MEFE
  - For additional information please refer to NESC-RP-TM-12-00783 (NASA TM TBD)

Forward Work

- Included within the recommendations section of NESC-RP-TM-12-00783 are the following with regard to possible forward work related to this effort
  - Conduct additional testing to include a skin-stiffened composite layup as a variable to evaluate its dynamic response
  - Since composite panel design and construction, influences shock response, evaluate and correlate acoustic modal response with pyroshock response for each composites type
  - Conduct higher-fidelity (more flight-like) pyroshock testing on composite ring structures, of sufficient size to minimize edge effects, to corroborate post-test data processing and MEFE predictive evaluation

BACKUP

Test Outline

Group I – Solid Composite Panels						
Test Number	**Material**	**Panel Thickness**	**Ply**	**Orientation**	**Type**	**LSC Core Load**
1	Composite, IM7/TC350	0.200	Fabric	0-Deg, 18 ply	Solid	10
2	Composite, IM7/TC350	0.200	Fabric	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 18 ply	Solid	10
3	Composite, IM7/TC350	0.300	Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 54 ply	Solid	10
4	Composite, IM7/TC350	0.300	Fabric	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 27 ply	Solid	22
5	Composite, IM7/TC350	0.200	Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 38 ply	Solid	22
Analyzed results from Tests 1-5 to incorporate any re-planning for tests 6 through 10 was deemed necessary. (Note: No re-planning was required.)						
6	Composite, IM7/TC350	0.200	Fabric	0-Deg, 18 ply	Solid	22
7	Composite, IM7/TC350	0.200	Fabric	+45°/-45°, 0° (2x), +45°/-45°, 90°, 18 ply	Solid	22
8	Composite, IM7/TC350	0.300	Fabric	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 27 ply	Solid	10
9	Composite, IM7/TC350	0.300	Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 54 ply	Solid	22
10	Composite, IM7/TC350	0.200	Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2x), 38 ply	Solid	10

Test Outline Cont'd…

Group II – Sandwich Composite Panels						
Test Number	**Material**	**Panel Thickness**	**Fill/Ply**	**Orientation**	**Type**	**LSC Core Load**
11	Composite, IM7/TC350	8 Ply/ 1-inch-thick fill	Al Honeycomb & Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2X), 8 ply both faces	Sandwich	10
12	Composite, IM7/TC350	8 Ply/ 1-inch-thick fill	Al Honeycomb & Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2X), 8 ply both faces	Sandwich	22
13	Composite, IM7/TC350	8 Ply/ 1-inch-thick fill	ROHACELL® Foam &Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2X), 8 ply both faces	Sandwich	10
14	Composite, IM7/TC350	8 Ply/ 1-inch-thick fill	ROHACELL® Foam &Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2X), 8 ply both faces	Sandwich	22
15	Composite, IM7/TC350	8 Ply/ 1-inch-thick fill	Al Honeycomb & Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2X), 8 ply both faces	Sandwich	10
16	Composite, IM7/TC350	8 Ply/ 1-inch-thick fill	Al Honeycomb & Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2X), 8 ply both faces	Sandwich	22
17	Composite, IM7/TC350	8 Ply/ 1-inch-thick fill	ROHACELL® Foam &Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2X), 8 ply both faces	Sandwich	10
18	Composite, IM7/TC350	8 Ply/ 1-inch-thick fill	ROHACELL® Foam &Tape	+45°/-45°, 0° (2x), +45°/-45°, 90° (2X), 8 ply both faces	Sandwich	22

Test Outline Cont'd…

Group III – Sandwich Composite Panels							
Panel and Test Number	**Material**	**Panel Thickness**	**Fill/Ply**	**Test Panel Ply Orientation**	**Type**	**LSC (gpf)**	**LSC Plate***
19	Composite, IM7/TC350	8 Ply/1-inch-thick fill	Al Honeycomb & Fabric Face Sheets	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	10	Fabric Composite, IM7/TC350
20	Composite, IM7/TC350	8 Ply/1-inch-thick fill	ROHACELL® Foam & Fabric Face Sheets	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	22	Fabric Composite, IM7/TC350
21	Composite, IM7/TC350	8 Ply/1-inch-thick fill	Al Honeycomb & Tape Face Sheets	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	22	Al
22	Composite, IM7/TC350	8 Ply/1-inch-thick fill	ROHACELL® Foam & Fabric Face Sheets	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	10	Al
23	Composite, IM7/TC350	8 Ply/1-inch-thick fill	Al Honeycomb & Fabric Face Sheets	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	10	Al
24	Composite, IM7/TC350	8 Ply/1-inch-thick fill	Al Honeycomb & Fabric Face Sheets	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	22	Al
25	Composite, IM7/TC350	8 Ply/1-inch-thick fill	Al Honeycomb & Fabric Face Sheets	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	22	Fabric Composite, IM7/TC350
26	Composite, IM7/TC350	8 Ply/1-inch-thick fill	ROHACELL® Foam & Tape Face Sheets	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	22	Tape Composite, IM7/TC350
27	Composite, IM7/TC350	8 Ply/1-inch-thick fill	ROHACELL® Foam & Fabric Face Sheets	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	10	Fabric Composite, IM7/TC350
28	Composite, IM7/TC350	8 Ply/1-inch-thick fill	Al Honeycomb & Tape Face Sheets	90°/+45°/-45°/0°/0°/ -45°/+45°/90°, 8 ply both faces	Sandwich	10	Tape Composite, IM7/TC350

