Acknowledgement and authors

As one of the world's largest electronics companies, Hewlett-Packard's expenses for packaging materials are in excess of a hundred million dollars annually. In addition to the cost of packaging materials, other business expenses, such as shipping, warehousing, and manufacturing processes depend in part on efficient package designs. The expenses for transportation, for example, are several times higher than for the protective materials themselves, therefore, a change in the package or product design can have a major impact on the transportation cost. To maintain their dominance in the market place, HP has hired and retained very talented packaging engineers who continually develop and refine new processes, techniques, and research studies.

The information contained within this document was derived through extensive research and contributions by many individuals within Hewlett-Packard Company and has resulted in millions of dollars in saving through using less material and reduced distribution damage.

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A portion of all sales of this book will be donated to select packaging universities.

1.0 Package Testing is Important to a company's Profit and Reputation for Quality

Packaging is necessary to protect and distribute products to customers. To safeguard a company's profit and quality reputation, all products must be delivered effectively to their worldwide customers. One responsibility of a Packaging Engineer is to design packaging that protects the product against the hazards of the distribution environment and have the packaging and product meet the quality expectations of our customers at delivery. The principal goal of a package is to maintain the functional and visual quality of a product throughout the distribution channel. In many instances, the packaging itself can be a key ingredient for presenting an image of quality, which enhances customer satisfaction and loyalty

Package testing is an extremely important tool set in evaluating the product/package system and assuring that the product will be adequately protected under normal logistical conditions such as vibration, impact, compression, temperature, and humidity. Testing new package designs also aids a company to minimizing the total costs of materials and processes associated with the introduction of a new product packaging solution, thus enhancing the company's profitability.

Another responsibility of the Packaging Engineer is to influence the ruggedness of new company products. A more robust product design can result in lower costs for packaging materials and logistical processes. During the design phase, engineers have the opportunity to balance the costs attributable to product design with the projected costs of logistics. In fact, the entire business plan can be positively affected by marrying product and packaging design and testing early in the product development stage. Customers benefit from improved quality, cost, and delivery when product manufacturing and distribution are fully integrated. Localization and packaging postponement are good examples of this.

This manual is intended as a guide or handbook for packaging professionals. It provides detailed information to aid selection of the most effective product/package tests and test levels. It will further guide companies in planning and managing package development and testing for new products. Appendices offer all people easy to understand applications of packaging theory appropriate to design and testing.

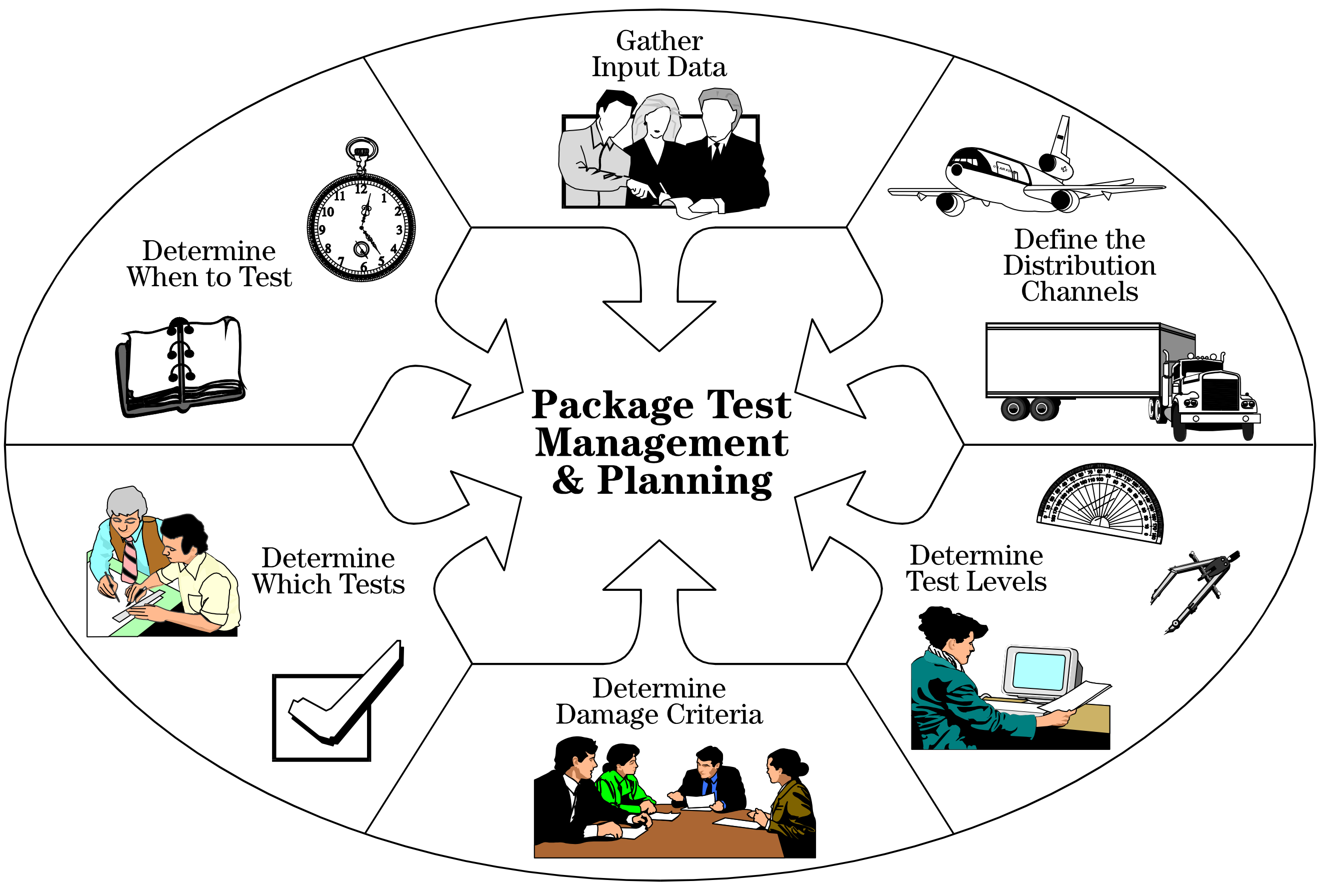
Package Test Management & Planning (section 2)

1.0 Introduction

Package test management and planning consists of:

* Gathering data from all design, production, marketing and logistics management
* Defining the distribution channels
* Determining appropriate test levels
* Determining damage criteria with which to test and evaluate the product packaging
* Determining which tests are appropriate to perform
* Deciding when and where to perform each test and on how many units

There is not a generic test sequence that applies to all products. Each product will have its own set of package test requirements depending on the distribution channels used, size and shape of product, cost of product and package, time to market, available test equipment, desired confidence level, etc. One of the functions of the package designer is to negotiate with all concerned to determine which tests and test levels are applicable to any particular product, when, and where to perform the tests. The result will be a test plan managed by the packaging designer.



2.0 Gather Input

In order to determine appropriate package tests, test levels and pass/fail criteria, the package designer must first obtain agreement on items, such as, product fragility, projected sales forecast, distribution channels, cost goals, damage risk, and schedule.

2.1 Fragility Goals - Product strength or ruggedness, commonly called fragility, is usually the most significant factor affecting package design and cost. R&D must establish a product fragility goal which is expressed in terms of critical acceleration (G-Level), velocity change (drop energy), and shock pulse shape. The fragility goal can be used to evaluate the package design's effectiveness, and will also be used in product shock testing as a product design criteria. The goal can dramatically affect cost and design time. Often a real product is not available at the time a package must be designed. In these situations a product mock-up made from wood or plastic can be used to monitor the interior cushioning characteristics of the package.

2.2 Projected Sales Forecast And Cost Goals - Product or package damage can result in a dissatisfied customer. Factors influencing the level of package design risk to be taken include the projected sales forecast, order lead times, product sales price and cost goals. A low risk of damage may demand higher than normal test levels.

2.3 Distribution Channels - Product distribution channels will define the shipping environment which the package will encounter and can help determine which package tests to perform. This information usually comes from the Marketing and Logistics areas. Refer to Section 4 for more information.

2.4 Schedule - The product design schedule can also have a dramatic effect on package design and testing plans. Ordinarily the product design schedule allows for adequate time to reduce cost by testing and comparing various alternative package designs. A product which has a very short design cycle will probably demand a less risky (more robust) package design. The schedule can also affect R&D's ability to make product design refinements to strengthen the product areas which are weak, in order to reduce package cost.

2.5 Historical Data - Historical data from products of similar size and type will help in determining appropriate tests and levels to avoid past problems. Warrantee or Annualized Failure Rate data can also be helpful in determining appropriate tests for a particular product.

3.0 Define the Distribution Environment

In order to determine which tests are appropriate to perform, it is necessary to understand the distribution channel's environment for each particular product. There are many package tests which could be performed, but not all of them apply to all products and all distribution channels. The package designer must decide how much testing is reasonable based on the needs of the product, its distribution system, time available, cost goal and the confidence desired.

Single box (not palletized) distribution using common carriers would require different test criteria than full container (palletized) ocean shipments between company divisions. Marketing, Distribution Centers, and entity's Logistics Departments have the most knowledge on intended distribution channels for the product. Take into consideration that this environment may also include the distribution system used for life cycle support, such as, field returned units. Refer to Section 4 for more information.

4.0 Determine Test Levels

All distribution systems have a certain amount of mishandling risk which could result in product damage. The package designer must balance the consequences of product damage in the field against the cost to obtain the desired level of protection. Each package test can have different levels of pass/fail criteria, and the acceptance quality level chosen can have a dramatic impact on the package cost and design time. Refer to Section 5 for more information.

5.0 Determine Package Test Pass/Fail Criteria

Some package test procedures suggest pass/fail criteria. However, the criteria can sometimes be interpreted differently by persons doing the evaluation. If it is acceptable for something to slightly bend and not break, then it should be defined before testing begins.

The following considerations can be used to guard against ambiguous test criteria. In general product damage (mechanical or electrical operation) or cosmetic defects are unacceptable.

- Is it required that the package cushioning be able to protect the product during the entire test sequence, or, is it acceptable to exchange damaged cushioning part way through the test?
- Is it acceptable for the box to show some signs of stress after a compression test?
- Is it acceptable for the foam to show signs of fatigue, such as, stress cracks from dropping, or is the cushioning meant to be reusable and must remain undamaged?
- Is it necessary to test to failure to determine the margin of safety?
- Is it necessary to monitor the shock pulse inside of the package and determine the safety margin through shock response spectrum analysis? Refer to Section 5 for more information.

6.0 Decide Which Tests to Perform

The determination of which tests to perform will be influenced by how the distribution environment is characterized for the product, and how much time and personnel can be committed to the project. For example, if the product is heavy and tall, then a tip-over test is probably appropriate. It is best to review each potential test and determine the appropriateness for the package being designed. If package testing equipment is not available in house, it is possible to do the applicable test at any number of outside testing services. When deciding which tests are appropriate, also consider that the package may be required to protect field return units as part of the company's life cycle support.

7.0 Decide When and Where to Perform Each Test and on How Many Products

Package design and testing can be broken down into a few basic steps, some of which will be reiterated depending on how many design trials are needed. (Refer to The Package Development Process, Section 8, for more detailed discussion). The product design-and-build schedule will determine the best time for each test and how many units will be available. Choice of test location is influenced by the available test equipment on site and whether an outside source, such as an OEM, is doing the product and package design. Negotiation with all affected project personnel will help determine when and where to perform the testing, and how many product units will be available for testing. In the early phases of the product design cycle it may be necessary for the package designer to construct a product facsimile or mock-up for package testing. The mock-up can be made from wood or plastic and should reflect the product's size, mass and center of gravity.

The timing of many tests is usually a function of product availability. It is best to confer with project management early in the product design cycle and negotiate how many units can be made available and at which check points in the product design cycle. <u>The following outlines a typical product design cycle and how it may relate to the package testing.</u>

7.1 Investigative (I-Phase) - This is the earliest part of the new product development cycle when the product features, basic design, and size are solidified. At this point, the package designer needs to consult with all affected project personnel to help determine a package test plan. If the outer design of the product has stabilized, the package designer may begin designing a product mock-up to use for package design and testing in the likely event that real product will not be available.

7.2 Lab Prototype (LP-Phase) - The development team produces a few hand built products using machined and stereolithographed parts. These prototypes are used for product feature testing and design evaluation and are not usually robust enough to survive package testing. This is a good time for the package designer to be involved with the product designers to evaluate existing designs for ruggedness. It may be possible to aid in preliminary shock testing of subassemblies to determine weak areas and how they may affect package design and cost. A little involvement at this phase can prevent many difficult problems later on. The package designer can use a mock-up of the product to complete most of the initial package design and testing for the single product package. Increasingly shorter product design cycles may require the tooling used for the package cushioning to be designed and finished before this phase is complete and before actual product prototype units are available.

7.3 Production Prototype (PP-Phase) - Small to medium quantities of the product are built using tooled parts that are very similar to the anticipated production units. Package testing should continue in this phase using real product to obtain a better understanding of the package's ability to protect the product. In addition, this testing can lead to ways of modifying the product design for additional ruggedness and reduced packaging cost. The package designer should be involved in the product shock and vibration testing to facilitate communication of potential problems in the product fragility as it relates to the package design. As more product is available during this phase, additional package testing can be performed for multiple units, if required, such as, pallet load vibration and compression, and bulk pack testing.

7.4 Pilot Run (PR-Phase) - Usually, this is a large build of the intended product design to verify the manufacturing processes, production tooling, and product performance. Package testing needs to be performed again to verify that the production package meets all of the package test goals. Only very minor product changes can be implemented at this phase. This is an excellent time to ship some product round trip through the intended distribution system for additional verification of the package's worthiness in the real transportation environment.

7.5 Manufacturing Release (MR-Phase) - At this point, production quantities of product are produced and stored as finished goods inventory in anticipation of a scheduled release date. In the case of low volume build-to-order products, customer’s shipments actually begin. Additional package testing should be conducted in this phase to increase the level of confidence that the package is performing its function as intended. This is a good opportunity to "ship" production units in the intended unit load configuration to verify multiple or "bulk" packaging in the intended distribution environment.

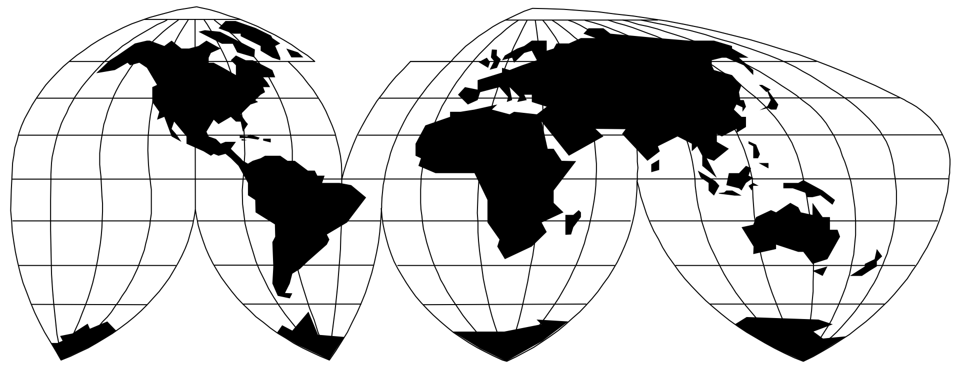
7.6 Production Audit - A systematic product audit may be performed on a predetermined number of units after specified time periods. Package testing should be one of the tests performed to verify that both the package and product designs are sufficient and have not degraded due to manufacturing variation, or due to changes in the product design. The package designer should help determine which tests are applicable

7.7 Customer Support - Consistent with a company's Life Cycle Development Plan for all new products, shipping protection must be assured for product and parts during customer service operations. In some cases the production package may be adequate for use within the return system intended for customer repairs, but most often a special returnable package may be needed. The packaging designer should work with the customer support organizations to help provide and test appropriate package systems needed for all field replacement parts, assemblies and products. This is normally done in the PP, PR, and MR phases but can start during earlier phases for better results.

Distribution Channel Analysis (section 3)

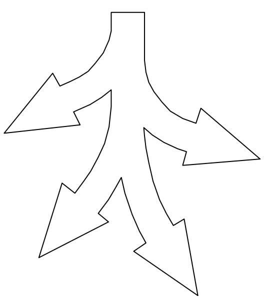
1.0 Introduction

Understanding the distribution channel is an important step in mapping out an effective test plan for the packaged product. This section will provide insights into common hazards encountered when the products move through typical distribution lanes via common modes of transport.



2.0 Define the Distribution Channel

The flow of a product from the production plant to the end user is the distribution channel.



Sometimes, the product can have more than one manufacturing location until the product achieves its full value as a final product. The product can be handled many times before it is received by the end user (primary customer). Various modes of transportation can be used to accomplish getting the product to the end user. The distribution channel will have its own unique "hazards" acting on the product. The following three factors will produce hazards of various intensity: time of year, geographical location, and mode of transportation. The package design should be tested to ensure that the product will be protected from these hazards.

3.0 Identify the Distribution Channel

Two sources should be consulted to gain an understanding of the distribution channel. The first source should be the marketing organization. Obtain the following: target markets, sales methods, distribution channels, and a customer profile. The profile should include information identifying the primary end users, dealer networks, VARs (Value Added Resellers) and retail businesses.

Know where the customers are located and what order quantities are expected by each region, dealer or reseller.

This marketing picture should provide an understanding of where the products will go and what volumes are expected. The quantity of products shipped has a significant impact on how the product is packaged, handled, and transported.

The second source of information is the logistics (traffic, distribution or shipping) department. They plan and contract the various transportation services that will move the product toward the end user. Considering the marketing information of “who” and “how much," begin to get the last piece of the picture, “by what mode." The distribution plan will be based on “time” and “cost." Some company division’s require the product to be delivered to the customer within four days. This time requirement, combined with how much product will be moving to the region where the customer is located, will impact decisions made for choosing ground, sea or air transportation. Small quantities considered less than a full truck load (LTL) takes longer to deliver than full truck loads (FTL). Full truck loads are direct point to point delivery. LTL modes involve many transfers (break-bulk) at truck terminals where re-routing occurs until the product is delivered to the end customer.

4.0 Shipping Unit Classification

The shipping unit is defined as the specific configuration of the product and package as a system. Generally, the shipping unit is the smallest complete unit that will be subjected to the distribution environment. The packaged product will fall into one of three classifications. These classifications are significant in understanding how transportation services are selected, what hazards will be acting on the product, how many times the packaged product will be handled, and determine which testing methods are appropriate.

The severity of the distribution environment upon the product is dependent, in part, on the method of packaging used. For instance, unitized loads receive less severe drops than individual, small packaged products. The test procedures in this manual are designed to evaluate the effectiveness of various packaging methods.

The shipping unit to be tested must be classified according to the following **Type** definitions. A product may have more than one classification if it is packaged for distribution in both single packs (Type 1) and bulk packs (Type 3),or palletized single packs vs. individual single packs. If a product does fall under more than one classification type, it will need to be tested in each of its configurations.

Type 1 - Single or multiple product, boxed and non-palletized, which can be carried by one or two people. An individually packaged product which could be shipped as a single unit to an end user is defined as Type 1, even if the packaged product moves in pallet load quantities during a portion of its physical distribution. These products can be exposed to warehouse conditions where long term (up to 6 months) static compression can be encountered. These products are most frequently distributed by truck in LTL modes and express delivery services. Typical vehicles are trucks, container or truck trailer on rail car, and airplanes.

This class also represents multiple, like units, combined in a single shipping container, typically non-palletized.

Figure 4.1 Examples of Type 1 Shipping Units

Some packages may have an **integral pallet for internal or customer handling convenience**, but the size and weight would allow it to be carried by two people. This kind of package should be classified as Type 1, not Type 2.

Occasionally, two or more individually boxed products will be bundled, strapped or palletized for shipment according to the specific system and options included in the order. In this case, the individually boxed products will be tested as a Type 1 shipping unit, as they could ultimately be unbundled and handled separately by a sales office, distributor or end user. The pallet load should be evaluated for container integrity under pallet loading and stacking to ensure that excessive container compression does not occur.

