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Drop Tests for the 6M Specification Package Closure Investigation

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ABSTRACT

Results of tests of drum-type RAM packages employing conventional clamp-ring closures have caused concern over the DOT 6M Specification Package. To clarify these issues, a series of tests were performed to determine the response of the clamp-ring closure to the regulatory Hypothetical Accident Condition (9m) drop tests, for packages at maximum allowable weight. Three enhanced closure designs were also tested: the Clamshell, plywood disk reinforcement, and J-Clip. The results of the tests showed that the standard closure was unable to retain the top for both Center-of-Gravity-Over-Corner and Shallow Angle cases, for the standard package, at its maximum allowed weight. Similar results were found for packages dropped from a reduced height. The Clamshell design provided the best performance of the enhanced closures.

BACKGROUND

Results of tests of drum-type RAM packages employing conventional clamp-ring closures have shown that the clamp-ring design may not be adequate in some cases. These results have caused concern over the DOT 6M Specification Package which employs the clamp-ring closure. To clarify the issues associated with use of the 6M, a series of tests were performed to determine the response of the clamp-ring closure on the 6M to the regulatory Hypothetical Accident Condition (9m) drop tests.

TEST PROGRAM

Specimen packages were obtained from a manufacturer regularly involved in the production of 6M packages (Reference 1). The packages were assembled with dummy contents (representing the maximum content weight) using an assembly procedure consistent with the specification requirements and the manufacturer's recommendations. The 55 gallon drum size 6M package was chosen as the representative case for these tests.

The test program consisted of packages with both standard 6M clamp-ring closures and with various enhanced closures, Table 1. Each configuration was tested in the Center-of-Gravity-Over-Corner orientation and in the Shallow Angle orientation. Subsequent tests investigated the margin of safety through tests from lower drop heights.

Test packages were dropped in orientations which have resulted in large openings, or complete loss of the lids in earlier tests of drum type packages References 2 through 5. Earlier tests of drum type packages have shown that the Center-of-Gravity-Over-Corner (CGOC) orientation and the Shallow Angle orientation challenge the closure in different ways. To capture both types of response, tests were conducted at 55º (for the CGOC case) and at 17.5º for the shallow angle case.

Following the pattern of earlier testing of packages with clamp-ring closures, each test was preceded by a Normal Conditions of Transport (NCT) test from a height of four feet. The preconditioning tests were planned to challenge the drum's lock ring closure arrangement so that the effects of the subsequent 9 m (30 ft) drop would be maximized. For this reason, the target point for each NCT drop was located 90°, circumferentially, from the target point for the HAC drops. . The closure bolt was oriented to coincide with the longitudinal seam of the body of the drum, 45° from the HAC target point on the side opposite the NCT target point. Previous testing has shown that the HAC drop typically produces a buckle across the top having an angular width of around 90º. The orientations selected will cause this buckle to occur midway between the NCT and HAC contact points. In addition, the buckle will coincide with the clamp-ring closure bolt and lug assembly. NCT preconditioning tests were performed in the same orientation (CGOC or shallow angle) as the subsequent HAC drop.

Because the object of the test was investigation of the response of the closures, the details of the internals were not important. Accordingly, stainless steel cylinders were used to simulate the 2R Containment vessel and to ballast the package to the required weight.

The ratio of internal weight (containment vessel and contents) to the overall package weight has been shown to be an important parameter in determining the probability of a significant lid opening or lid loss occurring in a drop test, Reference 3. For this reason, the 6M tests were performed with the packages at the maximum weight allowed by the specification for the 55 gal Drum configuration 290 kg (640 lb). The dummy contents consisted of stainless steel round sections,25.4 cm (10 in.) in diameter and 48.9 cm (19.25 in.) long, for a typical contents weight of approximately 208 kg (458 lb).

The acceptance criterion for the performance or the overpack was that the lid be retained in such a way that a significant reduction in effectiveness of the overpack did not occur.

PROCEDURE AND FACILITY

The drop tests were performed in the SRS drop test facility. The test sequence consisted of a 1.2 m (4 ft) NCT preconditioning drop, a 9 m (30 ft) HAC drop. The NCT drop was conducted at the same orientation as the 9 m drop (CGOC or shallow angle).

