MEASURING THE
DISTRIBUTION ENVIRONMENT

PREPARED BY:
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I. INTRODUCTION

To properly design a protective package system, the engineer requires three important pieces of information. These are:

1. **Quantification of the severity of the distribution environment** in terms of those inputs likely to cause damage to a product. Typically these are impacts and vibration.

2. Knowledge of the **fragility of the product** to be protected.

3. Information on the **performance characteristics of various cushion materials and systems** in terms of shock and vibration response.

The normal procedure used to obtain the information has been assembled into a concise set of easy-to-follow steps such as the 5-step method (1) originally published by MTS Corporation, the 6-step procedure (2) published by Lansmont Corporation, and similar documents. Most of these procedures were an outgrowth of studies conducted at Michigan State University during the late 1960’s (3). Basically these steps lead the engineer through a systematic approach for defining product fragility, defining cushion material performance, and conducting a laboratory test of the prototype package design.

A substantial history has been developed by companies that have used these procedures over the years in their package design processes. However, there does not appear to be overwhelming consensus that use of the method results in an optimum package design. In many cases, the method results in a grossly overpackaged product (4), and in other cases, unacceptable levels of damage have been recorded.

It is generally recognized that the use of the Damage Boundary method for product fragility assessment typified by ASTM D3332 (5) results in a conservative estimate of the fragility of a product. That is to say, a product whose fragility is determined to be 30 G’s, using this test procedure, may routinely survive a 45 or 50 G shock pulse in the distribution environment. The reason for this dilemma is primarily due to the use of a rectangular or trapezoidal shock pulse to determine the “critical acceleration” sensitivity of the product.
It has also been shown that the currently available cushion test procedures, typically ASTM D1596 (6), do not necessarily give the most accurate data for package design purposes. In general, these procedures result in an overly conservative estimate of the actual performance of cushion materials in systems.

Thus, two of the five or six steps in “the method” may result in an overly conservative package design. While this may explain some of the overpackaging which results from its use, it certainly does not explain the experience of companies that report higher than anticipated incidences of damage in shipment even after a well engineered package has been designed and tested. The answer to this seeming dilemma may lie in one of two possible areas:

1. The potentially **damaging effects of vibration** which until recently have not been widely considered in the package design process or in the testing of package systems. (7)

2. Information on the severity of the **distribution environment may not be as accurate** as we once thought it was.

This paper deals specifically with the last point; namely, an analysis of how drop height data and vehicle vibration data is obtained for packages in distribution and what significance that has for package design and testing in the future.

II. **BACKGROUND**

Much of the terminology used in the study of the distribution environment is fairly common to other areas of packaging design and product fragility assessment. A list of commonly used terms is contained in Appendix I.

Most currently available information on the drop height environment is well summarized in General Technical Report FPL-22 published by the Forest Products Laboratory at the University of Wisconsin in 1979. (8) This report is a summary of numerous other studies which attempt to define, among other things, the frequency and severity of drops or impacts based primarily on package weight. Typically the data is summarized as a package drop height vs. weight chart or frequency of occurrence vs. drop height for a given package weight. Typical forms of that data are shown in Figures 1 and 2.
The vast majority of this data has been collected using spring/mass type recording devices, typified by the Impact-O-graph. These recorders have been shown to be very frequency sensitive and generally lack the accuracy necessary for precise definition of the true drop height environment. (9)

In most cases, the data from a number of different trips is lumped together in order to produce a composite chart showing the drop height vs. package weight information. (8) Data on various types of transport vehicles have also been lumped
together, and it is difficult to determine where impacts have occurred as a function of the type of shipment or the time history within that shipment or the orientation of the package. It has been generally assumed that air freight represents a more severe drop height environment; that is, higher average drop height and larger number of impacts due to the larger number of manual handlings that occur. However, this is difficult to prove conclusively because most data is based on a lumped sum of impacts rather than on impacts per shipment. Thus the treatment of the data has a great deal to do with how we define the distribution environment. This area will be reviewed in more depth later in this paper.

III. WHY STUDY THE DISTRIBUTION ENVIRONMENT?

A protective package can be thought of conceptually as a device which provides a protective interface or filter between a fragile product and a potentially harmful environment. The optimum protective package consists of a product of known ruggedness and a package which together provide sufficient resistance to damage during distribution without overpackaging. The chart in Figure 3 graphically demonstrates this concept.

![Figure 3](Source: Lansmont Corporation)

The relationship between these areas has been expressed by equation

\[ \text{PDE} = \text{PR} + \text{C} \]

(Physical Distribution Environment = Product Ruggedness + Cushion)

(Source: R. M. Fiedler & Associates)
Thus the job of package design for fragile products amounts to defining and quantifying the variables in this simple equation.

It can be seen from the bar chart in Figure 3, however, that the very first piece of information necessary is an accurate quantification of the severity of the distribution environment. Without accurate knowledge of this environment, the remainder of the steps are of questionable value, and optimum package design is a hit or miss proposition.

Note that the environment must be quantified in terms of all potentially harmful inputs. These may include temperature and humidity extremes, atmospheric pressure changes, compression, mechanical shock, vibration, electro-static discharge, and others. Only the effects of shock and vibration are dealt with here. However, the designer must be aware of all likely hazards in the environment and quantify them in terms of their ability to cause damage.

It’s important to recognize that different means of distribution present different levels and modes of hazards for a packaged product. For example, it’s known that shipment via ocean freight subjects the product to long duration’s of low intensity vibration input and possibly high humidity extremes, but little else. (10) On the other hand, overnight delivery normally presents the highest level of damaging shock inputs due to the large number of handlings involved. A study by Westpak of the overnight delivery distribution environment of a large express delivery firm confirmed this. (11)

The severity of most distribution lies somewhere in between the above two examples. Common carrier shipment, while known to be highly variable, is viewed as less severe than the overnight distribution environment. Delivery to international destinations is also thought to be significantly different than domestic distribution. Other studies have shown that distribution within the United States itself can result in substantially different data depending on the origin and destination of the package, among other things. (11)

Thus it can be said that the distribution environment is highly variable in its nature and quantifying it is fraught with problems.
IV. HISTORY OF QUANTIFYING THE IMPACT OR DROP DISTRIBUTION ENVIRONMENT

Three primary methods have also been used to quantify impacts in the distribution environment. These are:

1. Literature review
2. Direct measurement
3. Observation

In all cases, defining this environment amounts to quantifying the drop height experienced by packages as a function of their weight.

Until recently, devices used to record the distribution environment have been suspect in their accuracy. Most of the available literature, especially FPL-22 (8) and related documents, relied on the Impact-O-graph or similar spring/mass recording systems. The system consists of a single- or multi-axis device that relies on gravity to push a mass in response to a shock input. The mass is connected to a scribe that will strike paper on a revolving drum resulting in a series of scribe marks that somehow are related to the drop height or other excitation of the device. (See Appendix II) Studies by the author have shown these devices to be almost totally inaccurate in their predictive ability. (9) This is particularly distressing because much of the available literature is based on the information from these devices.

An improvement was introduced in the market in the late 1970’s with the B & K Bump Recorder. This device utilized a triaxial accelerometer and measured the actual velocity change associated with an impact. The drop height was calculated from the integral of the acceleration vs. time pulse from the resultant vector of the impact. (See Appendix III)

While an improvement over the spring/mass recorder, the Bump Recorder nonetheless suffered from a number of serious faults. These included:

1. Accuracy of no better than perhaps ±20%
2. Limited recording life
3. Relatively large size and weight
4. The output was a printed paper tape and all data had to be manually collected and reduced.

