# VIBRATION TESTING EQUIVALENCE

## HOW MANY HOURS OF TESTING EQUALS HOW MANY MILES OF TRANSPORT?

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William I. Kipp, International Safe Transit Association

## ABSTRACT

How many hours of vibration testing equals how many miles (or kilometers) of transport? A simple question, but unfortunately the answer is neither simple nor straightforward. This paper examines the factors involved in attempting to construct such an equivalence, explains the methodology behind an accepted and proven approach, and discusses the issue of accelerated (time-compressed) vibration simulation in detail.

## TESTS AND TRANSPORT

In order to begin adequately addressing the question of vibration testing equivalence, we need to be specific about the *types* of tests and the *types* and *conditions* of transport.

### Vibration Tests

There are three categories of commonly-used tests in the transport packaging field. First is the "fixed-displacement" test, also known as a repetitive shock or "bounce" test, in accordance with ASTM D999 Method A1 or A2[1] or similar. In this test, the specimen is placed on the table of a machine which moves with a constant one inch (25 mm) displacement, either linearly or in a circular motion. The test is usually conducted at a frequency (typically around 4.5 Hz.) where the specimen just begins to intermittently leave the table surface, as evidenced by the ability to insert a thin shim under it. Technically this is not vibration at all; the motion causes a small shock or "bounce" each time the package re-contacts the table. This test is *not* a simulation of actual transport – although there may be "bouncing" of packages in transport vehicles, it is not at a constant frequency and amplitude.

The second category is a sinusoidal (sine) test, in accordance with ASTM D999 Methods B and C or similar. Here the vibration table moves in smooth sinusoidal motion, with independently variable and controllable frequency and acceleration. Sub-categories are sweep tests (slowly varying frequency) and dwell tests (constant amplitude, constant frequency). In some specifications, the entire vibration requirement is met by one or several sine sweeps. But as typically used for transport packaging, sweep tests are used to search for resonances (natural frequencies) in the product or product/package system, and then dwell tests are used to assess the potential for damage at each resonance. These tests are also *not* simulations of actual transport – real vehicles do not vibrate in smooth sinusoidal motion.

The third vibration test category is random vibration, in accordance with ASTM D4728 or similar. The vibration table moves with a constantly-changing complex mixture of frequencies and amplitudes, generally similar to the way transport vehicles actually move. As a result, these tests can most nearly simulate actual field and transport conditions. Random vibration is typically described by power spectral density (PSD) plots – graphs of "average" acceleration intensity in the frequency domain (PSD as a function of frequency).[2] Different transport vehicles and conditions can be related to different PSD shapes and amplitudes.

Given these three very distinct test types, the question cannot begin simply "How many hours of testing…", but must ask how many hours of *what category* of testing, and often the specific test parameters as well.

### Types and Conditions of Transport

There are four basic modes of transport: road, rail, air, and ocean. And within each mode can be a number of variables – types and sub-types of vehicles; lading amount and configuration, transit conditions (highway, track, turbulence, sea state); etc. The result is an almost infinite number of possible combinations. It is unrealistic to think that a single or simple test could simulate all these different combinations. A stiffly-sprung truck traveling over rough roads may produce very high vibration levels yet only cover a few miles in a period of time. In the same amount of time, a jet airplane flying in smooth air may produce very low vibrations but travel a great distance. Any attempt to relate laboratory testing time to transport distance must take into account the variables and combinations.

So the question cannot end simply "…how many miles (kilometers) of transport?", but must specify the mode and conditions to be simulated.

## EQUIVALENCE BETWEEN LAB TESTS AND TRANSPORT

Once we are able to adequately specify the test to be conducted and the type of transport vibration to be simulated, then we can begin to address the issue of equivalence.

### The Repetitive Shock ("Bounce") Test

Historically, claims have been made about the equivalence of this test to actual transport. One still occasionally hears the old "one hour equals a thousand miles" nonsense, but there is no existing research which corroborates this in a general sense. There *can be* instances where repetitive shock tests are shown to produce the same damage or performance as that observed in actual transport. Certainly this has occurred for particular packaged-products, particular test times, and particular transport modes and distances. But a narrow correlation should not be construed as general equivalence. Users should be extremely wary of extending such specific results to generalized product/package and transport situations.

Current wisdom holds that the repetitive shock test does not "simulate environmental occurrences"[3] – i.e., cannot and should not be related to specific modes of transport or transport distances. This is not to say that the tests aren't useful, only that they're not intended as simulations and therefore cannot adequately represent actual transport.

