DANGEROUS GOODS PANEL

Dubai, 31 March to 4 April 2003

MICHIGAN STATE UNIVERSITY STUDY

(Presented by R. Richard)

1. INTRODUCTION

1.1 Testing was conducted by Michigan State University on a number of dangerous goods packagings. A description of the test methods and the results of the testing are provided in the attached report. While some of the testing was conducted using methods that are not consistent with the current requirements of the Technical Instructions, panel members are requested to consider the test methods and the results with respect to the requirement in 4;1.1.6 that requires packagings for which retention of liquid is a basic function to be capable of withstanding without leakage an internal pressure test which produces a pressure differential of not less than 95 kPa. Panel members are requested to consider whether the tests simulate normal conditions of air transport (e.g. simultaneous application of vibration and pressure differential). Comments relevant to the test method used and the results are requested.

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PACKAGE PERFORMANCE FOR HAZARDOUS MATERIALS IN HIGH ALTITUDE SHIPMENTS

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ABSTRACT:

This paper discusses the impact of high altitude shipments on package integrity. High altitude shipments are encountered when trucks travel over high mountain passes or when cargo and feeder aircraft transport packages in non-pressurized or partially-pressurized cargo holds. Both these types of transport methods will result in severe changes in pressure and temperature conditions as compared to packages being transported close to sea-level. The testing of packages under these conditions is critical since package integrity may be compromised. The current shipping tests are performed in test labs that do not account for pressure changes. This study showed that combination packages for dangerous goods and hazardous materials that are tested to existing UN, ICAO and US DOT requirements are limited, and can result in significant number of leaks.

INTRODUCTION

The Federal Aviation Administration has observed an increase in the number of package failures of hazardous materials in commercial and cargo aircraft over the past three years (Singh and Burgess, 2001). Figure 1 shows the different classifications of products that had package related failures. Table 1 shows the causes of failure by package type. For plastic and metal packages, failure of the closure/seal accounted for about 65% of failures. For glass containers, drops account for about half, with seal failures down to 23% (McLaughlin, 2001).

In addition to the above findings, the United Parcel Service presented a study to the American Society of Testing and Materials (ASTM) describing the conditions that packages experience in the single parcel shipping environment (ASTM, 2001). The study resulted in the following key observations (ASTM D6653-01):

- Cargo air jets are typically pressurized to approximately 2,438 m (8,000 ft). Temperature is maintained at approximately 20 to 23 °C (68 to 74 °F)
- Packages transported on the ground may experience altitudes as high as 3,658 m (12,000 ft) when shipped over certain mountain passes, especially in Colorado. Temperature extremes range from –15 to 30 °C (5 to 86 °F) with an average mean temperatures ranging from

approximately –4 to 18 °C (25 to 64 °F)

- Non-pressurized "feeder aircraft" typically fly at approximately 3,963 m to 4,877 m (13,000 to 16,000 ft). The highest recorded altitude in a non-pressurized feeder aircraft was 6,017 m (19,740 ft). Temperatures ranged from approximately –4 to 24 °C (25 to 75 °F).

Based on these findings, it is evident that packaged products transported via the feeder aircraft network used by cargo carriers like United Parcel Service, Federal Express, and United States Postal Service are liable to experience altitudes as high as 6,100 m (20,000 ft). Packages transported on the ground may experience altitudes as high as 3,658 m (12,000 ft) when shipped over mountain passes in the United States. When exposed to these conditions, products and/or packages may be adversely affected by the changes in pressure or temperature.

In an attempt to create a laboratory test method that replicates the environment, ASTM developed and approved a new test method, D6653-01: "Standard Test Methods for Determining the Effects of High Altitude on Packaging Systems by Vacuum Method" (ASTM, 2002). The test method recommends that the package be subjected to a reduced pressure of 59.5 kPa representing an altitude of 4,267 m (14,000 ft.) for 60 minutes.

There are other test methods aimed at simulating the high altitude environment used by Department of Transportation (DOT) and International Civil Aviation Organization (ICAO). The problem with all of the existing test methods recommended by ASTM, DOT and ICAO is that they do not consider the combined effects of pressure, temperature and vibration. Furthermore, the existing DOT specification for shipping and handling HazMat containers requires that the packages be placed with the closure facing up at all times. While this practice can be easily followed for ground shipments, it is difficult to control in air transport. Air shipments are generally "cubed out" and therefore packages are placed in the orientation most likely to provide the highest volume efficiency. In various studies (Singh, et-al, 1996; Newsham, et-al, 1999) there is a clear indication that single parcels get exposed to impacts and vibration in all orientations during parcel handling, sorting, and transportation. The result is that these performance tests often lead to validating packages that have problems in real life shipments.