5. Inability to distinguish impact orientation

6. A number of other problems were associated with the device, including its ability to stand up in the rough environments that it was designed to measure and its high cost.

In the late 1980’s true acceleration recording devices using solid state RAM became available and have been revised and redesigned in recent years to become truly accurate recording systems. These will be dealt with later on in this paper.

V. REVIEW OF EXISTING LITERATURE DESCRIBING THE IMPACT DISTRIBUTION ENVIRONMENT

As was stated earlier, the primary document used to define the distribution environment in literature search is the FPL-22 report published in 1979. (8)

It’s important to recognize that this report was basically a literature search itself, combing carefully some 53 separate papers describing various aspects of the distribution environment. In reviewing the literature cited in the FPL-22 document, it’s important to note that the dates on many of the items are in the 1960’s or earlier.

It can be deduced, although not stated, that much of the drop height data collected in these studies was based on Impact-O-Graphs or similar spring/mass recording devices. Since the accuracy of these devices has been called into serious question, the accuracy of these reports is similarly very questionable.

Of particular concern is the inability of spring/mass recorders to accurately judge the extreme drop heights known to occur on rare occasions during shipments. These high drop heights are known to be of higher frequency nature (shorter duration) and the spring/mass recording devices are also known to be frequency sensitive. (See Appendix II) Thus, it is presumed, and it was later shown, that these spring/mass recording devices inaccurately skewed the drop height data toward lower drop heights with longer durations (lower frequencies) which they were better able to measure. A study of the overnight delivery distribution environment concludes the following (11):
“Perhaps the most startling finding was the occurrence of extremely high drop heights recorded every one in eight trips on average. Extreme height was more than double the 99 percentile level in all cases. This would imply that product/package systems designed to withstand 99 out of 100 impacts will likely be damaged 12% of the time in this environment. This is indeed significant.

This data indicates that the traditional drop height vs. number of occurrences plot (Figure 2) may be misleading when packaging engineers attempt to define the overnight distribution environment. Instead of being satisfied with 99 percentile data or even 99.5%, it may be necessary to look at 99.7% of the total number of inputs in order to arrive at the design drop height.”

The inability to record extreme drop heights is only one of the problems associated with the current literature. A study done in the late 1980’s brings into serious question the accuracy of devices used since that time. (13) This includes currently available digital recording devices that were not properly set up to accurately record the data. Figure 4 gives a comparison of drop heights of various recording instruments during a laboratory test designed to calibrate the devices for use in a data recording system. The data clearly indicates that the accuracy of the information is highly dependent on the orientation of the impact surface and is largely skewed.

Conclusions of this study include the following:
1. Spring/mass recorders of the type used previously cannot accurately quantify package drop height.

2. Data previously collected with spring/mass recorders is suspect. This includes nearly all the data contained in FPL-22 and similar documents.

3. Accuracies of $\pm 30\%$ may be the norm for newer equipment. Note that this is the accuracy of the recorded data, not the absolute accuracy of the device.

4. More study of the package environment is essential.

5. Coordinated data collection and uniform data reduction will speed up the process of updating the literature.
VI. DESIGN OF AN EFFECTIVE SHOCK AND VIBRATION MONITORING SYSTEM

As was stated earlier, updated instruments utilizing current technology apparatus have become available recently than have been shown to be very effective and accurate at measuring a wide variety of inputs, including the drop height during distribution. (13) In order to utilize effectively the accuracy built into these devices, it is necessary to design a recording system, including the recorder itself, some means of placing it in a protective package, and the design of the package itself. Properly utilized, these techniques have been shown to be effective in helping characterize the distribution environment accurately. The following procedures were recommended by Mr. Mark Kerr of IBM Corporation in a study done in the early 1990’s. (14)

CHARACTERIZATION AND CALIBRATION
OF DROP HEIGHT MEASURING DEVICES

1. Package Design

   a. Choose the expected drop height range of most interest.
   b. Know the weight and size of the instrument and any fixtures necessary.
   c. Choose a cushion material that gives a flat acceleration projection level across the drop height of interest and desired acceleration level (less than 100 G’s). Note that “flat” equals a similar G level over a broad range of static stress.
   d. Design the cushion with a flat static stress range to give similar responses in all orientations.

2. Drop Test of the Package System

   a. Use multiple drops at each drop height of interest. A suggested range is 18 to 42 inches.
   b. A minimum of four drops per axis at each drop height is essential.
   c. Be sure to test both flat impacts, corners, and edges.
   d. Multiple package designs may be required to minimize the effect due to cushion and package deterioration.
   e. Record drop height and impact orientation.
3. **Analyze Drop Test Data**

   a. Use a default correlation factor and process recorded data to analyze the drop heights.
   
   b. Create a chart to calibrate the actual drop height using the correlation factor.

4. **Compare Data and Calculate New Correlation Factor**

   a. Compare actual drop heights to calculated drop heights.
   
   b. Calculate variance by orientation and drop height.
   
   c. Calculate new correlation factor to have a zero percentage average variance for all drop heights.

5. **Analyze Drop Test Data with New Correlation Factors**

   a. Using new correlation factors and drop height recorder software, process recorded test data. Create a new chart for the revised correlation factor.

**UNDER 100 POUNDS**

In most cases, the device will be used to measure drop heights for packages weighing less than 100 lbs. The most effective way to do this is to mount the recording device in a dummy package surrounded by a suitable cushion material. It’s important that the triaxial measurement system be maintained by using either internal accelerometers or externally mounted ones with careful attention paid to the orientation.

**OVER 100 POUNDS**

It is also convenient to use a recording device to measure the shock input to a large frame unit weighing more than 100 lbs. In this case, the unit should be rigidly attached to a frame member or some other rigid portion of the product. It’s important to remember that the device functions by measuring the acceleration vs. time pulse produced by an impact and determining the velocity change of that pulse. This is a direct measure of the energy content which is the best indication of drop height.
**IMPACTS OTHER THAN DROPS**

Dealing with impacts other than freefalls has always been a problem for recording systems. Certain devices utilize software techniques to determine if a zero G condition existed prior to a recorded impact. If this is the case, the velocity change measurement is made and a drop height assigned to the data. Otherwise, the event is described as an impact without assigning a drop height. Acceleration vs. time pulse are normally recorded regardless of the type of impact.

Sometimes the horizontal impacts can be equated to equivalent freefall drop by using a standard integration technique of the waveform. Thus a horizontal impact would be described as an equivalent of a freefall drop using the conservation of energy approach. Accuracy of this type of data has not been determined.

**VII. USING RECORDING DEVICES FOR MEASURING VIBRATION INPUT**

Measurement of vibration input of all types of vehicles used in transit is one of the areas of current interest in dynamic package development. Historical data was known to be collected on vehicles wherein the accelerometers or other sensing devices were rigidly attached to the vehicle itself. (12) Little heed was paid to the effective lading and other influences on the vibration environment actually experienced by packaged products.

Shock recording devices can be effectively used to measure vibration input utilizing a timed recording window wherein vibration input at timed intervals is recorded to the solid state RAM. Thus the information gained will represent the exact vibration response experienced by the package regardless of the vehicle in which it is traveling with the location on that vehicle. A much broader, and perhaps more accurate, characterization of the vibration environment is thus possible.

