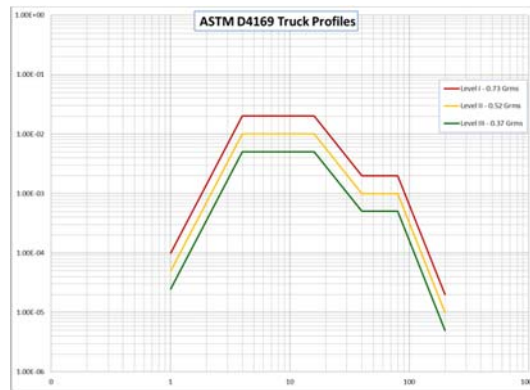


ASTM D4169 Truck Profile Update Rationale

Revision Date: September 22, 2016

Over the past 10 to 15 years, many truck measurement studies have been performed characterizing various over-the-road environment(s) and much of the truck measurement data is available in the public domain. The shape and intensity of the more recently measured data does not correlate well with the truck vibration profiles referenced in ASTM D4169 [1]. The truck transportation profiles in ASTM D4169 Section 12.4 are generally based on data from the Forest Products Lab Report FPL-22 [2]. After comparing the shapes of the current D4169 Truck profiles to recently compiled North and South America profile measurements, the differences become evident.

Figure 1-ASTM D4169 Truck Assurance Levels 1 to 3 as listed in standard Section 12.4



Measured Data, Figures 2 to 5:

Figure 2-Pennsylvania to California – Fall 2013

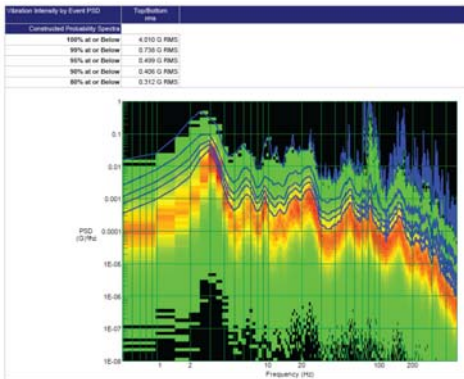


Figure 3- South America – Spring 2013

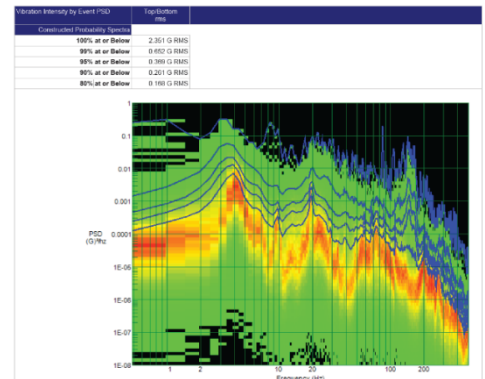


Figure 4 - South America – Winter 2012

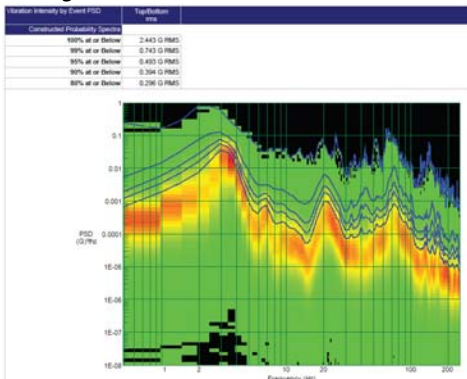
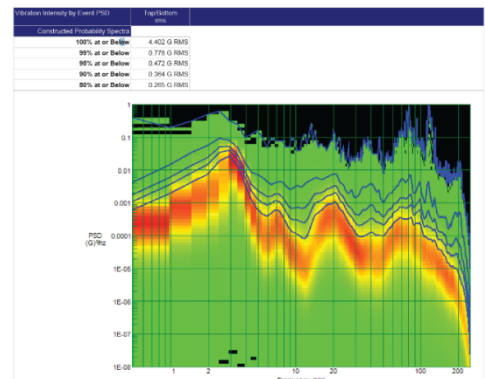


Figure 5 - South Carolina to Texas – Fall 2012



ASTM D4169 Truck Profile Update Rationale

Revision Date: September 22, 2016

The measured data shown in Figures 2 to 5 indicates the truck trailer spectral shape is fairly well defined and is generally the same shape regardless of the geographic location the data was measured in.

In Figures 2 to 5, the darker orange profile areas represent the most frequently occurring vibration intensity across the measured spectrum. The Blue line in Figure 6 helps to highlight the general shape of the profile which is the typical truck vibration profile with three distinct peaks. The peaks correspond to the trailers' primary vibration response characteristics (suspension, wheels/tires, and rigid body structural members) [3]. Trailers respond to roads with the same three peak spectral shape. The trailer responses vary in intensity (y scale) based upon the road roughness or surfaces traveled. Overlaying that blue line (general shape) on top of the current ASTM D4169 Truck profiles, Figure 7, highlights the differences in the vibration spectral shapes. (Note: the scaling is not absolute; this comparison intention is to highlight vibration profile shape differences).