The purpose of this study was to investigate the effects of vibration alone, altitude alone, and vibration in combination with altitude on the performance of UN approved HazMat packages containing liquids in the sideways and upside down orientations. Temperature effects were not considered because it is difficult to do so (in combination with vacuum and vibration) and because the shipping temperatures found in the UPS study (25 - 75F) were not thought to be significant. Furthermore, lowering the temperature of a test package acts to reduce the headspace air pressure, which lowers the pressure differential and makes altitude effects less severe. Testing was therefore done at room temperature to incorporate a small safety factor. Testing was done in five phases. Each test phase represents the different conditions of low pressure and vibration that packages are likely to be exposed during high altitude shipments. Based on the results, a new test method was proposed to ASTM for the testing of packages that undergo high altitude shipments.

MATERIALS AND TEST METHODS:

Samples of UN approved HazMat packages were procured by Michigan State University from three leading HazMat packaging suppliers. The test packages were certified to meet both the UN/ ICAO and applicable US DOT requirements. The confidentiality of the package suppliers was maintained for the study at the request of the sponsoring agencies. Table 2 shows package types tested during the different phases of the study. In addition to these HazMat packages, two test packages were prepared that consisted of glass test tubes with rubber stoppers. PACK 1 and PACK 2 are glass test tubes with rubber stoppers, but PACK 1 has tape wrapped around the stopper and test tube in the neck area. These types of rubber stoppers are also referred to as friction-type closures.

When performing vibration tests, a decision must be made regarding the severity of the environment. ASTM D 4169 describes three different test level intensities (Assurance Levels I, II and III) for evaluating shipping container performance. These test intensity levels are related to uncertainties in environmental conditions. Assurance Level I corresponds to a high level of intensity, but a low probability of occurrence. This leads many people to consider Assurance Level I as conservative, with plenty of safety factor built in. Upon consultation with the FAA and DOT, and from past experiences with various tests, a decision was made to use Assurance Level II for this project. Assurance level II is also the most commonly used intensity level by testing facilities.

Phase I (Truck/Air Vibration and Vacuum at 4267 m (14,000 ft.))

This test consisted of simultaneous low pressure representing an altitude of 4,267 m (14,000 ft.) and random vibration using combined truck/air Power Spectral Density (PSD) data. The test procedure was as follows. Figure 2 shows the test setup.

- Packages were conditioned at 73.4 ± 3.6°F for a minimum of 24 hours before testing.
- The primary containers were filled to the recommended fill-level with water and the recommended application torque was applied to the closure.
- Secondary packaging was applied, as if preparing for shipment, in accordance with the manufacturer's instructions.
- Two samples of each stock keeping unit (SKU) were used for this phase.
- The test specimen was placed upside down in the vacuum chamber and the vacuum chamber was placed on an electro-hydraulic vibration table.
- After sealing the vacuum chamber, the vacuum pump was turned on and adjusted to reduce the pressure at a rate of 305 meters (1000 ft.) in 30-60 seconds as recommended in ASTM D6653-01. This replicates normal take off conditions on an airplane of 1000 – 2000 feet/minute.
- A vacuum of 59.5 kPa (pressure equivalent of 14,000 feet) was achieved with a permissible error of ±2%.
- While maintaining a vacuum of 59.5 kPa, the vibration table was operated for 30 minutes using the random mode under combined truck/air-shipping environment (Assurance level II, ASTM D 4169) representing shipments of 250 miles.
- The chamber inlet valve was opened and the vacuum released at a rate of 305 meters (1000 ft.) in 30-60 seconds.
- The test specimen was removed and any leakage was recorded.
- The closures were removed and the removal torques were measured and recorded.

Some of the results of the Phase 1 test are shown in Figures 3-9 and Tables 3-5. Figures 3-4 show that large closures had a greater tendency to leak compared to smaller ones. Tables 3-5 show that 15 out of 32 packages tested leaked.

Phase II (Truck/Air Vibration Only)

The purpose of this test was to remove the pressure differential in order to study the effect of vibration only. So the test procedure was exactly the same as in Phase 1 but with the vacuum chamber steps omitted. An additional step not done in Phase 1 was to place alignment marks on the container and closure to see if the closures were backing off. This was not found in any of the tests, including Phases 3-5 that follow, probably because tape was applied around the closure after it was torqued on, as recommended by the manufacturer. The results of the Phase 2 tests are shown in Table 6. With only 2 leaks out of 14 tested, these results clearly show the influence of pressure differential.

Phase III (Vacuum Only at at 4,267 m (14,000 ft.))

The purpose of this test was to remove vibration in order to study the effect of pressure differential only. So the test procedure was exactly the same as in Phase 1, but with vibration related steps omitted. The results are shown in Table 7. There were no leakers, indicating that vibration is a necessary component for failure.

Phase IV (Truck/Air Vibration and Vacuum at 2,438 m (8,000 ft.))