It should be remembered, however, that the information recorded is a response transmitted through (filtered by) a cushioned package in which the recorder is riding. Thus, it is necessary to use the data in a response mode in the laboratory when doing focused simulation testing. That is to say, the spectra generated by the recorder in a package system represents a response spectra (the transfer function), not the input used to program laboratory vibration test equipment.
This data can be used effectively by placing the same recording system on the vibration test machine and determining the required input necessary to achieve the same response within the package system as measured by the recording device.

It is important to remember that the data collected by the recording device has not only been filtered mechanically by the package system surrounding the recorder but also by the orientation in which it was collected and the effective lading nearby the recording package. Great care must be exercised in properly utilizing this data.

**Focused simulation** techniques have been used recently with solid state RAM data recording devices in order to measure vibration input from distribution vehicles. (15) These devices work by taking a snapshot of the data using pre-programmed software windows to measure vibration from vehicles.

This information is recorded directly to the solid state memory and then at a later date played back in order to develop a power spectral density (PSD) plot showing the acceleration density as a function of frequency for the vehicle being measured. This information is then used to program a random vibration test machine in a package testing laboratory. Typically the vibration machine is programmed at a 2 or 3 Sigma level higher than the recorded information from the distribution vehicle. This is done in order to condense the test cycle from many hours to perhaps one or two hours. Refer to Appendix IV for more details on this technique.

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**VIII. TEMPERATURE AND HUMIDITY DATA**

It should be recognized that most up-to-date solid state sensors will also record temperature and humidity data if programmed to do so. Remember that this data comes from within the package system which in many cases is an effective thermal barrier. As such, both temperature, and especially humidity, will be affected by the environment in which it was measured.

Thus the measurement of temperature is the temperature within a package, not the actual environment through which the package travels. Likewise, humidity data will be skewed by the fact that a “semi-enclosed” environment will change drastically in relative humidity as the temperature changes. It is possible for the dew point to be exceeded, for example, in a package system with a minor change in temperature, without the actual outside humidity changing at all. Again, care must be exercised in utilizing this recording technique.
IX. DATA ANALYSIS AND REDUCTION TECHNIQUES

It is important to remember that the statistical significance of a single trip is insignificant. It is necessary to plan statistically valid number of trips using the sampling techniques described in this paper.

Be certain to avoid repetitive trips through the same distribution environment and basing information on the recorded data. A commonly seen, and often disastrous technique, is to send the recording device from one plant to another within a certain company and to base the distribution environment on this data. Products leaving a company heading to a customer will not travel the same route and therefore not be subjected to that type of environment. It is therefore important that the recording technique involve measurement of the distribution environment through which actual products will travel from the manufacturer to the customer.

It’s also been noted that summing data from different recording devices will be enhanced if a common recording format is utilized for collecting the data and analyzing it. Currently groups such as Institute of Packaging Professionals (IoPP) and International Safe Transit Association (ISTA) are making great strides toward recommending common formats for information sharing.

X. CONCLUSIONS

The information previously generated on drop height environment for package systems is suspect based on the accuracy of the recording devices and the problems associated with proper calibration of these devices.

Likewise, the vibration data currently collected utilizes inputs from certain locations on vehicles and is not representative of the environment of packages mixed with other packages in a random lading. Both of these situations can be corrected through the use of accurate recording devices and proper techniques to calibrate these devices.

The equipment is now available and is affordable in its current format. We stand on the verge of being able to completely update existing information on the distribution environment resulting in more optimum package systems and hopefully reduced levels of damage in shipment.
References:

1. MTS Systems Corporation, “5 Step Packaging Development”.


APPENDIX I

DEFINITIONS OF COMMONLY USED TERMS IN PACKAGING DYNAMICS
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACCELERATION</strong></td>
<td>A vector quantity describing the time rate of change of velocity of a body in relation to a fixed reference point. It is usually expressed in G's which are multiples of the gravitational constant.</td>
</tr>
<tr>
<td><strong>AMPLIFICATION</strong></td>
<td>The ratio of the peak response acceleration to the peak input acceleration.</td>
</tr>
<tr>
<td><strong>AMPLITUDE</strong></td>
<td>The magnitude of variation in a changing body from its zero value. It may refer to displacement, velocity, or acceleration.</td>
</tr>
<tr>
<td><strong>COMPRESSION SET</strong></td>
<td>The loss of thickness of a cushion after a specified time interval following the removal of a compression load.</td>
</tr>
<tr>
<td><strong>CREEP</strong></td>
<td>The strain time response of a material to a constant stress.</td>
</tr>
<tr>
<td><strong>CUSHION</strong></td>
<td>A material used as a shock and vibration isolator.</td>
</tr>
<tr>
<td><strong>CYCLE</strong></td>
<td>A complete sequence of values of a periodic quantity occurring over a definite time period.</td>
</tr>
<tr>
<td><strong>DAMPING</strong></td>
<td>The dissipation of oscillatory or vibratory energy with motion or with time. CRITICAL DAMPING is the minimum viscous damping that will allow a displaced system to return to its initial position without oscillation.</td>
</tr>
<tr>
<td><strong>DISPLACEMENT</strong></td>
<td>A vector quantity describing the change of position of a body and usually measured from a position of rest.</td>
</tr>
<tr>
<td><strong>DURATION</strong></td>
<td>When referring to a shock pulse, duration is the time required for the acceleration of the pulse to rise from some stated fraction of the maximum amplitude and to decay to this same value. The usual practice is to use ten percent of the maximum amplitude as the fraction.</td>
</tr>
<tr>
<td><strong>EQUIVALENT DROP HEIGHT</strong></td>
<td>The height of a free fall required by a body in a vacuum to attain a particular instantaneous velocity at impact.</td>
</tr>
<tr>
<td><strong>FRAGILITY</strong></td>
<td>The ratio of the maximum acceleration that an object can safely withstand to the acceleration of gravity.</td>
</tr>
<tr>
<td><strong>FREQUENCY</strong></td>
<td>The reciprocal of the period necessary for one complete oscillation. This is often described in cycles per second or &quot;Hertz&quot; abbreviated Hz.</td>
</tr>
<tr>
<td><strong>FREQUENCY, FORCING</strong></td>
<td>The frequency of excitation.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<td>-------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>FREQUENCY, NATURAL</td>
<td>The frequency of free oscillation of a system.</td>
</tr>
<tr>
<td>FREQUENCY, RESONANT</td>
<td>The frequency at which a spring-mass system displays its maximum response.</td>
</tr>
<tr>
<td>HARMONIC</td>
<td>A sinusoidal quantity having a frequency that is an integer multiple of a fundamental or resonant frequency.</td>
</tr>
<tr>
<td>IMPACT</td>
<td>A single collision of one mass with a second mass.</td>
</tr>
<tr>
<td>ISOLATOR</td>
<td>A device or material used to reduce the severity of applied shock and/or vibration to a packaged item.</td>
</tr>
<tr>
<td>MASS</td>
<td>A physical property indicating the acceleration resulting from a given force.</td>
</tr>
<tr>
<td>OSCILLATION</td>
<td>Variation with time of the magnitude of a quantity with respect to a specified reference.</td>
</tr>
<tr>
<td>OVERSHOOT</td>
<td>Excessive momentary response of a recording system to an applied signal.</td>
</tr>
<tr>
<td>PERIOD</td>
<td>Smallest interval of time in which a reoccurring event repeats itself.</td>
</tr>
<tr>
<td>PERIODIC VIBRATION</td>
<td>An oscillation whose waveform repeats at equal increments of time.</td>
</tr>
<tr>
<td>PIEZOELECTRIC</td>
<td>The capability of some crystalline materials to generate an electric charge when stressed.</td>
</tr>
<tr>
<td>PIEZOELECTRIC TRANSUDER</td>
<td>A device which depends upon deformation of its sensitive crystalline element in order to generate an electrical charge and voltage.</td>
</tr>
<tr>
<td>PIEZORESISTIVE TRANSUDER</td>
<td>A device that depends upon deformation of its sensitive element in order to change resistance of that element.</td>
</tr>
<tr>
<td>POWER SPECTRAL DENSITY</td>
<td>A term used to describe the intensity of random vibration in terms of mean squared acceleration per unit frequency. The units are $G^2/Hz$.</td>
</tr>
<tr>
<td>RESILIENCE</td>
<td>A material characteristic indicating an ability to withstand temporary deformation without permanent deformation or rupture.</td>
</tr>
<tr>
<td>RESONANCE</td>
<td>Resonance of a system in forced vibration exists when any change, however small, in the frequency of</td>
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excitation causes a decrease in the response of the system. Resonance represents a maximum of response of a spring-mass system to forced vibration.