Figure 6 - General Truck Profile Shape Highlighted in Blue

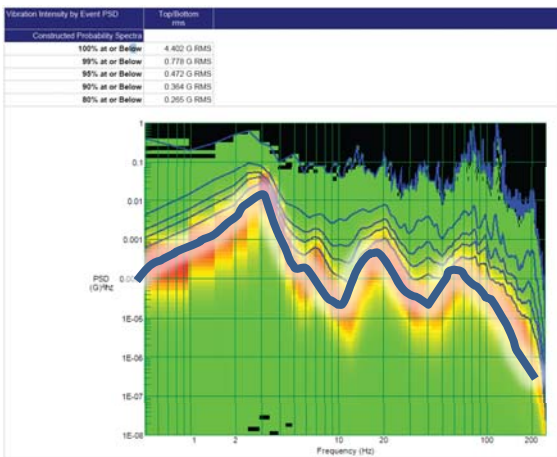
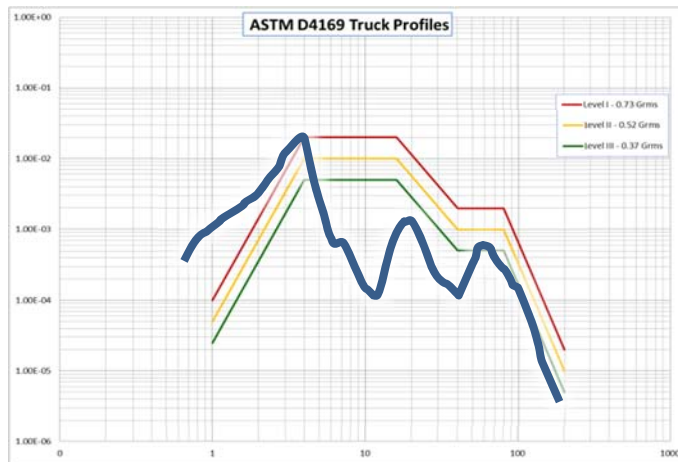
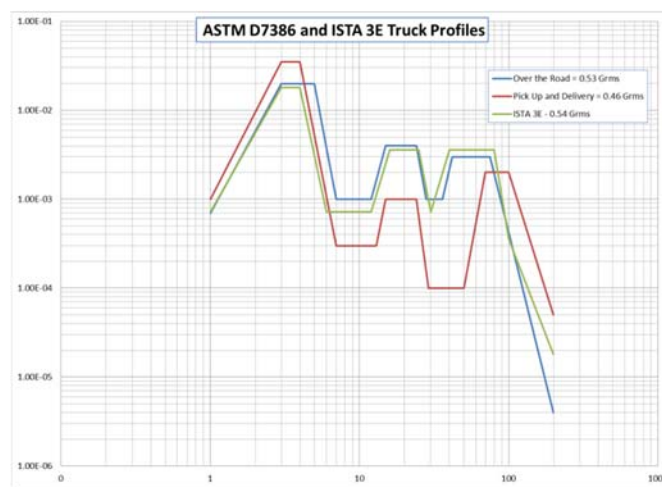


Figure 7 - General Truck Profile over D4169 Truck Profiles



ASTM D7386 and other current industry standards such as ISTA 3A, 3B, 3E, 3F, and 3H¹ were developed and based on more recently measured truck vibration data, similar in shape to the measured data shown in the figures 2 to 5. See Figure 8 for a profile comparison of ASTM D7386 and ISTA 3E random vibration profiles.

Figure 8- ASTM D7386 [4] and ISTA 3-Series Steel Spring Truck Random Vibration Profiles



¹ These will be referred to as "ISTA 3-Series Protocols" for the remainder of the paper

ASTM D4169 Truck Profile Update Rationale

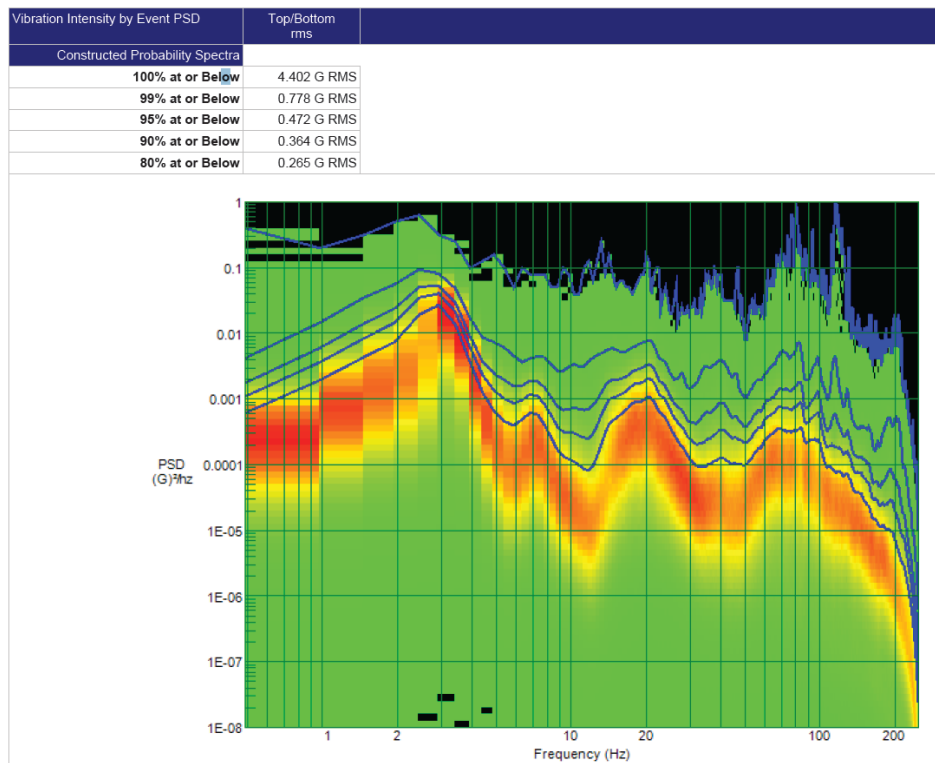
Revision Date: September 22, 2016

More In-Depth Data Analysis:

Historically, most transport vehicle vibration measurements presented and published referenced a summary Power Spectrum Density (PSD) profile constructed by averaging the individual time-history acceleration events together. The breakpoints associated with the summary PSDs were typically accelerated (increased) using a widely accepted “accelerated vibration testing formula” [5]. However, during the past 10 to 15 years, a number of presentations and associated papers have focused on efforts associated with advanced random vibration testing techniques. One common goal of the advanced testing techniques is to represent the vibration intensity ranges experienced during transport without arbitrarily or artificially increasing test intensities. Through more detailed field data statistical analysis, it is possible to evaluate different intensity levels (such as average and 95% percentile levels) and the time measured or associated with the different intensity levels.

The PSD-versus-Frequency plot below provides a more robust statistical analysis of a given measurement. The reddish areas represent more frequently measured PSD-versus-Frequency data. The green areas represent levels measured less often. In Figure 9, the darker orange area can be considered comparable to the summary average commonly referenced in older papers and presentations.

Figure 9- PSD-versus-Frequency Plot Example



By definition, there is measured vibration data that falls both above and below the average from an intensity perspective. Product and package designers are more concerned with data that *exceeds* that average since they are ultimately responsible for creating solutions that will protect the product from environmental hazards possessing the greatest damage potential. To more accurately replicate the truck vibration with the greatest damage potential, it is better to vary the test intensity and corresponding test time at that intensity based upon representative variability present in actual truck field data. This is a better approach than selecting a single artificially accelerated test intensity for the complete duration of the random vibration test.

ASTM D4169 Truck Profile Update Rationale

Revision Date: September 22, 2016

The truck vibration data, other current industry truck vibration profiles, and varied intensity vibration testing techniques discussed in the preceding sections are the basis for the proposed updates to the ASTM D4169 Schedule E Truck Vibration random test method.

Proposed Change:

When considering any random vibration test, the three key characteristics to define are:

1. Profile spectral shape
2. Profile intensity (Grms²)
3. Profile duration (time)

1. Profile Spectral Shape:

Based upon a number of recent North and South American truck measurements (see Figures 2 to 5), the spectral shapes measured match current and widely used industry test specifications, such as ASTM D7386 and ISTA 3-Series Profiles. The spectral shape highlighted in Figure 9 is similar to the spectral shapes found in current industry standards and provides justification to cross-reference the widely accepted ISTA Steel Spring Truck profile as the basis for the proposed ASTM D4169 truck profile spectral shape.

2. Profile Intensity:

By reviewing the current measured truck data (Figures 2 to 5), comprehensive statistical data summaries show:

- 90% of the measured data is at or below an intensity of 0.40 Grms
- 95% of the measured data is at or below an intensity of 0.50 Grms
- 99% of the measured data is at or below an intensity of 0.73 Grms

The proposed update recommends conducting the test using a consistent shaped profile at varying test intensities. The following paragraphs explain the proposed levels of intensity.

Low Level -

The measured data indicates that most truck vibration—90% of it—occurs at a lower intensity level of up to 0.40 Grms. The proposed update to the D4169 Truck Profile recommends testing using the proposed spectral shape starting at an intensity level that is comparable to the 90th percentile of the referenced measured data (Figures 2 to 5).

Medium Level -

The current ASTM D4169 Truck Assurance Level II profile shape is not representative of the truck environment but its intensity level—0.52 Grms—is comparable to the 95th percentile intensity level of 0.50 Grms. The ISTA 3-Series [6] Steel Spring Truck Profile also has a similar intensity (0.54 Grms). The proposed update recommends testing using the ISTA Steel Spring Truck Profile at the 0.54 Grms intensity level which is slightly higher than the 0.50 Grms level and can be considered a worst case medium intensity level vibration.

High Level -

The measured data also contains some vibration occurs at a higher intensity (0.73 Grms). To simulate these more intense vibration events, the proposed update recommends testing using the proposed spectral shape with an intensity level that is comparable to the 99th percentile of the referenced measured data (Figures 2 to 5).

3. Profile Duration:

Currently, when performing an ASTM D4169 simulation for Distribution Cycles 1, 3, 4, 5, and 6, the truck vibration test is performed at a single intensity level (e.g. Assurance Level II) for the entire test duration. The proposed update, however, is recommending the use of three different intensities—Low, Medium, and High—that correspond with the 90th, 95th, and 99th percentile intensities as discussed above. The same measured vibration data used to determine the Low, Medium, and High intensity levels can also be analyzed to determine the relative amount of time that those intensity levels occur. By definition, 90th percentile (Low) intensity vibration occurs more often than the 95th percentile (Medium) intensity which occurs more often than the 99th percentile (High) intensity.