Type 2 - Single Product, Palletized. This class represents the individual product, packaged or prepared for shipment such that it would **only** be handled by mechanical equipment and could **not normally** be carried by two people. Type 2 shipping units could include individually palletized product (i.e., cushioned pallet) or a large cabinet type product shipped unpackaged which would not realistically be carried by two people. These products are most frequently distributed by truck in LTL modes, container or truck trailer on rail car, and air freighters.

Figure 4.2 Examples of Type 2 Shipping Units

Type 3 - Multiple Products, Unitized on pallets or slip sheets. This class represents multiple products which are unitized and shipped **only** on pallets or slip sheets. This classification would include “bulk packed” products. “Bulk Pack” packaging refers to a design which hold and transport multiples of the same product, shipped as a whole unit, on slip sheets and/or pallets. Unlike a pallet load of boxed units, where an individual unit could be withdrawn from the unitized load and shipped by itself, a bulk packed unit cannot be shipped in any other configuration. In other words, protection from the distribution environment exists only in the conglomerate bulk pack, as opposed to individual protection around each product. Bulk pack designs require mechanical handling and are usually shipped in Full Truck/Sea Load container quantities. These palletized loads can be exposed to warehouse conditions where short to medium term (up to 3 months) exposure to static compression can be encountered. These products are most frequently distributed by truck, rail cars, sea freighters and air freighters.

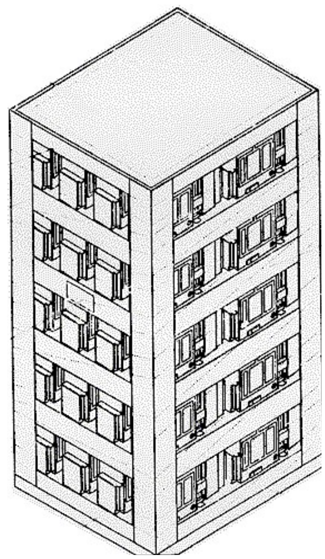


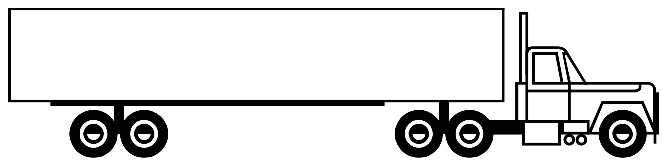
Figure 4.3 Drawing of a Bulk Pack

If the unitized load consists of individually boxed products that could ultimately be transported as single units, then the single boxed product must also be tested as a Type 1 shipping unit. Additionally, this product should also be tested as a Type 3 shipping unit. This is necessary due to the different kinds of stress and strain seen under one configuration versus another. For instance, in a bulk pack a product may support 100% of the compression load during storage, whereas, when the same unit is packaged, the outer container will support much of the compression load. Similarly, a drop test to a single product produces high acceleration forces, but a drop test of a unitized load from a lower drop height causes lower shock levels but produces higher dynamic compression forces. Testing only one of the possible shipping configurations will increase the risk of unforeseen damages in distribution.

Typical hazards for all three classifications include vibration, shock, dynamic compression, ambient weather conditions (temperature, humidity and precipitation), low pressure altitude effects, and particulates.

5.0 Transportation Environments

A transportation environment refers to the freight movement activities and the hazardous incidents and elements occurring during these activities. Freight movement activities are categorized into “modes” of transportation. Some modes impart hazards of the same type, but more severely than others. It is important to understand typical hazards and typical activities associated with each transportation mode.



5.1 Road Transport

This may be considered as the most universal transport mode, providing a door to door service in all parts of the world, whether by modern fuel powered vehicles or by animal or human drawn carts. At some time during the distribution cycle, companies moves virtually 100% of its products via this mode.

5.1.1 Inherent Hazards - Road

The main hazards of road transport are vibration, shock, and dynamic compression. The intensities of these hazards depend on road conditions, the vehicle’s speed, condition of the vehicle, methods of loading and unloading, and the total weight of the loads acting on the trailer’s suspension system.

Vibration measurements taken on trucks are higher in severity levels than those taken on trains, airplanes, and boats. There are three dominant forcing frequency ranges that occur on trucks traveling on modern (improved) road systems which are identified in Table 4.1.

	SOURCE	**FREQUENCY**
1.	Sprung Mass (everything on top of the main springs)	2 to 7 Hz Range (with 4 Hz center frequency)
2.	Unsprung Mass (everything beneath the bottom of the truck, predominantly tire frequency)	12 to 20 Hz Range (with 15 Hz center frequency)
3.	Structural Frequency (the truck body)	55 to 70 Hz Range

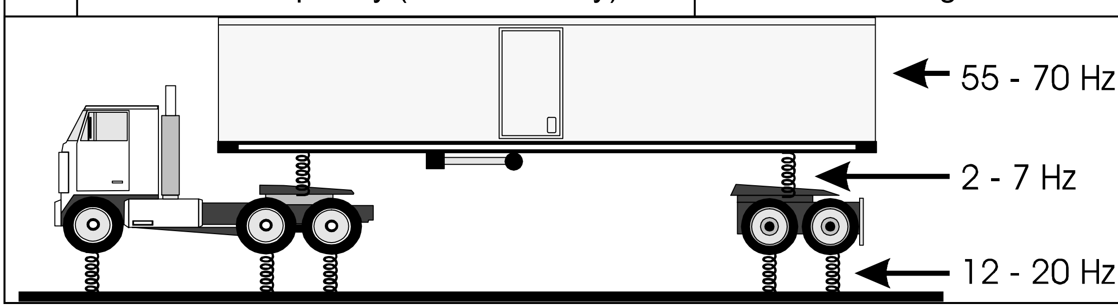


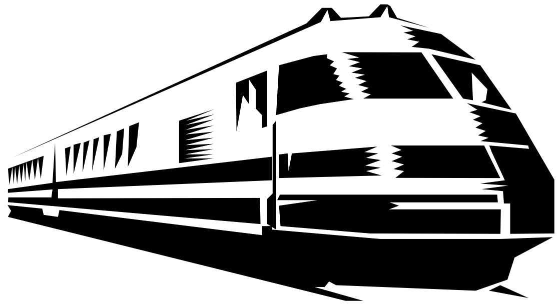
Table 4.1

These vibrations are transmitted to the freight from the truck's trailer bed, wheels and suspension. The engine and transmission will also contribute to vibrations transmitted to the freight. Measurements indicate that there is a continuous vibration acceleration level of 0.5g at the lower frequency. Design the packaged product to avoid any of the natural frequencies listed above if they can cause damage to the product. The vibration frequencies listed above should be accounted for when testing the packaged product if the product has a natural frequency in these ranges. A worse case condition would be a cushion design with the same natural frequency as a critical component that is sensitive to vibration, and both of these match one of the dominant forcing frequencies. This condition is know as stacked resonance.

Shock acceleration levels are random in time. Transient shocks occur when a truck hits potholes, expansion joints and railroad crossings. These shocks will cause products to jump off the floor and slam back down again. These transitory events overlay the dominant forcing frequencies that are often present. Transitory shocks can cause damage when freight is not properly blocked and braced. Stacked products, particularly those on top, can experience magnified acceleration levels as the energy is transmitted up through the load. The packaged products located in the middle and lower portions of a stack will experience dynamic compression. Collapsing could result if compression loads exceed the stacking strength of the container. This presents a danger of stack failure, where the top products could fall from heights of 80 inches (2.03 m) or more, inducing impact shock.

Trucks can be loaded one of two ways, LTL and FTL. LTL (Less than Truck Load) compared to FTL (Full Truck Load) presents a more frequent assault upon the product. LTL shipments contain a variety of loose freight that reduces good blocking and bracing by other freight. LTL shipments result in an increased need to handle the freight in cross docking (transferring from truck to depot to truck) operations. Cross docking also involves break-bulk operations (removing products from their secured positions either inside the trailer or on the pallet it shares with other products of the same purchase order). LTL inherently involves more handling, both manual and mechanical, as the trucker picks up and unloads freight throughout the planned route. FTL generally gives the Packaging Engineer the opportunity to influence the stacking pattern within the truck, as well as, to plan for specific package sizes to fill the container. It is important to utilize the space efficiently for FTL and sea containers because costs are fixed per container type and size.

For LTL, the interaction between goods carried inside the trailer is generally influenced by loading practices motivated by "high lading" economies. High lading refers to the practice of getting the most freight into the truck as possible to increase the point-to-point travel profits. The primary concern is dynamic compression caused by other freight placed on top of the product that bounces repeatedly from road bumps. Other considerations to consider are side impacts due to load shifting and heavy braking, and crushing from restraints (strapping, load bars, ropes, ...) that may be used to prevent freight movement. Random vibration can also be significant, leading to toppling of stacks and/or vibration induced scuffing of external graphics.

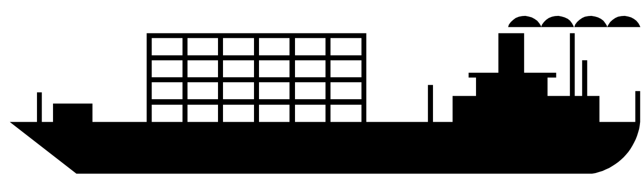


5.2 Rail Transport

Rail transport throughout the world has been favored for low cost ground transit of goods. Goods usually moved by rail are those described as "bulk" commodities, such as coal, oil, stone, ore, etc., since packaging is not needed to facilitate their handling. Rail transport is generally used as one "leg" of the journey the product will undertake in its movement toward the end customer. Since most end customers do not have private rail sidings, the final "leg" requires the use of a road transport service. The use of rail to transport packaged freight has declined in recent years due to the versatility of road transport on an improving public road network. Rail companies are utilizing container or truck trailer on rail car systems to help regain market share. This shipping method places truck trailers on top of flat bed rail cars. This truck-on-rail system provides an opportunity for road transport companies to take advantage of rail benefits over long distances.

5.2.1 Inherent Hazards - Rail

Modern rail systems impart low level vibrations. These vibrations are similar to the dominant forcing frequency ranges experienced during trucking. The exception is for the absence of the 12 to 20 Hz frequency range (no tires on a train). Vibrations are transmitted to the freight in response to the interaction between the rail car's wheels and the rail tracks. The vibration acceleration levels are about half the levels found on truck (0.25g vs. 0.5g). Shock is not the primary concern for rail transport. However, dynamic compression can be a problem due to improper blocking and bracing of the freight. The intensity of these hazards depends on the condition of the rails, and the speed employed during coupling, de-coupling, stopping and starting.



5.3 Sea Transport

This mode can cover quite a variety of traffic dependent upon certain features such as the size of rivers, inland lakes, canal systems, river channel enhancements and ocean distance between ports. This mode is applicable to all goods for intra-continental and inter-continental shipment. Sea transport is chosen as one "leg" of the journey when rapid delivery is not required. As with rail transport, the more popular choice of goods moved by sea transport are "bulk" commodities. Some ships are custom built to accommodate bulk products such as oil, ore or grain. Container ships are becoming more prevalent between major port cities. These ships are designed to haul “sea cargo containers” similar in size to truck trailers, but without the wheels. Some companies have been increasing the use of this mode of transport to feed postponement operations managed by our distribution centers. Using sea cargo containers gives the Packaging Engineer an opportunity to design a package to “cube-out” the container, much like a FTL condition. This focus on volume density can represent considerable dollar savings. Sea transport is usually charged by volume in less than container load or a fixed charge for a specific container size.

5.3.1 Inherent Hazards - Sea

Compared to other modes of transportation, sea transport (both inland waterways and ocean navigation) produces relatively lower risks of typical shock and vibration hazards. There are three main hazards to be concerned about.

- Exposure to high humidity (up to 100%) over long periods of time.
- Compressive forces where stacking heights of up to 102 inches (259 cm) in ocean containers can occur. Also, loose freight (in non containerized cargo holds) can be stacked to heights of 16 ft (5 meters) to 29 ft (9 meters).
- Low level vibrations originating from the engines and propellers.

During inland and port navigation, vessels can suffer appreciable impacts from contact with narrow locks, canal walls and wharf piers. During sea and ocean navigation, vessels can suffer from rolling and pitching events that impart side impacts to freight during load shifting. Some cargo containers are loaded with product at the dock, where rain, snow and other climatic hazards will contact the package. Container loading and unloading can also impart significant shock to the freight.

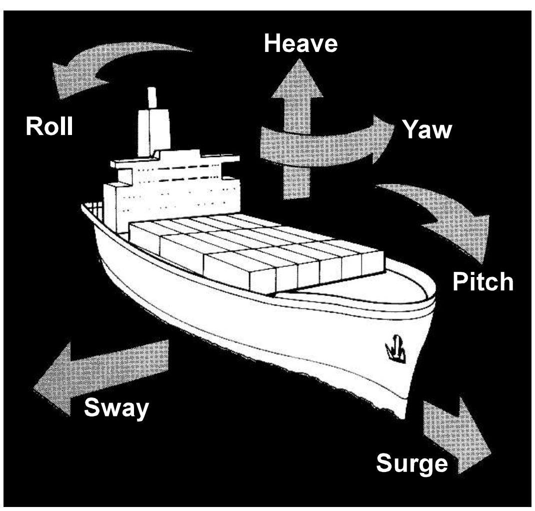


Figure 4.4 - A ship at sea may move in six different directions simultaneously.

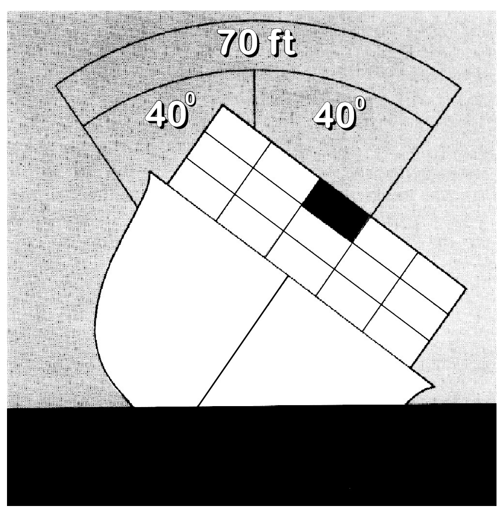
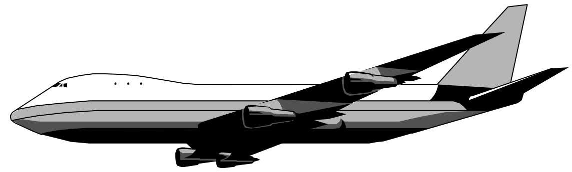


Figure 4.5 - This container (black) may travel seventy feet with each complete roll; as often as 7 - 10 times each minute.

5.4 Air Transport



This mode of transport provides the most rapid means of delivery, even though other modes must be utilized for the final door-to-door service to the end customer. Air transport is expensive and, therefore, is usually restricted to those goods that can benefit by rapid delivery. Companies utilizes air transport to meet product availability windows, generally 4 days, promised to customers. Air cargo is carried either by dedicated cargo aircraft (known as air freighters), or by most of the larger bodied passenger aircraft. Air freighters can accommodate large loads stacked on special "air freight pallets." A large variety of air cargo containers are also available to consolidate packaged goods inside. Lower deck freight services are generally less expensive than upper deck freight services. They also provide faster delivery schedules. In addition to regular air freighters, large bodied passenger aircraft can haul limited sizes of cargo containers and loose freight in their cargo hold, below the passenger level. Reference Appendix D for standard air pallet dimensions and size restrictions for upper and lower deck stowage.

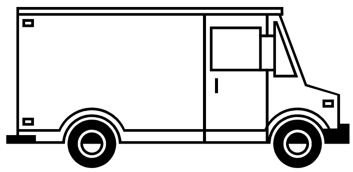
If the product is expected to utilize air shipment frequently in multiple quantities, designing a package size and pallet pattern to fit air pallet sizes can reduce exposure to damage. When volumes do not support full pallet loads, a freight forwarder can be used. Consider one experienced in air freight consolidation that can provide services to prepare the products on air pallets or in cargo containers prior to delivery to the airplane. Some do's and don'ts when designing an air pallet load are identified in Table 4.2.

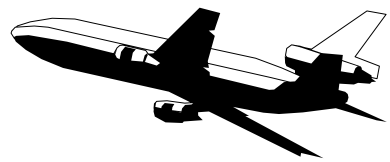
DO'S	DON'TS
Build the pallet load with corner and edge protectors.	Overhang products on pallet loads.
Use 2 way banding (to keep the load pattern in place when pushing occurs) or stretch wrap.	Use low compression box values. Expect heavy freight to be stacked on top of the product.
Use all available space to avoid other freight being placed in, around, or on top of the load.	

Table 4.2

5.4.1 Inherent Hazards - Air

Aircraft vibrations are generally higher in frequency, originating from the engines. These vibrations typically range from 100 Hz to 500 Hz in frequency, but have very low energy content. This is not much of a problem because packaging materials typically attenuate this range of forcing frequencies. Some aircraft holds are not pressurized or heated. Non-pressurized, non-heated cargo holds can present hazards to freight. The lack of temperature controlled holds can present temperature values less than 50°F (10°C) at 16,000 ft (4.88 Km) compared to 100°F (37.8°C) or higher at sea level. Rapid temperature changes can lead to condensation (and potential corrosion) accumulating on products when suddenly exposed to warmer more humid conditions. For some varieties of freight, these hazards can be serious, and must be mitigated by the packaging. Air cargo containers are usually oddly shaped and do not always hold squared pallet stacks. Know the air plane's height limitations. If the pallet load is too high, expect the pallet load to be broken down, manually handled and packed in any orientation to fit into the cargo space. Time available to unload and reload is short. The available space is highly maximized to obtain the most revenue possible per flight. Because time and space are at a premium, carriers promote rougher handling than other modes of transport.





5.5 Express Services

The movement of goods by an express service is one of the strongest growing segments of the freight delivery business. These services combine ground delivery and air transport to deliver freight around the world in several days or less. These services are set up to process freight of limited size and weight quickly. Table 4.3 references these restrictions.

EXPRESS SERVICE REFERENCE TABLE			
UNITED MAXIMUM SIZE =	GIRTH + Larger of Length or Width		
GIRTH (see figure 4.6)=	2*WIDTH + 2*DEPTH		
	MAX.	MAX.	MAX.
	Weight	United Size	Dimension
	Lb. (Kg)	in (cm)	in (cm)
FEDERAL EXPRESS: 1-800-238-5355	150 (68)	165 (419.1)	119 (302.3)
UNITED PARCEL SERVICE: 1-800-222-8333	150 (68)	130 (330.2)	105 (266.7)
AIRBORNE EXPRESS: 1-800-874-6663	150 (68)	108 (274.3)	45 (114.3)
U.S. POSTAL SERVICE: 1-800-222-1811	70 (31.8)	108 (274.3)	45 (114.3)
DHL: 1-800-225-5345	NONE	NONE	NONE
EMERY: 1-800-443-6379	NONE	NONE	NONE
BURLINGTON AIR EXPRESS: 1-714-752-4000	NONE	NONE	NONE
COMMERCIAL AIRLINES	72 (32.7)	62 (157.5)	NONE
American 800-433-7300	(LUGGAGE CHECK-IN LIMITS)		

Delta 800-221-1212	(LUGGAGE CHECK-IN LIMITS)
United 800-241-6522	(LUGGAGE CHECK-IN LIMITS)

TABLE 4.3

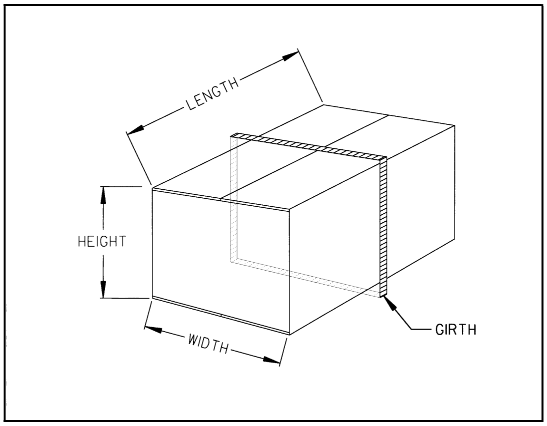


Figure 4.6

5.5.1 Inherent Hazards - Express

Hazards inherent to this transportation mode are shock, vibration, climatic conditions and sorting activities. Sorting activity includes potential damage caused by the conveyor systems. Handling personnel are usually on the lookout for accident prone packages. These include packages where the contents seem to be loose inside and those which are considered "non-conveyables." “Non-conveyables” include packages whose shape is round or one of its dimensions exceeds the maximum limit. Non-conveyable packages undergo special handling via carts to get them from one destination to another. Freight is categorized by size and weight. “Forklift handled products” are used to describe large (exceeding a length plus girth of 180 inches (457 cm)) and heavy freight (exceeding 150 lb. (68 Kg)). The term “manually handled products” is used to describe small and light weight freight. Most express service companies recommend the “Do’s and Don’ts” listed in table 4.4 to assist in the safe and rapid movement of the package.