The purpose of this test was to subject the test package to lower altitudes, but for longer times in order to recreate the environments found in pressurized cargo holds of large commercial aircraft. The procedure was the same as in Phase 1, except that the test pressure was 75.3 kPa instead of 59.5 kPa, simulating 8,000 ft. instead of 14,000 ft. In addition, the vibration table was operated for 3 hours instead of 30 minutes, as recommended in ASTM D4169, in order to simulate longer flights. The results are shown in Table 8. There were 4 leakers out of 14 tested. These results again show that vibration appears to be more important than pressure differential in producing leakers.

Phase V (Truck Vibration Only and Vacuum at 2,438 m (8,000 ft.)

The purpose of this test was to remove the air transport PSD data from the vibration test spectrum to see if there was any difference in pure ground transport and combined ground/air transport. So the test procedure was exactly the same as in Phase 4, but with only the truck PSD data. The results are shown in Table 9. There were 3 leakers out of 14, slightly less than in Phase 4. This was expected since the overall vibration levels were reduced somewhat.

DISCUSSION:

Figure 10 summarizes the results of the five different tests. Phase 1, which simulated the environment experienced by the packages in short feeder aircraft shipments, showed the greatest percentage of leakers. Phase 4, which had the same vibration environment but at a lower altitude showed only about 20% leakers. Phase 2, which simulated only the vibration component, and Phase 5, which simulated only truck vibration but at low altitude were equal at 10%. Phase 3, which simulated only altitude effects at 14,000 ft., showed no leakers. These results clearly show that vibration is the key factor involved in package failures. Pressure differential effects appear to only amplify the problem.

The torque data in Tables 3-9 do not show any correlation between leakers and loss of application torque. It is normal for the removal torque to be somewhat less of application torque. It was expected however that leakers would be the result of the cap backing off or the liner failing in some way, which would show up as an exaggerated loss in torque, but this did not happen. The mechanism responsible for leaks must therefore be somewhat different.

The most likely cause of leaks is localized compression of the liner. When the container is turned upside down and vibrated, it has a tendency to tilt to one side. The live load consisting of the weight of the package bouncing up and down on the closure compresses the liner on one side as shown in Figure 11. This has the effect of squeezing the liner more on one side than the other. The extra amount of compression depends on how large the live load is, and how long it lasts. Truck trailers typically vibrate up and down on the order of five cycles per second (Pierce, et al., 1992). Assuming an average G of 0.5 during vibration, the live load could go from $W(1+0.5)$ to $W(1-0.5)$ in half a cycle of vibration, or 0.1 seconds, where W is the weight of the bottle and contents.

No matter how large the live load is, or how long it lasts, the net effect of vibration is to *compress* *and then uncompress* the liner in *rapid* succession. This can easily render the seal force temporarily *zero* at isolated locations. A *rapid* removal of the compression force, such as occurs naturally during vibration, does not allow the liner to recover in time. It takes several seconds, even minutes, for the liner to spring back to its original thickness, once the cap is removed, if it even fully springs back at all. But once the live load is removed, the cap springs back *immediately*. So all during the time that the cap has sprung back, the liner is recovering, and there is a gap between the two. The size of the gap depends on the specifics of the package. Regardless, however, it represents an opportunity for a leak.

The fact that large closures tend to leak ore than small ones is related to two independent effects. The first is the pressure differential itself. As the external pressure is reduced, the air trapped inside the container tries to get out. The force tending to push the closure off the container is the area of the cap multiplied by the pressure differential. The area of the cap increases as the square of the diameter of the cap, so doubling the diameter quadruples the force for a given pressure differential. Larger caps also tend to distort more easily. This, combined with the increased force, causes the cap to "dome", which in turn allows the liner to raise up a little, making it easier for vibration to create gaps between the liner and the rim of the container.

The second effect is related to the industry practice for recommending application torques: the recommended application torque in inch-lbs is half the diameter of the closure in millimeters. So a 1 inch (25.4 mm) closure would have an application torque of 12.7 in-lbs. The manufacturers recommended application torques for the closures used in this study appeared to follow this practice almost without exception. The problem with this rule is that it leads to larger liners being compressed less than smaller ones for the following reasons. The sealing force, which is the force pressing the liner against the rim of the bottle is

$$S = \frac{T}{\mu . D}$$

where, S = seal force (lb)

D = cap diameter (in)

T = application torque (in-lb)

$\bar{\mu}$ = coefficient of friction between the liner and rim

If the recommended application torque is proportional to the diameter, then the sealing force becomes independent of the diameter. So following industry practice leads to the same sealing force for all closure sizes. But this is not what we want because the sealing force is distributed around the rim of the container. Consequently, larger closures place less stress on the liner and therefore cause them to compress less. This makes it easier for vibration to open up gaps.