<table>
<thead>
<tr>
<th>Term</th>
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<tbody>
<tr>
<td>SHOCK</td>
<td>A sudden, severe, non-periodic excitation of an object or system.</td>
</tr>
<tr>
<td>SHOCK MACHINE</td>
<td>A device for subjecting a system to a controlled and reproducible mechanical shock.</td>
</tr>
<tr>
<td>SHOCK PULSE</td>
<td>A substantial disturbance characterized by a rise and decay of acceleration from a constant value in a short period of time. Shock pulses are normally displayed graphically as curves of acceleration as a function of time.</td>
</tr>
<tr>
<td>SHOCK SPECTRUM</td>
<td>A plot of the maximum response experienced by a single-degree-of-freedom system as a function of its own natural frequency in response to an applied shock input. The response may be expressed in terms of acceleration, velocity, or displacement.</td>
</tr>
<tr>
<td>SIMPLE HARMONIC MOTION</td>
<td>Periodic vibration that is a sinusoidal function of time.</td>
</tr>
<tr>
<td>SINGLE-DEGREE-OF-FREEDOM SYSTEM</td>
<td>A system consisting of a rigid mass attached to a referenced foundation by a massless spring that is constrained along a straight line.</td>
</tr>
<tr>
<td>STRAIN</td>
<td>Deformation per unit length.</td>
</tr>
<tr>
<td>STRESS</td>
<td>Force per unit length.</td>
</tr>
<tr>
<td>TRANSDUCER</td>
<td>An instrument that converts shock and vibration or other mechanical phenomena into a corresponding electrical signal.</td>
</tr>
<tr>
<td>TRANSMISSIBILITY</td>
<td>The dimensionless ratio of the response amplitude of a system in steady state forced vibration to the excitation amplitude. The ratio may represent acceleration, forces, displacements or velocities.</td>
</tr>
<tr>
<td>VELOCITY</td>
<td>A vector quantity describing the time rate of change of displacement of a body in relation to a fixed reference point.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>VELOCITY CHANGE</td>
<td>The difference in system velocity magnitude and direction from the start to the end of a shock pulse. The magnitude may be determined from the integral of the acceleration versus time signature.</td>
</tr>
<tr>
<td>VELOCITY SHOCK</td>
<td>A mechanical shock resulting from a rapid net change in velocity. The velocity change is rapid if it takes place in a time that is very short compared to the natural period of the test specimen.</td>
</tr>
<tr>
<td>VIBRATION</td>
<td>The oscillation of an element of a mechanical system about a fixed reference point.</td>
</tr>
<tr>
<td>VIBRATION, PERIODIC</td>
<td>A vibration consisting of a wave form that is repeated at equal time intervals.</td>
</tr>
<tr>
<td>VIBRATION, RANDOM</td>
<td>An oscillation having an instantaneous frequency and amplitude that can be specified only on a probability basis.</td>
</tr>
<tr>
<td>VISCOELASTIC</td>
<td>An adjective indicating that a material or system has both energy storing and energy dissipating capability during deformation.</td>
</tr>
</tbody>
</table>
APPENDIX II

SPRING/MASS RECORDING DEVICES
WHAT THE IMPACT-O-GRAPH IS

- For monitoring over-the-road driving habits
- For detection of concealed shipping damages
- For evaluating packaging
- For monitoring shock during coupling of railroad cars

WHAT THE IMPACT-O-GRAPH DOES...

The Impact-O-Graph is a mechanical recording accelerometer whose patented feature is its ability to record shock and impact from all directions. The Impact-O-Graph records on chart paper (no ink required) the total number of impacts that have occurred, the magnitude, the direction and the time at which they occurred. Impact is recorded in both magnitude and direction through three independently operating axes, which record:

1. Lateral Shock ("X" axis)
2. Longitudinal Shock ("Y" axis)
3. Vertical Shock ("Z" axis)

The Impact-O-Graph is omnidirectional. It records impacts of shocks which can occur from any one of an infinite number of directions. All models are self-contained, small in size, light in weight, and can operate in any position.

STYLOUS ASSEMBLY

The heart of the Impact-O-Graph is its three independently operating mass-spring-styled sensing elements, each of which is an angular vibration system with one degree of freedom in the direction it monitors (see Figure 2 above). Mechanical friction-free linkage from each stylus inertia mass converts longitudinal, lateral and vertical motions into the same plane for convenient reading of the graph. All stylus bracket assemblies are available in any combination of sensitivities. Figure 1 describes the planes in which "X", "Y" and "Z" inertia masses move. The "Z" mass or weight moves in the perpendicular plane as shown by the dot (end view of the arrow).

HOW THE IMPACT-O-GRAPH IS OPERATED...

Where possible, the Impact-O-Graph should be firmly secured to the object under investigation so that one monitors the object rather than just the recorder. A stylos guard is removed. The time is set. The recorder is then turned "ON" and the cover is closed. The cover may be locked or sealed if desired.

MONEY SAVING USES OF IMPACT-O-GRAPH

- Monitoring over-the-road driving habits.
- Monitoring shock during coupling of railroad cars.
- Evaluating packaging and handling through dummy shipments.
- Identifying concealed damage.
- Testing product fragility.
- Proof of damage claims.
- Identifying abnormal machinery jolts for preventive maintenance.
- Proving vehicle ride (i.e., truck, freight car, fork lift, elevator).
- Measuring shock and impact.
SELECT CORRECT STYLUS ASSEMBLY

OMNIDIRECTIONAL

Figure 4
STYLUS BRACKET

SPECIFY STYLUS SENSITIVITY

At the right is a complete table of available full scale "g" ratings or sensitivities. Full scale is the maximum "g"s which can be read when a particular stylus has deflected to its maximum reading position (see Figure 4 above). Brackets may have all equal full-scale readings: 6 x 6, 6 x 8, 6 x 10, 60 x 60. They may have different full-scale readings: 8 x 10, 60 x 60. They are available with three stylus of different sensitivities monitoring the same plane: 4 x 15 x 1000.

Recorders are often used in pairs: one attached to the leading and the other attached to the vehicle. 100% momentary overload will not damage recorders.

