

VIBRATION DATA COLLECTION: A ROAD WORTH TRAVELING?

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Introduction

There's been a great deal of interest and activity in the last decade or so focused on measurement of the distribution vibration environment. This activity has largely been made possible by the availability of portable digital data instruments which can accurately record field information and present it in useful formats. A number of significant studies have been undertaken and reported, covering major modes of transport and wide geographical areas (see below).

All this activity might lead to the impression that modern random vibration testing in the packaging laboratory must necessarily begin with the recording of one's own environment. But of course just the opposite is true, for as more is known about transport vibrations, less remains to be known. As a matter of fact, the nature of the environment, the mechanism by which random vibration produces damage, and the way laboratory vibration tests are run, all make it increasingly efficient and effective to leverage from existing data. Simply select and load an appropriate spectrum into your vibration system's controller, and begin immediately achieving the cost control, time-to-market, and other benefits that random vibration testing (particularly compared with other types of vibration testing) can deliver.

Field Vibration Data Collection

Measuring the transport vibration environment typically involves not only capital outlay but considerable effort. Appropriate recording instruments often cost US\$5,000-10,000 or more, and multiple units are typically required for even moderately-sized programs. The instruments are furnished with specialized software which must be learned. The modes and routes to be studied must be carefully selected, and the variables (vehicle type and configuration, loads,

speeds, etc.) must be controlled and documented. For a degree of statistical confidence, several trips of each type and under the same conditions should be measured.

The instruments must be deployed and retrieved. To be most effective, they should be attached directly to the load floor structure of the vehicle to be measured. This is because the usual goal is to have the table of a laboratory vibration system simulate the motion of the vehicle load floor, so direct measurement at the floor (and therefore direct attachment) is best. But this means hands-on involvement with the carrier – coordination with the vehicle, actual mounting of the instrument, retrieval at the destination – for accurate results, one cannot simply put a recorder in a package and ship it in the normal manner. And finally, the collected data must be uploaded, analyzed, and then translated into a meaningful laboratory test profile. This requires not only proficiency with the instrument's software, but some knowledge of the principles of random vibration, testing equipment, and laboratory operations.

Given the above, it's little wonder that the largest studies of the transport vibration environment have been undertaken by academic institutions (as student thesis projects, often with borrowed recorders), large carrier organizations with a direct interest, consortia of various kinds, and governments. Many private companies have conducted studies also, but generally much smaller in scope, and with less general applicability. Taken in the aggregate, however, these can also be significant.

Measurement Studies

Nearly every major transport packaging educational conference in the last decade has included at least one report on a study of the transportation/distribution environment. "Dimensions", ISTA's annual forum^{1, 2}, has included no less than a dozen in the last five years! Significant studies have been published in various ways by Michigan State University³ and other educational institutions⁴, the Association of American Railroads⁵, United Parcel Service⁶, the "China

Project” consortium⁷, and the European Commission for Standards⁸. Many private organizations and companies have conducted smaller studies, and some of these are also available. Geographic areas covered include the U.S., Eastern and Western Europe, China, other areas in Asia, some regions of Central and South America, and others. Data from all major modes of transportation have been reported: road, rail, air, and ocean.

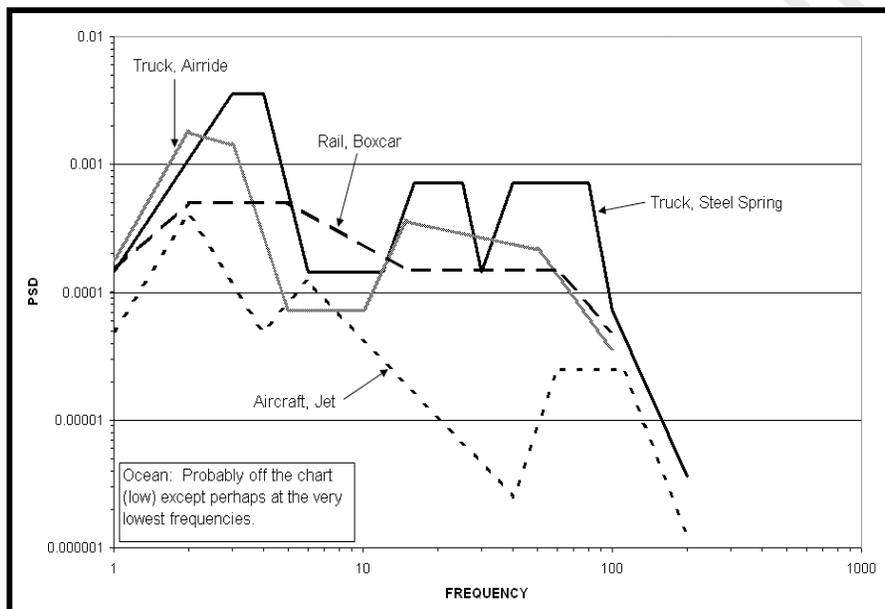
The results from a number of these studies have made their way directly into industry-standard test methods⁹ and are readily available. Others may take more effort to locate, but can be found without too much difficulty¹⁰. ISTA's¹ web-based testing protocol Project 4AB (currently under development) will include vibration data from a broad range of vehicle types and geographical locations.¹¹