EXPRESS SERVICE RECOMMENDED PRACTICES		
	Mechanical Handling	**Manual Handling**
Material Handling basics:	By standard fork lift trucks and pallet jacks	By one and two person lifting
Bearing Surface Weight:	Must be less than 100 lb. per square foot (4788 N/m^2)	N/A
Address markings:	Each piece should be legibly and durably marked with the name and address of the shipper and consignee outside & inside pkg.	
Package Shape:	Don’t ship irregular-shaped packages. Do Square off pallet load tops.	Over pack irregular-shaped packages in another box.
Closure & Retainment:	Don’t ship packages loose on skids. Do secure with banding, shrink-wrap, or stretch-wrap. Keep strapping away from pallet entry openings to prevent breaking by equipment forks.	Don’t use string, rope, household cellophane tape or masking tape to seal package flaps. Do use packing sealing tapes (plastic or reinforced paper).
Pallets:	Do use skids that match the size of the package base or the package layer pattern.	N/A
Wheeled Packages/Cases:	Don’t ship wheeled packages because they may exceed floor bearing weight and roll into other freight. Do secure wheeled packages to skids, enclose them in a box, or remove their wheels.	
Bin Containers:	Don’t ship packages with legs, feet or nesting devices because they may exceed floor bearing weight or puncture ULD containers, other packages or equipment. Do place these packages on a skid, enclose in a box/crate, or remove their legs/feet/nesting devices.	
Container Closure:	Don’t seal perpendicular to the flap seams. Do seal along the flap seam and down each side several inches.	
Box Material:	Don’t exceed the gross weight limits on box maker's certificate	

Table 4.4

As the package moves through an express service distribution network, it will experience shock and vibration of various intensities. Expect exposure to climatic conditions for up to several hours at any time including outside the airplane during unloading, reloading, and delivery truck activities. At strategic locations, packages are moved and sorted by a combination of manual handling and conveyor system process. This conveyor system method for the input, sorting, and output of freight is a common method of processing freight by all express service depots.

5.5.2 General Data

AIRPLANE: Express services use many plane models to move freight. The use of air freighters in combination with air pallets and air freight containers represents the typical movement of freight in-between the sorting centers. See Appendix D for size information.

GROUND TRANSPORT: Pick up and delivery is accomplished by the use of a small truck with a single person provided by the express service company. Packages and containers too large to accommodate this standard method must be specially handled according to the express services instructions.

STANDARD CONVEYOR SYSTEM: Packages weighing up to 75 lb. (34 Kg) will travel through standard conveyor sorting systems. The package size will be kept to a maximum of 36 inches (91.4 cm) in length or width and a maximum height of 25 inches (63.5 cm). The standard conveyor sorting system operates at heights of 25 to 30 inches (63.5 to 91.4 cm). The belt width ranges from 48 to 54 inches (121.9 to 137.2 cm).

HEAVY FREIGHT CONVEYOR SYSTEM: Packages weighing more than 75 lb. (34 Kg) will travel through the “Heavy Freight” conveyor system. The “Heavy Freight” conveyor sorting system operates at heights of 8 to 12 inches (20.3 to 45.7 cm).

5.5.3 Shock & Vibration on Belt Conveyor Systems

A. SHOCK: Shock occurs during the loading and unloading steps and during conveyor activities such as placement onto the conveyor, encounters with diverters and collisions with other packages at collection points. When packages are unloaded from airplanes and trucks to be placed onto conveyors, they are subject to rough handling. Sometimes package handlers will throw the package into carts or onto the conveyor. Tossing several feet and drops of varying heights can occur frequently during the rush to process the freight quickly.

B. VIBRATION: Vibration on conveyors can be caused by several factors. The most prevalent factors are:

1. Unbalanced Pulleys - This is not a major vibration hazard in the distribution system.

2. Roller Chains on Sprockets Not Perfectly Aligned.

3. Direct Shaft Connected Reducers Not Properly Aligned.

4. Lacing of Belt Impacting Carrying Rollers and Support Bars.

C. HORIZONTAL ACCELERATION: Packages on belts are subject to horizontal acceleration as a result of sudden starts and sudden increases in velocity.

1. Sudden Starts - (See Figure 4.7) Sudden starts occur when packages are inducted into the automatic sort (AS) lines. Sorting information is usually read manually when the package is standing still and keyed into the computer controlling the diverters. The automatic sort (AS) belts can run at speeds between 300 to 500 feet (91.4 to 152.4 m) per minute. The keyed package must be diverted onto the AS belt from a stand-still condition.

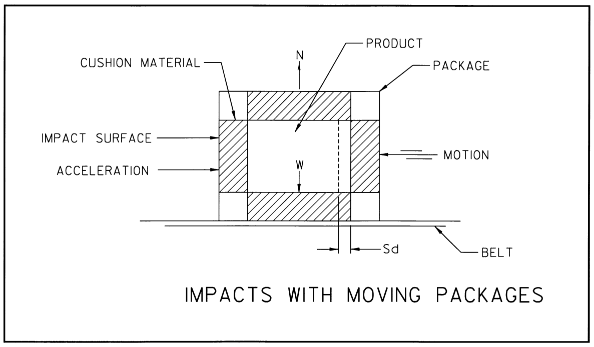


Figure 4.7

2. Sudden increase in velocity - When packages enter the automatic sort lines from the belt conveyor lines running at relatively slow speeds, they are closely spaced together. They must be spread apart due to required spacing between diverters. Increased spacing is achieved by the difference in belt speeds of the sort belt and the slower feeder belt. When the package moves from the slower speed belt to the higher speed belt, it experiences a sudden acceleration that is felt by the package contents.

D. IMPACT WITH DIVERTERS BLADES: Packages are diverted off belts via blade type diverters. Diversion generally occurs by two methods, by a stationary angled blade and by a push/pull diverter used for sorting.

1. Stationary Angled Blade (See Figure 4.8) - Packages conveyed on the belt will impact the stationary diverter positioned at an angle to the direction of the belt travel. After the package impacts the diverter blade, it is guided off the belt either

onto a slide or onto another belt for further conveying. The impact on the package depends on the speed of the belt, the angle of the diverter, resiliency and weight of the package.

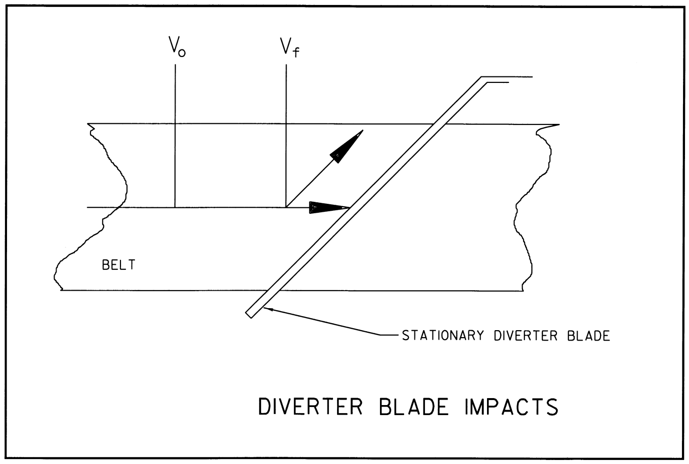


Figure 4.8

2. Push/Pull Diverters (See Figure 4.9) - Diverters moving packages off a moving belt may be a push type (pushing the package off the belt) or a pull type (pulling the package off the belt). The force of impact between the diverter and the package depends on the speed of the belt, the speed of the diverter, the weight of the package, the direction of motion of the diverter when it contacts the package, the surface of the diverter blade (bare or padded) and the rigidity of the package.

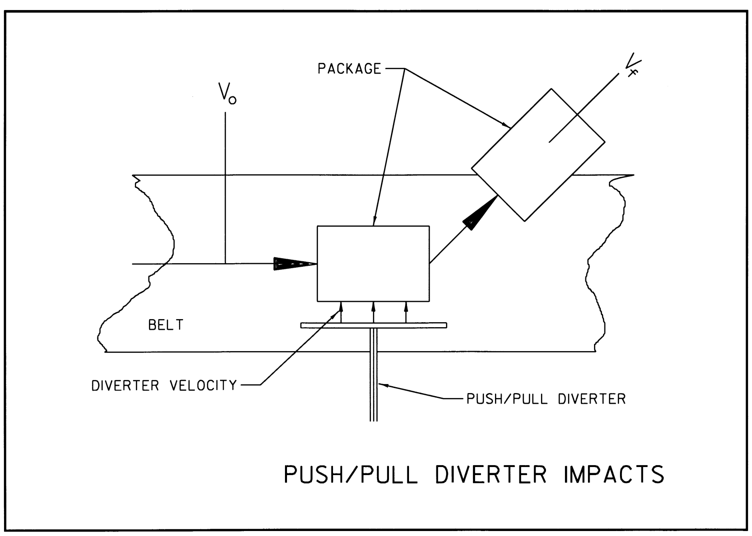
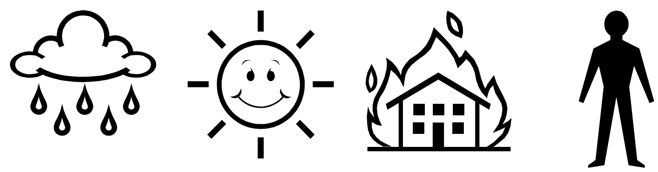


Figure 4.9

E. IMPACT WITH OTHER PACKAGES WHEN MOVING DOWN SLIDES AND CHUTES: Packages will often negotiate turns on conveyors by sliding down curved chutes from a higher level to a lower level. During sorting, packages will be pushed off belts either manually or by diverters. The surface onto which the package is pushed is usually a declining surface (slide) which causes the package to slide to a lower level for further manual processing. Space is usually a precious commodity inside the processing warehouse. Steeper slides take up less space. The steeper the slide, the more it causes the package to accelerate on the decline, imparting higher impact shock on it and on other packages as they accumulate at the bottom of the slide. For this reason, the declining angle of slides is usually limited to about 18 degrees. In cases where it is necessary to increase the declining angle beyond 18 degrees, velocity limiting baffles are often used. These baffles limit the velocity of the package as it descends the slide. On chutes, decelerating rollers may be used to slow down the package. These are rollers which have brakes applied to them so that they will slow down the package as it passes over them.

6.0 Distribution Channel



The combination of categorizing the product type and choosing modes of transportation characterizes the distribution channel. All modes of transport have limiting sizes of their respective containers. Keep in mind that different countries have different sized containers and vehicles for the same transport mode.

It is possible to sometimes reduce the severity of the hazards that are present in each transport mode. This can be accomplished by package design features such as dimensions, mass, shape and the presence of handling aids (hand holes, handles, unit pallets) and how the package is consolidated into pallet loads.

The utilization of freight containers can also reduce how hazards act upon the packaged product. Freight containers can be a large box fastened to a pallet or the rental of standard metal containers (various sizes available from freight forwarders associated with air and ocean shipments). Large freight containers enable the transport of small packages by all forms of surface transport to occur without intermediate handling of the contents. Compared to single unit shipments, freight containers can drastically reduce the hazards of vertical impacts, they minimize stacking hazards to those available inside the container and they reduce the loads superimposed during vibration. Freight containers also simplify customs inspection, reduce pilferage opportunities, and lower the cost of freight insurance.

In addition to the hazards inherent in the mode of transport chosen, there are common hazards that may be classified as:

Loading, sorting and unloading
Storage or warehousing
Climatic
Biological

Contamination

6.1 Loading, Sorting & Unloading Hazards

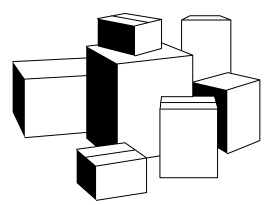
This activity occurs throughout the distribution chain. The intensity of the hazards associated with this activity depends partially on the size and weight of the package and the handling equipment available.

In developed countries, these hazards are reduced by the more frequent use of mechanical handling devices and the practice of assembling goods into unit loads or freight containers. Breaking down bulk loads presents the greatest exposure to damage because this activity is manually performed.

The principal hazard encountered during loading, sorting and unloading is that of vertical and horizontal impacts when the goods are dropped or thrown. The severity will depend on the height from which the goods fall, their weight, position (orientation of package) in which they fall and the nature of the impacting surface.

Horizontal impacts can be found with swinging, rolling of cylinders, throwing goods, and freight marshaling by forklift trucks when pushing and placing freight.

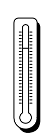
Piercing, snagging or compressing by handling equipment such as grabs, hooks, nets or fork lift trucks are other hazards that may be encountered. These are extremes and cannot always be avoided.

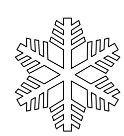


6.2 Storage and Warehousing Hazards

Compression is the primary hazard influenced by the activity of stacking loads. The severity of this hazard will be influenced by the way the stack is built, the period of time over which the stack is maintained, relative humidity, and temperature. Uneven support of the floors (causing leaning stacks) or racks (causing concentrated compression on small portions of the bottom surface) may be an additional hazard. Storage and warehouse areas may or may not be climatically controlled. Exposure to heat, frost and humidity (condensation) can occur if no climate controls are employed. High humidity can be the most serious hazard acting on the compression strength of a corrugated box, even if it is well designed. Studies show cyclical temperatures and humidity changes can have dramatic effect on box compression strength.

6.3 Climatic Hazards



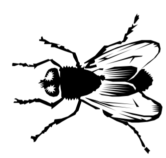
There are several hazards associated with climate. These include exposure to precipitation (rain, snow or other variations of precipitation), temperature and humidity (prevailing, changing and cyclic) and exposure to light or solar radiation. Liquid water may present itself as rain, condensation or ship sweat (condensation on cold ship walls).

Temperatures (both high and low) and wide fluctuations in humidity can be hazardous to certain goods. High ambient air temperatures and fluctuations affected by direct sunshine in vans, sheds, etc., or close proximity to heating systems and boilers can occur. A United States Government study of truck containers stored in the Arizona Desert indicated that inside air tempertures can be in excess of 150º F (65º C) for a short period of time, and in excess of 130º F (54º C) for up to 7 hours per day. Low temperatures may occur due to ambient air or transportation wind. Solar radiation or exposure to light (usually the ultra-violet region) can also be hazardous to certain goods by causing chemical property changes to sensitive parts. Radiation can also fade artwork printed on cartons, and weaken hydrogen bonds in paperboard cartons. It can also warp wood shipping containers.

Finally, the amount of water vapor in the atmosphere causes goods to adjust their moisture equilibrium content. This may mean loss or gain of moisture content to the atmosphere. Salty sea water may also influence the start of corrosion. Desiccant may be needed to help control this problem. Some ESD (Electro Static Discharge) packaging material properties may also be adversely affected by very high or low humidity, so care must be taken when packaging ESD sensitive parts.

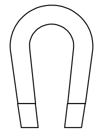
It is important to understand that all the climatic hazards affect both the product and the packaging. Packaging degradation due to climatic exposure must be anticipated and compensated for in the package design process.

6.4 Biological and Social Hazards

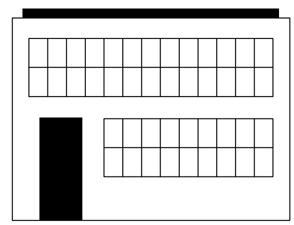




Biological hazards may be micro, such as bacteria, molds and fungi, or macro such as insects, rodents or human beings. Micro hazards usually require favorable climatic conditions for micro organisms. These conditions include humidity values higher than 70% and temperatures within 68 to 86 °F (20 to 30 °C). Macro hazards for insects require humidity conditions higher than 50% and temperatures within 59 to 86 °F(15 to 30 °C). Macro hazards from rodents require suitable food sources or nesting materials. Macro hazards from people may become prevalent when the business atmosphere such as poor security is conducive to sampling, pilferage or tampering with the freight. For international shipments, customs personnel have the right to inspect and/or hold packages. Inspection may include opening (and sometimes damaging or destroying) the package. Other human hazards can be the protection of goods from unsupervised children.

6.5 Contamination



This class of hazards can occur infrequently. They can be devastating to some types of products. Contamination can be caused by close proximity to other goods or degrading atmospheric conditions. Contamination can be foreign odors, air borne chemical tainting, electrical discharges, ionizing radiation, and magnetic field emissions, and dusting from corrugated.

7.0 Distribution Channels

A company's diversified business units provide many different products to many different customer types. Common to all distribution channels is the complexity value measured by the number of handling cycles and the modes of transportation used. Three distribution channel scenarios are presented for the purpose of understanding how complexity affects the exposure to "hazards" that will be acting on the product. The final package design may need to be adjusted accordingly.

7.1 Manufacturing Site to End Customer

A direct ship-to-customer distribution channel can be easier to define, but not less severe than more complex distribution channels. To determine whether the product falls into this scenario, begin by asking the following questions: What shiiping unit classification fits the product? Who is the customer? Where are the customers typically located? Are they far away (worldwide distribution) or local (regional distribution)? Is it safe to assume that the duration of the shipping period is shorter than 14 days and that the minimum handling cycles can be as low as 6?

7.2 Manufacturing Site to Distribution Center to End Customer

This scenario is more complex, containing more handling cycles and warehousing hazards. Warehouse handling, storage, and retrieval activities introduce more potential hazards to the product. Questions to ask include the following: What shiiping unit classification fits the product? Who are the customers? Where are the customers typically located? Are they far away (worldwide distribution) or local (regional distribution)? How long can the product remain at the DC? What are the DC’s storage conditions (stacking height, temperature, humidity, etc.? Will the DC or VAR (Value Added Reseller) remove the product from the package to perform some value added service? Will localization be performed through a slot in the box? How likely will there be a need for rework that will require the removal of the product from the package?

7.3 Manufacturing Site to DC to Customer DC to Store to End Customer

This scenario is typical in the “retail” or “consumer” market place. A complex, multi-handling and storage scenario will come to fully bear on the products. Begin with understanding what shiiping unit classification fits the product? The product may fit more than one category as it moves through the distribution channel. What are the warehousing hazards and limitations at both the company and the customer’s DC? Each warehouse handling, storage, and retrieval activity will bring additional time and hazards to bear on the product. How long can the product remain at each DC? What DC storage conditions (stacking height, temperature, humidity, etc.) will the product face? What are the typical “store” conditions (storage, display, delivery services, etc.). Who are the end customers? How will the end customers take the product to its operating place (home or business)?

7.4 Other Distribution Channels

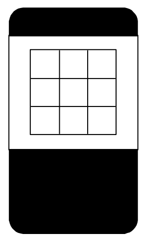
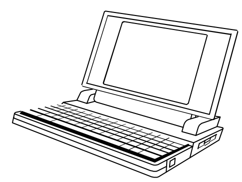
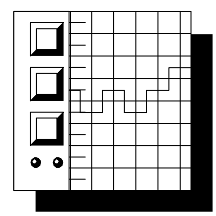
Some of the business scenarios use distribution channels other than those discussed above or in combinations. In Customer Support for example, there are several possible distribution channels for replacement parts, exchange assemblies, and whole units.

