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Measurement and Analysis of 'Small' Packages in Next-day Air Shipments

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SUMMARY

Packaged goods are shipped globally using various means of transportation. Over the past two decades, there has been a continuous increase in studies that measure and analyse dynamic events that occur to packages during transportation and handling. These data offer useful information to design and test packages, and provide protection from potential hazards like drops and impacts. However, none of the past studies are directed towards single packages regarded as 'smalls'. 'Smalls' or small-package product systems are defined as those with volume of less than 0.013 m^3, a longest dimension of 0.356 m and a weight of 4.54 kg or less. Packages that qualify for these specifications are often mixed together in a large carrying bag and handled with other single parcel shipments. This study measured and analysed the effect of moving this category of single packages through expedited shipments in the USA. The results showed that these packages experienced as many as 27 events comprising of drops or tosses in a one-way shipment, and a maximum of 5.01 m of near-zero G travel distance representing long 'tosses'.

KEY WORDS: parcel shipments; small packages; impacts; drops

INTRODUCTION

Packaged goods are shipped from one place to another using various means of transportation. During these transfers, packages are usually exposed to many physical and climatic stresses. Vibration, compression forces, shocks and temperature and humidity changes can drastically affect a product and its package's structural strength. There has been a continuous increase over the past two decades in measuring the dynamic events that occur to packages in different transportation modes. These data offer very useful information to design and test packages to counteract potential hazards like drops and impacts. This study focused on measuring a new segment of the packages termed 'smalls' through the overnight single parcel shipping environment of FedEx that has not been previously measured. Various researchers have investigated the distribution environment segments for various transport modes to get a better understanding of the effects of physical hazards on packages. This information provides a basis for developing test methods to design economical protective packaging. Various previous studies have been done to quantify the impact and drop levels that packages experience in single parcel shipments of different carriers. A summary of these studies describing packaging types, carriers and their findings are discussed in the next section.

- Goff developed performance requirements that were necessary for parcel post packages in 1974.[1] The study recommended performance-based test methods that could be used to reduce physical damage to parcel post packages.
- Singh and Voss, and Singh and Cheema measured the dynamics of small parcel environment in the UPS ground-shipping environment.[2,3] The study tested packages of different sizes and weights that were instrumented with drop-height recorders and then shipped through UPS. The study showed that the highest drop height measured was 1.06 m, and that the size of the package had no significant effect on the drop heights associated with medium- and larger-size packages. However, small-size and lighter-weight packages did experience higher drop heights. This was attributed to the use of automated handling for the larger and heavier packages in the UPS sorting environment. The smaller and lighter packages are often placed on top in the delivery truck and are therefore subject to higher drops.
- Singh *et al*. measured the environment within UPS for packages weighing up to 64.0 kg.[4] In addition, the effect of label position on drop orientation has also been studied in parcel shipments for large and heavy packages.[5]
- A study by Singh *et al*. concluded that the package size and weight had no effect on measured drop heights for packages classified as small and lightweight within the FedEx Second-day Air Delivery system.[6] The study also found that warning labels reading 'Fragile – Handle with Care' had no significant effect on the handling of packages.
- In another study measuring the parcel shipping environment within FedEx for lightweight and small-size packages, the authors concluded that neither the package size/weight nor the labels had any significant effect on the severity of drop heights.[7] The highest drop height measured was 1.85 m.
- A study measuring and analyzing the express shipping environment for mid-size and lightweight packages for DHL, FedEx and United Parcel Service, concluded that the handling environments within FedEx and UPS are not significantly different between ground shipping, second-day and next-day, regardless of package size and weight of packages.[8]
- In a recent study, Singh *et al*. summarized that the number of drops experienced by the packages in the overnight (next-day) environment for the United States Postal Service (USPS) was comparable with average of those for DHL, FedEx and UPS.[9] The priority (second-day) shipments in the USPS environment, however, experienced 2.30 times lesser drops as compared to the average of those experienced in DHL, FedEx and UPS shipments. The study also found that the average drop height of the 10 highest drops experienced in the USPS shipping environment for both the express (next-day) and priority (second-day) service was higher than that for DHL, FedEx and UPS.
- Another study measured and analysed the effect of placing precautionary labels on mid-size and lightweight packages when shipped using next-day and second-day services provided by DHL.[10] For the next-day service, packages with labels, as compared to those without labels, were subjected to approximately the same number of drops for shipment to California, and approximately 35.2% less drops for shipments to New York. For the second-day service, approximately 37.4% more drops were noted for shipments to California for packages with labels, whereas the shipments to New York experienced the same number of drops.