CONCLUSIONS

The following conclusions can be drawn from the results of this study:

1. The UN approved HazMat packages tested did not prevent leaks under combined vacuum and vibration characteristic of air and high altitude ground shipments.
2. A pressure differential alone does not appear to cause leaks, but vibration alone can. Simultaneous vibration and vacuum testing is therefore necessary to recreate the shipping environment for both air and high altitude ground shipments.
3. An increase in altitude affects larger caps much more than smaller ones because the pressure differential acts over a greater area. The potential for leaks is greater for larger caps.
4. The effect of vibration is to subject the liner to *intermittent* compression loads. If the liner material is slow to recover, and most are, then vibration produces intermittent gaps which open and close at concentrated pressure points, in step with whatever frequency the bottle vibrates at during transportation.
5. The shippers of these HazMat packages do appear to be following the industry rule regarding the application torque.

6. The industry rule is equivalent to requiring that the seal force be the same for all bottles, regardless of cap diameter, and this has the consequence of compressing the liner less for larger caps, so larger caps have greater potential for leaks.

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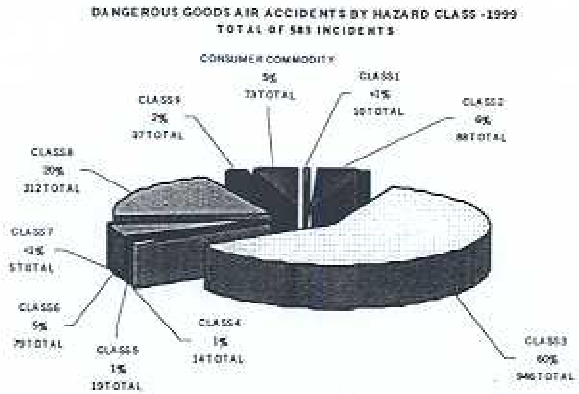
Figures