² The root mean square acceleration (Grms) is the square root of the area under the acceleration spectral density curve in the frequency domain. The Grms value is used to express the overall energy of a particular random vibration event and is a statistical value used in vibration for analysis purposes.

ASTM D4169 Truck Profile Update Rationale

Revision Date: September 22, 2016

Many test labs have a historical precedent for using three-hour test durations for ASTM D4169 [1] vehicle vibration tests. The three-hour test duration allows enough time for test items to respond to the test intensity and maintain an efficient time window from a test laboratory productivity perspective. To maintain that overall test duration of three hours (180 minutes), it is recommended that the proposed truck profile spectral shapes are used at the proposed test intensities (levels) for a total amount of time as follows:

- **Low Level:** 120 minutes
- **Medium Level:** 45 minutes
- **High Level:** 15 minutes

Distribution Cycles 9, 10, 12, and 13 require simulating more than one type of vehicle vibration and only recommend a 60-minute Truck test. In other cases, it may be necessary to rotate the test item so it experiences the vibration in different orientations. To accommodate all the different manners in which the Truck vibration will be utilized, the proposed Low, Medium, and High test profiles should be performed in 60 minute sequences as detailed below in Table 1. For a 60-minute Truck test, only one sequence would be performed. For a 180-minute Truck test, three sequences would be performed back-to-back.

Table 1- Recommended ASTM D4169 Truck Profile Sequence

	Test Sequence	Proposed Grms	Proposed Test Time	COMBINED SUGGESTED PROFILE
Loop	Low	0.40	40 minutes	<p>The graph displays three Power Spectral Density (PSD) profiles for different test levels: Low (0.40 grms), Medium (0.54 grms), and High (0.70 grms). The x-axis represents Frequency in Hz on a logarithmic scale from 1 to 1000. The y-axis represents PSD in g²/Hz on a logarithmic scale from 1.00E-06 to 1.00E-01. All profiles show a similar shape with peaks around 2 Hz and 20 Hz, and a sharp drop-off after 100 Hz. The High level profile is the highest, followed by Medium, and then Low.</p>
	Medium	0.54	15 minutes	
	High	0.70	5 minutes	
Total Sequence Time:			60 minutes	
Sequence repeated three times				

The proposed changes described above are the recommended test levels and test durations. If more detailed information is available on the truck vibration environment, then the procedure can be modified to use such information.

ASTM D4169 Truck Profile Update Rationale

Revision Date: September 22, 2016

Truck Profile Test Procedures:

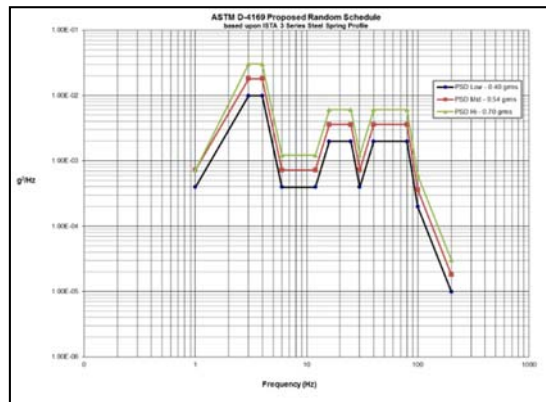
It is recommended to use a combination of all three Test Levels (low, medium and high) for a better simulation of actual Truck vibration environments. The Truck test should be performed in a 1-hour (60-minute) sequence. The recommended test durations for the random vibration truck profile are:

- Low Level for 40 minutes.
- Medium Level for 15 minutes.
- High Level for 5 minutes.

The Truck Profile PSD breakpoints are listed in Table 2 below. These breakpoints can be entered and saved into random vibration test control systems.

Table 2 – New Truck Profile PSD Breakpoints

Power Spectral Density Level G ² /Hz			
Frequency	High Level	Medium Level	Low Level
1	0.00072	0.00072	0.0004
3	0.030	0.018	0.010
4	0.030	0.018	0.010
6	0.0012	0.00072	0.00040
12	0.0012	0.00072	0.00040
16	0.0060	0.0036	0.0020
25	0.0060	0.0036	0.0020
30	0.0012	0.00072	0.00040
40	0.0060	0.0036	0.0020
80	0.0060	0.0036	0.0020
100	0.00060	0.00036	0.00020
200	0.000030	0.000018	0.000010
Overall G_{rms}	0.70	0.54	0.40



Test Scenarios:

The following three paragraphs are provided to better understand how to incorporate the 2016 truck profile as part of the random vibration test for section 12.4 of D4169 in the various distribution cycles.

1-hour (60 minute) test duration - single shipping orientation:

For Distribution Cycles 9 and 10, a 1-hour (60-minute) test using the Truck Profile followed by a 2-hour (120-minute) test using the Rail Profile is recommended. Typically, the vibration tests for DC 9 and 10 are performed in only one shipping orientation. The 1-hour Truck vibration test should be performed per the recommended sequence.

Test duration greater than 1-hour (60 minutes) – single shipping orientation:

The Truck Profile test is recommended for Distribution Cycles 1, 3, 4, 5 and 6. For test durations longer than 1-hour (60-minute), the 1-hour test sequence should be repeated (Example, for a 3-hour test, repeat the 1-hour sequence three times).