"Drop ship" refers to a manufacturer (Division or OEM) sending the product directly from the point of manufacture to the customer or to a designated location, such as a sales and service or repair facility. The origination and destination points can be practically anywhere in the world. Any manner of transportation mode and multiple transfer points may be used. The "drop ship" process may include single unit or bulk packaging. In the "exchange" process, dealers or customers sometimes must obtain packaging materials and choose a transportation mode in returning the product to the company or to a designated repair location. This can result in a variety of packing and transportation modes, including common carrier and express service such as UPS or FedEx. In developing countries, this may need special attention to assure product protection. Increasingly, whole units are being shipped to and from customer sites and from support repair facilities via third party courier services. Sometimes the transfer point is a drop box located along a street in a busy section of the city. Often, service units will be transported in automobiles, station wagons, and vans between the customer location and the pickup/drop points.

It is recommended that product divisions work closely with packaging engineers at Support Materials Organization to assure the safe and economical service packaging of their product's replacement parts, exchange assemblies, and whole units.


8.0 Warehousing & Storage

Main warehousing activities for finished goods occur at our major distribution centers and affiliated third party operations. Expect the pallet loads to be stacked up to 180 inches (457.2 cm) for periods up to 6 months. In some cases the stack heights and storage times may be higher. Distribution centers located in tropical regions can experience high humidity in excess of 80%.

9.0 Measuring the Environments

It is important to understand the relationship between hazards encountered in the distribution environment and the effects they have on the product in developing a package design and testing strategy. Measuring distribution cycles with portable instruments can provide detailed, specific information on hazard intensity levels acting on the packaged product. These recorders are able to capture shock pulse data, and calculate the supposed drop height associated with the pulse. These recorders are most helpful when a controlled (fully managed point to point deliveries) distribution channel is used. The information recorded can be used to optimize the package design to pass a customized testing plan based on data recorded.

9.1 Equipment

Several companies have developed self-contained instruments which measure drop heights, shock levels, temperature and humidity. Currently (1996), two companies are considered the technological leaders. They can be reached for current product information at:

Lansmont Corporation
21c Mandeville Ct,
Monterey, CA 93940
USA
Phone: 831-655-6670
FAX: 831-655-6606
Web: http://www.lansmont.com

Instrumented Sensor Technology, Inc.
4704 Moore Street
Okemos, MI 48864
Phone: 517-349-8487
FAX: 517-349-8469

9.2 Collection Techniques

When setting up the environmental study plan, it is important to provide for recording adequate information on a uniform basis. This enables useful comparisons to be made of data obtained at different times and under various circumstances.

Refer to ISO 4178-1980 (E) "Complete, filled transport packages - Distribution trials - Information to be recorded" to structure the gathering and reporting of information in the Measurement Plan.

9.3 Data Collection Precautions

The data collected by the recorder could be misleading. Completely understand the principles being used by the recorder to gather and store data. Know the limitations of the equipment. Limitations, inaccuracies in data calculations and variations in instrument calibrations can compound errors and reduce the effectiveness of the data. The following are some of the important limitations of most data recorders:

1. Drop Height Calculation Algorithm: Make sure the recording instrument does not treat velocity change as a vector. Instead, the algorithm should vectorally add the acceleration, and then determine the drop height from the resultant pulse. Very few recorders do this.

2. The Problem of "e": Some instruments require the user to supply the value of e, the coefficient of restitution. This can be dangerous, since e is very dependent on the impact surface. Large errors in drop height calculation can be made if the value of e is only off by .1 or .2 (where e has a value between 0 and 1).

$$\Delta V = (1 + e)\sqrt{2gh}$$ *where e = coefficient of restitution*

3. Pulse Duration: Most recorders define the shock pulse duration by “cutting off” the first and last 10% of a pulse (based on the peak acceleration). There are some problems with this. First, the product/package will be exposed to all of the energy, not just the amount left after trimming. Filtering algorithms using FFT (Fast Fourier Transform), are dependent on the data duration. Changing the pulse duration can in some instances give misleading data when it is filtered.

4. Edge/Corner Drop Algorithm: Measuring true drop heights from edge and corner drops is very complicated. The three angles present in a corner drop, or the two angles present in an edge drop, are critical for a correct calculation. Very few, if any, algorithms and accelerometers are able to take these into consideration. Therefore, it is usually not possible to accurately demonstrate what the drop height was from an edge or corner drop.

5. Sampling Errors: Because of limited memory in any recording device, measurements are only made every few milliseconds, and the pulse is later reconstructed from a series of unconnected points. This can result in “missing” the peak of a pulse, because the sampling was taken just before and just after the peak. Depending on the frequency of collection, gross errors can be introduced.

6. Accelerometer Errors: Every accelerometer will have accuracy errors and transverse sensitivity errors. Error values as small as 2-5% can compound and give misleading data.

For the most accurate results, choose a data recorder that uses a “Zero G” channel. “Zero G” channel recorders depend on sensing the time duration a package free fall to calculate drop heights. To date, these are the most accurate recorders available. However, even these recorders have limitations, such as not indicating whether the package was dropped in a free fall, or impacted from the side. Also, the problem of measuring drop height from a corner or edge drop remains.

Acceptance Criteria & Test Levels (section 4)

1.0 Scope

The product and packaging system must provide acceptable levels of product protection and storage integrity. The scope of this section is to provide the packaging engineer and the product development team a basis for determining what constitutes damage or failure of the package and/or product, and guide them in establishing a test level.

2.0 Purpose

The acceptance criteria and test levels described in this section are intended to guide the product development team through the process of establishing package performance criteria. To ensure that packaged products can survive the rough handling they may experience in the normal distribution environment without damage, an appropriate test level is required to keep product damage to a minimum. Since Hewlett-Packard manufactures a variety of products which range in weight and price, the determination of the appropriate test levels can be a complicated business decision.

This section is aimed at identifying some of the key factors that must be considered when developing the package performance acceptance criteria and test levels. Product development teams designing for specialized markets or distribution channels may want to modify the list below to include additional factors which are particularly important for their products.

3.0 Acceptance Criteria

The responsible engineering organization must establish acceptance criteria prior to testing. The acceptance criteria must be suitable for their purpose, considering the required condition of the product and package upon receipt to the final customer. It is advisable to compare the type and quantity of damage that occurrs during package testing with the damage that occurs during actual distribution and handling of products whose shipping history is known or with test results of similar containers.

Examples of some general acceptance criteria are as follows:

- Criterion 1 - Product is damage-free and functions to specification.
- Criterion 2 - Package continues to maintain product position.
- Criterion 3 - Cosmetic areas are not degraded.

Generally, the appropriate acceptance criteria means the container's contents are suitable for normal sale and use at the completion of testing. Detailed acceptance criteria may allow for accepting specified damage to a product or its package. The form and content of acceptance criteria may vary widely in accordance with the particular situation. Methods may range from simple pass-fail judgment to highly quantitative scoring or analysis systems.

3.1 Damage

3.1.1 Product Damage Product damage can be any condition which causes the product not to meet its performance test specifications and/or cosmetic damage which makes the product unacceptable for sale to the customer. It is recommended the same standards for final inspection during manufacturing be used to determine cosmetic damage.

Cosmetic damage caused by test preparation such as mechanical fixturing, instrumentation, and prior handling should not be considered a failure.

Structural damage can be defined as any part which is detached, loose, fractured or deformed beyond manufacturing tolerances. No conductive particles should be present due to abrasion. In summary, the product should be able to meet all data sheet and manufacturing specifications and tolerances after testing.

3.1.2 Package Damage. The package's purpose is to absorb or modify the energy imparted by the environment, to sustain ordinary degradation as a result, and to protect and preserve the product in its original or undamaged condition as defined by the acceptance criteria. Thus, some package degradation is expected and is acceptable. Unacceptable package damage can be defined as, but is not limited to: (1) any change in package condition that results in product damage, (2) inability of the package to contain the product in its intended position, (3) cosmetic or structural damage requiring repackaging at a distributor's location. Refer to Table 5.1 for examples.

Table 5.1 Examples of Acceptance Criteria for Containment Type Damage

SHIPPING UNIT TYPE	DAMAGE LOCATION	UNACCEPTABLE PACKAGE DAMAGE	EXAMPLE	ACCEPTABLE PACKAGE DAMAGE	EXAMPLE
Type 1 (Small boxed Product)	Container (External)	- Any rupture to the extent that it can no longer contain or support the product. - Compression damage from a palletized load that creates unstable pallet loads. - Failure of closure such that one or more flaps are free to open or cannot support the weight of the product. - Serious cosmetic or aesthetic deterioration. - Carton carrying device failure that creates a safety hazard.	- Glue joint breaks open and exposes internal contents. - Crushed cartons leading to an unstable pallet load which creates a safety issue during storage or handling. - Tape, snap-lock, or fastener failure compromising containment. - Delamination, discoloration, or illegible product graphics. - Hand hole or handle failure .	- Localized ruptures of edges from impacted corners. - Compression damage from a palletized load, but the pallet load remains stable. - Localized failures in closure in area of impact (carton is still effectively closed.). - Dents, dirt, small punctures from handling impacts. - Carton carrying device which tears or cracks, but maintains structural integrity.	- Edges or corners have small localized cracks/ruptures. - Minor compression which is supported by internal package or product support, or corner pads and stretch wrap. - The tape splits across bottom edge. - Dented corners, dirty flat panels, small partial carton punctures. - Handle corner tearing.
	Cushioning (Internal)	- Failure of bonded joints or surfaces which results in internal packaging to lose original configuration. - Fractured or deformed material which no longer maintains product position. - Product contamination or abrasion from cushioning resulting in cosmetic or functional defects.	- Laminated material separation. - Cushioning deteriorated to a point that the product is no longer held in its intended position or it can not continue its protective funtion. - Topcase texture worn and contaminated with foam powder.	- Fracture or permanent deformation that still permits internal packaging to maintain product position. - Product contamination from cushioning not resulting in cosmetic or functional defects.	- Cracked and crushed ribbing. - Loose foam beads or pulp fiber on the product.
Type 2 (Large Single Product Palletized)	External	- Non-functional pallet. - Ruptured wraps, bands, clips, or strapping. - Fractured bolts, fastening systems, or other hardware used in pallet construction which are beyond their usable function or create a human hazard.	- Protruding nails or bolts, or sharp wood sections.	- Splits, cracks or breaks in wood members that do not degrade its function. - Loose stretch wrap, banding, or fasteners.	- Cracked stringers or blocks.
	Internal	- Same as Type 1 internal.		- Same as Type 1 internal.	
Type 3 (Multiple Product Unitized)	External	- Same as Type 2 external. - Unitization method (i.e., straps, stretch wrapping) allows individual products to leave the load. - Unusable slip sheets.	- Immovable slip sheet due to torn tab, product shifting.	- Carton or load shift, where carton edges are no longer aligned but load configuration is stable for transport. - Torn slip sheets, bent or curled but usable.	
	Internal	- Same as Type 1 internal.		- Same as Type 1 internal.	

Note: Accumulative testing of one container may result in unacceptable damage. Please keep in mind that it is extremely unlikely that any one container will experience all the distribution elements tested for in this series. Therefore, at the engineer's discretion, it is acceptable to change out the packaging materials some number of times during testing; the product may also be changed.

4.0 Test Levels

The recommended level of test intensity is based on the probability of distribution hazards. A higher or lower assurance level may be chosen if the recommended levels are too mild or severe for the product's known distribution channel. Please note that a more severe test level can be used to lower probability of damage occurrence but usually means higher packaging and logistics costs.

Levels specified in each test of section 7 are based on experience and industry/competitors' practices. The authors of this guideline, along with many other electronic companies, have tried to set realistic test levels which would protect the product during normal shipping, storage, and handling. Depending on the distribution system used for any product, it may be prudent to increase or decrease the test level for any test.

Examples are:

1) Overnight express shipping environments. There is evidence that 70 lb. (31.75 kg) packages may experience drops of 36 inches (91.44cm). Therefore, drop levels should be increased for heavier products which will be traveling through this type of environment. Expect exposure to climatic conditions for up to several hours at any time (including outside the airplane during unloading and reloading and during the delivery truck activities).

2) Third world countries. Due to the lack of good roads and sophisticated handling equipment means products may be transported in any orientation, even on animals or pull cart. Therefore, all test levels should be increased and the packaged product should be tested in all orientations.

3) Unitized/Palletized loads. No individual handling of products occurs and there is low probability of single drops. Therefore, drop levels may be decreased.

5.0 Example a Test Report Form

Cover Sheet

Date:	4/26/96	**Number of Units:**	5
Product:	Denali (OfficeJet)		
Serial Number:	PP0 -82, 86, 95, 47, 57		
Entity Name & #:	SDD PL6K Division - site 1100		
Phase:	Production Prototype	Mfg:	Lab: PP0
Conducted by:	Jose Avila		
Test Requester:	Rod De Gesero	Extension:	4362
Product Mass:	13 lb. (net) 17 lb. packaged	(6kg/8kg)	

(Check one)		
	x	Type I - Product will be boxes, not palletized.
		Type II - Will be single, palletized product.
		Type III - Will be multiple products, palletized.

Tests Performed

Test		Test	
Random Vib.		Rolling Impact	
Sine Vib.		Ramp Clearance	
Impact	x	Humidity/Temp.	
Compression		Slip Sheet Tab	
Stability		Field Shipment	
Tipover		Altitude/Decompression	
Layover		Rain	
Strapping		Other	

Test Purpose

(Why are these tests being conducted?)

To test the present packaging design with the PP0 products. These tests will validate the packaging to procure tooling.

Failure Definition

(How is success or failure measured?)

Product Failures

External

The unit has cosmetic or structural damage to end caps, door, rear and front panels. The input paper trays (packaged separately) are cosmetic or structural damaged. The output tray is dislodged or cosmetic or structural damaged.

Internal

Carriage has lost containment in service station. Pen cable damaged (cut or dented). Slider rod height out of specification. (Contact Olev Tammer). Paper Detect sensor dislocated from position. Starwheels and springs loose, missing, dented. Paper feed tray springs bent or broken. The Print Mech (PM) straps must maintain straightness. Power supply, speaker, torroid must maintain positions.

Functionality - Unit must function (scan, copy, and print) equal to baseline samples from pre-testing.

Packaging Failures

External - Box containment compromised. Box flaps or glue tab failures.

Internal - Foam broken, and unable to hold product and be re-packaged after testing. components (pens, cable, trays, LIU) not held in position. Scanner contaminated with packaging debris.

Deviations & Notes

Impact testing was as follows:

1. Each unit was dropped on 6 faces. The foam was replaced.
2. Each unit was dropped on 8 corners. The foam was replaced.
3. Each unit was dropped on 12 edges. The foam was replaced.

This testing deviates from 762.

Summary and Conclusions

(Was the Test Purpose met? / What's next?)

The units and packaging did survive the impact testing. There were no defects at 36”. PP0 82 was dropped from 42” and unit received structural damage to PM chassis, creating a failure. The unit will be further tested in shock testing to uncover the true weakness of the PM (print mech.).

Based upon this testing foam tooling for PR will be initiated for the June build.

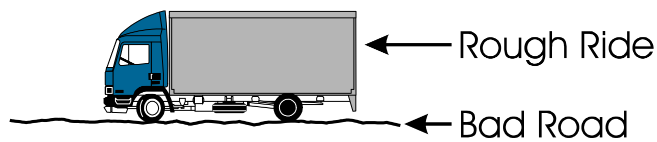
Test Rationale & Meaning (section 5)

1.0 Introduction

This section will explain the rationale for the tests and limits called out in section 7. Each test type will have the following items:

- Rationale for the test
- What happens in the real world
- What the test is trying to simulate
- Why the test should be conducted
- Test compared to real events
  - Are the test levels higher
  - Are the tests accelerated
- Comparison of test results to real events - history

2.0 Rationale for Tests



2.1 Random Vibration - *Recommended*

Rationale for the test: All packaged products will encounter some kind of transportation and handling, and therefore will be exposed to some levels of random vibration. Products may become damaged due to resonant frequency vibration excitation of spring/mass components, fatigue of velocity dependent components, and damage to surface parts because of abrasion. Vibration may also separate stacked loads, and cause units to shift and possibly fall off stacks. Most, if not all, vibration experienced in transportation does not consist of perfect sine waves, but of some “random” mixture of frequencies and amplitudes. Random vibration testing can be used to observe the interaction of the internal and external product components, and the packaged product.

What happens in the real world: Products shipped by truck, air or rail will experience vibration from several sources, including motors, tires, road surfaces, etc. As the product moves through the distribution channel, the package/product will be exposed to vibration of many different frequencies. This phenomena is evident from a quick survey of transportation environments. The major sources of vibration from truck transport include the suspension, the truck bed frame, tires, and road surface profile. For air, the engines and tires provide the major vibration inputs. Rail cars experience vibration due to suspension, track layouts, and conditions. Generally, all initial sources of vibration are excited at the same time, in a specified order, based on the source of input (driving over a pothole, for example). Even though the sources and frequencies of vibration are somewhat predictable and known, their combined effect produces a “random” signal, compared to a pure sine wave. It is important to note, however, that there will almost always be several dominant forcing frequency ranges that underlie the random signal, which are always present. In the case of trucks, because of the suspension, wheels and structure, inspection of the random signal will show dominant amplitudes for frequencies in the ranges of 2-7 Hz, 12-20 Hz and 55-70 Hz. Most vibration related damage is caused by these dominant frequencies.

What the test is trying to simulate: Random vibration tests attempt to expose the product/package to the same vibration energy envelop that would be found in a truck trailer bed. Power Spectral Density (PSD) plots input frequency and acceleration data into controllers, which drive the base of the vibration table. By testing the packaged product on the vibration table, it is hoped the same inputs found in real world situations are transmitted to the package in the lab.

Why the test should be conducted: All products experience vibration during shipping, and therefore the test is necessary. Despite some serious limitations (described later), this is perhaps one of the most useful package tests to perform. Since most transportation vibration occurs randomly, albeit overlaid on top of the dominant frequencies present for the particular mode of transport (see above). The test is useful for uncovering potential weak points in the product, and/or package design, and gives pass/fail feedback for anticipating performance in the distribution channel.

Test compared to real events: Random vibration, defined by a PSD plot, is an accelerated test. Since PSD plots are generally constructed from some kind of collected data, the signals inherently have some level of validity; namely, the frequencies and amplitudes for that particular shipment. The PSD plot used to drive the vibration table should reflect higher G^2/Hz values near the dominant frequencies for a particular transport mode. However, it is important to keep in mind the following limitations:

1. Exclusion of spikes. PSD plots are calculated using RMS Gs (Root Mean Squared) data, therefore acceleration peaks are averaged out of the signal (such as the shock due to a pothole). Some RV controllers are able to add these spikes, if so desired.

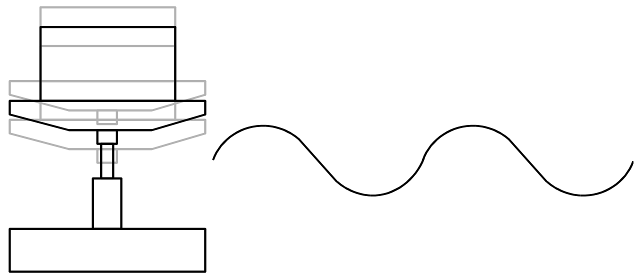
2. Editing the original signal. Since random vibration testing is an accelerated test, the quiet parts of the original captured signal are removed. This leaves only the more severe levels of shock, which is different than what was actually experienced. It is difficult to decide what to keep and what to remove, since if you keep quiet parts with lower G levels, the PD (Power Density) decreases in intensity.

3. Random mixing of sine waves. Random vibration controllers do not mix the frequencies in the order they naturally occur. This is because the PSD plot is only an "ingredient list" that tells the controller what frequencies and what amplitudes to include. It does not tell the controller in what order to mix them, it is done randomly. This is important, because there is a natural order, the various sources of vibration are all excited at the same time (the suspension of a truck, the tires, and the structure are all excited at the same time as they move over a pothole). Since they are excited at the same time, they are all mixed in-phase, not out-of-phase, as the controller mixes them.