It may be noted here that although a considerable amount of research has been conducted in the past evaluating the different shipping environments, none have considered the 'smalls' category. 'Smalls' or small-package product systems are defined as those with volume of less than 0.013 m^3, a longest dimension of less than 35.6 cm and the weight of 4.54 kg or less.[11] Packages that fall into this category are usually consolidated into bags measuring approximately 0.991×0.686 m for efficient handling. Each bag weighs a maximum of 36.3 kg and contains small packages destined for the same geographic location.[11] During the distribution of packaged goods, small parcel shipping environment typically is subject to hazards because of mechanized sortation and multiple manual handlings. Shocks account for one of the most severe hazards and typically result from drops, kicks, tosses and mechanized handlings. A typical hub-and-spoke model based on small package delivery system is illustrated in Figure 1. The hub-and-spoke distribution paradigm is a system of connections

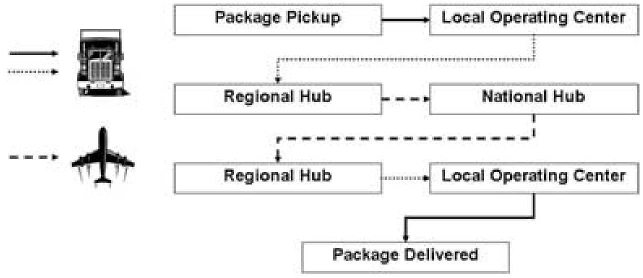

Figure 1. Parcel movement from origin to destination.

Figure 2. SENSR GP1 tri-axial motion recorder.

arranged like a bicycle wheel, in which all traffic moves along the spokes connected to the hub at the centre.

- The focus of this study was to measure and analyse shock-related events that occur to small-size packages in domestic expedited single parcel shipments. The study had the following objectives: (a) to characterize the dynamics of the next-day express shipping shock and drop environment for 'small' packages shipped by FedEx within the USA; and (b) to provide recommended test levels for drop testing for packages specified as 'smalls' for the single parcel shipping environment.

INSTRUMENTATION

In order to achieve the objectives of this study, data recorders were used to collect dynamic data that could be used to develop test methods to simulate the next-day express shipping environment for FedEx for small packages. There are several types of instruments available to measure dynamic events that packages experience during shipping and handling. These range from single-drop counters that only record if the package is dropped above a pre-set height, to recorders that measure impacts along all three axes of the package. The latter typically monitor acceleration – time histories for all events.

Because of the size and weight limits of the small packages, SENSR GP1 (Reference LLC, Elkader, IA, USA)[12] data recorders were selected to monitor the shock levels in these packages. SENSR GP1 (Figure 2) has a trial-axial programmable accelerometer which allows monitoring; recording; and evaluating motion, impact, shocks, drop, orientation and temperature in all three axis.

The measuring and reporting parameters for SENSR GP1 used in this study were as follows: (a) sampling rate per axis (100 Hz); (b) accelerometer range (±10.0 G); (c) temperature range (–20.0 to +80.0°C); (d) epoch setting (6.00 s); (e) threshold (0.500 G); (f) alerts enabled (vector magnitude max); and (g) test duration (7 days).

The SENSR GP1 recorder has limitations on calculating drop heights from resultant velocity change. The method used to determine drop heights is based on correlating vector magnitude *G* levels measured in laboratory drops conducted from fixed and known drop heights, and comparing this to measured vector magnitude *G* levels obtained from actual shipments of these package types in FedEx environment. Preliminary drops were done using a precision drop tester (model no. PDT-56, Lansmont™ Corporation, Monterey, CA, USA) at predetermined drop heights of 0.305, 0.762 and 1.22 m. Table 1 below shows the maximum vector *G*s recorded during the calibration testing in the lab at these heights. The highest vector magnitude *G* was recorded from each drop height based on several drops on each face, edge and corner. The maximum vector magnitude *G* for each package type was correlated with actual trip to lab-measured values to estimate drop heights. An extensive set of drops and tosses were conducted in a lab in the three package types, and the corresponding vector magnitude *G* levels were measured. A correlation chart was developed that can be used to estimate the drop height levels and associated toss distances based on these vector magnitude *G* levels.[13]