### Sine Tests

Sine tests are also not environmental simulations, therefore it follows that they also cannot and should not be related to specific modes of transport or transport distances. The recommended dwell times of ASTM D4169 and ASTM D999 (5-15 minutes) are not generally intended to be related to actual transport, only to determine if an identified resonance is *critical* (could result in damage).

As with the repetitive shock test, a possible exception would be in the case of a specific product/package system and specific modes/conditions of transport where actual field performance is known. If "x" minutes of a sine dwell test of a specific packaged-product were shown to consistently create the same damage or performance as "y" miles of the specific transport, the two could be deemed equivalent in that case. But, as before, the user should be *very* cautious about extending this conclusion to any other product/package and transport situation.

### Random Vibration

Random vibration tests *are* intended as environmental simulations. This is the *only* commonly-used vibration test category in the transport packaging field that can be realistically related to actual transport. Assuming that the PSD profile and intensity used is a reasonable and accurate representation of the mode and condition of transport, then one hour of the test would equal one hour of the represented transport motion. Notice that this is not a "time vs. miles" relationship, it's "time vs. time". But since transport time is the actual "in motion" duration (not the total elapsed trip time), a relationship to distance could be established. If, for example, the vehicle moved constantly at 60 miles/hour and while doing so produced a PSD profile and intensity which is then used in the laboratory, 1 hour of the test would be equivalent to 60 miles.

## ACCELERATED VIBRATION TESTING

So a properly-configured laboratory random vibration test *can* be related to actual transport. But the idea of testing for an hour to simulate only 60 miles or so (as outlined above) isn't very appealing. This is where the concept of *accelerated* vibration testing comes in.

In a 1971 Shock & Vibration monograph, Curtis, Tinling, and Abstein of the Hughes Aircraft Company postulated a methodology for the time-compression of vibration tests[4]. In 1993, Dennis Young (then ISTA's Technical Director) referenced that in his paper "Focused Simulation"[5], where he presented a formula for calculating the amount of acceleration increase corresponding to a test time decrease. Restated, the formula is

$$I_T = I_0 \sqrt{T_0 / T_T}$$

Where $I_T$ = the test intensity in Grms (the overall intensity of the PSD profile)

$I_0$ = the original intensity (overall Grms of the original profile)

$T_0$ = time duration of the original profile

$T_T$ = the test time

A time-compression ratio of not greater than 5:1 is recommended to preserve validity. Based on the $T_0$ / $T_T$ ratio chosen, a new test intensity is calculated from the formula. The *shape* of the profile remains unchanged; it simply gets translated *up* on the PSD plot to increase its intensity.

So in our “1 hour = 60 miles” example above, if we multiplied the test intensity (overall Grms) by a factor of $\sqrt{5}$, we could accelerate the test (compress the time) by a factor of 5, making it “1 hour = 300 miles”.

## ASTM D4169 TRUCK, ASSURANCE LEVEL II

The ASTM D4169 Truck, Assurance Level II random profile may be the most widely used general simulation vibration test in the world. It has been on the books for many years, has been used by hundreds of organizations to run tens of thousands of tests, and has been instrumental in solving or avoiding countless transport problems. It’s a bit outdated now and there are more up-to-date spectra available[3], but nonetheless it works adequately in many cases. It has an overall intensity of 0.52 Grms, and is specified to be run for a total of 180 minutes (3 hours). Can it be equated to some number of miles with a rationale that makes sense and explains its effectiveness? ASTM does not mention any sort of equivalence, and what follows is *strictly the author’s experience and opinion*. But it seems to have reasonable merit, based on two key pieces of information:

1. In the last 6 years, we have participated in and been aware of the data from a considerable number of actual over-the-road truck vibration measurements. Of course there are variances in both the profile shapes and intensities, but for trailers with leaf/coil spring suspensions, the overall Grms usually falls in the range of 0.2 to 0.3 Grms, and seems to “average” around 0.25 Grms.

2. At ISTA Con 96, the keynote speaker was Donald Bowman of the American Trucking Associations.[6] During his address, he mentioned that the “average” length of long-haul truck transport in the U.S. was 750 miles. He didn’t mention an “average” speed, but if it was 60 miles/hour the “average” trip length would be 12.5 hours.