Source: FAA, Office of Aviation Security

Figure 1: Dangerous goods air accidents by hazard class –1999

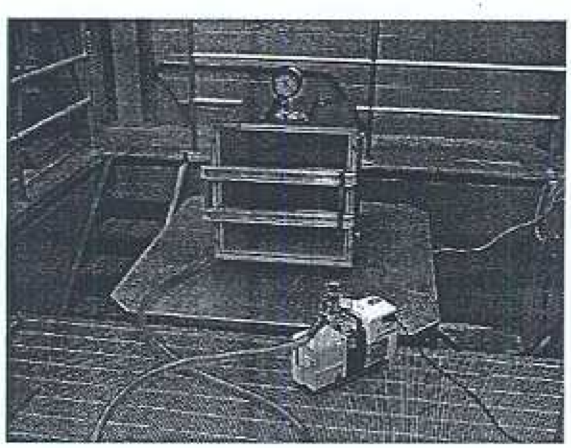


Figure 2: Experimental Setup for Phase I

Figure 3: Closures that failed

Figure 4: Closures that passed

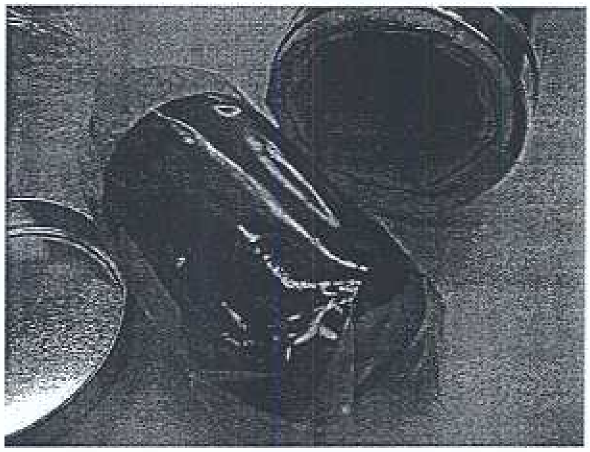


Figure 6: Phase I, UNHWS16

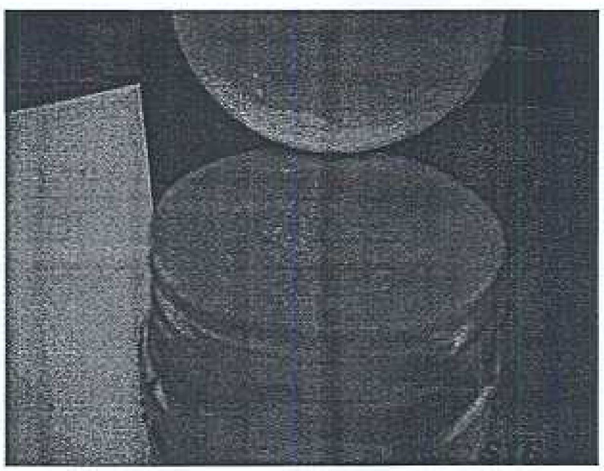


Figure 7: Phase I, UNHWS16

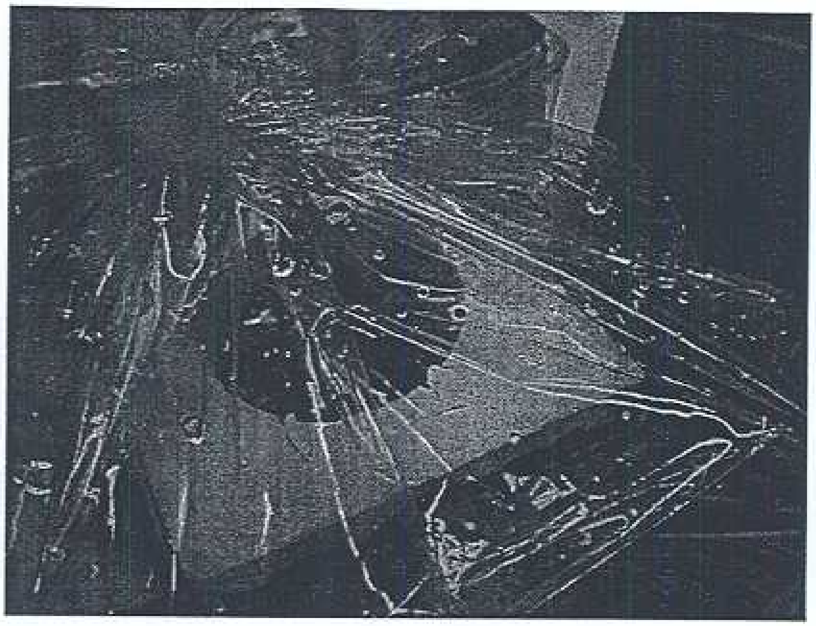


Figure 8: Phase I, UN32PPS, Labelmaster Inc.

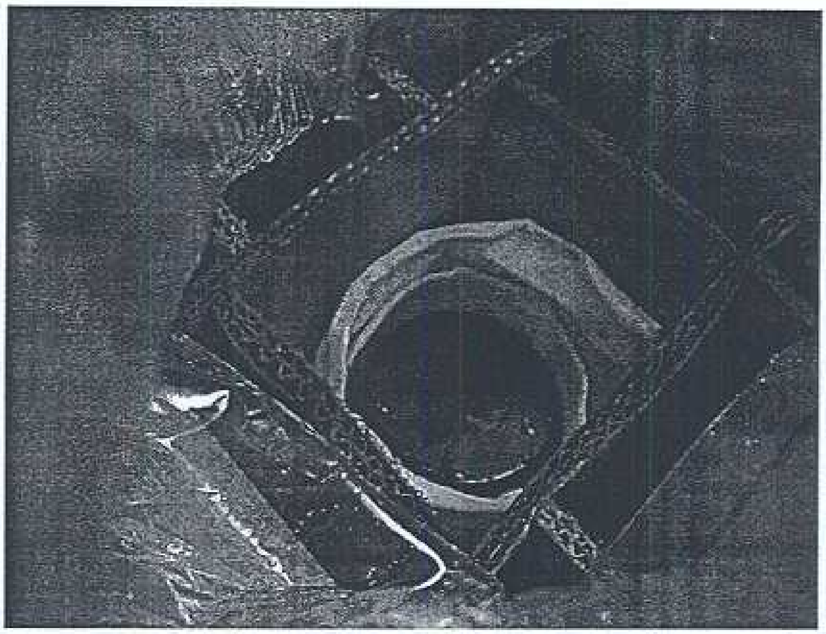


Figure 9: Phase I, CT-SP-0002, CARGOpak Corp.

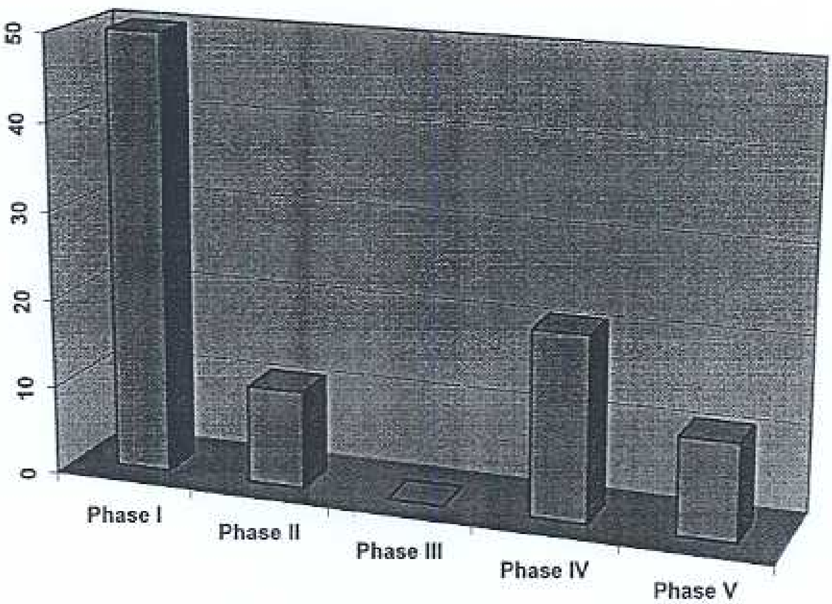


Figure 10: Comparison of Leakage Failures (%) for the Five Phases of Testing (Supplier 1)