For each drop, the package was aligned to within one degree of its nominal orientation prior to the drop. Each drop was recorded at 1000 frames per second, using a high speed video camera, as well as normal speed video. Following each drop, the package was measured and photographed to document the extent of damage.

The drop test surface was constructed from a 15.9 cm (6.25 in.) thick armor plate, approximately 1.52 m (5 ft) square, anchored in a 76 cm (30 in.) thick reinforced concrete slab. The target slab is isolated from the concrete floor of the building. The target slab weighs approximately 7076 kg (15,600 lb), which is over 24 times the weight of the test packages (290 kg or 640 lb.).

Table 1. Drop Test Conditions

9975 Drum Lid Retention Test Matrix[c] All test packages subjected to NCT and HAC tests.	
Test	Orientation
Baseline (Standard 6M), 6M-S-1	CGOC, 9 m
Baseline (Standard 6M), 6M-S-2	Shallow Angle, 9 m
Clamshell, 6M-CS-1	CGOC, 9 m
Clamshell, 6M-CS-1	Shallow Angle, 9 m
Plywood Disk , 6M-PD-1	CGOC, 9 m
Plywood Disk , 6M-PD-2	Shallow Angle, 9 m
Plywood Disk, 6M-PD-3	CGOC, 9 m
Standard 6M, 6M-S-7	Shallow Angle, 6 m

TESTING

NCT preconditioning tests typically resulted in minor damage. The CGOC NCT drops typically resulted in the top of the package being bent downward about 6 mm, while the shallow angle drops resulted in the flattening the side by a similar amount. In both cases, the damage was typically local to the point of impact.

CGOC Test of Standard 6M Package

The 9 m CGOC drop resulted in crushing of the “corner” of the package around the point of contact and separation of the top from the drum over the remainder of its circumference (approximately 270º). The Celotex overpack disks were separated and damaged, and the interior cavity was exposed.. The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and top in the damage region. The results of this drop are shown in Figure 1.

Shallow Angle 30 Ft Drop Test for Standard 6M-S-2

The 9 m Shallow Angle drop (axis 17.5°, top down) resulted in separation of the top and flattening of the rim and closure ring of the package at the point of contact, and associated flattening (about 28 cm wide) along the length of the drum. The top buckled outwards along a line parallel to the flattened side. This buckling resulted in the top pulling out from under the closure ring on both ends of the flattened region. These openings then propagated around the lid, so that it became disengaged from the clamp-ring and the drum over its full circumference. The raised and curved (inverted J) rim of the top was buckled inward and folded down on to the horizontal disk section of the top, at the point of impact. The results of this drop are shown in Figure 2.

CGOC 30 Ft Drop Test for 6M-CS-1 with Clamshell

The 9 m CGOC drop resulted in crushing of the "corner" of the package around the point of impact. Minor flattening of the lower rolling rings and chime resulted from the bottom striking the impact surface, following the initial hit. The vertical height through the point of impact was reduced 6.4 cm. The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and top in the damage region and reduction in height on the impact side. However, the top remained securely retained all around its circumference, with no openings present. The package rebounded more energetically than the standard package. The results of this drop are shown in Figures 3 and 4.

Shallow Angle 30 Ft Drop Test for 6M-CS-2 with Clamshell Closure

The 9 m Shallow Angle drop resulted in flattening of the closure ring of the package at the point of contact, and associated flattening along the length of the drum. The axial distance between the reference marks on the impact side was not changed. The damage was typical of low angle drops, with local buckling of the drum and top in the damage region. The top was retained securely all around and no openings resulted from the deformation. The results of this drop are shown in Figures 5 and 6.

Plywood Disk Enhanced Closure

The plywood disk enhancement consisted of replacing the top 2.54 cm (1 in.) of Celotex with a 2.54 cm (1 in.) plywood disk.

CGOC Test of Plywood Disk Enhanced Closure

The 9 m CGOC drop resulted in crushing of the "corner" of the package around the point of contact and separation of the top from the drum over an arc of approximately 120º. The maximum height of the opening was about 7.62 cm (3 in.), exposing the Plywood disk and the Celotex overpack disks. The height of the package, measured through the point of impact wasreduced by approximately 7.62 cm (3 in.) Other dimensions were little affected by the damage. The results of this drop are shown in Figure 7.