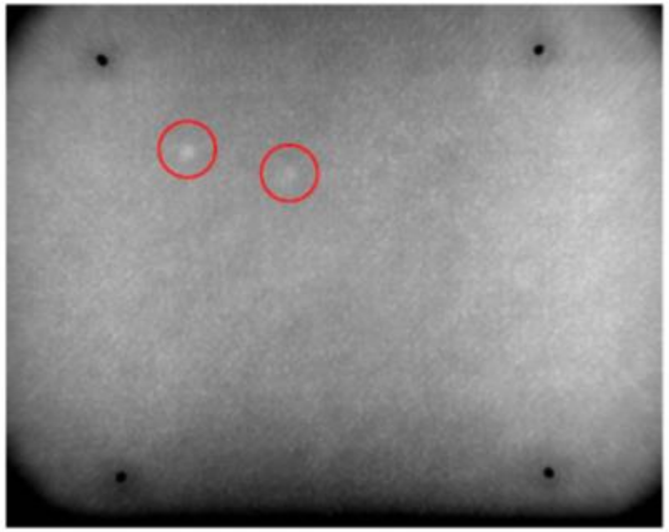
Pyroshock Composite Group II Re-Tests

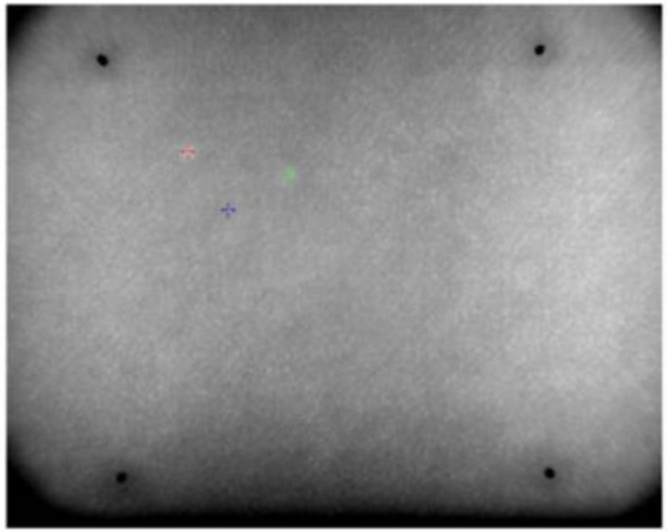
Test No.	Group I Previous Test #	LSC Core Load	Panel Thickness (in)	Composite Ply
Rep 1	10	10	0.2	Tape
Rep 2	4	22	0.3	Fabric
Rep 3	2	22	0.2	Fabric
Rep 4	9	22	0.3	Tape

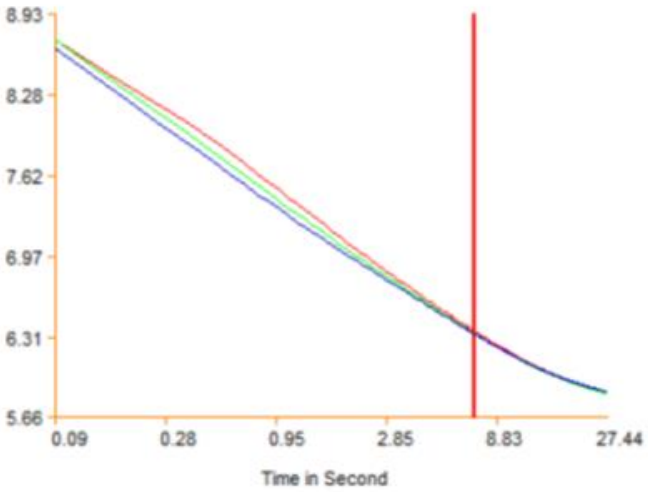
Melamine Foam Damped Test Series

Test Order	Panel No	Type	Core Load	Dampening
1	17	ROHACELL®	22	0
2	12	Monolithic	22	Damped
3	8	Al	22	0
4	18	ROHACELL®	22	Damped
5	11	Al Honeycomb	22	0
6	Pathfinder	Al	22	0
7	Pathfinder	Al	22	Damped
8	17	ROHACELL®	22	Damped
9	11	Al Honeycomb	22	Damped
10	8	Monolithic	22	Damped

Indication: D3







Two indications, approximately 0.25" by 0.25", were found in inspection location D3 and denoted by the red circles. Time-temperature cursors, shown in red and green, were placed on each indication and measured the average intensity value of the local 3 by 3 pixel area. A blue reference time-temperature cursor was placed over a nominal area for comparison. Plotting the data from the two indications and the reference point shows that both indications deviate from the behavior of nominal areas of the panel.

In addition to infrared thermography, phased array ultrasound (PAUT) was used to inspection the panel. PAUT did not detect any anomalies at grid location D3, and as a result, it is believed the indications present in the thermographic data are the result of a surface condition.

IR Thermography Indications not present using phased array ultrasonic testing (PAUT)

Pyroshock Composite LSC Plate Ply Layup

Ply Number	Orientation Fabric Ply	Orientation Tape Ply
1	45°	45°
2	-45°	-45°
3	0°	0°
4	0°	0°
5	45°	45°
6	-45°	-45°
7	90°	90°
8	90°	90°
9	-45°	45°
10	45°	-45°
11	90°	0°
12	90°	0°
13	-45°	45°
14	45°	-45°
15	0°	0°
16	0°	90°
17	-45°	90°
18	45°	0°
19		-45°
20		45°
21		0°
22		0°
23		-45°
24		45°
25		90°
26		90°
27		-45°
28		45°
29		0°
30		0°
31		-45°
32		45°