An Emerging Picture of the Transport Vibration Environment

As more and more information on the transport vibration environment is available, definite similarities, trends, and findings have begun to emerge. For example:

- Steel-spring truck-trailer vibration in developed regions consistently shows suspension, tire, and structural resonances in reasonably well-defined frequency bands, and overall intensities in the 0.20 to 0.35 Grms range. This has been shown many times over; we may be reaching the point where it is no longer necessary to collect this type of data.
- Airride truck trailers exhibit lower-frequency suspension resonances and roughly 50% lower overall intensities compared to steel-spring vehicles of the same type.
- Data from similar road vehicles in developing regions shows similar characteristics, but at higher overall intensities. Of course, there are vehicle types which are unique and different in various countries and regions.
- Rail vibration intensities are much like those from airride trucks, above. Of course, rail transport also includes horizontal impacts from car coupling operations and lateral sway, but these are not part of vibration simulations.

- Air transport vibrations are quite low. This goes against the “conventional wisdom” of 25 years ago (much of which continues today) which held that air vibrations were both high-level and wide-frequency, but the contrary has been borne out by recent studies.
- Ocean transport vibration intensities are extremely low. Studies showing this are limited, but the fact that there are no ocean vibration spectra in the popular international test specifications¹², helps to confirm that ocean vibration is not a significant issue. This is not to say that ocean shipment does not present damage hazards to cargo, only that ocean vibration is not a major factor.



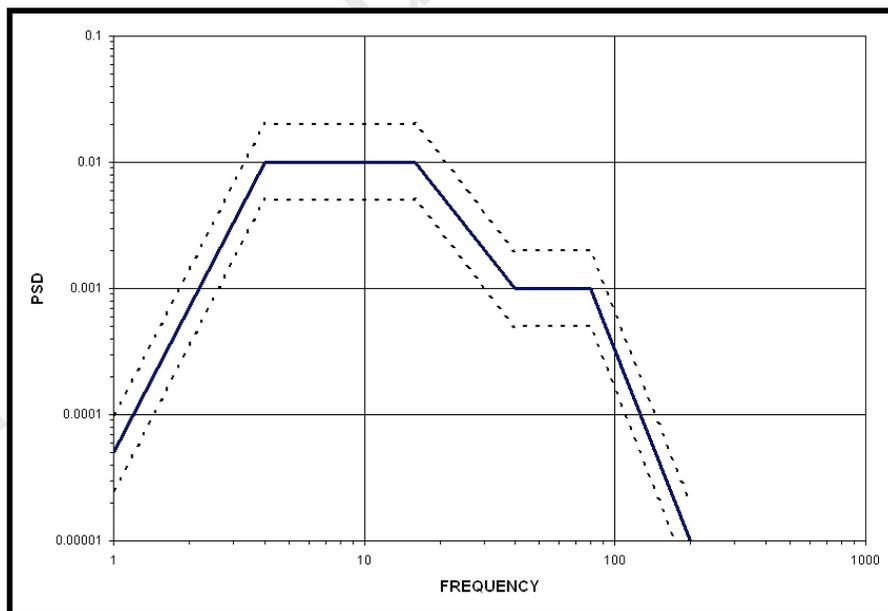
Generalized comparison of the indicated transportation modes, representative of current field data. See the following section for an explanation of the “PSD vs. Frequency” chart format

So in summary, it appears that truck transport often presents the greatest vibration damage hazard. The spectra generally envelope and have greater overall intensities than rail, air, or ocean transport. And since truck transport typically serves as a link to the other modes, it could be argued that an effective laboratory random vibration program might be run with only truck spectra. If this were the case, there would be little or no need for field vibration data collection, since truck vibrations have been amply measured, reported, and included in popular test specifications.

Laboratory Random Vibration Testing

Random vibration, by its very nature, cannot be precisely defined. After all, it's *random*! The methods of presenting and specifying random vibration give us a clue to this fundamental and rather low-level precision.