Shallow Angle Test of Plywood Disk Enhanced Closure

The 9 m Shallow Angle drop resulted in flattening of the rim and closure ring of the package at the point of contact, and associated flattening (about 29 cm . wide) along the length of the drum.. The height on the impact side was not changed. The damage was typical of low angle drops. The raised and curved (inverted J) rim of the top was buckled inward and folded down on to the horizontal, disk section of the top, at the point of impact. The flattened side of the disk section of the top, near the contact point, was less extensive with the plywood disk than in the previous shallow angle tests. The region where the raised rim of the top was folded back was smaller than in the previous shallow angle tests. The top remained securely attached, without openings. The results of this drop are shown in Figure 8.

Tests of Closure Enhanced With Two Plywood Disks, Package 6M-PD-3

Package 6M-PD-3 was further strengthened by employing 5.1 cm (2 in) thick plywood disk, to determine if the modification would enable it to withstand the 9 m CGOC drop.

30 Ft Drop Test for 6M-PD-3

The 9 m CGOC drop resulted in crushing of the "corner" of the package around the point of contact and separation of the top from the drum over an arc of approximately 100º. The maximum height of the opening was about 5.1 cm (2 in.), exposing the Plywood disk and the Celotex overpack disks. Minor flattening of the rolling rings and the chime of the drum resulted from the second hit. The height of the package at the point of impact was reduced by approximately 10.2 cm (4 in.). The results of this drop are shown in Figure 9.

Reduced Height tests

Following the unsatisfactory results of the 9 m drop tests of the packages with standard closures, 6M-S-1 and 6M-S-2, drop tests from lower heights were planned, to more closely characterize the response of the package closure under impact conditions. As the first part of this additional characterization, drop tests of packages with standard clamp-ring closures were performed from a height of 6 m (20 ft), in the Shallow Angle and CGOC orientations. The packages for these tests were 6M-S-7 and 6M-S-6, respectively.

20 Ft Drop Test for 6M-S-7

The 6 m (20 ft) Shallow Angle drop resulted in flattening of the rim and closure ring of the package at the point of contact, and associated flattening (about 30.5 cm wide) along the length of the drum. The package height on the impact side was essentially unchanged. The damage was typical of low angle drops, with local buckling of the drum and top in the damage region. This buckling resulted in the top pulling out from under the closure ring, resulting In an opening approximately 18 cm (7 in.) long with a maximum height of approximately 1.3 cm (1/2 in.) The raised and curved (inverted J) rim of the top was bent inward, but remained retained under the clamp-ring. The results of this drop are shown in Figure 10.

6 m Drop Test for 6M-S-6

The 6 m (20 ft) CGOC drop resulted in crushing of the "corner" of the package around the point of contact and separation of the top from the drum over an arc of approximately 120º. The maximum height of the opening was about 7.62 cm (3 in.), exposing the Celotex overpack disks. The height of the package through the point of impact was reduced by approximately 9 cm (3 1/2 in.). The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and top in the damage region. The results of this drop are shown in Figure 11.

4.5 m Drop Test for Package 6M-S-5

The results of the reduced height drops showed that the standard closure was marginal in its ability to retain the top for shallow angle impact. The opening that resulted from the 6 m (20 ft) CGOC drop revealed that, for the standard closure, the threshold of failure was significantly less than 6 m (20 ft). To further examine this behavior a CGOC drop from 4.5 m (15 ft) was performed. The 4.5 m (15 ft) drop test in the CGOC orientation used package 6M-S-5.

4.5 m Drop Test for 6M-S-5

The 4.5 m (15 ft) CGOC drop resulted in crushing of the "corner" of the package around the point of contact and separation of the top from the drum over an arc of approximately 120º. The maximum height of the opening was about 6.35 cm (2 1/2 in.), exposing the Celotex overpack disks. The heght of the package through the point of impact was reduced by approximately 7.62 cm (3 in.). The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and top in the damage region. The results of this drop are shown in Figure 12.

7.62 m DropTest for Package 6M-S-8

The results of the reduced height drops showed that the standard closure was marginal in its ability to retain the top for shallow angle impact. To further examine this behavior a Shallow Angle drop from 7.62 m (25 ft) was performed.