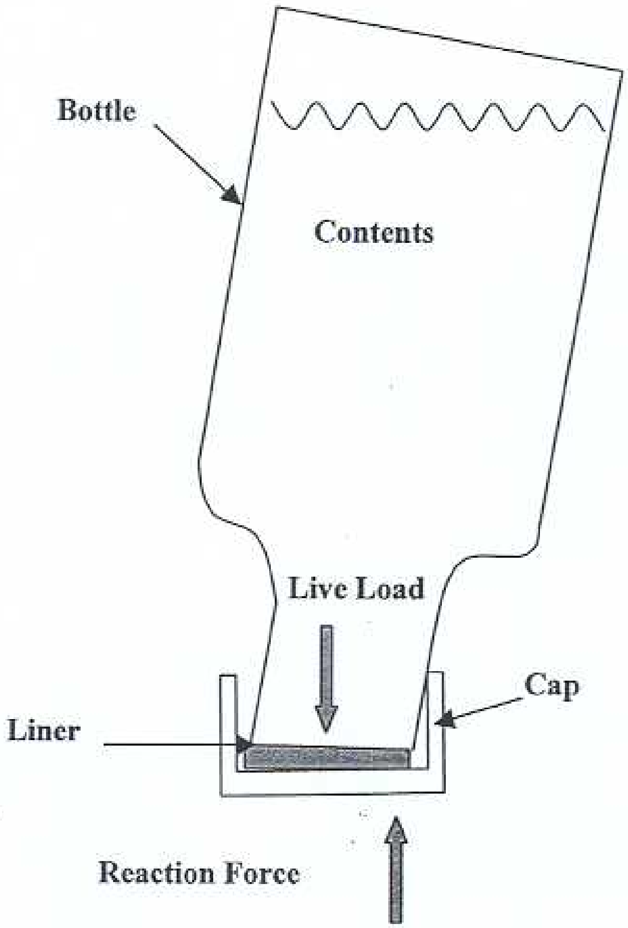


Figure 11: Localized Compression of the Liner

Tables

Table 1: Factors contributing to combination packaging failures

Packaging Type	Seal Closure	Unknown	Inner Broken	Punctured	Fork Lift	Seam	Other Freight	Chime	Drop	Possible Drop	Total
Plastic/4G	65% 111	3% 5	1% 2	2% 4	3% 6	0	5% 8	0	9% 16	12% 20	100% 172
Metal/4G	66% 44	4% 3	0	4% 3	6% 4	4% 3	0	0	7% 5	7% 5	100% 67
Glass/4G	23% 15	6% 4	17% 11	0	5% 3	0	1% 1	0%	22% 14	25% 16	100% 64
Unknown/4G	27% 8	33% 10	0	0	13% 4	0	7% 2	0	13% 4	7% 2	100% 30

Source: FAA, Office of Aviation Security

Table 2: Packages Tested

Supplier	UN Numbers for Combination Packages Tested
1	HMS-08, UN950PPT, UN950GPT, UN16FFPS, UN32FFPS, UNHWS16, UN32NPVB, HMSP-32N, UN32PPS, UN4FFPS, UAC32FPS, UN32FAPS
2	UNE151, UN112, UN1541, UN61, UN62, UNIS80, UN51, UN52, UN78, UN79
3	CT-SP-0002, CT-1-92-1000N, CT-1-92-1000-N, V1-0125-N, V1-0500N, V1-1000N, V1-0500W

Table 3: Results for Phase 1, Supplier 1

SKU	*PHASE I*							
	SAMPLE A				SAMPLE B			
	AT		RT		AT		RT	
	N.m	lb.in	N.m	lb.in	N.m	lb.in	N.m	lb.in
HMS-08	2.39[L]	21.2[L]	2.18[L]	19.3[L]	2.44[L]	21.6[L]	1.86[L]	16.5[L]
UN950PPT	2.27	20.1	1.75	15.5	2.26	20.0	1.85	16.4
UN950GPT	1.26[L]	11.2[L]	1.24[L]	11.0[L]	1.25	11.1	0.91	8.1
UN16FFPS	1.26	11.2	1.13	10.0	1.25	11.1	0.99	8.8
UN32FFPS	1.84	16.3	1.45	12.8	1.84	16.3	1.46	12.9
UNHWS16	3.97[L]	35.2[L]	3.56[L]	31.5[L]	3.96[L]	35.1[L]	2.50[L]	22.1[L]
UN32NPVB	6.32	56.0	4.03	35.7	6.37	56.4	3.68	32.6
HMSP-32N	2.04	18.1	1.51	13.4	2.05	18.2	1.65	14.6
UN32PPS	2.27	20.1	2.21	19.6	2.27[L]	20.1[L]	2.16[L]	19.1[L]
UN4FFPS	1.25	11.1	1.12	9.9	1.28	11.3	1.04	9.2
UAC32FPS	1.81	16.0	1.78	15.8	1.82	16.1	1.60	14.2
UN32FAPS	1.26	11.2	1.04	9.2	1.28[L]	11.3[L]	0.85[L]	7.5[L]
PACK 1	L	L	L	L	L	L	L	L
PACK 2	L	L	L	L	L	L	L	L