ASTM D4169 Truck Profile Update Rationale

Revision Date: September 22, 2016

1-hour (60-minute) and 2-hour (120-minute) test durations - three different shipping orientations:

A 1-hour (60-minute) Truck vibration test followed by a 2-hour (120-minute) Air vibration test is recommended for Distribution Cycles 12 and 13. It is common to orient the test item in three axes (bottom, side and adjacent side) during the 1-hour Truck and the 2-hour Air tests. Therefore, it is necessary to perform a shorter 20-minute test sequence for the truck profile and a 40-minute test for the air profile for each orientation. Table #3 below outlines the recommended sequence of orientations and test durations for the Distribution Cycles 12 and 13:

Table 3: Distribution Cycles 12 & 13 Sequence

Step #	1-Hour Truck Sequence (Three, 20-min test sequences)	Step #	Followed by: 2-Hour Air Sequence (Three, 40-min tests)
1	Orientation #1: Bottom <ul style="list-style-type: none"> • Low Level for 13-minute, 20 seconds. • Medium Level for 5-minutes. • High Level for 1-minute, 40 seconds. 	4	Orientation #4: Bottom <ul style="list-style-type: none"> • 40-minute Air profile
2	Orientation #2: Side <ul style="list-style-type: none"> • Low Level for 13-minute, 20 seconds. • Medium Level for 5-minutes. • High Level for 1-minute, 40 seconds. 	5	Orientation #5: Side <ul style="list-style-type: none"> • 40-minute air profile
3	Orientation #3: Adjacent Side <ul style="list-style-type: none"> • Low Level for 13-minute, 20 seconds. • Medium Level for 5-minutes. • High Level for 1-minute, 40 seconds. 	6	Orientation #6: Adjacent Side <ul style="list-style-type: none"> • 40-minute air profile.

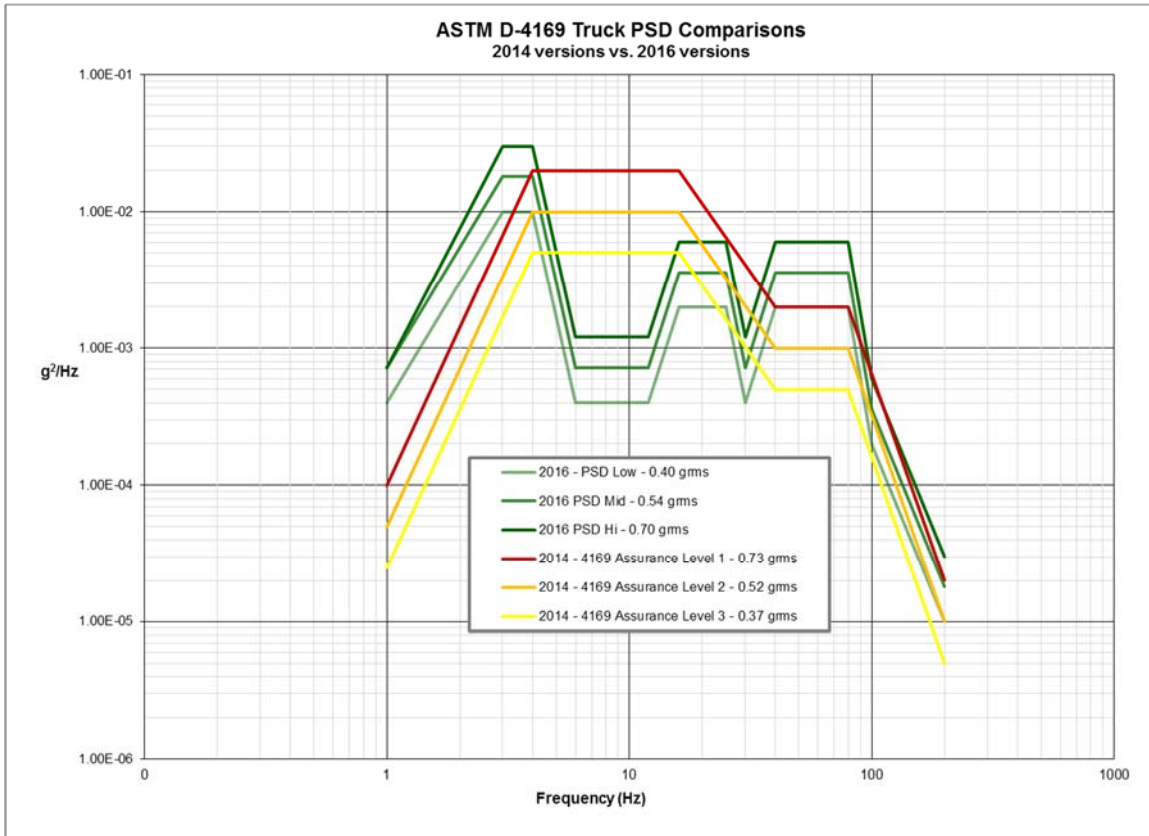
ASTM D4169 Truck Profile Update Rationale

Revision Date: September 22, 2016

PSD Comparison Plots

The following three PSD overlays provide visual comparisons between the new 2016 Truck profiles and the 2014 Truck, 2016 Rail (unchanged from 2014) and 2016 Air (unchanged from 2014) profiles respectively. To better understand how to compare overall severity of a PSD plot, refer to page 11 of this document.