The 7.62 m (25 ft) Shallow Angle drop resulted in separation of the top and flattening of the rim and closure ring of the package at the point of contact, and associated flattening (about 30.5 cm wide) along the length of the drum. The height of the package on the impact side was essentially unchanged. The damage was typical of low angle drops, with local buckling of the drum and top in the damage region. The top separated from the drum over an arc beginning at the end of the HAC damage region closest to the clamp-ring lugs, and extending counter-clockwise for over 120º. The resulting opening had a maximum height of approximately 2.54 cm (1 in.). The raised and curved (inverted J) rim of the top was bent inward, and folded inward and downward onto the horizontal, disk section of the top, at the impact point.. The results of this drop are shown in Figure 13.

J-Clip Enhanced Closure

CGOC and Shallow Angle drop tests were also performed on packages which employed a J-Clips retainer, fitted over the standard clamp ring closure. The J-Clip arrangement was successful in retaining the drum lids, but allowed small fish-mouth openings between the clips.

Discussion

The objective of the test was to investigate the ability of the standard 6M closure ring assembly to provided adequate margin against loss of the top from the package during the 9 m (30 ft) HAC drop test. Loss of the lid from a 6M could result in loss of geometric control of the contents, a potential criticality issue, and loss of protection for the containment vessel seals during a subsequent fire, with resulting loss of containment.

There are many factors which affect the performance of a drum closure during drop tests. Important test conditions are: weight of package, height of drop and angle of impact. Structural characteristics of the package determine its ability to withstand the test conditions imposed. These characteristics include: package diameter, shell material and thickness, strength of internal fill material (e.g., Celotex), and configuration of closure (clamp-ring, bolted flange, etc.).

For the clamp-ring closure configuration, like that employed by the 6M, the performance of drum type packages subjected to drop tests have been compared (Reference 4) and the ratio of internal weight to overall package weight has been found to be an important guideline for package performance. In the Reference 4 study, it was shown that packages having a weight ratio of less than 50% were typically able to retain their tops in HAC drop tests. Those having weight ratios greater than 50% typically failed. Because the object of the present testing was to challenge the closure, the packages were tested at the maximum weight allowed by the 6M specification, 290 kg (640 lb), resulting in a weight ratio of 72%.

The results of the present tests are compared with those for other drum type packages subjected to drop tests in Figures 14 and 15. The present results are designated "6M" or "6M, .72" in the legends on these figures. The comparison considers all three of the principal test conditions, weight (weight ratio), impact angle, and drop height. These figures provide insight into the shape of the pass-fail threshold surface defined by these test parameters. Figure 14 shows that packages having weight ratios less than 50% are typically able to withstand the HAC 9 m (30 ft) drop test, regardless of package orientation. For some packages, shallow angle drops are more challenging (e.g., the 9975, Reference 5), while the Center of Gravity Over Corner orientation is more challenging in other cases. For the 55 gallon size 6M with standard clamp-ring closure, used in these tests, the CGOC orientation was more challenging than the shallow angle case.

The drop height has a strong effect on top retention, as would be expected. For example, all packages are expected to survive the 1.2 m (4 ft) NCT, preconditioning drop. The extent of failure at 9 m (30 ft) suggested that the failure threshold would be at a lower elevation. The 6 m (20 ft) drops were performed to better define this threshold. The CGOC case resulted in a failure due to large lid opening. The Shallow Angle case resulted in a marginal pass, yielding an opening about 17.8 cm (7 in.) long and 1.3 cm (½ in.) wide. As noted above, to further explore the performance boundary, the Shallow Angle test was repeated from a drop height of 7.62 m (25 ft) and the CGOC was repeated from 4.5 m (15 ft). Top openings occurred for both of these additional cases.

The mechanism for lid loss appears different for the CGOC and Shallow Angle cases. Proposed mechanisms include volume change induced pressurization of the air in the package, translation of the internal components, and the combination of load applied by bending of the top and closure ring with unloading of the ring due to deformation. Examination of the high-speed video indicates that various combinations of these factors are the probable cause.