Test packages were instrumented with the recorders to measure the dynamic events in priority overnight service provided by FedEx. The study focused on three types of protective packages: Jiffylite® Bubble Mailer #1 (Figure 3a) and Jiffy Rigi Bag® mailer #1(Figure 3b, Sealed Air Corporation, Elmwood Park, NJ, USA)[14] and a single-wall E-flute regular slotted container (RSC) corrugated fiberboard box with Ethafoam 220 cushions (Figure 3c, Dow Chemical Company, Midland, MI, USA). The Jiffylite Bubble Mailer #1 consisted of 0.476 cm Barrier Bubble® layer for air retention and cushioning, and the Jiffy Rigi Bag mailer #1 comprised of 90% recycled paper fibers. The dimensions of the mailers as well as the box fit the requirements of the category of parcels proposed for this study.

The drop height during free fall can also be measured using time of free fall. Such free-fall drop heights can be calculated as:

$$h = \frac{1}{2} g t^2$$

Table 1. Maximum vector magnitude ***G*** from drop tester.

	Drop height (m)		
Package type	0.305	0.762	1.22
Jiffy Rigi Bag® Mailer	16.0	17.4	20.9
Jiffylite® Bubble Mailer	15.0	16.8	18.0
Corrugated box	17.2	18.4	20.7

Figure 3. Instrumented test packages.

where h = free-fall drop height (m or in); g = acceleration due to gravity, 9.81 m/s^2; t = free-fall duration, expressed in seconds.

Because most bumps and shocks that a package experiences in supply chain are not perfect free-fall drops, but lateral impacts or tosses,[7] in lab testing was done using these recorders to determine what the reported vector magnitude G levels were corresponding to a range of drop heights or lateral tosses.[13] This method was utilized to determine corresponding distances of lateral tosses and vertical drops.

TEST PACKAGE SHIPMENTS

The SENSR GP1 recorders were placed in the two types of mailer envelopes, with the top facing the packing label and were secured by using the self-seal closure or cohesive self-seal. No void fill material was inserted. For the RSC-style corrugated boxes, the data recorder was snugly encased at the geometric centre of the box with cushions placed on all six sides. The boxes were closed with a 5.08 cm wide general-purpose plastic box sealing tape.

The size and weight of the data recorder and packages were as follows:

1. size (outer dimensions)
- SENSR GP1 Recorder: 10.0 × 6.50 × 2.90 cm
- Jiffylite Bubble Mailer #1: 18.4 × 27.3 cm
- Jiffy Rigi Bag Mailer #1: 18.4 × 26.7 cm
- E-flute corrugated box: 14.3 × 11.1 × 6.05 cm

2. weight
- SENSR GP1: 221 g
- Jiffylite Bubble Mailer #1: 17.0 g
- Jiffy Rigi Bag Mailer #1: 62.4 g
- E-flute corrugated box: 79.4 g

The packages were shipped via FedEx priority overnight service from the East Lansing, MI to two destinations: San Luis Obispo, CA and Rochester, NY. Six instrumented packages were shipped simultaneously per package type for each round trip. After their return, the data from each recorder were downloaded and analysed using the software provided by the manufacturers of the device. A total of 24 round trips (48 one-way trips) were conducted for the three package types for both destinations. The study was conducted from June to August 2007, and January to February 2008.

RESULTS AND DISCUSSION

The data gathered from all shipments are tabulated and expressed in graphical form. Table 2 represents the total number of near-zero Gs and maximum vector magnitude Gs observed for the six round trips to California and New York for each package type. Near-zero G values cannot fully represent free-fall drops and are referred to as tosses. Different methods have been developed in the past that are used to analyse and present results of drop and impact data. Two of the most widely used methods have been presented by Sheehan and Singh.[15] One of these is used to show the results of this study and is discussed in the next section.