If we take this information into the “accelerated vibration testing” formula from the section above, using 0.25 Grms for $I_0$, 12.5 hours for $T_0$, and 3 hours for $T_T$ (from D4169), we get

$$I_T = 0.25\sqrt{12.5\ /\ 3} \qquad \text{or} \quad I_T = 0.51 \text{ Grms.}$$

Almost exactly the Grms of ASTM D4169 Truck, Assurance Level II! This could lead to the conclusion that the test simulates an “average” truck trip of 12.5 hours, or about 750 miles. While this is certainly based on a number of arguable assumptions, the numbers seem reasonable and the method of arriving at them seems sound.

Some caveats: First, if this is valid at all, it likely only applies well for U.S., Western Europe, and similar highways and trucks. We know that in many regions of the world the roads and vehicles can be significantly different, which could greatly affect any equivalence. Second, it focuses only on the Grms levels, and ignores the spectra shapes, which can have a great effect on test results. The spectrum in D4169 needs updating, and more realistic spectra are available[5].

We feel comfortable in believing that ASTM D4169 Truck, Assurance Level II is a reasonable simulation of a 750 mile leaf spring suspension truck trip over U.S.-type roads. The use of a more modern spectra would probably improve the simulation. At this point we have no similar supporting rationale, however, to form opinions about the other D4169 profiles or levels.

## HOW TO ACHIEVE VIBRATION TESTING EQUIVALENCE

The above discussion illustrated a “reverse” method of calculation: we started with a test, and calculated its equivalence to a transport distance. Generally one wants to create, from estimated or known transport conditions and distance, a realistic laboratory test. In this case, the steps would be as follows:

1. Select or determine PSD profile(s) and intensities which are accurate and reasonable representations of the mode(s) and condition(s) of transport to be simulated. This is not a trivial matter. Industry-standard recommendations usually represent accelerated tests, but don’t give the acceleration factors. Even when working with baseline data, they should be closely examined regarding their origins and applicabilities to any given testing/simulation situation. Often the best approach is to measure (suitable transport environment measuring recorders are available[15]) a number of shipments that are directly applicable to your particular situation, then compile that data into customized PSD profiles. Also, be aware that shipments may include different road conditions or other parameters; if so, the PSDs and tests should change, to maintain the proper relationship. It’s obvious that, for maximum accuracy and equivalence, the overall test must correspond to actual field conditions. If this correspondence is degraded, so will be the equivalence.

2. Estimate or determine the time of the trip (or the times of the trip segments/-conditions) to be simulated. If actual measurements have been made, this information can come directly from the data, as the total “in-motion” times. Estimate or equate these times to distances.
3. Use the “accelerated vibration testing formula” to compress the time (and distance), and calculate the increased test intensity. A time compression of not greater than 5:1 is recommended. If multiple trip segments/conditions with different parameters are to be simulated, a separate test must be configured for each.
4. The resulting test(s), at the increased test intensities and the compressed times, will be equivalent to the distances of step 2.

Example: Assume we had a PSD profile, with an overall Grms of 0.15, which was an accurate representation of a segment of a particular trip. We’d like to simulate 5 hours of that condition (which we feel would represent a distance of 250 miles) in the laboratory. Using the maximum recommended time compression of 5:1, $\sqrt{T_0 / T_T} = \sqrt{5/1} = 2.24$. Multiplying 0.15 Grms by 2.24 gives a test intensity (using the same profile shape) of 0.336 Grms. So one hour of this 0.336 Grms test would be equivalent to 250 miles of the given transport condition.

## THE BEST DEMONSTRATION OF EQUIVALENCE

This was mentioned previously, but warrants a further clear explanation: the best demonstration that a laboratory test or test series is equivalent to some transport condition is <u>*correlation of damage or performance*</u>. If a reasonable test consistently reproduces damage or results that are similar to actual field experience, it’s probably a good test – at least for those particular situations. Too many times we hear, “I don’t understand it – we passed all the lab tests, but we’re still having problems in the field”. Then the tests are wrong! The opposite can also happen, “We don’t have any damage in shipment, but we can’t pass the laboratory tests”. Then the tests are wrong!

The transport packaging engineers’ work is not done just because the product and package have been designed and the lab testing has been completed. Field performance data should be gathered and carefully studied for proper correlation, and adjustments should be made if necessary.

## SUMMARY, CONCLUSION

How many hours equals how many miles? The short answer is that “bounce” tests and sine sweep/dwell tests, although widely used and useful for other purposes, are not simulations of the transport environment; therefore they cannot be thought of as “equivalent” to actual shipment times or distances. Only a truly “representative” random vibration test, properly configured, can be considered in any way “equivalent”. An established methodology for accelerating a random vibration test may be used to compress the test time by properly increasing the test intensity.

## REFERENCES


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