For typical CGOC cases, top is observed to first pullout from beneath the clamp-ring at one or both ends of the flattened region caused by the HAC drop. This is the location where the plane of the damaged region intersects the plane of the undeformed region of the top of the drum. The opening then grows progressively and rapidly from the initial openings, and may propagate completely around the circumference of the top. The internal pressurization resulting from reduction in volume results in a load on the top on the order of 132 N (30 lbf), which is not likely to contribute significantly to the loss of the top, for the CGOC case. Translation of the Celotex fill material is prevented in the crush region, but the Celotex disks are bent out of plane by the impact, and tend to fan-out. The central mass is observed to translate, breaking the center of the Celotex layers immediately ahead of it. The lid opening mechanism consists of the following processes: The deformation relaxes the grip of the clamp-ring on the top in the buckled zone at the ends of the impact region. The bending loads associated with the deformation of the top and clamp-ring, combined with the loading caused by translation of the central mass, result in the top pulling out from the clamp ring. If the top is completely separated from the clamp-ring, the bending load in the top causes it to continue opening, beyond the influence of the displaced central mass.

The Shallow Angle impact results in a different set of conditions. To a greater extent than in the CGOC case, the shallow angle impact relaxes the tension in the clamp-ring (at least as a transient effect). The radial deformation of the top results in a buckled region, parallel to the impact surface. The combination of these effects results in the top pulling out from under the clamp-ring at one, or both ends of the buckled region. Though not as great as in the CGOC case, the bending load associated with the buckle tends to cause the opening to propagate. For the shallow angle case, loading due to translation of the central mass is not observed. However, the increased internal pressure caused by volume change (resulting from deformation of the drum) can impose a load on the top on the order of 660 N (150 lbf). The relaxation of the clamp-ring tension, combined with the bending load and pressure load can result in complete loss of the top, in some cases.

The Plywood Disk enhancement had the objective of strengthening the closure radially, so that the clamp-ring would remain engaged with the curl of the drum and the top. The Plywood Disk package subjected to the Shallow Angle test successfully withstood the impact. Although their performance was better than the standard closure package, neither the 1 in. or 2 in. Plywood Disk packages were successful in the CGOC drop tests.

The Clamshell Closure enhancement was highly successful in both orientations. The extended skirt of the Clamshell integrated its response with that of the drum , while the annular top extension prevented separation of the top from the drum.

Conclusion

It was concluded that the closure ring design employed on the 6M is inadequate to retain the top during the regulatory test sequence, for packages at the maximum allowed weight.

For large heavy packages, the Center-of-Gravity-Over-Corner case is more challenging than the Shallow Angle case.

The Clamshell design securely retained the top for all HAC test cases, and prevented formation of any opening which could compromise fire test performance.

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Figure 1. Effect of CGOC 30 ft HAC drop on 6M Package with standard closure.

Figure 2. Effect of Shallow Angle 30 ft HAC drop on 6M Package with standard closure.

Figure 3. Effect of CGOC 30 ft HAC drop on 6M Package with Clamshell closure.

Figure 4. The Clamshell closure retained the top securely, with no openings being formed.

Figure 5. 6M Package with Clamshell closure following Shallow Angle 30 ft HAC drop.

Figure 6. The Clamshell closure retained the top securely, with no openings being formed.

Figure 7. Results of CGOC 30 ft HAC drop on 6M Package with Plywood Disk enhanced closure.

Figure 8. The Plywood Disk enhance closure successfully retained the top for the Shallow Angle HAC drop test. Flattening of the side of the package is typical for Shallow Angle tests.

Figure 9. Effect of CGOC 30 ft HAC drop on 6M Package with 2 in. Plywood Disk enhanced closure.

Figure 10. The 20 ft Shallow Angle drop resulted in an opening about 7 in. long and ½ in. wide.

Figure 11. The 20 ft CGOC drop produced an opening extending for over 120º, with a maximum width of 3 in.

Figure 12. The 15 ft CGOC drop resulted in an opening extending over an arc of approximately 120º, with a maximum width of about 2.5 in.

Figure 13. The 25 ft Shallow Angle drop resulted in separation of the top over an arc of more than 120º.