TYPICAL SENSITIVITY (g rating) VALUES

<table>
<thead>
<tr>
<th>packages (under 40 lbs)</th>
<th>70-150</th>
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</thead>
<tbody>
<tr>
<td>packages (40-100 lbs)</td>
<td>60-80</td>
</tr>
<tr>
<td>packages (over 100 lbs)</td>
<td>20-50</td>
</tr>
</tbody>
</table>

Vehicle situations ("ride")

Passenger car — smooth roads 1
Vans — smooth or rough roads 6
Truck trailer — smooth roads 6
Truck trailer — rough roads 15
Off-road vehicles 15
Rail freight cars 10

IMPROT-O-GRA PH CHART PAPER

Figures 1 and 4 show the standard pre-printed, pressure sensitive (no ink required) chart paper which comes with each unit. All chart paper is 4 inches wide and divided into 5-inch increments. An operating manual is sent with each unit. This manual contains a simple chart which allows the user to convert spaces of deflection to "g" ratings. The chart paper length is marked in one-hour intervals of 1 to 12 a.m. and 1 to 12 p.m. Along the margin are numbers printed every 12 inches to show the number of feet left in the supply roll. Movement of the graph paper under the stylus is powered by the clock or motor. Ratchet advance models contain 2 feet of chart paper (24W), enough for 700 impacts. Each impulse advances the take-up roll enough to separate each record on the chart paper from the one to follow.

See Price List for Chart Paper ordering information.
HOW TO ORDER

Specify Model and Stylus Sensitivity

MODEL “M”
Our most popular shipping and handling recorder

MODEL “F”
to test packaging and for scientific applications

MODEL “T-24”
Ratchet advance model

All units are shipped from the factory ready to operate with battery and chart paper installed, and an operating manual.

Customer need only specify model number and the full-scale “g” level for each of the 3 axes; for example, Model M4 4x 10y 15z.

<table>
<thead>
<tr>
<th>THREE-DIRECTIONAL MODELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>F-12-S</td>
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<tr>
<td>F-6-S</td>
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<td>T-24</td>
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<tr>
<td>T-O</td>
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SPECIFICATIONS

<table>
<thead>
<tr>
<th></th>
<th>Model M</th>
<th>Model F</th>
<th>Model T-24</th>
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</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>9½&quot; x 6½&quot; x 3½&quot;</td>
<td>11½&quot; x 1½&quot; x 4½&quot;</td>
<td>9½&quot; x 6½&quot; x 2&quot;</td>
</tr>
<tr>
<td>Weight</td>
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<td>12 lbs.</td>
<td>1½ lbs.</td>
</tr>
<tr>
<td>Shipping Weight</td>
<td>5 lbs.</td>
<td>13 lbs.</td>
<td>2 lbs.</td>
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<td>Temperature</td>
<td>-20°F to +220°F</td>
<td>+20°F to +140°F</td>
<td>-20°F to +140°F</td>
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<tr>
<td>Case Material</td>
<td>Poly Carbonate</td>
<td>Fiberglass</td>
<td>Tente</td>
</tr>
<tr>
<td>Maximum Recording Time</td>
<td>160 days</td>
<td>10 days</td>
<td>-</td>
</tr>
<tr>
<td>Batteries</td>
<td>Type &quot;C&quot;</td>
<td>6 Volt</td>
<td>-</td>
</tr>
</tbody>
</table>
-LIMITED WARRANTY-

Each recorder is calibrated before shipment according to generally accepted calibration procedures. A certificate of compliance is available upon request from The Impact-O-Graph Division of Chatsworth Data Corporation. All units are warranted against defects in material and workmanship for a period of 90 days. Supplier shall replace or make repairs at its option during the warranty period upon return of units to Chatsworth, California plant. Customer is responsible for transportation charges to and from Impact-O-Graph. THIS WARRANTY SHALL BE IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED. In no event shall supplier be responsible for consequential damages of any kind.


LEASING: All Impact-O-Graph units are available for lease. Leasing period, one month minimum begins date recorder is shipped and ends date recorder is received by Impact-O-Graph. Possession beyond the one-month period automatically renew lease. Lessee is responsible for transportation charges from and to Impact-O-Graph. Damages to and/or loss of instrument(s) is responsibility of lessee.

LEASE/PURCHASE: First month lease charge is allowed toward purchase price of recorder, if Impact-O-Graph is notified prior to expiration of first month lease period. If lease period is extended, one half of monthly lease charge is allowed toward purchase, if Impact-O-Graph is notified while instrument(s) is still under lease period. A break in the lease period cancels the options above.

SHIPMENT: From stock, 1 week for standard equipment; 3 weeks for special equipment.

APPLICATION OR PRICING ASSISTANCE

For technical assistance please call us at (213) 341-1000 or write to the address on the back of this brochure.

OPTIONS

1. Viewing Window.
2. Remote power via 16-foot extension cord.
3. Special cases upon request.
4. Special Models, produced to customer requirements.

USER INFORMATION

1. Operating manual, and calibration tables are supplied with each unit.
2. Three-directional stylus brackets are interchangeable between all units.
3. Maximum ambient temperature for wax-coated chart paper is 140°F, and for plastic-coated paper it is 220°F.
4. Accuracy of units is ±10% when pulse duration is known.
5. Instruments can withstand 100% momentary overload without damage.

MODEL MT

Long Term Temperature Recorder

Makes continuous written records of temperature

Model MT produces a complete time-based record of all ambient temperatures continuously for up to six months. Contained in the same rugged housing as the Model M Impact Recorder, the Model MT is perfect for long-term unattended monitoring of warehouses, freezers and containers. Model MT is supplied complete with a standard recording range of -20°F to +110°F and at the customer’s option, can be supplied with a plexiglass viewing window.

SPECIFICATIONS

CALIBRATION: -20°F to +110°F
RECORDING TIME (MAX): 180 days
CASE: 9½" x 6½" x 3¾" poly carbonate, hinged, weatherproof.
WEIGHT: 4 pounds
BATTERY: Type "C" LIFE: 6 months
Where IMPACT-O-GRAF Can Save You Time and Money!

The manufacturer of a $2,000,000 electronic instrument uses Impact O-Grafe to monitor alignment after it leaves factory. Impact O-Grafe is read through panele in packing case to ensure quality of delicate apparatus before installation.

During environmental tests, contractor installs Omni-O-Grafe to monitor System of Lunar Module 3 to test and avoid assembly. Omni-O-Grafe is used to monitor during shipment.

Dummy of a portable electric typewriter was used to test shipment in two-case corrugated container. Complete dummy with 24-T Impact O-Grafe came in lightweight and positioned to avoid product. With information on how this size and weight package is handled and knowledge of quality factor, proper cushioning can be provided.

Impact O-Grafe used on a Centurion engine. Impact O-Grafe is approved for instrumentation by National Safe Transit Committee and may be used to calibrate the Centurion machine.

Two Impact O-Grafe are used to check mounting of machine tool on flat truck. One checks jets experienced by truck, the other monitors machine tool. Charts from both instruments are compared.

Transformer manufacturer installs Impact O-Grafe on flat car to record parts and impact during shipment. Chart shows whether impacts are within "safe" area. If damage occurs, chart is used to support claim.

Before final purchase truck lines and fleet owners use Impact O-Grafe to compare risks of various makes and models. Impact O-Grafe is used to evaluate drivers' seats.

Actual chart from rental model Impact O-Grafe consists of lecture. Upon test, a claim of $1,200,000 was paid for freight bill of $364. Presence of Impact O-Grafe on loading proved to avoid damage handling.

Elevator manufacturer uses Impact O-Grafe to monitor loads of and integrals of elevators. Chart shows how elevator trip from one floor position to another.

Motor carriers and railroads use Impact O-Grafe to check drivers and engineers' habits. Truck drivers: running off pavement, hard braking for speed, and excessive long, delays with late night driving to make up time. Yard locomotive engineers: jumping freights cars at too high speed.