The graphical presentation of a random profile is by means of a power spectral density (PSD) plot. The PSD plot shows Grms intensity (a type of average) vs. frequency, both on logarithmic (powers of 10) axes as shown below. These log-log scales are used to display a wide range of values on a reasonably-sized chart, but in the process tend to make large differences look small. The figure shows an industry-standard PSD plot¹³, with the nominal required profile drawn as a solid line and the permissible tolerance limits drawn as dotted lines. This type of specification looks reasonable on a log-log plot (and *is* reasonable in the context of random vibration), but upon closer inspection it's obvious that the tolerance bands are a factor of two (2) different in intensity from the nominal profile. That's +100% and -50%! Which means that this specification could be met by random vibration motion which is really quite a bit different.



An industry-standard random vibration PSD plot, used to simulate truck transport. The solid line is the nominal profile, the dotted lines are the allowable test deviation from nominal.

A reasonable conclusion might be that damage from random vibration is not so strongly related to PSD shape. *Overall intensity* (total average Grms) is perhaps more important – the test referenced above requires that overall Grms be within 15% of nominal. If true, this means that a laboratory random vibration test could likely be a good simulation if the shape were only reasonably close to what occurs in the real world and the Grms level were proper.

An Effective, Pragmatic Approach

Taking the above into account, a straightforward approach to transport vibration simulation in the lab could be based on the following:

- Recognize that any reasonable random vibration test is a better simulation than other available types of laboratory vibration (sinusoidal, repetitive shock, etc.)
- Since typically trucks are involved to some extent in all modes of transport, and since truck vibration is usually the most damaging, base the majority of lab tests on currently-available truck spectra.
- Be aware of, and have available, the latest transport vibration environment data. Fortunately, truck transport has been studied extensively, and truck data of all kinds is the most readily available
- Use a spectrum representative of the type of truck and geographical region of interest, if possible¹⁴.
- If the above is not possible, choose the closest available spectrum (in terms of vehicle and region). Recognizing that overall Grms is more important than shape, increase or decrease the Grms appropriate to the relationship between the origin of the data and what is desired to be simulated¹⁵. Intensity can also be adjusted to provide more or less “safety factor”, or degree of assurance.
- Be aware of the (probably rare) atypical situations where the above approach may not be appropriate.

Is There a Need to Continue Measuring?

Measurement of the transportation vibration environment continues. Although some aspects are – or are becoming – quite well defined (the acknow-

ledged low levels of ocean vibration, standard truck transport in developed regions, etc.) there is still an ongoing need to record and quantify. Vibration spectra from more geographical areas outside the U.S., and data from more varieties of mode and vehicle types would be particularly helpful. But no organization should delay adopting laboratory random vibration testing simply because it cannot conduct its own transport environment studies. There is more than enough available current data, and beyond that a sound rationale to extrapolate from it, to support meaningful and effective laboratory simulations. And those simulations can lead directly to reduced costs, reduced damage, avoidance of future problems, faster product and package development, and increased customer satisfaction.

Footnotes and References

1. International Safe Transit Association, www.ista.org.
2. Dimensions, the International Forum on Transport Packaging, www.dimensions-info.com.
3. Michigan State University School of Packaging, Consortium for Distribution Packaging Research, <http://packaging.msu.edu>.
4. Among them Clemson University Department of Packaging Science, <http://virtual.clemson.edu/groups/pkgsci/home.php>, Rochester Institute of Technology Packaging Science, <http://www.rit.edu/~703www>, Victoria University (Australia) <http://www.vu.edu.au>, San Jose State University Packaging Program, <http://www.engr.sjsu.edu/ise/pkg/>, and others.
5. Association of American Railroads, www.aar.org.
6. See “*Quantifying the Vibration Environment of a Small Parcel System*” by Young, Gordon, and Cook, Transpack 1997, and subsequent studies.
7. See “*The China Project: “An Assessment of the China Shipping and Handling Environments*”, Dimensions.04.
8. “*Source Reduction by European Testing Schedules*”, Braunmiller, EC contract SMT4-CT95-2005, project 2109.
9. Such as ISTA 3-Series Test Procedures, ASTM D4169 (ASTM International, Committee D10 on Packaging, www.astm.org), and ISO 13355 (International Organization for Standardization, Technical Committee TC122, www.iso.ch).
10. Through contact with the above organizations, attendance at their conferences as appropriate, and access to their publications and reports.

11. See a complete description of Project 4AB at www.ista.org/Testing/4AB.htm.
12. ISTA, ASTM D4169, ISO 4180.
13. This is taken from ASTM D4169 and ASTM D4728.
14. L.A.B. vibration controllers are preloaded with a variety of industry-standard and other spectra from which to choose.
15. It is a simple matter to increase or decrease the Grms of a given profile with an L.A.B. vibration controller.

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