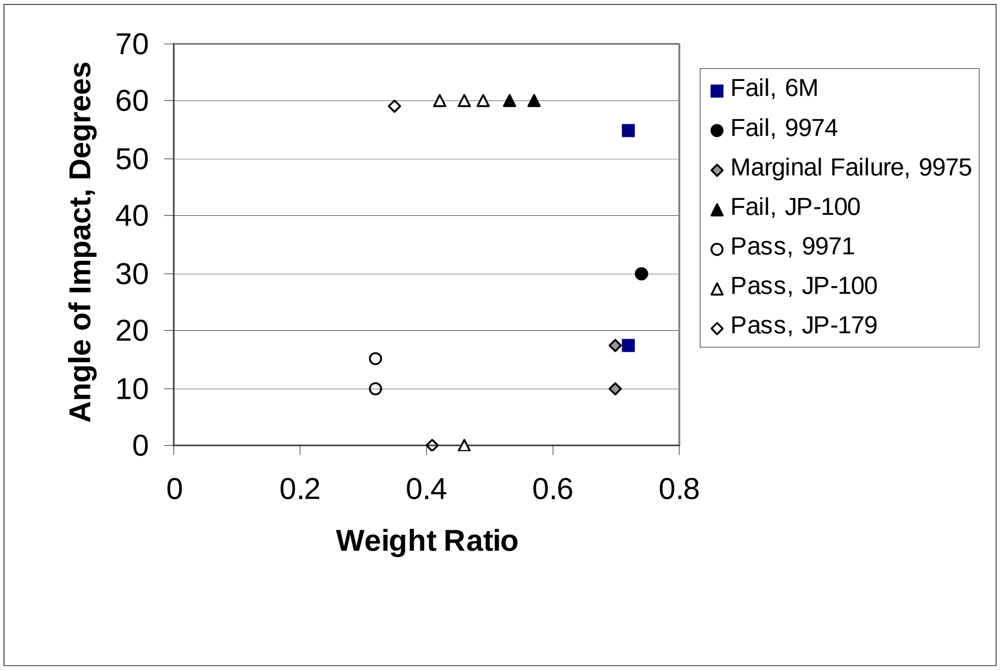

Figure 14. Effect of Weight Ratio and Angle of Impact on retention of tops of drum type packages subjected to regulatory 30 ft drop test.

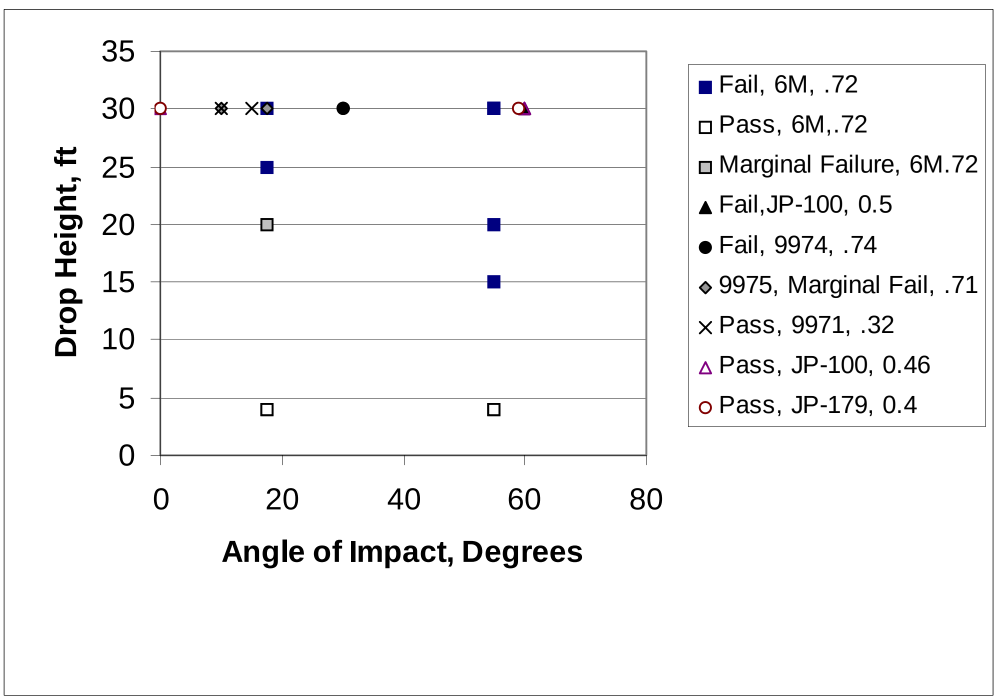

Figure 15. Effect of Drop Height and Angle of Impact on Retention of lids of drum type packages subjected to drop tests. The Legend indicates outcome (pass or fail), package tested and ratio of internal to overall package weight.