2014 Truck versus 2016 Truck



PSD Breakpoints - Frequency (Hz) versus PSD (G^2/Hz)

ASTM D4169-14 Truck Profile Breakpoints

Frequency, Hz	I	II	III
1	0.0001	0.00005	0.000025
4	0.02	0.01	0.005
16	0.02	0.01	0.005
40	0.002	0.001	0.0005
80	0.002	0.001	0.0005
200	0.00002	0.00001	0.000005
Overall, g rms	0.73	0.52	0.37

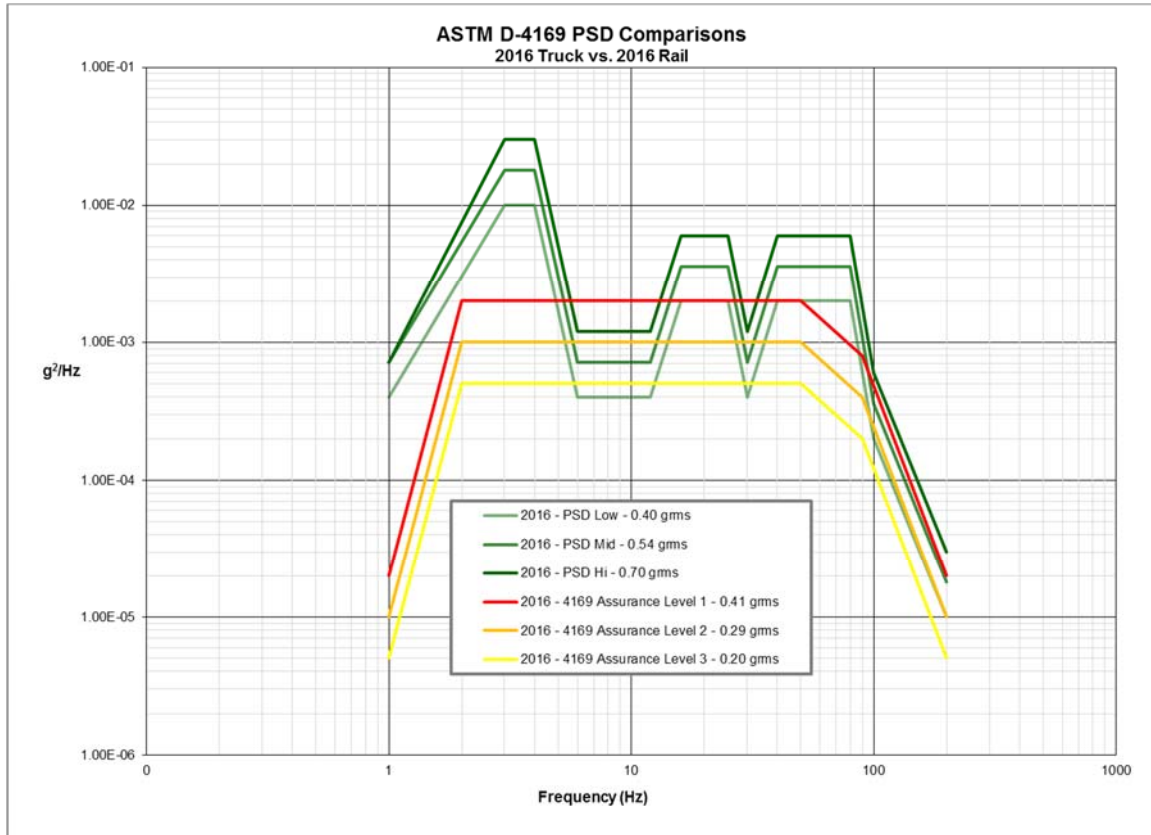
ASTM D4169-16 Truck Profile Breakpoints

Frequency, Hz	Low	Mid	High
1	0.00040	0.00072	0.00072
3	0.01000	0.01800	0.03000
4	0.01000	0.01800	0.03000
6	0.00040	0.00072	0.00120
12	0.00040	0.00072	0.00120
16	0.00200	0.00360	0.00600
25	0.00200	0.00360	0.00600
30	0.00040	0.00072	0.00120
40	0.00200	0.00360	0.00600
80	0.00200	0.00360	0.00600
100	0.00020	0.00036	0.00060
200	0.00001	0.00002	0.00003
Overall, g rms	0.40	0.54	0.70

ASTM D4169 Truck Profile Update Rationale

Revision Date: September 22, 2016

2016 Truck versus 2016 Rail



PSD Breakpoints - Frequency (Hz) versus PSD (G²/Hz)