4. Test time in the lab versus actual road time. There is no correlation for how much lab testing recreates actual road time. The very nature of how PSD plots are generated excludes any direct or indirect correlation. A common way to overcome this is to allow

testing for as long as needed until damage similar to that found in the field is recreated. Based on this, the lab can begin to set minimum pass/fail test parameters for future products. Again, it is up to the Package Engineer to understand that the damage recreated may be coincidental (see item above). Ideally one wants to recreate the same damage with the same inputs.

5. PSD plots have been driven from particular vehicles, roads, and seasons. All three introduce wide variations depending on many variables. A truck traveling in Detroit during the spring time, for example, will experience quite different levels of vibration than a truck traveling over Texas roads in the summer. Standardization therefore appears to be impractical. Picking a “worst-case” PSD plot is necessary when deciding on a common, standardized test method.



2.2 Sine Sweep Vibration (see Container Resonance & Vertical Stack Resonance; ASTM D-999) - *Recommended*

<u>Rationale for the test</u>:

Container Resonance: Resonance at a particular frequency may occur for significant periods of time in transport modes, particularly trucks over highways, due to the underlying dominant forcing frequencies from the tires, suspension and truck bed. This test may also be useful to predict scuffing problems on external carton graphics, and other problems related to vibration induced friction. It is difficult to use this test for monitoring the response of internal product components, as some test specifications recommend. (ASTM D-999 does not recommend this test be used for internal component analysis. This test is meant to evaluate the package performance only. Monitoring cushion response is encouraged).

Vertical Stack Resonance: This test is useful for determining the presence and effects of resonance in multiple unit stacked loads, and whether or not the strength of containers is sufficient to withstand dynamic loads when stacked. This test can be performed with the stacked loads secured together (stretch wrap, banding, etc.), or loose-load, to simulate LTL (Less than Truck Load) conditions.

<u>What happens in the real world & What the test is trying to simulate:</u>

Container Resonance: As the vehicle travels, the packaged product also may experience resonance from different vibration sources. Almost always, more than one frequency will be present, which may excite more than one component inside the product, as well as, or in addition to, the package/product system. The package may experience scuffing and external carton damage, as well as internal packing piece damage due to this vibration. It is very important for the Packaging Engineer to know what data he or she is trying to collect with the container resonance test. If one is trying to monitor components inside the product, a different approach must be taken than if the goal is only to monitor the product/package system, since the product/package may be excited into resonance, while the internal components are not, (or vice versa). It is also very difficult to monitor internal components, since they tend to be small, lightweight, and easily influenced by the weight of an accelerometer. Visual inspection may also be difficult while the product is packaged. Depending on the failure mode, different dwell times are appropriate.

Vertical Stack Resonance: Resonance of stacks will almost always occur to some degree, especially in truck trailer beds. It is possible for whole stacks of product to tip over, some may fall off the top of the load, or packages may bounce and bump into each other. Stretch wrapping, banding or loose load configurations will contribute to the propensity of the stack to resonate at some particular frequency, as well as product/package weight and material combination. The resonance stack test is useful to predict performance.

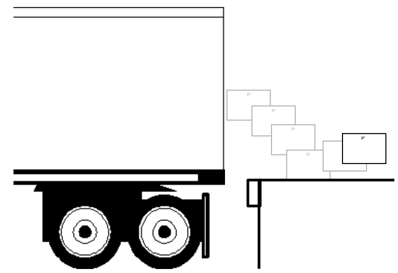
<u>Why the test should be conducted:</u> These two tests should be used to uncover any potential product/package weaknesses. The vertical stack resonance test is also useful for monitoring stacked product behavior for resonance and/or stability problems. Finally, the tests can be useful for assessing potential damage from vibration induced abrasion.

<u>Test compared to real events:</u> The fundamental problem with dwelling at a particular frequency is that it does not account for real life variations found in vibration inputs. In other words, real vibration inputs are made up of more than one frequency input at the same time. This means dwelling at one particular frequency can be too harsh physically, or too weak, qualitatively. The test can be too harsh physically, because the product/package may not dwell on one particular frequency for any appreciable time. Recall that most real vibration inputs are not pure sine waves, they are a combination of frequencies. On the other hand, if the natural frequency of a package system falls within one of the three dominant ranges for trucks, the package may in fact be excited for a significant period of time. This could be critical for understanding whether the package/product system could be vulnerable to these frequencies. In some ways, this test can also be considered qualitatively weak. This can happen because dwelling at one frequency will only excite components with the same frequency. In reality, many frequencies and their respective components are excited simultaneously. These separate components (with different natural frequencies) may bang into each other, if in close proximity. This is known as “simultaneous resonance”. Dwelling at one frequency may not uncover this “interference” damage potential.

Relying on the container resonance test for determining product component damage poses another potential problem. Note that the ASTM D-999 recommends that the sine dwell test not be used for product component damage. Since it is very difficult to monitor internal product components while the product is packaged.

Generally speaking these tests are useful for uncovering frequencies that may induce damage from unsecured stacks, and for assessing the potential damage from vibration-induced friction. In particular, the sine sweep is essential to verify the package/product system does or does not have a natural frequency that matches the dominant frequency ranges found in the trucking or rail, and to a lesser degree air and ship, transport modes.

2.3 Impact Test From Free Fall Drops (ASTM D-775, D-5276, D-1083) - *Recommended*



Rationale for the test:

a) Type 1 Packages: Manually handled products may be dropped anywhere in the distribution chain. Overnight delivery services handle huge numbers of packages each day, exposing products to shock hazard. Packaging Engineers need a reproducible test to evaluate cushion design changes. The impact test is also necessary to evaluate and qualify product and/or package design changes. Generally speaking, shock poses the greatest threat to product/package integrity.

b) Type 2 and 3 Packages: Products in these categories are heavy and usually bulky, requiring mechanical handling. The threat of shock due to free fall is very small, so different testing must be used. These type of packages are usually handled by pushing, sliding, dragging, or tipping when handled manually. Automated movement may drop the product from low heights, or onto one corner or edge as it is set down. In some cases (less than truck load shipments), free fall is a possibility, so some testing may be included. The impact test is also necessary to evaluate and qualify product and/or package design changes. Generally speaking, shock poses a threat to product/package integrity, though for these categories of products or pallet loads, vibration may be the greatest potential enemy.

What happens in the real world:

a) Type 1 Packages: Manual handling introduces the potential for free fall drops from a variety of heights. Generally, products are carried waist-high as they are transported from one location to another, or as they are pulled off a retail shelf (sometimes products are placed high on retail shelves). Automated machinery used by overnight delivery services use conveyor lines to move products through hubs. Mechanical arms shove the product into different bins, shocking the package and product. The typical conveyor height is about 36 inches (91.4 cm) from the ground, and packages have been known to fall off while being moved along the conveyor. Extreme handling is also common at break-bulk shipment sites, where packages are handled individually to fit into transportation vehicle spaces. Packages shipped by air are notoriously handled roughly, including tosses and tumbles, as well as compression, to fit the awkward cargo area in the airplane's belly. Several studies have been conducted in recent years to quantify drop heights and frequency of drops in the distribution channels. While conclusions from the studies can be debated, they do suggest individual packages have the potential to be handled roughly, including free fall drops. Packages can also be dropped onto other packages, soft surfaces, and other surface areas that result in non-flat impacts (corner, edges, etc.). As the parameters in the drop environment change, so do the equivalent deceleration levels. Therefore, drop testing conducted in a controlled lab environment (hard surface, flat drops, etc.) may not necessary be experienced in the real world distribution environment.

By observation, packages are almost never dropped completely flat on any one face. This is due to a variety of factors, including center of gravity, and friction. This becomes important when setting up tests and interpreting test data, since flat drops usually represent the worst shock to a product, in terms of deceleration values. Real life drops almost always will have rotation, meaning the product will hit the surface on an edge or corner. In this case, damage to the product may occur to outer skins, or plastic parts, and not internal components. Drops for this type of packaged product are random, and so the packaging should protect the product on all faces, edges and corners. Packages may fall onto other packages, the ground, and any number of a variety of surfaces, affecting coefficient of restitution, friction, and hence deceleration and velocity change values.

b) Type 2 and 3 Packages: These products are much heavier than Type 1 products, and so require mechanical machinery to be moved. The products are moved in a controlled fashion, so the potential for free-fall drop is minimized. Typically these products cannot, or will not, be unpalletized before reaching the customer. They move through the distribution environment handled by pallet jacks, fork trucks, and other mechanical machinery. There may be shock to the product if, for instance, the forks are set down too quickly on the ground. Sometimes physical structures, such as poles, walls or other products, are used to buttress against while moving and stacking these products. Lateral shocks will be encountered, especially as the fork truck driver loads the vehicle. Even if the product or pallet load is raised to a high height (for pallet stacking, as an example), the product will not generally be in danger of falling off in a free-fall. Extreme damage may result from special situations, such as spearing from forks, hydraulic failure while the product or pallet is suspended in the air, or a broken pallet. As a matter of practicality, packaging cannot be expected to protect against such “disasters”, unless previously agreed to by the product line management, for special classes of products.

<u>What the test is trying to simulate:</u> Free-fall testing attempts to replicate worse case impacts encountered during normal handling in the distribution channel.

<u>Why the test should be conducted:</u> Drop testing, though theoretically repeatable, is not always practically repeatable. Even with mechanical drop test machines there is no assurance of achieving a true flat drop, due in part to package placement on the drop device, friction, etc. The use of nets and other hoisting devices also introduce conditions that are not always repeatable. Despite these limitations, changes to packaging, even minor, can be evaluated quickly and easily. Drop testing also provides the Engineer with data about cushion performance, as well as the ruggedness of the overall product design. Shock is usually the most severe event occurring, so drop testing provides a means for evaluating package design. While all packages may not experience free-fall drops, this test represents a real-world “worst-case” scenario to which packaging can offer a solution.

<u>Test compared to real events:</u> Drop testing is perhaps the most useful, directly correlated, package test that can be performed. Flat drops, although not usually encountered in real-life situations, are fairly reproducible and serve as worst-case scenarios in the lab for acceleration inputs. Corner and edge drops may represent worst case inputs for velocity change damage, such as breaking plastic housing pieces. Useful data can be collected for evaluating package performance, including cushion performance and product shock. Electronic data collection may not always be convenient, or easy to interpret, but visual and functional tests of the unit are simple and straight forward. Drop heights and drop frequency are not easily determined or applied uniformly for different products, so thoughtful consideration must be taken when planning drop testing. Drop testing should be patterned after the Engineer's understanding of the distribution environment, and the expected hazard to be encountered. Some drop test specifications demand limiting deceleration values to 30 G's (or some other G level) or less in order to pass. Although the intention is to limit the shock to the unit, this is not the criteria that should be used. The 30 G limit says nothing about the duration or shape of the input shock pulse. For instance, a 30 G trapezoidal input, with a duration of 20 milliseconds is much more damaging (imparts more energy) than a 30 G sinusoidal input with a duration of 20 milliseconds (see figure 6.1). The criteria that should be used is whether or not there is damage to the unit that makes the unit non-functional, or cosmetically unacceptable. Also, when a product does survive drop testing, an effort should be made to then quantify the margin of safety the package provides. For instance, would a product that survived a set of 30 inch (76.2 cm) drops actually be able to survive 48 inch (121.9 cm) drops too? The answer to this question would indicate the amount of possible over packaging being used, assuming the test standard is reasonable to begin with.

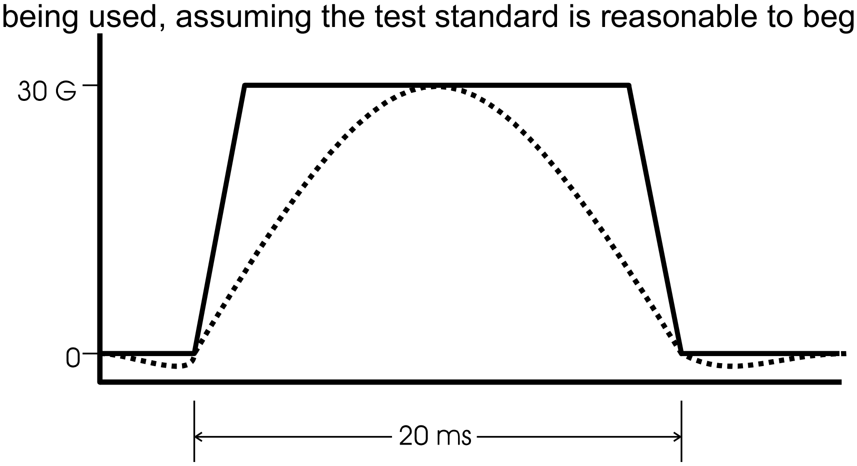


Figure 6.1

Finally, there has been much conjecture that free fall drop tests could be simulated on a shock machine by generating the same velocity change on the shock table as the impact velocity for a specific drop height. The perceived advantages are enticing: one could measure the exact input shock to the test specimen, and flat impacts would be absolutely repeatable. However, there can be radically different results between the two tests. The conjecture is that the shock table exhibits a tremendous amount of rebound energy and it couples with the packaged product's cushion system. If a net weren't held over the package, it would be propelled several feet up from the table. In other words, the energy imparted, in this test, to the product is different than during the drop test, where the floor does not shoot upward and cause the unit to rebound several feet. Until more study is done on the efficiency of matching free fall drops to shock machine testing of cushioned products, we would not recommend using the shock machine in place of free fall drop tests.

2.4 Slip Sheeted Loads - *Recommended*

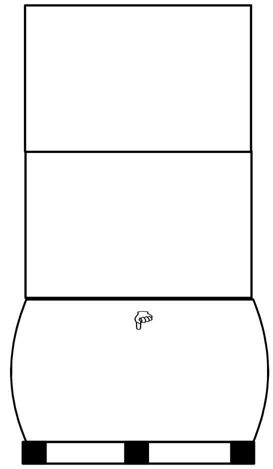
Rationale for the test: Many of the same reasons for conducting tests on slip sheeted loads are the same as for those stated in the rationale for palletized and crated products (Type 2). There are also some additional tests and evaluations due to the unique dynamic conditions slip sheeted loads encounter.

What happens in the real world: Slip sheeted loads are handled much the same way as pallet loads, in terms of handling frequency, load stacking, etc. A major difference exists in the dynamic stresses that may be imparted to products on slip sheets, especially products on the top and bottom layer during loading and unloading from the platen. Slip sheet attachment equipment generally requires that the platen be angled from the ground as the slip sheet load is grabbed and pulled onto the platen, causing flexure to the units. The slip sheet loads are also tilted from the horizontal during this movement, much more so than when pallets are handled. Another obvious difference is that there is no solid physical barrier between the ground, or vehicle bed, and the products with slip sheets. This may have implications in areas that have standing water, or some other hazard that a pallet affords some protection against.

What the test is trying to simulate: The test uses actual slip sheet equipment, so real dynamic slip sheet handling conditions are expected to be reproduced.

Why the test should be conducted: Any product that will be handled on slip sheets should undergo this testing, especially products that may be susceptible to stress and/or flexural damage. Bulk packs shipped on slip sheets should also be tested, to evaluate the physical integrity of the bulk pack material (i.e., foam, corrugated, etc.).

Tests compared to real events: Normal handling procedures can be readily reproduced with this test. The test does not necessarily uncover potential damage from unusually rough handling. Specific conditions, such as a combination of high humidity combined with some other factor, may not be readily reproduced, unless the conditions are purposefully tested for.



2.5 Compression Testing - *Recommended*

Rationale for the test: The purpose of this test is to ensure the paper combination and flute type chosen for a specific box will endure compressive loading during normal world-wide warehousing and distribution.

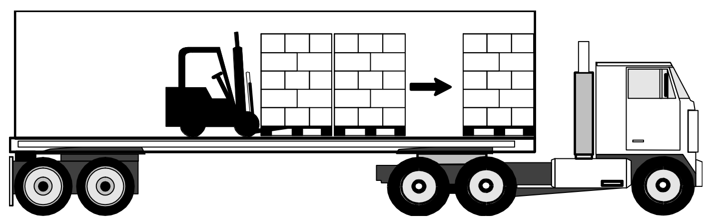
What happens in the real world: Boxes are stacked in a variety of ways, in a variety of environmental conditions. The most common ways for boxes to be handled are in pallet loads, and as individual units. Packages must be able to withstand abuse found as the bottom box in a stack in storage or back of a truck, and to a lesser degree the compression forces found in less than truck load shipments. There are four main factors affecting compression strength of a box, in addition to paper selection and flute type: humidity, time, box style, and stacking pattern. Humidity has been shown to be a critical consideration for specifying box strength, simply because paper is a hydroscopic (water absorbing) material. Generally speaking, humid conditions above 50% begin to rapidly deteriorate the compression strength of the box. Cycling humidity and temperatures has also proven to be detrimental to box strength. High humidity may also cause the facings and/or flutes to de-laminate, causing severe problems. Time is also very important, with longer periods of time requiring the box to bear “dead loads”, which cause the box to relax and lose strength. Relaxation is the tendency for an object under fixed compression to internally deform to relieve the load on it. Stacking pattern is the third significant factor contributing to box compression strength. A stack of identical boxes aligned perfectly in a vertical column can be stacked much higher than if the boxes are somewhat staggered (out of alignment). Whenever the compression load on a box is not supported by its strongest members, the vertical edges, the strength of the box is compromised. A stack of different sized boxes has the same effect as staggering identical boxes: the compression strength is reduced because the vertical edges are not aligned. Other factors to consider include “localization doors” that may be cut or perforated into sidewalls; kind of printing; added substrates to liners; internal support (such as divider walls or foam), and closure method (tape, staples, glue, etc.). Dynamic compression is also common during distribution, especially for package systems that have a natural frequency falling within one of the three dominant forcing frequency ranges found in the trucking environment.

What the test is trying to simulate: The purpose of this test is two-fold. First, it can be used as a quality control check for corrugated shipping containers. In addition, instead of specifying corrugated materials (specs which can be difficult to test), compression strength specifications can be developed and placed onto drawings. Requiring suppliers to conduct compression testing on shipping cartons will provide a method of judging the combined quality of materials and construction of a container. The second purpose of this test is to provide an accurate way of assessing the overall strength of a filled container and determining if the product/package will survive the compression loads expected within distribution. This method can also be used to test loading points of unboxed products, where the compression load is transmitted to the product via packaging. When the inherent strength characteristics of the product can be harnessed to survive the rigors of distribution, packaging costs can decrease (an example would be some bulk packs).

Why the test should be conducted: Almost all products are delivered in corrugated shipping containers, which are expected to not only contain the product, but provide a structure that allows for stacking and storage over a certain period of time.

Test compared to real events: There are two important limitations that should be mentioned. The first is deciding whether to use a fixed platen or floating platen during testing. For fixed platen compression testers, the platen remains horizontal and parallel to the base of the box during compression. If the corners of the box have different heights, then the platen will contact the highest corner of the box first. This corner then takes the bulk of the load until the platen contacts the next highest corner, and so on. If the platen contacts all four corners before the box fails, then the compression strength so obtained represents a reasonable estimate of the actual dead load it could support from other boxes on top of it. One way to overcome this limitation is to use the floating platen, which swivels to automatically adjust its position until it contacts at least three points on the box before it applies any load. This simulates actual loading by other boxes much more accurately because it is testing the weakest vertical edges. This test does not propose to simulate dynamic compression environments.

2.6 Pallet Marshaling - *Optional*



Rationale for the test: Unitized loads and large containerized products experience horizontal impacts from typical mechanical handling, such as fork trucks and pallet jacks. Loads must keep their structural integrity, and pallets must remain functional after such impacts.