Table 3 summarizes the drop data as number of near-zero Gs (number of drops and tosses); maximum drop height; and the 90.0, 95.0, 99.0% vector magnitude G occurrence levels. The data show that the Jiffylite Bubble Mailer experienced the highest combined number of drops and tosses as well as the highest drop heights greater than 1.22 m during the six round trips to California and New York. The occurrence level for maximum vector magnitude of 15.9 Gs (California, Jiffylite Bubble Mailer, 95%) as reported in Table 3 means that 95.0% of all max vector magnitude Gs observed were below this level. Figures 4 and 5 provide graphical representations of the cumulative percentages versus the maximum vector magnitude occurrence levels.

The drop heights reported in Table 3 are based on averaging the results of 12 round trips each between Michigan and California, and Michigan and New York. This format is often used as the basis

Table 2. Near-zero and maximum vector magnitude ***G***s observed.

Trip	Total number near-zero *G*			Maximum vector magnitude *G*		
	Jiffy Rigi Bag® Mailer	Jiffylite® Bubble Mailer	Corrugated box	Jiffy Rigi Bag® Mailer	Jiffylite® Bubble Mailer	Corrugated box
One-way trip to California						
1	24	32	12	16.3	18.2	15.5
2	18	29	31	16.5	15.9	19.4
3	22	28	18	18.2	19.0	17.0
4	19	16	13	16.4	16.5	16.7
5	21	29	13	20.5	18.2	17.8
6	21	29	15	18.2	17.8	17.3
One-way trip to New York						
1	19	21	14	18.3	16.9	17.4
2	20	22	15	18.9	19.8	19.2
3	23	25	33	18.4	16.5	17.1
4	23	23	9	15.8	18.3	19.1
5	22	22	12	19.5	19.9	15.0
6	23	27	11	17.6	21.7	18.8

Table 3. Summary of dynamic events measured.

Drop data	Michigan to California			Michigan to New York		
	Jiffy Rigi Bag® Mailer	Jiffylite® Bubble Mailer	Corrugated box	Jiffy Rigi Bag® Mailer	Jiffylite® Bubble Mailer	Corrugated box
Number of drops and tosses	21	27	17	21	23	16
Maximum drop height (m)	1.22	>1.22	0.991	1.22	>1.22	0.965
Maximum vector magnitude at 99.0% occurrence (*G*)	18.2	17.8	17.6	18.4	19.8	18.8
Maximum vector magnitude at 95.0% occurrence (*G*)	15.7	15.9	16.2	16.2	15.9	16.5
Maximum vector magnitude at 90.0% occurrence (*G*)	14.6	14.3	15.5	15.0	14.3	14.8

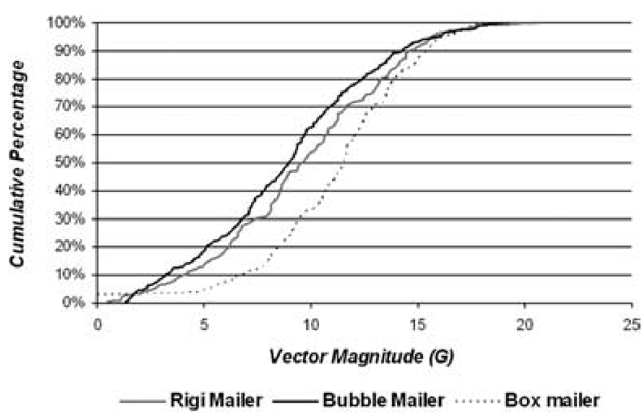

Figure 4. Cumulative percentage versus vector magnitude for shipments to California.

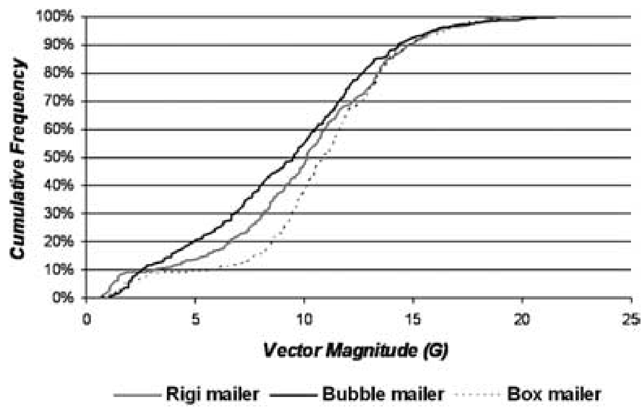

Figure 5. Cumulative percentage versus vector magnitude for shipments to New York.