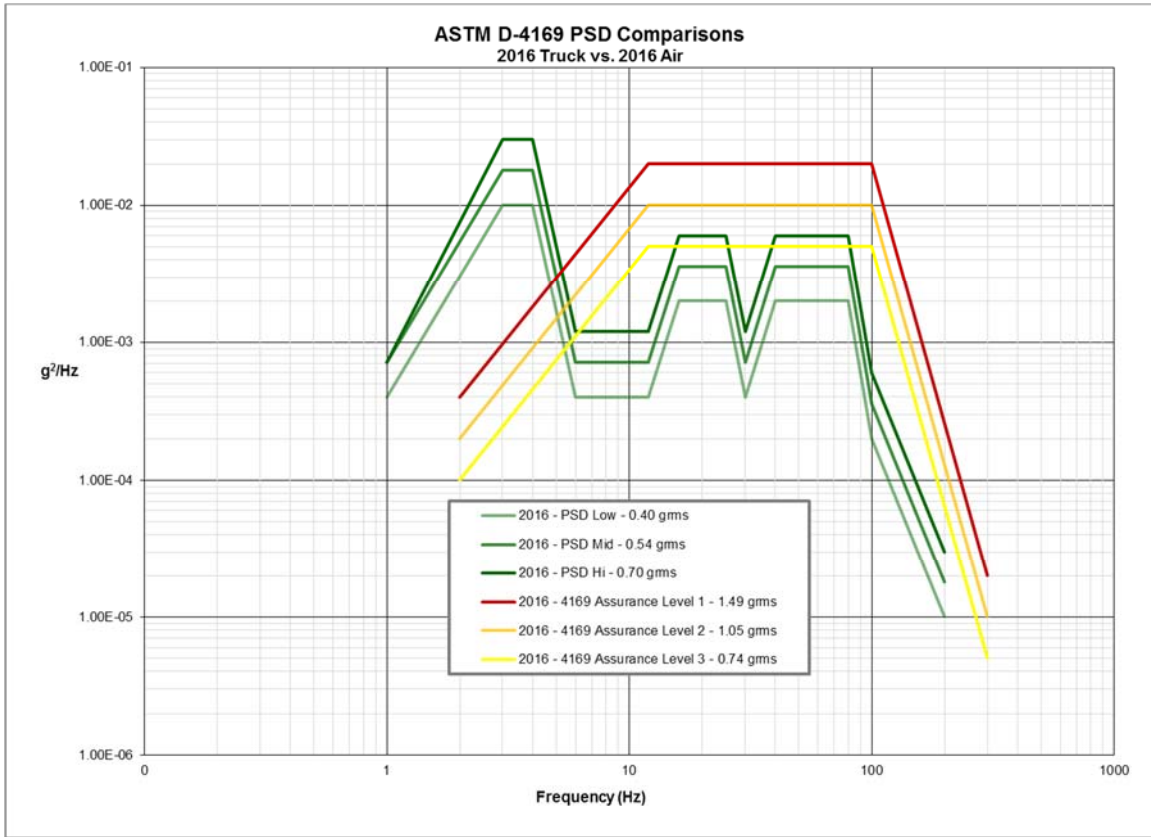
ASTM D4169-16 Rail Profile Breakpoints			
Frequency, Hz	I	II	III
1	0.00002	0.00001	0.000005
2	0.002	0.001	0.0005
50	0.002	0.001	0.0005
90	0.0008	0.0004	0.0002
200	0.00002	0.00001	0.000005
Overall, g rms	0.41	0.29	0.20

ASTM D4169-16 Truck Profile Breakpoints			
Frequency, Hz	Low	Mid	High
1	0.00040	0.00072	0.00072
3	0.01000	0.01800	0.03000
4	0.01000	0.01800	0.03000
6	0.00040	0.00072	0.00120
12	0.00040	0.00072	0.00120
16	0.00200	0.00360	0.00600
25	0.00200	0.00360	0.00600
30	0.00040	0.00072	0.00120
40	0.00200	0.00360	0.00600
80	0.00200	0.00360	0.00600
100	0.00020	0.00036	0.00060
200	0.00001	0.00002	0.00003
Overall, g rms	0.40	0.54	0.70

ASTM D4169 Truck Profile Update Rationale

Revision Date: September 22, 2016

2016 Truck versus 2016 Air



PSD Breakpoints - Frequency (Hz) versus PSD (G^2/Hz)

ASTM D4169 Air Profile Breakpoints			
Frequency, Hz	I	II	III
2	0.0004	0.0002	0.0001
12	0.02	0.01	0.005
100	0.02	0.01	0.005
300	0.00002	0.00001	0.000005
Overall, g rms	1.49	1.05	0.74

ASTM D4169-16 Truck Profile Breakpoints			
Frequency, Hz	Low	Mid	High
1	0.00040	0.00072	0.00072
3	0.01000	0.01800	0.03000
4	0.01000	0.01800	0.03000
6	0.00040	0.00072	0.00120
12	0.00040	0.00072	0.00120
16	0.00200	0.00360	0.00600
25	0.00200	0.00360	0.00600
30	0.00040	0.00072	0.00120
40	0.00200	0.00360	0.00600
80	0.00200	0.00360	0.00600
100	0.00020	0.00036	0.00060
200	0.00001	0.00002	0.00003
Overall, g rms	0.40	0.54	0.70