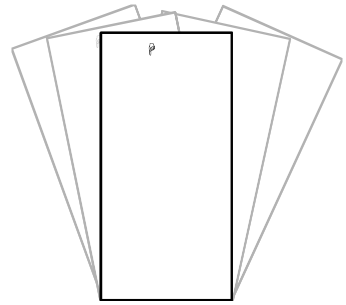
What happens in the real world: Typical activity during loading/unloading of trailers and warehouse operations include moving loads with motorized and non-motorized fork trucks and pallet jacks. Operators must handle and arrange these loads for storage, staging, loading and unloading from vehicles. As the fork truck or pallet jack contacts the load, horizontal impacts are imparted, which may cause damage to the product(s) and/or the pallet. Typically the fork truck or pallet jack is traveling at some speed as it makes contact with the load.

What the test is trying to simulate: The test attempts to simulate warehouse handling conditions for unitized and large containerized products, specifically the impacts encountered as material handling equipment contacts the loads.

Why the test should be conducted: Unitized loads and large containerized products will be handled with mechanical material handling equipment, and will be subject to horizontal impacts.

Test compared to real events: In general this test simulates real world events accurately, for specific scenarios tested. It would be impossible to test every conceivable scenario the product may encounter, but results will generally be accurate for the environments tested.

2.7 Stability Test - *Optional*



Rationale for the test: Some Type 2 and Type 3 products and pallet loads may be awkward in size and weight when transported, or moved when in small corridors. This test is used to evaluate the tendency for these kind of products to tip over.

What happens in the real world: Typical handling procedures, including transport up and down ramps, slip sheet handling, and mechanical handling, may tilt the product to such a degree that the unit becomes unstable. Stacking heights in warehouses may also reach points where the loads become unstable, with box strength, time and humidity playing roles in stability. Some products may also be subjected to manual handling forces, such as a worker trying to push or pull the product to a new location.

What the test is trying to simulate: The test attempts to simulate the propensity of a package to tip over in normal handling conditions used for heavy and/or awkward sized products.

Why the test should be conducted: Large, heavy units can become unmanageable when they exceed their stable center of gravity alignment. Units that are easily tipped can become hazards that may result in personal injury. All packages with a weight equal to or exceeding 100 pounds (45.4 Kg), or any package taller than 36 inches (91.4 cm) in its shipping orientation should be subjected to this test. This test is particularly relevant for products having large center of gravity ratios (height of center of gravity to smallest dimension of the base), or a high height ratio (ratio of the height to the smallest dimension of the base). General ratios for these scenarios, above which there may be a problem, are .25 and .5, respectively.

Test compared to real events: Generally this test is realistic in its attempt to simulate real world events. Dynamic forces causing tip over should also be considered during testing, to have a more complete representation of field conditions.

2.8 Tipover Test - *Optional*

Rationale for the test: Any package which does not meet the requirements in the stability test should be tested with this specification. Units that do not exhibit stability in normal handling may be susceptible to tipping over onto their sides or ends.

What happens in the real world: Unstable products may tip over, such as a unit on a pallet jack that is being moved up or down a ramp from a truck. Units are sometimes stacked quite high at warehouses, resulting in unstable loads that may fall. Large, tall products may be manually maneuvered by the customer, to fit through doorways or other tight spots in their environment. Units shipped by truck may also topple over from forces due to sudden starts and stops within a truck.

What the test is trying to simulate: The test attempts to simulate real world handling scenarios for unstable products.

Why the test should be conducted: Large, heavy units can become unmanageable when they exceed their stable center of gravity alignment. Units that are easily tipped can become hazards that may result in personal injury. All packages with a weight equal to or exceeding 100 pounds (45.5 Kg), or any package taller than 36 inches (91.4 cm) in its shipping orientation that do not meet the stability test, should be subjected to this test. This test is particularly relevant for products having large center of gravity ratios (height of center of gravity to smaller dimension of the base), or a high height ratio (ratio of the height to the smaller dimension of the base). General ratios for these scenarios, above which there may be a problem, are .25 and .5, respectively.

Test compared to real events: This test in general simulates real world events accurately, for specific scenarios tested. It would be impossible to test every conceivable scenario the product may encounter, but results will generally be accurate for the environments tested.

2.9 Layover Test - *Optional*

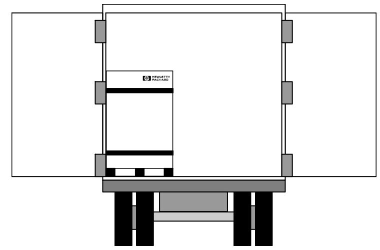
Rationale for the test: This test is designed to determine if a container and the contained product can be laid on their side without damage resulting to the product or to the package. This test is not intended to determine if the package can be dropped or shipped in the non-base orientations.

What happens in the real world: Large bulky units may be laid on their sides to gain easier access through doorways, hallways, elevators, etc. Mechanical advantage may also be gained when moving the product in tight corridors when laid on its side.

What the test is trying to simulate: The test attempts to simulate real world handling conditions for large and/or heavy items.

Why the test should be conducted: Packages weighing more than 100 pounds (45.4 Kg) should be subjected to this test. This test is designed to determine if a container and the contained product can be laid on their side without damage resulting to the product or to the package. This test is not intended to determine if the package can be dropped or shipped in the non-base orientations.

Test compared to real events: This test in general simulates real world events accurately, for specific scenarios tested. It would be impossible to test every conceivable scenario the product may encounter, but results will generally be accurate for the environments tested.



2.10 Strapping Test - *Optional*

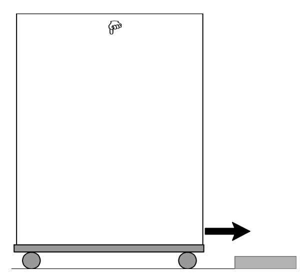
Rationale for the test: This test is designed to determine whether the product and/or package will withstand the strapping forces that are expected in transportation. Strapping is typically used to secure product within a truck during shipment. This test may also be adapted to include strapping for pallet loads and Type 2 products that require boxes to be secured to unit pallets.

What happens in the real world: For large units, trucking companies may deliver the product by “padded van”, which means the product is not part of a larger pallet load sized shipment. The unit is sometimes secured to the wall of a truck to prevent the unit from shifting and falling over during shipment. Straps may be made of fiber (like belts), or rope. For Type 2 products, strapping may also be used to secure a cover box to a unit pallet, often with a polyester, nylon or polypropylene strapping material. The strapping can in some cases, depending on box style and strap tension, dig into the corrugate, causing unacceptable damage. Strapping may also be used for securing stacked loads, causing the same box and/or product damage.

What the test is trying to simulate: The test attempts to recreate the tension forces applied by strapping materials to packages found in real world situations.

Why the test should be conducted: Strapping is generally narrow in width compared to the box and/or product it is securing, which may cause permanent mechanical deformation, or unacceptable cosmetic damage.

Test compared to real events: This test in general simulates real world events accurately, for specific scenarios tested. It would be impossible to test every conceivable scenario the product may encounter, but results will generally be accurate for the environments tested.



2.11 Rolling Impact Test - *Optional*

Rationale for the test: This test is designed to ensure that packages designed to be rolled or pushed along the ground can withstand normal impacts encountered during such handling.

What happens in the real world: Packages with castors are designed to be rolled may encounter hazards during movement. Typically products that are rolled or pushed by the customer must move over ramps between trucks and docks, carpet hold downs, door jams, and other normal hazards found in everyday situations. The product must be protected from these impacts, even if it tips over.

What the test is trying to simulate: The test attempts to simulate the impacts encountered when rolling or sliding products over typical structural hazards found at customer sites.

Why the test should be conducted: Large, bulky packages, especially those with castors, can be awkward to handle and move, and often must pass over obstructions on the floor or ground. The package must protect the unit while impacting these hazards.

Test compared to real events: This test in general simulates real world events accurately, for specific scenarios tested. It would be impossible to test every conceivable scenario the product may encounter. However, the result of this test will generally indicate the ability of the package/product to protect against normal environment hazards associated with rolling impacts. The four inch height in this test is a typical height for a street curb.

2.12 Ramp Clearance Test - *Optional*

Rationale for the test: This test is designed to determine whether a non-palletized, product with castors or transit case (crate on wheels) can be rolled up a typical ramp in the distribution and customer facilities without bottoming out, tipping over, or being damaged.

What happens in the real world: Many distribution and customer sites have ramps that are used to move products. Products with castors are generally designed to be rolled up or down these ramps because of their awkward size or weight. If wheel size or wheel base is not large enough, the package may tip over, bottom out, or in some other way become damaged.

What the test is trying to simulate: The test attempts to recreate the forces and handling motions found in real world situations.

Why the test should be conducted: All castored products or transit cases should be subjected to this test, since the intent of including castors is that they will be used for these kinds of circumstances.

Test compared to real events: This test in general simulates real world events accurately, for specific scenarios tested. It would be impossible to test every conceivable scenario the product may encounter, but results will generally be accurate for the environments tested.

2.13 Humidity/Temperature Storage Test - *Recommended*

Rationale for the test: This test is designed to determine whether the packaged product can survive the extreme humidity/temperature distribution environments without being damaged. This test should be used when environmental extremes are expected to affect the reliability of the product and/or package. In addition, this test can be used to condition the product and packaging material prior to other tests called out in this section. For example, conducting random vibration testing immediately upon removal from high humidity testing may simulate damages found in a trucking environment in a country with high humidity.

What happens in the real world: Many materials from which containers and packages are made, especially paper based materials, undergo changes in physical properties as the temperature and the relative humidity (RH) to which they are exposed are varied. Many Asian and Latin American countries, for example, exhibit climate patterns that dramatically affect the performance of corrugated. Arctic and desert temperature extremes can also be experienced in some shipping environments. Combining temperature and humidity with shock and vibration can yield unexpected results, as well as accentuate existing problems.

What the test is trying to simulate: Depending on the temperatures and humidities chosen, and the duration or cycling of the them, many different climates can be simulated. Examples are desert, tropical, winter and temperate climates.

Why the test should be conducted: Any package that will be exposed to known humidity and/or temperature extremes should use this test, especially combined with other appropriate handling tests. Real world environments may not be similar to a laboratory's controlled atmosphere of 70 °F (21.1 °C) and 50% relative humidity.

Test compared to real events: The conditions called out in this test are representative of their respective climates, but do not necessarily duplicate actual field conditions. However, these conditions do tend to simulate real world conditions and have similar effects on the packages and materials, and at least point out potential problems.

2.14 Slip Sheet Tab Testing - *Optional*

Rationale for the test: This test is designed to determine whether the slip sheet tabs can survive repeated handling throughout the distribution system without being damaged.

What happens in the real world: Slip sheets are handled several times throughout distribution, so tabs must withstand repeated pushing, pulling and grabbing forces. Environmental conditions not seen during testing, such as high humidity or standing water, may effect the performance of paperboard slip sheets. Tab tearing may occur, which can make the slip sheet practically useless on some sides.

What the test is trying to simulate: The test attempts to simulate the forces applied to slip sheet tabs during normal slip sheet handling procedures.

Why the test should be conducted: Any product using slip sheets for the first time should undergo this testing to ensure the slip sheet material and specifications meet the handling requirements. Unusually heavy products should also use this test to ensure tab strength is appropriate.

Test compared to real events: This test in general simulates real world events accurately, for specific scenarios tested. It would be impossible to test every conceivable scenario the product may encounter, but results will generally be accurate for the environments tested.

2.15 Field Shipment Testing - *Optional*

Rationale for the test: Using the same distribution channel, or a similar transportation leg, that a product typically goes through for testing seems intuitive to collect actual field data. Field shipping conditions are, after all, what laboratory testing attempts to simulate.

What happens in the real world: Products are handled by many different transportation modes, and are exposed to several different environmental conditions. Knowing how the product is distributed, and through which channels, gives an opportunity to monitor and evaluate packaging in that environment. Limited field shipments may not, however, uncover all of the potential hazards faced in a distribution environment, especially for other specific channels.

What the test is trying to simulate: The test is used to determine if a package can survive in a particular distribution environment.

Why the test should be conducted: This is a useful test to gather real field data, but because each product may reach its destination in a slightly different way each time, the results may not be conclusive. This test should supplement, not supersede, the other recommended tests in this section.

Test compared to real events: The results obtained from limited field shipment testing may not be statistically significant in assuring damage free distribution of products in full production. However, if enough products are tested in this way, field shipment testing is the most useful source of data for package integrity within a distribution environment, especially in light of other laboratory testing that attempts to simulate the same environment.

2.16 Altitude/Decompression Test - *Optional*

Rationale for the test: This test determines if the non-operating packaged product can withstand a low pressure/cold environment encountered during air shipment, and during transportation legs where the altitude is above 7500 feet (2286 m) above sea level.

What happens in the real world: Two transport modes may expose products to low pressure environments. The first is air shipment, where cargo holds are generally pressurized to an 8000 foot (2438 meter) level. However, there are some air carriers that use low altitude air craft which do not pressurize their cargo hold and they can experience altitudes up to 12,000 feet (3568 meters). The second is truck transport, where trucks may move product to high altitude areas.

What the test is trying to simulate: The test attempts to simulate the change in pressure experienced when moving from different altitudes.

Why the test should be conducted: Packages that need to maintain a hermetic seal to prevent leakage or pressure change, or packages that may be susceptible to collapse due to pressure change should use this test,

Test compared to real events: This test in general simulates real world events accurately, for specific scenarios tested. It would be impossible to test every conceivable scenario the product may encounter, but results will generally be accurate for the environments tested. This test is not designed to simulate a sudden loss of pressure.

2.17 Rain Test - *Optional*

Rationale for the test: This test is designed to determine whether the packaged product can withstand rain without being damaged. This test should be used when environmental extremes are expected to affect the reliability of the product and/or package. Many investigations have shown product can be exposed to rain while left unattended on docks, in open bed trucks, or on air tarmacs. This is especially true in developing countries, where distribution channels may not be as sophisticated as in developed countries.

What happens in the real world: Products in a variety of locations sometimes are exposed to rain. Facility limitations are usually to blame, such as open air docks, open truck beds, or cargo that sits on an air runway waiting for loading/unloading. These conditions are particularly prevalent in Latin American and Asian countries, where weather patterns often include rainy seasons or months with particularly high rainfall.

What the test is trying to simulate: The test is designed to simulate rainfall of different intensities, depending on local conditions.

Why the test should be conducted: Any product expected to be shipped into a country with a less developed distribution channel could be exposed to harsh weather conditions, including rain. Rain will obviously affect paper-based packaging materials, especially in combination with other shock and vibration.

Test compared to real events: Depending on the duration of testing, this test simulates rainfall conditions fairly accurately. Combining this test with other environmental factors, such as wind and temperature, would increase the simulation, although it may be arbitrary what those factors would be. Also, combining this test with other shock and vibration testing can give valuable insight into package performance.

Package Development Process (section 6)

1.0 Introduction

The Package Development Process provides a sequential approach to package development and test direction within the Hewlett Packard new product development environment. This section follows the product development cycle and lists recommendations for packaging analysis, design, and testing for each product development phase.

2.0 Purpose

The purpose of this section is to provide a step-by-step tool for guiding the Packaging Engineer through each phase of the new product development cycle or packaging redesign. This section is designed as a platform to reference the other sections for specific analysis, testing, and commentary.

3.0 Overview

The following **new** package development phases describe the packaging input required to support the product development cycle:

3.1 Design Objective (DO)

The DO-Phase is a new product feasibility study. This feasibility study evaluates the product feature set, cost and price points to ensure the product meet the market requirements. Since the product has not been designed yet, it vital to provide the R&D team with optimal product design features to minimize the distribution, packaging and process costs (example; designing removable paper trays would reduce the package size and material). Providing these cost avoidance options may have direct effect for launching the product into the next phase. The DO and I-Phases were combined in the matrices since the packaging input would
be similar.

3.2 Investigative (I-Phase)

The I-Phase is the beginning of the new product development. The product feature set, industrial and physical designs are solidified in this phase. It is critical to provide packaging guidance to the product development team. This input will ensure that the product development team has all of the packaging data sufficient to define the industrial and physical designs of the product. Whenever possible, service delivery models should be considered.

3.3 Lab Prototype (LP-Phase)

In this phase the development team produces a small build of units for testing. In the LP-Phase, the package design is initiated to meet the requirements and direction established from the I-Phase. Product and package testing should be integrated to facilitate an awareness of their limitations within the intended distribution environment. The packaging test plan should be solidified for the next phases. Whenever possible, service delivery packaging solutions should be identified during this phase.

3.4 Production Prototype (PP-Phase)

The PP Phase verifies the manufacturability of the new product, small to medium builds of units are produced to test the product improvements, performance, and production reliability. Major changes to the product often occurs in this phase, requiring timely packaging design analysis and testing for each modification. The packaging design should be finalized and materials ordered for the next phases. Production component parts and service assemblies should be identified and corresponding parts packaging designed in this phase to ensure timely support. In some service delivery models, this can include whole units.

3.5 Pilot Run (PR-Phase)

The PR-phase tests all the facets of product production and reliability with near production volume builds. The final production package testing should be completed, with all product packaging issues being eliminated before the next phase. Parts packaging, production component parts, and service assemblies should be tested and documented in this phase.

3.6 Manufacturing Release (MR-Phase) and Production

The MR Phase is where the product has been released for production and inventory is being built for a scheduled introduction date. In this phase, it is crucial to test the transportation and handling variability within the distribution channel with large volumes. Production component parts, service assemblies and parts packaging specifications should be documented in this phase.

4.0 Phase Matrices

The following pages contain matrices for the different phases of a new product development cycle.

DO/I-PHASE

Analysis/Testing Recommendations	Best Practices	Minimum Requirements	Remarks (Reference)
Product Design for Distribution	Input Design Features Review - External Topcover & Base (shell) Fit, loading surface areas, radii edges & corners, inserted parts bezels, trays). - Internal Mechanical - moving components, internal to external impact/loading points. Output - Design Alternatives - Design Improvements - Product/Package Interface	Input Benchmark an existing product with similar product features such as O.D., wt, internal mechanism(s). Output Provide historical design issues concerning a product with a similar platform or design features. Outline the improvements to key components to minimize the defects due to the hazards in the distribution channel.	Reviewing the product's initial industrial design models/drawings is critical at the I-phase. In this early phase product design changes can be made much more easily. The design for distribution objective of this phase should be to minimize the size of the product and maximize its ruggedness. Understand the functionality of the product to provide input on how to protect moving components during distribution.

DO/I-PHASE (cont.)

Analysis/Testing Recommendations	Best Practices	Minimum Requirements	Remarks (Reference)
Package Design Alternatives	Input - Product profile options (OD., Wt., loading areas) - Accessory List (Manuals, Pens, Etc..) - Product Fragility - Product Marketing plan - Dist. channels & methods Output - Package Profile (I.D. & O.D.) - Packaging options (Single, Unitized, Bulk) - Fragility/package sensitivity - Package Costs (comp. level) - Conceptual packaging designs - Time To Market Analysis - Environmental Matrix	Input Benchmark an existing product with similar accessories and distribution channels. Output Provide the following packaging data from an existing product: - Product Fragility - Packaging Designs - Dist. and packaging costs.	Providing packaging concepts is crucial in driving the packaging design, distribution modes and costs, as well as the fragility of the product. Review all of the components required for marketing the product. Provide a product and package profile for the packaging options (single, unitized, & bulk). Make conceptual drawings (dimensions) to illustrate each option. Provide the R&D team with a fragility level goal. Analyze the product/package in the distribution channels and their costs.
Packaging Process(es)	Input MFG. product/packaging plan (space, cycle time, storage, handling, equipment, dock doors, process strategy) D.C. localization strategies (processes, space, cycle times, storage, handling, equipment, dock doors, costs, quality) Output - Package/equipment interface - Potential packaging process(es) - Packaging cycle times - Packaging handling & storage	Input Benchmark an existing product with similar packaging process. Output Provide a packaging process document specifying the process, cycle time, space, storage and handling of a similar product.	The package must be designed with the packaging process. Every aspect of package interface must be considered throughout the channel to the customer, and even returns. Gather extensive knowledge of the current packaging processes available within. Analyze the new product packaging requirements throughout the distribution channel to evaluate if the current packaging processes accommodate the new product. Modifications to an existing process or a new process may be required.
Distribution Options	Input - Dist. methods & options plan - Dist. method costs (ocean, surface, and or air) - Container Dimensions (trailer/air or sea container) Output - Transportation cost analysis single, unitized, and bulk. - Container utilization analysis - Loading drawings - Carrying cost impact	Input Benchmark an existing product with similar distribution process. Output Provide a distribution process document specifying the container utilization, cycle time, transportation costs of a similar product.	Examine all of the projected distribution methods on the product (air, ocean, surface, rail, etc..). Review and modify the package design to ensure proper protection throughout the distribution cycle. Provide a distribution cost matrix which shows the per unit cost and transit duration for each leg. This data will provide the project team with a clear understanding of the distribution scheme of the product.
Package/Dist. Plan	Output - Provide a recommendation of the optimal package and distribution method for the product analyzed.	Output Provide a recommendation to follow a similar package and distribution method.	Using the analysis from the product and package design, packaging process, and distribution options provide a recommendation for the optimal product and package, process, and distribution method.