[L] = Packages that Leaked

AT = Application Torque, RT = Removal Torque, L = Leakers

Table 4: Results for Phase 1, Supplier 2

SKU	*PHASE I*							
	SAMPLE A				SAMPLE B			
	AT		RT		AT		RT	
	N.m	lb.in	N.m	lb.in	N.m	lb.in	N.m	lb.in
UNE151	1.25	11.1	0.81	7.2	1.25	11.1	0.82	7.3
UN112	2.27^{L}	20.1^{L}	2.07^{L}	18.3^{L}	2.29	20.3	2.12	18.8
UN1541	1.29	11.4	0.73	6.5	1.26	11.2	0.80	7.1
UN61	2.27	20.1	1.96	17.4	2.27	20.1	2.09	18.5
UN 62	6.33	56.1	5.32	47.1	6.39^{L}	56.6^{L}	5.07^{L}	44.9^{L}
UNIS80	4.00^{L}	35.4^{L}	3.35^{L}	29.7^{L}	4.02	35.6	3.65	32.3
UN51	1.28	11.3	0.95	8.4	1.26	11.2	0.68	6.0
UN52	1.82	16.1	1.70	15.1	1.82	16.1	1.51	13.4
UN78	3.96^{L}	35.1^{L}	3.48^{L}	30.8^{L}	3.96^{L}	35.1^{L}	3.62^{L}	32.1^{L}
UN79	3.96	35.1	3.59	31.8	3.99^{L}	35.3^{L}	3.70^{L}	32.8^{L}

^{L} = Packages that Leaked

AT = Application Torque, RT = Removal Torque, L = Leakers

Table 5: Results for Phase 1, Supplier 3

SKU	*PHASE I*							
	SAMPLE A				SAMPLE B			
	AT		RT		AT		RT	
	N.m	lb.in	N.m	lb.in	N.m	lb.in	N.m	lb.in
CT-SP-0002	2.39	21.2	2.17	19.2	2.39	21.2	2.24	19.8
CT-1-92-1000-N	3.77	33.4	2.31	20.5	3.79	33.6	2.44	21.6
CT-1-92-1000-W	6.34[L]	56.2[L]	3.65[L]	32.3[L]	6.45	57.1	4.14	36.7
CT-4-92-1000-N	3.74	33.1	2.04	18.1	3.75[L]	33.2[L]	1.89[L]	16.7[L]
V1-0125-N	1.30	11.5	1.12	9.9	1.25	11.1	1.04	9.2
V1-0500N	1.29	11.4	1.11	9.8	1.25	11.1	1.04	9.2
V1-1000N	2.30	20.4	1.19	10.5	2.27	20.1	1.65	14.6
V1-0500W	3.97[L]	35.2[L]	3.18[L]	28.2[L]	3.99[L]	35.3[L]	2.57[L]	22.8[L]

[L] = Packages that Leaked

AT = Application Torque, RT = Removal Torque, L = Leakers

Table 6: Results for Phase II

SKU	*PHASE II*							
	SAMPLE A				SAMPLE B			
	AT		RT		AT		RT	
	N.m	lb.in	N.m	lb.in	N.m	lb.in	N.m	lb.in
HMS-08	2.38	21.1	2.24	19.8	2.39	21.2	2.20	19.5
UN950PPT	2.31	20.5	2.05	18.2	2.31	20.5	2.13	18.9
UN950GPT	1.28	11.3	1.22	10.8	1.26	11.2	1.15	10.2
UN16FFPS	1.25	11.1	1.11	9.8	1.25	11.1	1.07	9.5
UN32FFPS	1.82	16.1	1.56	13.8	1.81	16.0	1.52	13.5
UNHWS16	3.99	35.3	3.13	27.7	3.96	35.1	3.51	31.1
UN32NPVB	6.40	56.7	5.04	44.6	6.36	56.3	5.39	47.7
HMSP-32N	2.07	18.3	1.81	16.0	2.07	18.3	1.65	14.6
UN32PPS	2.26[L]	20.0[L]	2.00[L]	17.7[L]	2.29	20.3	2.00	17.7
UN4FFPS	1.25	11.1	1.16	10.3	1.30	11.5	1.14	10.1
UAC32FPS	1.81	16.0	1.49	13.2	1.82	16.1	1.55	13.7
UN32FAPS	1.25	11.1	1.15	10.2	1.26	11.2	1.11	9.8
PACK 1	L	L	L	L	L	L	L	L
PACK 2								