Three-way Impact O-Grafe mounted inside freight cars records lateral and vertical check or oscillations which are components of all longitudinal impacts experienced by car.

A container Impact O-Grafe clearly identifies problems in molding and stamping operations. Significant portion in other than intended direction signals need for adjustment. Result: elimination of scrap, reduction of finishing costs and tooling damages.

Impact-O-Grafe
Division - Chatsworth Data Corporation

20710 Lassen Street
Chatsworth, CA 91311
(818) 341-3000
TWX #819 984 1244 CHATSDATA CHCA
APPENDIX III

B & K BUMP RECORDER
MONITORING THE TRANSPORTATION ENVIRONMENT USING A BUMP RECORDER

Richard A. Spearnock
Bruel & Kjaer Instruments, Inc.
185 Forest Street
Marlboro, MA 01752

Introduction

Any product damaged in shipment is costly. It is costly not only to the carrier, who may have a claim filed against him, but also to the shipper and the receiver, who must deal with repair or replacement, and lost time.

This article proposes that a significant reduction of these costs is possible with efficient and effective monitoring of the transportation environment. Specifically, it proposes the use of an instrument known as a bump recorder to monitor the transportation environment. After a brief description of the bump recorder instrument, the article will concentrate on the justification and benefits of use of the bump recorder by the three parties involved; the shipper, the carrier and the receiver of the shipped goods.

The Bump Recorder

This article limits the discussion to the bump recorder produced by Bruel & Kjaer (model 2503). Other manufacturers' electronic bump recorder operations will be similar in principle to the unit produced by Bruel & Kjaer. Mechanical recording instruments are also used for shock measurements, but they will not be discussed.

The bump recorder is an electronic instrument capable of recording the magnitude of the shock received and, in the case of the Bruel & Kjaer recorder, the time of occurrence relative to a specific "start-monitoring" time of the shock. Acceleration is measured in meters per second squared and velocity is electronically computed and read out in meters per second. All shock values for 1 to 5000 meters per second squared (1 to 500g) can be recorded or only those values exceeding threshold values of 10, 20, 50, 100, 500 and 1,000 meters per second squared can be printed. This allows the user to record only those levels of interest to him. The instrument's accuracy is +/- 20% for most (90%) directions of shock and +/- 10% if only one direction is to be monitored. The bump recorder is battery operated and can monitor continuously for eighteen days. Print-out of recorded values is on heat sensitive paper ensuring that recorded data can not be lost due to battery or instrument failure during the period of measurement.

The bump recorder consists of three main parts (see figure 1), a sensor known as an accelerometer, conditioning and measurement circuitry and a print-out device.
The accelerometer produces an electrical signal proportional to the shock acceleration. This accelerometer is a three-axis type which allows the computation of the magnitude of the shock in any direction.

The signal from the accelerometer is conditioned and amplified. The magnitude of this three-axis signal is measured and checked against the threshold value to see if print-out is required. Shocks occurring during print-out are stored so that their subsequent print-out can follow.

The bump recorder can be used in a self-contained configuration in its protective case and mounted on the product, or the accelerometer can be mounted at a critical point on the product with the bump recorder mounted elsewhere in the shipping container.

The operation of the bump recorder is covered in more detail in the data sheet available from Bruel & Kjaer Instruments, Inc. The remainder of this article will concentrate on the justified use of a bump recorder by shippers, carriers and receivers of goods.

**USE OF THE BUMP RECORDER FROM THE SHIPPER'S VIEWPOINT**

The use of the bump recorder by the shipper (and all three parties involved) is always justified by economic considerations. The question of whether or not to use a bump recorder for shock monitoring, really amounts to asking whether or not there will be sufficient payback to cover the cost of the bump recorder plus the cost of manpower to implement a monitoring program. Any payback over this is realized as additional profit.

The classification of shipped goods for shock monitoring breaks down into three major categories: the low value, high volume goods, the medium value, medium volume goods and the high value, low volume goods. Examples of these classifications are respectively: foodstuffs, appliances and high-end computers.

It is difficult to assess the amount of damaged goods relative to all goods shipped. It appears from a very limited survey that, independent of classification, the amount of damage lies somewhere between 0.2% to 2% of all goods shipped with probably 1/2% to 1% being the most often cited figures.

This may appear at first to be such a small amount of damage that shock monitoring may seem pointless. However, it may be more pertinent to ask what percent of profits are affected by damaged goods and also what the cost of insurance is on goods shipped. This may put the benefits of shock monitoring by use of a bump recorder in a more favorable and perhaps profitable position.

It may also be of value to look at these figures with a questionable viewpoint. Most of us are familiar with hidden values of statistics, unemployment being an example. It may be that marginal damage which causes some concern, but not enough to complain about, is occurring. This is probably a concern of the shipper from a customer relations and satisfaction point of view. These costs would be difficult to quantify.
type 2503

Bump Recorder

FIGURE 1.  
BRUEL & KJAER
Model 2503 Portable
Electronic Bump Recorder
The shipper is concerned with assessing two important areas of the shipping process. The first is the problem of adequate packaging techniques and product design to resist shipping damage. To ensure adequate packaging and design it would be extremely useful to know, on a statistical basis, what the products are likely to encounter in terms of shock throughout the transportation cycle. This not only allows the evaluation of adequate packaging, but can also help to determine whether or not the goods are being over-packaged resulting in lower profits for the manufacturer. With the data provided by the bump recorder, packaging engineers can optimize the packaging techniques to provide adequate protection at minimum cost. Also manufacturing engineers can implement design changes which improve the products' shock resistance and may perhaps reduce both manufacturing costs and packaging costs in the process.

The second area of interest is pinpointing the problem of when and where damage is occurring in the transportation cycle. This type of feedback to the manufacturer allows him to work with the carrier, his shipping department, or the receiver's shipping department to help reduce the problem to a reasonable level. This method has the additional advantage of maintaining good working relationships with the parties involved, since the problem is identified by hard data rather than unsupported accusations.

The transportation cycle can be evaluated using dummy shipments which include a bump recorder. After enough samples to assure statistical accuracy, the shock data can indicate where in the transportation cycle damage is occurring or is likely to occur.

Once it has been decided that the verification of existing shock data or the building of a non-existent shock data base is warranted, how can such a plan be implemented? If the shipper is a large enough company, the distribution or packaging departments could take on the task, employing additional manpower or using consultants as required. Where the shipper is not able to justify the expense on his own, multi-party cooperation could be the alternative. Working with agencies such as the National Safe Transit Association, companies can group together to initiate a study on shock data which would be mutually beneficial to all.

**USE OF THE BUMP RECORDER FROM THE CARRIER'S VIEWPOINT**

The carrier must examine the costs of damage, both apparent and hidden, to assess whether the use of shock monitoring by use of a bump recorder is worthwhile.

An estimate of damage has typically been stated as less than 1% of gross revenues. This figure has the unfortunate connotation as one indicating that there is no real problem. However, it is felt the cost of damage from the carrier's viewpoint is also best evaluated in terms of percent of profit. Then the effectiveness of shock monitoring can be more realistically assessed.

The carrier is interested in providing the highest quality of service at a competitive price. Shock monitoring allows him to evaluate his current service as well as assessing the change in the "shock environment" when changes in service are implemented.
Shock monitoring by use of a bump recorder is therefore a means by which the carrier can implement a quality control tool to his part of the transportation cycle. This allows him to first of all acquire a statistical base of the shock environment. Once this has been done, an evaluation of whether or not the amount of claims filed against him is reasonable or not can be ascertained.