LP-PHASE

Analysis/Testing Recommendations	Best Practices	Minimum Requirements	Remarks (Reference)
Product Design Review	Input Review the selected product design features/profile from the I-Phase development. Output - Design Improvements - Potential Design Issues - Product/Package Interface	Input Review the selected product design features/profile from the I-Phase development. Output None	Review the selected product designs, and generate awareness of potential weak product design features to R&D team. It will generally cost less to improve the product's design than to increase the packaging to compensate for the product weakness.
Package Design Review/Proposal	Input - Gather the accepted product profile (OD., Wt., loading areas) - Accessory List (Manuals, Pens, Etc..) - Product Fragility Agreement (Goal) - R&D/Marketing schedule - Selected distribution channels & methods. - Prototype packaging requirements for beta shipments and etc.. Output Provide a packaging design update from the I-Phase proposal. - Package design concepts - Packaging format concepts (Single, Unitized, Bulk) - Package functionality design - Package Costs - Packaging drawings/specifications - Prototype packaging strategy - Environment packaging strategy - Package test plan	Input Gather the same input from "Best Practices" Output Provide product data to a selected packaging supplier for packaging concepts and costs and submit this data to the project team.	Generate concrete packaging designs for the product, process and distribution channels. Provide the costs and environment impact. The goal is to initiate an anchoring effect for the package design. Having a fixed packaging design will provide R&D team with an acceptance baseline for their designs, and will facilitate product design improvements.
Packaging Process(es) Review /Proposal	Input Review the modifications of the product and its impact on the packaging process strategy. Output Provide packaging process strategy update from the I-Phase proposal. - Package and equipment interface - Potential packaging process(es) - Personnel requirements - Packaging cycle times - Specific packaging equipment - Packaging handling & storage	Input Gather production and D.C.s recommendations for packaging the product. Output Provide a packaging process document specifying the process, cycle time, space, storage and handling of a similar product.	Establish the packaging process to initiate the process development. The packaging must be designed to meet packaging process equipment capabilities. The packaging process may require additional modifications to the packaging designs, so it is important to incorporate these modifications early in the product design phase.
Distribution Review/Proposal	Input Review the modifications of the product and its impact on the package/distribution plan. Output Provide distribution strategy update from the I-Phase proposal. - Transportation cost analysis single, unitized, bulk - Container utilization analysis - Loading drawings - Carrying cost impact	Input Benchmark an existing product with similar distribution process. Output Provide a distribution process recommendation specifying the container utilization, cycle time, transportation costs of a similar product.	Examine all of the projected distribution methods on the product (air, ocean, surface, rail, etc..). Review and modify the package design to ensure proper protection throughout the distribution cycle. Provide a distribution cost matrix which shows the per unit cost and transit duration for each leg. This data will provide the project team with a clear understanding of the distribution scheme of the product.

Package & Distribution Plan	Output - Provide a final recommendation of the optimal package and distribution method for the product analyzed.	Output Provide a recommendation to follow a similar package and distribution method.	This should be the final proposal. Work on the package and product design will be based upon the agreed upon proposal.

LP-PHASE (cont.)

Analysis/Testing Recommendatio ns	Best Practices	Minimum Requirements	Remarks (Reference)
Package Testing **End User Packaging (Single & Unitized)** **Bulk Pack Packaging**	Input - Create a product model or secure LP prototype. - Gather prototype packaging - Identify testing parameters - Identify LP testing to be performed - Identify access. mounting locations. Output - Project team design review - Production and D.C. design review - Free fall drop testing - Vibration testing - Compression test - Temp. & humidity testing - Modify packaging designs from package test results. Input - Identify testing parameters - Identify LP testing to be performed Output - Project team design review - D.C. design review - Free fall drop testing - Vibration testing - Compression test - Temp. & humidity testing - Handling & storage testing - Modify packaging designs from package test results.	Input - Gather same data as “Best Practices". Output - Provide a model and sample accessories to a package supplier to create a package. - Have the supplier perform instrumented drop testing. - Validate the supplier’s results with in-house transportation testing. Input - Gather same data as “Best Practices". - Provide a model to a package supplier to create a bulk package. - Have the supplier perform instrumented drop testing. on partial pallet layer design. - Validate the supplier’s results with in-house transportation testing.	Perform package testing early in the LP-Phase to generate a product/package performance profile to be used with product shock test results and free fall product testing. Free Fall drop testing should include all faces, corners, edges to identify any weak points of the package. Vibration testing include single and unitized units (simulated) to identify the package's weaknesses. Storage and compression testing should be completed in the LP-Phase only if the testing is meaningful (ex. key molded parts). The packaging should be designed to meet the agreed test goal before the next phase. If possible, begin tooling for molded cushions.
Documentation	Output - Packaging component specifications - Packaging assembly specifications - Palletization specifications - Packaging cost analysis - Project timeline - Package test plan	Output - Same documentation as "Best Practices"	Provide a detailed report updating the current packaging and total costs for materials, labor, and distribution.
Product Component Packaging	Input - List of critical purchased sub-assemblies. Output - Initial proposal for the supplier.	Output - Same documentation as "Best Practices"	It may be necessary to determine packaging design of certain critical purchased sub-assemblies to meet the needs of the proto-type builds. .

PP-PHASE

Analysis/Testing Recommendations	Best Practices	Minimum Requirements	Remarks (Reference)
Package Testing **End User Packaging (Single & Unitized)**	Input - Gather additional or modified packaging samples. - Verify testing failure modes. - Validate testing parameters. - Identify PP testing to be performed. - Identify access. mounting locations. - Gather PP products for testing. Output - Project team design review - Production and D.C. design review - Free fall drop testing - Vibration testing - Compression test - Temp. & humidity testing - Modify packaging designs from package test results. - Request product design modifications from package test results. - Provide samples to production, D.C.s and key customers for review. - Provide sample packaging to production for review. - Order packaging for Pre-production shipments.	Input - Gather same data as "Best Practices". Output - Provide the latest packaging requirements to supplier. - Provide a modified model and sample accessories to a package supplier to create another package. - Have the supplier perform instrumented drop testing. - Validate the supplier's results with in-house transportation testing. - Provide packaging samples for Temp. & humidity testing -	Perform package testing in the PP-Phase to maintain a product/package performance profile with a constantly changing product and package. Free Fall drop testing should include all faces, corners, edges to identify any weak points of the product. Vibration testing include single and unitized units (simulated) to identify the package's weaknesses. Storage and compression testing should be completed in the PP-Phase to provide feedback to the product design team. If the test results are very encouraging, defects are understood and the improvements are initiated, then tooling for production should commence.
Bulk Pack Packaging	Input - Gather additional or modified packaging samples. - Verify testing failure modes. - Identify testing parameters - Identify PP testing to be performed. - Verify the modifications to the product. Output - Free fall drop testing - Vibration testing - Compression test - Temp. & humidity testing - Handling & storage testing - Modify packaging designs from package test results.	Input - Gather same data as "Best Practices". - Provide a model to a package supplier to create a bulk package. - Have the supplier perform instrumented drop testing on full layer pallet design. - Validate the supplier's results with in-house transportation testing. - Provide packaging samples for Temp. & humidity testing.	The packaging design should be developed enough to start tooling for long lead time packaging components. Tooling at this phase is usually at risk and modifications are to be expected. Bulk packaging should be tested layer by layer as units become available. Using weights to simulate the load under compression and vibration, will provide adequate results to initiate tooling for PR/MR bulk storage requirements. Drop testing may be completed by using the shock table with dead weight or a fixture and a hoist.

PP-PHASE (cont.)

Analysis/Testing Recommendations	Best Practices	Minimum Requirements	Remarks (Reference)
Production Component Packaging	Input - Gather a list of upper level parts and assemblies from production. - Gather the following from process engineering: Quantity per package Maximum package size Maximum weight per package Recommended package style - Gather the following from production and development engineers: Fragile part features ESD parts and sensitivity results Cosmetic parts Special features/orientations		Even though the required component packaging may change over the next phase, it is important to establish initial benchmark for use by purchasing and suppliers.
	Output - Initial component packaging specifications. - Provide component packaging documentation to supplier for review and pricing. - samples requested for fit and testing. - Provide general specifications for component packaging (pallets, labeling, etc..)	Output - Provide generic component part specifications including: Max. package size Max. weight per package Required package style ESD, fragile, cosmetic, or special feature packaging requirements.	Provide design guidance or specification to product component suppliers to ensure protection and ease of use.
Service Component/ Assembly Packaging	Input - Gather a list of service parts and assemblies from technical marketing. - Gather the following from the technical support and SMO engineering: Quantity per package Maximum package size Maximum weight per package Transportation network - Gather the following from production and development engineers: Fragile part features ESD parts and sensitivity results Cosmetic parts Special features/orientations	Output - Provide SMO service part specifications for SMO packaging design. ESD, fragile, cosmetic, or special feature packaging requirements.	Provide SMO with packaging specifications or service components or assemblies specifications to ensure service packaging is available.
	Output - Provide service packaging documentation to supplier and SMO for review and pricing. - samples requested for fit and testing.	Output - Work as liaison with SMO and component part supplier, or production to find a suitable existing package.	Establish packaging for product support and protection throughout the life of the product
Product Documentation	Output Update the packaging documentation - Packaging component specifications - Packaging assembly specifications - Palletization specifications - Packaging cost analysis - Project timeline	Output - Same documentation as "Best Practices"	Provide a detailed report updating the current packaging and total costs for materials, labor, and distribution. Documentation should indicate which parts have been ordered for production.

PR-PHASE

Analysis/Testing Recommendations	Best Practices	Minimum Requirements	Remarks (Reference)
Package Testing **End User Packaging (Single & Unitized)**	<u>Input</u> - Gather additional or modified packaging samples. - Verify testing failure modes. - Validate testing parameters. - Identify PR testing to be performed. - Identify access. mounting locations. - Gather PR products for testing. <u>Output</u> - Project team design review - Production and D.C. design review - Free fall drop testing - Vibration testing - Compression test - Temp. & humidity testing - Modify packaging designs from package test results. - Request product design modifications from package test results. - Provide samples to production, D.C.s and key customers for review.	<u>Input</u> - Gather same data as “Best Practices". <u>Output</u> - Provide the latest packaging requirements to supplier. - Provide a modified model and sample accessories to a package supplier to create another package. - Have the supplier perform instrumented drop testing. - Validate the supplier’s results with in-house transportation testing. - Provide packaging samples for Temp. & humidity testing	Perform package testing in the PR-Phase to maintain a product/package performance profile with a constantly changing product and package. Free Fall drop testing should include all faces, corners, edges to identify any weak points of the product. Vibration testing include single and unitized units (simulated) to identify the package's weaknesses. To provide the product design team enough time for modifications, Storage and compression testing should be finalized in the PR-Phase. Testing defects should be minor and modifications should come from the design team.
Bulk Pack Packaging	<u>Input</u> - Gather additional or modified packaging samples. - Verify testing failure modes. - Identify testing parameters - Identify PR testing to be performed. - Provide sample packaging to production for review. -Verify the modifications to the product. - Order packaging for production shipments. <u>Output</u> - Free fall drop testing - Vibration testing - Compression test - Temp. & humidity testing - Handling & storage testing - Modify packaging designs from package test results.	<u>Input</u> - Gather same data as “Best Practices". - Provide a modified model to a package supplier to create a bulk package. - Have the supplier perform instrumented drop testing on full layer pallet design. - Validate the supplier’s results with in-house transportation testing. - Provide packaging samples for Temp. & humidity testing.	Tooled parts should be available for testing validation. Bulk packaging should be tooled and available for production testing. Units should be loaded into the full bulk packaging. Bulk pack handling (moving, stretch wrapping, container loading, tilt loading) testing should be initiated. Units should be available for vibration and drop testing. Drop testing should be completed to simulate a forklift mis-handling. Units should be sent for a test shipment to the nearest D.C. to evaluate the bulk package in real handling conditions.

PR-PHASE (cont.)

Analysis/Testing Recommendations	Best Practices	Minimum Requirements	Remarks (Reference)
Production Component Packaging	Input - Gather pricing and supplier design, modification requests and review with production, process engineering, and procurement. - Gather and review sample package. Output Test component sample packaging - Free fall drop testing - Vibration testing - Compression test - Temp. & humidity testing - Handling & storage testing - Modify packaging designs from package test results. - ESD part/packaging testing Approve packaging design.	Input - Instruct the suppliers to send packaging designs and samples to manufacturing process development engineers for review and acceptance. - Have supplier test the compoment and its packaging. The supplier send documented evidence of testing as required: - Free fall drop testing - Vibration testing - Compression test - Temp. & humidity testing - Handling & storage testing - Modify packaging designs from package test results. - ESD part/packaging testing Output Approve packaging design.	In this phase all parties should have a agreed upon a packaging solution. The design should be field tested to provide enough validation time prior to MR. The packaging specification should be documented by ER division regardless of of design origin.
Service Component/ Assembly Packaging	Input - Gather pricing and supplier design, modification requests and review with production, technical marketing, SMO engineering, and procurement. - Gather and review sample package. Output Test service packaging. - Free fall drop testing - Vibration testing - Compression test - Temp. & humidity testing - Handling & storage testing - Modify packaging designs from package test results. - ESD part/packaging testing - Approve packaging design.	Input - Gather suppliers/SMO verification that service packaging has been approved, tested,and documented. Output - Documernt the packaging design origin, and the responsible parties maintaining the packaging documentation .	In this phase all parties should have a agreed upon a packaging solution. The design should be field tested to provide enough validation time prior to MR. The packaging specification should be documented if designed by ER division, if not, the design origin for each packaging should be maintained by the ER division for audit purposes.
Product Documentation	Output Update the packaging documentation - Packaging component specifications - Packaging assembly specifications - Palletization specifications - Packaging cost analysis - Project timeline	Output - Same documentation as "Best Practices"	Provide a detailed report updating the current packaging and total costs for materials, labor, and distribution. Ordered parts for production should be specified and documented.

MR-PHASE

Analysis/Testing Recommendations	Best Practices	Minimum Requirements	Remarks (Reference)
Documentation	Output Complete the packaging documentation (issue to A rev.) - Packaging component specifications - Packaging assembly specifications - Service packaging specifications. - Palletization specifications - Final packaging cost analysis	Output - Same documentation as "Best Practices"	Provide a detailed report on the final packaging and total costs for materials, labor, and distribution. Compare this cost with the initial cost models.

Glossary (appendix A)

Acceptance Criteria	The acceptable quality level that must be met after the shipping unit has been subjected to the test plan. (see section 5). [ASTM 4169]
Assurance Level	The level of test intensity based on its probability of occurring in a typical distribution environment. [ASTM 4169]
Attenuate	To reduce the amplitude of an electronic control signal or vibration output such that the response is less than the input. [ASTM 4728]
Broad-band Random Vibration	Random vibration that covers a wide and continuous range of frequencies. Any frequencies that exceed the narrow-band limitations are considered broad-band. [ASTM 4728]
CL	Carload. [ASTM 4169]
Closed-loop	A condition of control where the input may be modified over time by the effect of the output of the system. [ASTM 4728]
Coefficient of Restitution	The ratio of the rebound velocity to the impact velocity. [ASTM 4169]
Complex Vibration	Vibration whose components are sinusoids not harmonically related to one another. [ASTM 4728]
COFC	Container on flatcar. [ASTM 4169]
Critical Acceleration	The greatest non-damaging maximum faired acceleration , expressed in G, using a trapezoidal shock pulse on a bare product. [ETM 760]
DC	Distribution Center
DP	Distribution Provider
Deterministic Vibration	Vibration whose instantaneous value at any future time can be predicted by an exact mathematical expression. [ASTM 4728]

Double Amplitude — The maximum value of a sinusoidal quantity (peak-to-peak). [ASTM 999]

Drop Test: — Process of determining the level of impact a packaged product experiences when dropped from a pre-determined height. The drop height is dependent on the weight of the unit.

Duration of Shock Pulse — The time required for the acceleration pulse to rise from 10 percent of the maximum amplitude and decay back to 10 percent of the maximum amplitude. See *Product Shock Tests*, Appendix B, *Shock Pulse Parameters. [ETM* 760]

Edge Crush Test (ECT) — (Also known as Edgewise Compression Test or Short Column Crush Test) - The measure of the edgewise compressive strength of a short column of corrugated fiberboard. This property, in combination with the caliper of the combined board and the perimeter of the container, relates to the top-to-bottom compressive strength of corrugated fiberboard boxes.

Equalization Adjustment — Correction of the amplitude characteristics of an electronic control signal throughout a desired frequency range to maintain a desired vibration output spectrum and level. [ASTM 4728]

Equalizer — Instrumentation used to conduct equalization. [ASTM 4728]

ESD — Electro Static Discharge.

Faired Acceleration — The smooth curve through the actual shock pulse. See *Product Shock Tests*, Appendix B, *Shock Pulse Parameters. [ETM 760]*

Filter — A device capable of passing certain frequencies with little loss (pass band) but of causing large losses so that other frequencies (stop band) are attenuated. Filters may be classified as low-pass (high stop), high-pass (low stop) or band-pass (stopping frequencies below and above the pass band). [ASTM 4728]

Filtered Signal — Signal is said to be filtered when components have been removed by passing it through a filter. [ASTM 4728]

Fixed Platen Testing Machine — A testing machine equipped with two platens which are both restrained from tilting. [ASTM 642]

Flat	For the purposes of drop tests, tip tests, tipover tests, and rolling tests; no two points on the surface differing level by more than 0.080 in. (2 mm); however, where one of the dimensions of the test package in contact with the surface is greater than 40 in. (1000 mm), a maximum difference in surface level of 0.20 in. (5 mm) will be acceptable. [ASTM 1083]
Floating Platen Testing Machine	A testing machine equipped with two platens, one rigidly restrained from tilting while the other platen is universally mounted and allowed to tilt freely. [ASTM 642]
Free-fall Drop Height	The calculated height of free fall in vacuum required for the dropping platen to attain a measured or given impact velocity.
G	Symbol for the dimensionless ratio between an acceleration in length per time-squared units, and the acceleration of gravity in the same units. [ASTM D996]
g	The acceleration of gravity, equaling 9.81 meters per $second^2$ (32.2 feet per $second^2$).
g rms	The square root of the integral of *power spectral density* over the total frequency range [ASTM 4728].
Gross Mass	The sum of the masses of the product, the package materials, and miscellaneous components shipped with the product (i.e., Operating Manual, power cord, etc.).
Hertz (Hz)	A measurement of frequency in which one hertz equals one cycle per second.
Hysteresis	The failure of a property, that has been changed by an external agent, to return to its original value when the cause of the change is removed.
Item 222-Series	Provisions in the *National Motor Freight Classification* of the motor common carriers containing requirements for corrugated and solid fiberboard boxes.
LTL	Less than truckload. [ASTM 4169]
Modal Analysis	The determination of modes of vibration of a structure. [ETM 759]

Mode of Vibration	The characteristic shape assumed by a structure when vibrating at one of its natural frequencies. [ETM 762]
Narrow-band Random Vibration	Random vibration having frequency components only within a narrow band. It has the appearance of a sine wave whose amplitude varies in an unpredictable manner. A narrow band should be +/-10 % or +/-3 Hz whichever is greater, of the center frequency of interest. [ASTM 4728]
Octave	The interval between two frequencies having a ratio of two (2). [ASTM 999]
Open-loop	A condition of control where the input of a system is pre-established and is not affected by the output or response of the system [ASTM 4728]
Periodic Vibration	An oscillation whose waveform repeats at equal increments of time. (see also deterministic vibration) [ASTM 4728]
Power Spectral Density (PSD)	The limiting mean-square acceleration per unit bandwidth. Units are g^2/Hz on the Y axis and Hz on the X axis. PSD is the industry accepted measurement to describe random vibration amplitude. [ETM 759]
Random Vibration	Vibration whose instantaneous magnitude is not specified for any given instant of time. The instantaneous magnitude of a random vibration is specified only by probability distribution functions giving the probable fraction of the total time that the magnitude lies within a specified frequency range. Random vibration contains no periodic or quasi-periodic constituents. [ETM 759]
Repetitive Shock	Impacts of a package on a test platform which occur cyclically from input vibration. [ASTM 999]
Resonance	A vibration of large amplitude in a mechanical system caused by a relatively small periodic stimulus of the same or nearly the same period as the natural vibration period of the system. [ASTM 999]
Rigid	For the purposes of drop tests, tip tests, tipover tests; a surface that will not be deformed by more than 0.0040 in. (0.1 mm) when any area of 0.16 in^2 (100 mm^2) is loaded

statically with 22 lb (10 kg) anywhere on the surface. [ASTM 1083]

Root-mean-square (rms) The square root of the mean-square value. In the exclusive case of a sine wave the rms value is 0.707 times peak value. [ASTM 4728]

Rule 41 A rule in the "Uniform Freight Classification" of the rail carrier containing requirements for corrugated and solid fiberboard boxes.