[L] = Packages that Leaked

AT = Application Torque, RT = Removal Torque, L = Leakers

Table 7: Results for Phase III

SKU	PHASE III							
	SAMPLE A				SAMPLE B			
	AT		RT		AT		RT	
	N.m	lb.in	N.m	lb.in	N.m	lb.in	N.m	lb.in
HMS-08	2.39	21.2	2.07	18.3	2.39	21.2	1.92	17.0
UN950PPT	2.26	20.0	2.01	17.8	2.27	20.1	1.94	17.2
UN950GPT	1.25	11.1	1.15	10.2	1.26	11.2	1.21	10.7
UN16FFPS	1.25	11.1	0.99	8.8	1.25	11.1	1.04	9.2
UN32FFPS	1.84	16.3	1.60	14.2	1.81	16.0	1.67	14.8
UNHWS16	4.01	35.5	3.24	28.7	4.01	35.5	3.61	32.0
UN32NPVB	6.33	56.1	4.55	40.3	6.36	56.3	5.20	46.1
HMSP-32N	2.04	18.1	1.59	14.1	2.03	18.0	1.54	13.6
UN32PPS	2.28	20.2	2.00	17.7	2.27	20.1	2.00	17.7
UN4FFPS	1.25	11.1	1.23	10.9	1.26	11.2	1.24	11.0
UAC32FPS	1.81	16.0	1.78	15.8	1.82	16.1	1.72	15.2
UN32FAPS	1.25	11.1	1.22	10.8	1.25	11.1	1.23	10.9
PACK 1								
PACK 2								

AT = Application Torque, RT = Removal Torque, L = Leakers

Table 8: Results for Phase IV

SKU	*PHASE IV (TRUCK/AIR)*							
	SAMPLE A				SAMPLE B			
	AT		RT		AT		RT	
	N.m	lb.in	N.m	lb.in	N.m	lb.in	N.m	lb.in
HMS-08	2.39	21.2	2.21	19.6	2.44	21.6	2.09	18.5
UN950PPT	2.27[L]	20.1[L]	2.10[L]	18.6[L]	2.29	20.3	2.24	19.8
UN950GPT	1.26[L]	11.2[L]	0.41[L]	3.6[L]	1.25	11.1	1.04	9.2
UN16FFPS	1.30	11.5	1.24	11.0	1.28	11.3	1.23	10.9
UN32FFPS	1.82	16.1	1.78	15.8	1.85	16.4	1.74	15.4
UNHWS16	3.97[L]	35.2[L]	3.18[L]	28.2[L]	4.02[L]	35.6[L]	3.61[L]	32.0[L]
UN32NPVB	6.34	56.2	4.02	35.6	6.32	56.0	4.34	38.4
HMSP-32N	2.04	18.1	1.51	13.4	2.03	18.0	1.38	12.2
UN32PPS	2.29	20.3	2.24	19.8	2.26	20.0	1.90	16.8
UN4FFPS	1.25	11.1	1.23	10.9	1.26	11.2	1.16	10.3
UAC32FPS	1.82	16.1	1.60	14.2	1.83	16.2	1.41	12.5
UN32FAPS	1.26	11.2	1.23	10.9	1.28	11.3	1.22	10.8
PACK 1								
PACK 2	L	L	L	L	L	L	L	L

[L] = Packages that Leaked

AT = Application Torque, RT = Removal Torque, L = Leakers

Table 9: Results for Phase II

SKU	PHASE V (TRUCK ONLY)							
	SAMPLE A				SAMPLE B			
	AT		RT		AT		RT	
	N.m	lb.in	N.m	lb.in	N.m	lb.in	N.m	lb.in
HMS-08	2.38[L]	21.1[L]	1.95[L]	17.3[L]	2.38	21.1	1.78	15.8
UN950PPT	2.26	20.0	1.98	17.5	2.29	20.3	1.85	16.4
UN950GPT	1.25	11.1	1.22	10.8	1.24	11.0	1.15	10.2
UN16FFPS	1.25	11.1	1.15	10.2	1.26	11.2	1.19	10.5
UN32FFPS	1.81	16.0	1.67	14.8	1.82	16.1	1.72	15.2
UNHWS16	3.96[L]	35.1[L]	3.56[L]	31.5[L]	3.97	35.2	3.40	30.1
UN32NPVB	6.33	56.1	4.39	38.9	6.37	56.4	4.54	40.2
HMSP-32N	2.03	18.0	1.61	14.3	2.07	18.3	1.90	16.8
UN32PPS	2.29	20.3	1.94	17.2	2.30	20.4	2.12	18.8
UN4FFPS	1.25	11.1	1.16	10.3	1.28	11.3	1.17	10.4
UAC32FPS	1.81	16.0	1.64	14.5	1.83	16.2	1.69	15.0
UN32FAPS	1.24	11.0	1.11	9.8	1.25	11.1	1.15	10.2
PACK 1								
PACK 2					L	L	L	L

[L] = Packages that Leaked

AT = Application Torque, RT = Removal Torque, L = Leakers