Table 4. Near-zero ***G*** travel distance.

	One-way trip: California			One-way trip: New York		
Distance (m)	Jiffy Rigi Bag® Mailer	Jiffylite® Bubble Mailer	Corrugated box	Jiffy Rigi Bag® Mailer	Jiffylite® Bubble Mailer	Corrugated box
Highest	4.71	1.54	4.81	2.07	1.65	5.01
Second highest	4.43	1.43	3.46	2.01	1.54	3.06
Third highest	3.46	1.33	2.99	1.95	1.43	2.40
Fourth highest	2.99	1.28	2.76	1.59	1.38	2.20
Fifth highest	2.91	1.23	1.77	1.54	1.23	2.07
Sixth highest	2.62	1.18	1.65	1.38	1.04	2.01
Seventh highest	1.95	1.13	1.59	1.28	0.99	1.89
Eighth highest	1.83	1.08	1.54	1.23	0.95	1.59
Ninth highest	1.48	1.04	1.28	1.18	0.91	1.48
Tenth highest	1.38	0.99	1.23	1.13	0.87	1.43

Table 5. Impact orientation.

		Orientation of drops (%)		
Destination	Package type	Face	Edge	Corner
California	Jiffy Rigi Bag® Mailer	62.6	24.4	14.6
	Jiffylite® Bubble Mailer	25.5	55.3	20.5
	Corrugated box	44.6	31.7	24.8
New York	Jiffy Rigi Bag® Mailer	56.3	25.8	19.5
	Jiffylite® Bubble Mailer	29.5	51.8	19.4
	Corrugated box	50.3	30.0	20.3

for lab-simulated drop tests where drop testing is performed in sequentially reducing drop height levels.[6–10] Table 4 shows the 10 highest drop heights resulting from drops and/or tosses in descending order. The data revealed that lateral tosses associated with zero-*G* or ‘weightless’ condition in air could be as ‘high and far’ as 5.01 m. Knowing the physical constraints to drops inside of trailers or material handling conveyors in FedEx facilities, this can only be attributed to long tosses during manual sortation.

Table 5 categorizes the impact orientations for all shipments. In true free-fall drops, the likelihood of packages landing on their edges and corners is higher.[8] This impact orientation data can be used to develop test protocols for lab-based testing to simulate priority overnight service for small package products.

This paper provides data for the users to create test methods specific to the challenges of the distribution environment and the expected level of protection needed (or level of severity that packages get exposed to). Based on the previous studies, drop height levels of 99.0% occurrence (Table 3) are generally used for either very expensive products or when extremely low levels of damage are desired. Other product types may select between 90.0 and 95.0% occurrence levels of drop heights based on either the value or allowable (acceptable) damage.

As an example, based on the observations of this research, a drop testing protocol for corrugated boxes falling in the 'smalls' category that are shipped overnight through the small parcel shipping environment could be created. The number of drops on the same package ranges from 6, 10 and 12 based on current test methods of the American Society of Testing and Materials and International Safe Transit Association. A box has six faces, eight corners and twelve edges (total of 26 components), and hence the theoretical probability of face, edge and corner drops are 23.1, 46.2 and 30.8%, respectively. If the selected number of drops to replicate this environment in a lab is 10, the drops may be designated by orientation as two face drops, five edge drops and three corner drops. The data presented in Tables 3 and 4 can be used to determine the drop height for such a protocol as well.

CONCLUSIONS

This study presents the dynamic information on 'smalls' or small package products which are handled differently than other larger parcel shipments throughout distribution environment. For easy handling purpose, small package products are consolidated in a bag during most of its transit time. The maximum number of near-zero G measured was 27 times, and the maximum near-zero G travel distance was 5.01 m. The high travel distance could result from the high probability of being thrown or tossed because of its size. Both Rigi and Bubble Mailer envelopes showed similar maximum drop height at 1.22 m, whereas the drops on boxes with cushion were from 0.991 m. No significant difference on maximum vector magnitude occurrence level was observed for all three package types.

Test protocol developed for box package type recommended a total of 17 drops, with orientations of eight faces, five edges and four corner drops. Two drop heights were suggested at 95.0 and 99.0% occurrence level: 1.52 m for 99.0% occurrence level or 0.610 m for 95.0% occurrence level.

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