Shipping Unit The smallest complete unit that will be subjected to the distribution environment, for example, a shipping container and its contents. [ASTM 4169]

Sinusoidal Discrete Frequency A periodic function having a sinusoidal waveform of only one frequency. [ASTM 4728]

Spectrum A definition of the magnitude of the frequency components within a specified band width. [ASTM 4728]

SRS Shock Response Spectrum. For any particular input pulse, the theoretical response of an undamped, single degree of freedom spring/mass system with a particular natural frequency can be calculated using Newton's laws of motion.

STFI A test method to evaluate the short span compressive strength of paperboard. This method was developed by the Swedish Pulp and Paper Research Laboratory located in Stockholm in collaboration with Lorentzen & Wettre's instrument development resources. The letters STFI is the abbreviated acronym for Svenska Traforskininges Institute. This test method is also sometimes refered to as the SCT (short-span compression test).

Test Plan A specific listing of the test sequence to be followed to simulate the hazards anticipated during the distribution of a shipping unit. Included will be the test intensity and number of sequential tests to be conducted (see section 3). [ASTM 4169]

TL Truckload. [ASTM 4169]

TOFC Trailer on flatcar. [ASTM 4169]

Transmissibility

The non-dimensional ratio of the response amplitude of a system in steady-state forced vibration to the excitation amplitude. The ratio may be one of displacements, velocities, or accelerations. [ETM 759]

Velocity Change (Δ V)

The sum of the impact and rebound velocities. [ASTM 4169]

$$\Delta V = (1 + e)\sqrt{2gh}$$

where e = coeffecent of restitution which has the value of 0 to 1.

(appendix B)

Link Between Product Design and Package Design

by Don Clugston, San Diego Division

1.0 Product Strength Versus Package Cost

Product strength (fragility) and package cost go hand in hand. Stronger products require less packaging materials in order to protect the product as it travels to the customer. Of course, the reverse is also true, so a weak product can drive up over-all total costs, which includes the product, package and distribution costs. It is usually much less costly in the long run to invest in a little extra product material cost and product design time during the product development phase, compared to the continuing extra costs of a weak product coupled to a very expensive package with all it's inherent distribution costs.

A large benefit of a stronger product is the fact a customer receives a product which can withstand more abuse once it is removed from the package, thus increasing the company's quality image. Also, stronger products usually require a smaller package which helps reduce distribution and warehousing costs. The packaging is usually thrown away once the customer receives the product, so, if there is only so much to be spent on the total of package and product, it is best to invest into a stronger product, rather than a more protective and expensive package which becomes so much trash at the customers doorstep. If given a choice put money into the product, not the package, to gain the best product quality reputation.

Following are some of the relationships between the required product tests performed during product development and the corresponding packaging tests used to evaluate the package design. The hope is to gain some insight into the "why" behind some of this testing.

2.0 Link Between Product Tests And Package Tests

Many tests which are performed on the bare product have a significant impact on the resulting package design and cost of the package. A product designer that disregards the impact of the product design on package cost and just uses minimum product strength design goals, will usually cause the overall total cost (product, package and distribution costs) to be higher than it should be, thus reducing overall profit. Some product tests are performed to determine the ability of the product to survive from the time it leaves the production line until it reaches the ultimate user. Those product tests were intentionally written so that a direct relationship exists between the results of the product tests and the package design needed.

2.1 Product Shock Testing

The Transportation Shock test (ETM 760, Sec.7.3) is one of two product shock tests performed on the bare product. There is a direct relationship between the energy level input to the product during the shock test and the specified drop height of the packaged product. This is to help insure that the product shock testing adequately stresses the product to a similar amount of shock energy as would be seen in the transportation system for a product of a particular weight The data resulting from the product shock testing is the information needed by the package designer in order to make sure the package is adequately designed to protect the product during shipment to the customer. (This is covered in more detail later in this article)

2.2 Product Vibration Testing

One vibration test performed on the bare product, called Random Survival (ETM 759, Sec. 7.3), has a direct relationship to the package Random Vibration testing. The product random survival vibration testing ensures that the product sees during it's design stage, frequencies and energy levels typical of world wide distribution systems. It is important that the product design pass the product survival vibration testing and therefore be capable of surviving the typical distribution environment inside the package in route to the customer. If we hand carried each product from the end of the production line to the customer we would not need to have the product pass a random survival vibration test. The package vibration test is basically a repeat of the product survival test and is performed on the whole packaged product.

2.3 Product Compression Strength

There is not one particular product test which determines the ability of the product to withstand compressive forces over long periods of time. The product storage temperature (ETM 757, Sec. 5.3 and 5.6) does however evaluate the ability of product to support its own weight during storage at temperature extremes that could be encountered during product transit to the customer. That test should be conducted inside of the package so that the product is supported in the same manner that it would be during transit and in all three axis. There is no guarantee that a package will ship in any particular orientation on its way to the customer..

If a product will be shipped in bulk to distribution centers for postponement packaging, or if the product must support some of the weight of boxed units above it during palletized shipment and storage, it will be very important for the package designer to communicated directly with the product outer case designer in order to determine appropriate design measures and product tests. Usually a little forethought in the product design will add very little to the product cost and can contribute greatly towards reducing the overall packaging and distribution costs.

3.0 Relationship Between Product Shock Testing And Package Drop Testing

Two product shock tests are usually required during the product development stage and are performed on the bare product (no package) using a programmable shock machine. The **Handling Shock Test** is a high G, very short duration, sine shaped pulse, which is trying to simulate the affect of a customer knocking, bumping or lowering his unprotected product when it is <u>outside</u> of the package.

The **Transportation Shock Test** is a lower G, longer duration, trapezoidal shaped pulse which tries to duplicate the type of shock a product would receive <u>inside</u> of a package while in route to the customer. A trapezoidal pulse shape is used because it produces the greatest response of the various elements within the product to the shock input pulse, and over a wider frequency range, than does a sine shaped shock. The actual shock transmitted from the package cushioning (shape, duration, strength) to the product will vary with the type of packaging material, rib design, loading, etc., and will usually be somewhat sinusoidal shaped. Using a trapezoidal shaped product testing shock pulse is the best one to cover all circumstances and the most conservative.

The **Package Drop Test** is used to determine the package's ability to protect the product during shipping from a predetermined drop height that is usually based on product's weight, size, shape, cost, etc. The drop height equates to a certain amount of energy called impact velocity. The package cushioning will make the product rebound upward after hitting the floor with an additional amount of energy determined by the cushioning material's resiliency or rebound factor. The total energy transmitted to the product (called Delta V) is the total of both the impact velocity and rebound velocity added together. That energy has a shape of varying pulse height over a certain duration. The shock transmitted to various elements within the product will depend on the shock pulse shape (based mainly on the cushioning characteristics) and how each of the elements in the product will respond to that input shock pulse (based mostly on the natural frequency of those product elements).

The **Product Transportation Shock Test input parameters** are specified as Delta V and G Level and pulse shape. The pulse shaped has already been defined as trapezoidal. The Delta V is the total amount of energy transmitted to the product during the shock test <u>and is based on the drop height a product of similar weight might see in the distribution environment plus a average rebound factor.</u> The G Level used in the transportation shock test is the design criteria agreed to by the design team as a reasonable level of product ruggedness to achieve for that particular product. The duration of the resulting shock pulse is a result of the G Level and Delta V chosen as the input parameters. Basically, if G-level is the height of the shock pulse and duration is the length of the shock pulse, then the area under the shock pulse curve is considered to be delta-V.

What about the G-level inside the package during the drop test? You would think that the maximum overall G-level experienced by the product (as measured inside the package during a drop test) should be less than the programmed G-level the bare product received without damage on the programmable shock machine (transportation shock testing). That isn't true. You can have a much higher peak G-level inside the package and still not have the same product damage that occurred at lower G-levels on a shock testing machine.

The various elements inside of the product will "respond" differently to differently shaped input shocks. The actual shock seen by each element will depend on the natural frequency of the element. You can easily have a product in which an element failed on the shock machine at a certain G-Level input, but did not fail during the package drop test, even though the input shock to the product from the cushioning was larger. The reason is the fragile element within the product will respond differently to the two differently shaped input shocks from the shock machine and package drop, even though they may both have the same peak G-level. It is for this reason that the main criteria for a package drop test is "did the product survive and function", **not** "how high was the recorded G-level inside the package".

To account for this difference in shock response you can usually evaluate both the package test shock and the product test shock using a Shock Response Spectrum analyzer. Basically what it does is to display the input shock on a chart, showing how each element within the product will respond to the input shock based on the natural frequency of each product element. You can then visualize the reason why a fragile element of the product may break on the shock machine but can safely pass a higher shock inside the package, or actually see the delta between the two pulses. Each G-level response on the curve is determined by how the element "responds" to the input shock based on its own natural frequency.

What is the correlation between Shock Test velocity change and package drop height? The **package drop test** helps determine the package's ability to protect the product from a predetermined drop height based mainly on the product's weight. That drop height equates to a certain amount of energy called impact velocity. The internal package cushioning will make the product bounce upward after hitting the floor with an additional amount of energy called rebound, and is determined by the cushioning material's resiliency factor. The total energy transmitted to the product inside the package (called Delta V) is the total of both the impact velocity and rebound velocity added together, and can be calculated if the cushioning resiliency factor (called coefficient of restitution) is known. This factor can range between 0 and 1.

The **product transportation shock test** input parameters are specified as both Delta V and G Level and are meant to replicate the worst case shock experienced inside of the package during distribution. The Delta V is the total amount of energy transmitted to the product during the shock test and is programmed by changing the shock table drop height. The delta V as specified for the shock test must correlate to the delta V as experienced inside of the package by a similar weight package during the package drop test..

For consistency within the shock testing specification an **average coefficient of restitution of 0.75 has been specified**.. Therefore for any package drop height the equivalent shock table delta V can be calculated by multiplying the theoretical impact velocity by 1.75. For example, a 30" drop height is equal to the square root of 2 x gravity x drop height, or sq.

root of 2 * 386.4 * 30, or 152 inches per second. The equivalent shock table delta V would be 1.75 * 152, or 266 inches per second, which is assumed to be approximately the same impact plus rebound velocity inside of a package using typical cushioning materials such as polyethylene foam..

The G Level used in the transportation shock test is the design criteria agreed to by the design team as a reasonable level of product ruggedness to achieve for that particular product. The duration of the resulting shock pulse is automatically specified as a result of the G Level and Delta V chosen as the input parameters.

Reference Materials (appendix C)

The following addresses are where you can obtain the reference materials called out in this document. Typically, these materials may already be at your company in the research library or your Environmental Test Lab.

American National Standards Institute (ANSI)

Description: The ANSI Federation, organized in 1918, is made up of both manufacturing and service businesses, professional societies and trade associations, standards developers, academia, government agencies, and consumer and labor interests, all working together to develop voluntary national consensus standards. ANSI is the sole U.S. representative to the two major nontreaty international standards organizations: ISO (The International Organization for Standardization) and, through the U.S. National Committee, the IEC (The International Electrotechnical Commission). Standards from these organizations can be obtained by contacting their Customer Service office (see contact information below).

URL: http://www.ansi.org/home.html
Phone: 212-642-4900
Fax: 212-302-1286
Address: 11 West 42nd Street
New York, NY 10036
USA

American Society for Testing and Materials (ASTM)

Description: Organized in 1898, ASTM (the American Society for Testing and Materials) has grown into one of the largest voluntary standards development systems in the world. ASTM is a not-for-profit organization that provides a forum for producers, users, ultimate consumers, and those having a general interest (representatives of government and academia) to meet on common ground and write standards for materials, products, systems, and services. From the work of 132 standards-writing committees, ASTM publishes standard test methods, specifications, practices, guides, classifications, and terminology. ASTM's standards development activities encompass metals, paints, plastics, packaging, textiles, petroleum, construction, energy, the environment, consumer products, medical services and devices, computerized systems, electronics, and many other areas. ASTM Headquarters has no technical research or testing facilities; such work is done voluntarily by 35,000 technically qualified ASTM members located throughout the world. More than 9,100 ASTM standards are published each year in the 71 volumes of the Annual Book of ASTM Standards. These standards and related information are sold throughout the world. ASTM members develop the standards within the ASTM consensus process. Technical publications, training courses, and

	Statistical Quality Assurance Programs are other ASTM products. Standards from this organization can be obtained by contacting their Customer Service office (see contact information below).
URL:	http://www.astm.org/
E-mail:	service@local.astm.org
Phone:	(610) 832-9585
Fax:	(610) 832-9555
Address:	100 Barr Harbor Drive West Conshohocken, PA 19428-2959 USA

International Electrotechnical Commission (IEC)

Description:	The IEC was founded in 1906 as a result of a resolution passed at the International Electrical Congress held in St. Louis (U.S.A.) in 1904. The object of the Commission is to promote international co-operation on all questions of standardization and related matters in the fields of electrical and electronic engineering and thus to promote international understanding. The IEC is composed of National Committees, of which there are 51 at present, representing all the industrial countries in the world. The IEC co-operates with numerous other international organizations, particularly with the International Organization for Standardization (ISO), with which an agreement was passed in 1976, and increasingly with the International Telecommunication Union (ITU). At the regional level, there is a joint working agreement with the European Committee for Electrotechnical Standardization (CENELEC), which comprises 18 national committees of which most are also members of the IEC, and a co-operation agreement with COPANT, the Pan American Standards Commission. To accomplish its task, among other activities the IEC publishes International Standards and Technical Reports; the International Standards serve as a basis for national standardization and as references when drafting international tenders and contracts. IEC Publications are bilingual in English and French, while the Russian Federation National Committee issues Russian language editions. Among other important IEC Publications figure the International Electrotechnical Vocabulary (IEV) and the IEC Multilingual Dictionary of Electricity. Standards from this organization can be obtain by contacting their Customer Service office (see contact information below).
URL:	http://www.iec.ch/
E-mail:	inmail@iec.ch
Phone:	+41 22 919 02 11
Fax:	+41 22 919 03 00
Address:	3, rue de Varembé PO Box 131 1211 Geneva 20 Switzerland

International Organization for Standardization (ISO)

Description: The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies from some 100 countries, one from each country. ISO is a non-governmental organization established in 1947. The mission of ISO is to promote the development of standardization and related activities in the world with a view to facilitating the international exchange of goods and services, and to developing cooperation in the spheres of intellectual, scientific, technological and economic activity. ISO's work results in international agreements which are published as International Standards. Standards from this organization can be obtain by contacting your country's ISO Sales Agent which can be located at URL: **http://www.iso.ch/isob/direct/sales/e**

URL: http://www.iso.org

Phone: + 41 22 749 01 11

Fax: + 41 22 733 34 30

Address: 1, rue de Varembé
Case postale 56
CH-1211 Genève 20
Switzerland

International Safe Transit Association (ISTA)

Description: The International URL: **http://ista.org**

URL: http://www.ista.org

E-mail: ista@ista.org

Phone: 517.333.3437

Fax: 517.333.3813

Address: 1400 Abbott Road
Suite 160
East Lansing, Michigan USA
48823-1900

Air Cargo (Appendix D)

Aircraft Capacities and Dimensions

International Air Freight

		Cubic capacity ULD Standard pallet P1	Max Freight Capacity	Access Door dimensions	Design To
747-200F	Main Deck	2.1 X 3.0 M	2,500 Kgs	3m Side, 2.4M Nose	96 Inches
	Lower Deck	2.1 X 3.0 M	2,500 Kgs	1.68M	64 Inches

Key Design Rules:

Density Rule:

6000 cubic cm/1Kg	Metric
166 cubic inches/1Lb	Std

Note: *Cargo with a lower density than listed above will be charged on the basis of the density rule*

Formula:
(L cm x Wcm x Hcm) / 6000cm / kilogram

Example:
1. A shipping container 120 cm long by 110 cm wide by 100 cm high divided by 6000 cm/kg = 220 kg pallet. If actual weight is less than 220 (e.g. 180 kg) we will be charged the 220 weight. If the actual weight is 240 then you will be charged the actual weight of 240 kg.

If you take the 220kg/180 = 1.22 (anything more than 1 is BAD) You would be paying 22% more than actual weight.
If you take the 220kg/240 = .92 (anything less than 1 is GOOD)

Air Cargo Containers

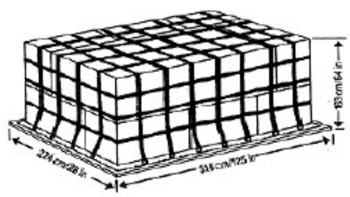
Internal Dimensions	Max Gross Weight	IATA
188 x 139 x 137 cm	500Kgs	LD3
291 x 226 x 147 cm	1,600Kgs	LD9

3.58 **m^3 for a LD3** **Cubic Volume**
9.67 **m^3 for a LD9**

NOTES:
1. These are commonly used aircraft. This is not an attempt to exhaust all of the possible aircraft used globally.
2 If you have specific packaging design constraint to design to or have a need for more specific information please contact the appropriate BU Liaison.

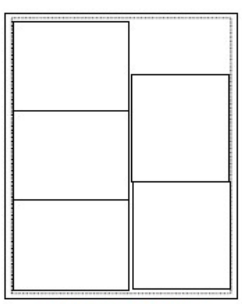
Domestic Airfreight

Aircraft Type	Max Door Height	Cargo Loading
B737	32 in/ 81.28 cm	Loose cargo only
A310	61 in / 154.94 cm	P1, LD3, or loose cargo
A319/A320	42 in / 106.68 cm	Loose cargo only
A340	32 in/ 81.28cm	P1, LD3, or loose cargo
US Domestic All Cargo AC	96 in / 243.84cm	Varies by airlines
DC10	61 in / 154.94 cm	LD3, LD11 or loose cargo
DC10Freighter	96 in / 243.84cm	PM, PG or LD3
DC-8	62 in / 157.48cm	PAP,PIP or PAG



P1 Pallet Load

Air Cargo cookie sheets
OD 125" x 96"
ID 121" x 92"



Using std 40x48