This tool gives him the feedback necessary to stop a problem before it begins. Changes in the transportation cycle can be identified as to whether they are handling problems, or packing location problems, or packaging problems belonging to the shipper. The use of this monitoring tool should be especially useful when changes in the carrier's process are to be implemented. New routes, involving new personnel, can be evaluated allowing for the implementation of adequate training and quality control procedures.

New methods of packaging can be discussed and evaluated with the shipper. This cooperative method can provide reduced packaging costs for the shipper and increased revenues for the carrier as a result of increased business generated by these "close working relationships."

As in the case of the shipper, dummy shipments containing a bump recorder can be shipped to gain statistical data on various transportation routes. This sampling can be varied using for example, package size, package weight, location on transport vehicle, time of year, etc., as parameters. In addition, this can be used as a quality control tool, much the same way as quality control charts are used in industry.

Shock levels versus locations on the transport vehicle evaluated, allows the optimum matching of cargo with location and therefore reduces the shock received by critical goods while using less favorable space for the more shock tolerable goods. Premium space and extra charge for this service could generate extra revenue.

**USE OF THE BUMP RECORDER BY THE RECEIVER**

The receiver of goods is interested in his shipments being received undamaged at the lowest possible cost. His cost considerations are not just those of receiving damaged goods, but also that his suppliers use methods of packaging and shipment that minimize his costs while providing for the highest quality possible.

Classification by value and volume are the same as for the shipper. The receivers of low volume, high value goods have an obvious interest in seeing that these goods are received undamaged. However, the other classifications have just as great an interest.

The information provided for by shock monitoring not only can be used for supporting damage claims, but also to help eliminate the problem of damage in the first place. This is important to the receiver because the cost of unrequired delays of his own manufactured products or services depend on receiving his goods in a timely and undamaged condition.
The use of the bump recorder also allows the receiver to create and maintain a statistical base of the shock environment for the goods he receives. This allows for a cooperative effort based on hard data to be initiated and maintained with the shipper and the carrier. This also allows the receiver to evaluate material handling problems within his own facility, eliminating false claims and accusations so costly to good working relationships. If the problem is his, it can be remedied and monitored to prevent such problems in the future.

CONCLUSION AND COMMENTS

It is hoped that this article stimulates discussion and evaluation of the worth of shock monitoring by use of a bump recorder.

The article points out some, but not all, of the benefits of monitoring by those involved in the transportation cycle. Those benefits being improved profits through lower costs due to the minimization of damage in shipment.

As a tool, the bump recorder should be very useful in providing enough of a statistical base to validate the damage figures cited. Additionally, it may help to point out some problem areas where damage is not reported, i.e., the no external damage but non-functioning product, or limited life product. The costs of such damage is hard to quantify, especially if we consider non-product costs of customer relationships, manufacturer integrity and so forth.
APPENDIX IV

FOCUSED SIMULATION MEASUREMENT AND TEST DEVELOPMENT
Focused Simulation: Bringing realistic distribution hazards into the laboratory.

by Dennis E. Young
Dennis Young and Associates
Charlotte, MI

Abstract: Focused Simulation technology links the field measurement of transit hazards to laboratory simulation. Test levels, intensities and times are determined with reference to actual field occurrences. Focused Simulation provides the opportunity for a robust and targeted laboratory test, treating established hazards without costly overtesting. A distribution experience is divided into categories, and a vibration spectrum determined for each category. These spectral events are then linked together to specify the test. The result is a temporal series of spectral events. The degree of specificity of the simulation may be determined by the user.

INTRODUCTION
Originally, the testing of protective packages was a crude and inexact endeavor. Thomas Edison is known to have supervised drop tests on phonographs that consisted of manually tilting the wooden crate off a scaffold onto its edge. As packaging became more sophisticated and a more important part of a total product delivery system, test techniques improved. The desire for effective testing of protective packages has borrowed from available technology in other fields, such as aerospace, to good effect. The general direction of this progress has been toward more and more responsive and simulative test techniques and protocols. Progress continues and we can project that the future will hold new advances.

One way of viewing protective packaging testing would be to categorize the various approaches as:

- Integrity Testing
- General Simulation, or
- Focused Simulation.
PERFORMANCE TESTING APPROACHES

Integrity Testing challenges the strength of the product and package by subjecting them to various punishing inputs. The logic here, very solid logic, is that by creating a strong package and product combination, they will be able to resist the hazards of transit, handling and warehousing. It is like the idea that by good health habits; good food, rest and exercise, we will be prepared to resist various sicknesses and diseases. The inputs and test types used for this approach include various types of drops, bounces and impacts. The inputs are generalized and to level and form, and typically not specific to defined transit mode or method. An overall objective of Integrity Testing is to avoid damage in transit through the mechanism of product and package strength. This is not a classic "throw-it-down-the-stairs" approach, since that type of effort is too ineffective to earn the performance testing label. Test protocols such as the widely used standards of the International Safe Transit Association (ISTA) could be included in this category, along with other well-proven and useful techniques. The widespread use of the ISTA test techniques, combined with the unique package "certification" that successful ISTA testing allows (see Figure 1), increases the effectiveness of this specific brand of integrity testing.

![ISTA Label](image)

Figure 1. ISTA Label

General Simulation challenges the performance of the product and package working together to overcome the hazards of the logistic environment. Testing seeks to simulate the motions and events of distribution along with the effects of distribution. Typically, test methods, equipment, and protocols are more complex. Some test equipment may be more expensive, while other tests may share the equipment of Integrity Testing but perform the evaluation in a different manner. By simulating distribution hazards in the lab, the reaction of the product and package to distribution may be assessed. Test intensities, such as drop heights, vibration levels and compression targets, are generalized. Levels are
based on broad categories of distribution types to allow evaluation of the sample for broad purposes. An overall objective of Generalized Simulation is to avoid cost by identifying potentially damaging relationships among package, product and transit. At the same time, a reduction of overpackaging is possible by careful design and development of a package suitable for avoiding identified general hazards. We might liken this approach to the use of broad-spectrum anti-biotics before an overseas trip to avoid contracting an illness. Test protocols such as the American Society for Testing and Materials (ASTM) D-4169-92a would fall into this category when performed with the recommended or default levels. (1) This standard, which has been found to be very effective in the prediction of transit damage or success, specifies recommended sequences of tests (example: drop, compression, bounce/vibration, vibration and drop), for the evaluation of shipping units in generalized modes (example: Motor freight, single package over 100 lb. (45.4 kg), or unitized). ASTM D-4169 further incorporates three generalized test intensity level, called Assurance Levels, to allow tuning of the test to the objectives at hand.

ASTM D-4169 has been used as a model of package performance test procedures by others, including the Institute of Packaging Professionals (IoPP) Carrier Regulations Committee. This Committee has drafted a test procedure for evaluation of packages in the Less-Than-Truckload (LTL) distribution environment. This procedure builds on ASTM D-4169 by utilizing tests and levels from that document. The proposed alternate to existing carrier rules incorporates a vibration/compression test and an impact/handling test.

Focused Simulation (Lansmont has trademarked the name Field-To-Lab to describe this technique) is a logical extension of Generalized Simulation, and challenges the effectiveness of product and package. Focused Simulation ties laboratory test intensities to levels measured under field conditions. Small battery powered instruments, capable of recording dynamic events in transit, are used for this purpose. The data collected in this manner is analyzed, typically in a personal computer, and the results converted to laboratory test levels. One key concept of Focused Simulation is that the degree of specificity of the resulting test is controlled by the user. The use of very generalized field measurements
yields a test like the Generalized Simulation approach. Typically, users are expected to target classes of distribution for detailed analysis and test conversion. For example, rather than use the broad "Truck" random vibration spectra from D-4169, a user may measure one or more typical vehicles and routes in actual use.