ASTM D4169 Truck Profile Update Rationale

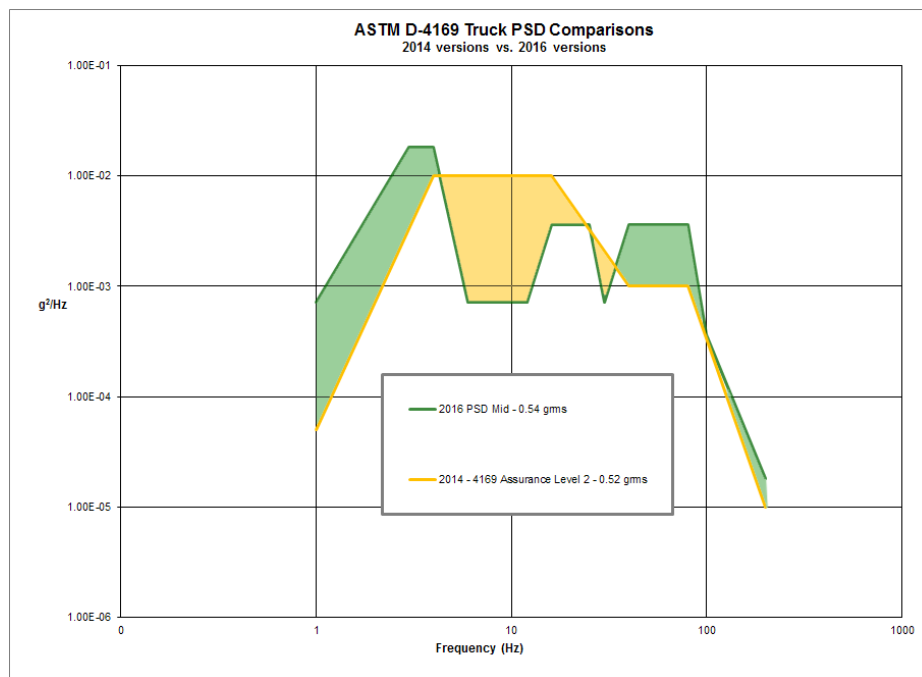
Revision Date: September 22, 2016

Key Considerations when Comparing PSD Intensities

Before comparing one PSD plot/curve to another, it's important to understand the key characteristics that define a PSD plot itself. PSD plots have a vertical axis of g^2/Hz and a horizontal axis of frequency in Hz. In simple terms, g^2/Hz describes the intensity of vibration at a given frequency. Random vibration PSD profiles are created by plotting various sets of g^2/Hz versus frequency breakpoints across a given frequency bandwidth. For cargo transport simulation, that bandwidth is usually defined between 1 and 200 Hz. Computing the area underneath the complete PSD curve, within that frequency bandwidth results in the overall Grms (intensity) of the random vibration PSD profile.

In Figure 10 below, both PSD curves have nearly the exact same Grms level (0.54 versus 0.52). However, we cannot use that value alone to presume the two PSDs have equivalent severities. One also needs to account for where the g^2/Hz intensity/energy is experienced in the frequency domain. For example, the green 2016 Truck PSD has more intensity (area) in the 1-5 Hz frequency bandwidth as compared to the yellow 2014 Truck Assurance Level II PSD (illustrated in shaded green area). Conversely, the 2014 Truck Assurance Level II profile has noticeably more intensity in the 6-25 Hz bandwidth (illustrated in yellow shaded area). Which PSD plot is more severe? The answer is that it depends upon the packaged product that would be tested using those profiles. At what frequency(s) do those products respond, or have inherent resonances? If they're sensitive to 3 Hz input, then the 2016 Truck profile may be considered more severe. Conversely, if the products respond to 10 Hz. input, then the 2014 profile would be considered more severe.

Figure 10 – Comparison of 2016 Truck Mid to 2014 Truck Assurance Level II



For this documents' purpose, the shape of a PSD plot defines the mode of transportation. The green 2016 Truck profile above is proposed to be more representative of the actual shape and corresponding intensity of over-the-road truck transport as compared to the 2014 Truck profiles. Considering that, it's important to expose packaged products to vibration intensity as it will be experienced in actual transport. This will reduce the likelihood of false negatives and/or positives associated with possible over or under testing in frequency bandwidths as described in the paragraph above.

ASTM D4169 Truck Profile Update Rationale

Revision Date: September 22, 2016

References

- [1] ASTM Standard D4169 (2014): Standard Practice for Performance Testing of Shipping Containers and Systems. ASTM International, West Conshohocken, PA.
- [2] An Assessment Of The Common Carrier Shipping Environment (1979), General Technical Report FPL 22, Forest Products Laboratory, US Department of Agriculture, Madison, WI.
- [3] Fundamentals of Packaging Technology (5th edition), 2014, IoPP, page 536
- [4] ASTM Standard D7386, 2008: Performance Testing of Packages for Single Parcel Delivery Systems. ASTM International, West Conshohocken, PA.
- [5] Vibration Testing Equivalence, How Many Hours Of Testing Equals How Many Miles Of Transport?, 2000, William Kipp, Lansmont Corporation, Monterey, CA
- [6] ISTA Procedures 3A (2008), 3B (2013), 3E (2009), 3F (2008), 3H (2011), International Safe Transit Association, East Lansing, MI.

Document Revision History

REV #	DATE	REV DESCRIPTION	AUTHOR	NOTES
0	11/5/15	Final Version of Rationale	D4169 Task Group	Submitted with ballot
1	9/22/16	Procedure Guidance <ul style="list-style-type: none">• Explained test orientation and sequence• Added PSD overlays and comparison guidelines• Added clarification of random vibration	D4169 Task Group	