Figures 2 and 3 show the standard ASTM Truck spectrum, at Assurance Level II, and a specifically measured spectrum for a 28 foot trailer/semi-trailer traveling from New York to Kansas City. While the overall levels are similar, the specific intensities at frequencies are different.

Figure 2: ASTM D-4169 Truck Random Vibration Spectra, Assurance Level II

Careful selection and analysis can lead to an excellent simulation of what happens in transit, while avoiding testing for conditions not encountered by the user's products and packages. The resulting test is a robust and highly simulative evaluation tool. Again using our health care analogy, Focused Simulation is like receiving a flu inoculation before the flu season to insure against that health hazard. An overall objective in Focused Simulation is a tendency to optimize the performance and cost of the distribution system; product, package, mode and even route or other factors. With the sensitivity and degree of focus under user control, a match between needs and the test is possible. ASTM D-4169-92a allows and encourages the user to utilize detailed information such as that developed in a Focused Simulation technique.

Figure 3: Trailer Vibration Spectrum, 28 ft., Light Load, Interstate, NY to KC
APPLICATION OF FOCUSED SIMULATION

Focused Simulation (Field-To-Lab™) techniques are applicable to all of the common test methods. Devices to monitor handling shocks and estimate drop heights are available. A program of drop height monitoring will show the frequency of significant drops and their distribution by height. A recent study by the School of Packaging at Michigan State University, sponsored by the Consortium for Distribution Packaging, undertook a series of 100 monitored shipments through small parcel environments. Among other things, the researchers reported a total of about 1700 significant drops (roughly those which exceeded 5 inches, or 13 cm, in height) in the 100 trips. As might be expected, the vast majority were from low drop heights, and only a small percentage of all drops were from heights exceeding 24 inches (65 cm). To use such data in a Focused Simulation, a tester might perform a number of low level drops, a few middle height drops and perhaps one high drop. The maximum drop height would be selected as a function of the allowable exposure to damage for the product as well as the cost of protection from these unlikely hazards.

Field measurement of atmospheric conditions such as temperature and humidity and their times of exposure may be used to set conditioning specifications. An available device to measure compressive forces in warehousing may be used to establish the time and top-load force characteristics of one or many storage facilities. These results are easily programmed into a modern compression test system.

Recently, significant effort has gone into the measurement and test specification of transit vibration(2). Electronic devices, such as the Dallas Instruments SAVER, sample the vibration environment and record acceleration versus time waveforms in on-board computer memory. After the measurement trip, data are uploaded to an analysis computer equipped with appropriate software. Data events from one or several sources may be sorted according to a class of variable they represent; for example, position in the vehicle, vehicle load, type of vehicle, vehicle speed or road conditions. Like, representative events are averaged together into a power spectral density versus frequency characteristic, using standard analysis techniques. Figure 3 is an example of such a spectrum.
This target spectra is converted for direct use as a vibration test specification, and stored in the control system. In the case of Lantosm's TouchTest vibration control system, up to 100 such test definitions may be stored and strung together into a simulative test.

Vibration specifications reflect the occurrence of various conditions over time for the target environment. If most of the typical transit conditions are smooth, high speed road, with only small portions of rough road and local delivery conditions, then the test can reflect these conditions. Use of such a test prevents testing for conditions which do not occur, while focusing on conditions which do occur and may cause damage to products or deterioration of packages. For relatively short distribution routes, real-time testing at measured levels is appropriate. For longer transit legs, where test times might prove inconvenient, accelerated testing is possible. While this technique, increasing vibration intensity and reducing test time, is somewhat new to the packaging testing arena, it has been used in other areas for years. Users are experimenting to gain confidence, but the success of ASTM type tests in simulating longer distribution is encouraging. The basic relationship among test time and level and field time and overall level is as follows:

\[ W_2 = W_1 \left( \frac{T_1}{T_2} \right)^{n/b} \]

where,
\[ W_2 = \text{test intensity (Grms overall)} \]
\[ W_1 = \text{measured field intensity} \]
\[ T_1 = \text{distribution vibration time} \]
\[ T_2 = \text{test time} \]
\[ n = \text{slope of the } \sigma-N \text{ (stress-number of cycles) curve} \]
\[ b = \text{a stress-damping factor} \]

\( n \) and \( b \) each have a range of possible values. Using values thought to be typical yields figures for \( n/b \) of around 0.3. Using an exponent of 0.5 or higher will give a somewhat more conservative test, and may prove to give better results in some cases. As experience is gained, a better definition of accelerated testing will become available.

Bringing realistic, focused simulation to bear on product and package testing involves sorting of hazard data. Information collected by electronic devices is stored as "events." Each event is usually a short snapshot of what occurred dynamically at the time of the event.
Events in total are a small portion of all the activity in a transit trip. In a general simulation, the test spectrum is a very general average, and is run for the entire test time. In focused simulation, events are sorted into categories, spectra developed for the events in each category and an appropriate test time assigned. To run a test, these timed spectra are chained together to simulate the type of distribution measured.

As an example, in a recent project vibration measurements were taken in a 48 foot semi-trailer with steel spring suspension, lightly loaded. The data from the entire trip was sorted into categories of "peak" and "base" depending on whether the event capture came from a threshold crossing (no special time) or at a timer interval (no special intensity). The peak data represented approximately 6% of the trip time. Table 1 shows the relationship between the trip as measured and the designed test. Test levels are calculated using the formula above and an exponent of 0.5.

<table>
<thead>
<tr>
<th>Time Type</th>
<th>Trip</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Time (min)</td>
<td>32</td>
<td>11</td>
</tr>
<tr>
<td>Base Time (min)</td>
<td>508</td>
<td>169</td>
</tr>
<tr>
<td>Total Time (min)</td>
<td>540</td>
<td>180</td>
</tr>
<tr>
<td>Peak Level (g rms)</td>
<td>0.479</td>
<td>0.82</td>
</tr>
<tr>
<td>Base Level (g rms)</td>
<td>0.209</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Table 1: Example trip/test relationship

To run this test specification, the user will examine the record or make a logical decision on how to distribute the times indicated. For example, the class of distribution represented might be simulated by the series:

1. Peak @ 0.82, 5.5 minutes
2. Base @ 0.36, 169 minutes
3. Peak @ 0.82, 5.5 minutes

The 180 minute total test time is patterned after ASTM D-4169, which has shown success as a generalized simulation test method.

CONCLUSION
The ability to "ship" a product and package, observing how it reacts to the hazards inherent in distribution, is a worthy goal. The use of available performance testing techniques; Integrity Testing, Generalized Simulation and Focused Simulation, are the tools to reach that goal. The potential benefits of such use include lowered system cost, reduced impact on the natural environment, and better satisfaction of customer needs.
References:


Note: This paper was originally presented under the title Field-To-Lab at the PIRA Transit Packaging Conference, Surry, UK, 1993. Additional material was added and changes made for the 11th Educational Conference on Distribution Packaging and Handling conducted by the Institute of Packaging Professionals (IoPP), San Antonio, February, 1994, and published under the title Plugging In: Using Electronically Collected Information on the Physical Characteristics of the Distribution Environment to Develop a Package Performance Testing Series. Additional material was added for this version, presented at the IoPP Michigan West chapter conference, May 1994.