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Recommendations for DOT 7A Type A Drum Closure and Drop Testing with Additional 49 CFR 173.465(c)(2) Testing and Analysis

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Preparers:

Signature on File

____Date_______________

E.T. Ketusky, Engineer
Packaging Technology & Transportation Engineering
Savannah River National Laboratory

Signature on File

____Date_______________

D.S. Hoang, Engineer
Packaging Technology & Transportation Engineering
Savannah River National Laboratory

Signature on File

____Date_______________

C.A. McKeel, Engineer
Packaging Technology & Transportation Engineering
Savannah River National Laboratory

Reviewed By:

Signature on File

____Date_______________

P.S. Blanton, Program Manager
Packaging Technology & Transportation Engineering
Savannah River National Laboratory

Approved By:

Signature on File

____Date_______________

R.W. Watkins, Manager
Packaging Technology & Transportation Engineering
Savannah River National Laboratory

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ACRONYMS

ASME	American Society of Mechanical Engineering
BA	balance angle
CFR	Code of Federal Regulations
CGoT	center-of-gravity over top
CMM	coordinate measuring machine
DOE	U.S. Department of Energy
DOE-HQ	U.S. Department of Energy-Headquarters
DOT	U.S. Department of Transportation
FEA	finite element analysis
RA	radial angle
SPAT	single point articulation test
SRNL	Savannah River National Laboratory
SRS	Savannah River Site

KEY TERMS AND DEFINITIONS

Note: This report focuses on closure testing and analyses and a series of drop tests (from 1 and 4ft) and analyses performed by the Savannah River National Laboratory on DOT 7A Type A Drums, specifically on Skolnik model CQ5508L drums. To add in clarification, the key terms and definitions are grouped as associated with either: Closure; Drop Testing; or Common to both. Closure and Drop terms are further sub grouped as belonging to "facility, tools and equipment" or "testing, modeling, and analyses."

COMMON

- DOT 7A Type A – Packing meeting the requirements of 49 CFR 178.350, "Specification 7A; general packaging, Type A.

CLOSURE

facility, tools and equipment

- Dead Blow Hammer – A mallet helpful in minimizing damage to the struck surface, with minimal elastic rebound from the struck surface. The minimal rebound is helpful in avoiding accidental damage.
- Single Point Articulation Test (SPAT) – SPAT is specified by ASME B89 4.22. It establishes the capability of the instrument to measure the same point in space as the arm is articulated through a wide range of movements. Three measurement positions (with respect to radial distance from the center of the arm) are used – near, middle and far – with the arm base rotated so that the direction of the measurement position relative to the front of the instrument is different for each position.

testing, modeling, and analyses

- Rapping – Standard practice with the single bolt closure ring is to tighten the bolt to the specified torque in stages. Between stages (i.e., at intermediate torques), a 1.5- to 3-lb dead blow hammer is used for rapping the closure ring to equalize the tension over the entire closure ring length. The premise is that the closure ring to drum friction causes the closure ring tension to be initially focused in the area next to the lugs/closure bolt. Rapping vibrates the closure ring, temporarily reducing contact between the closure ring and lid, distributing the closure ring tension around the full circumference of the closure ring, thus providing a uniform vertical compressive force on the gasket and overall drum closure.
- Stress Relief Impact Angle – Angle at which dead blow hammer impacts closure ring.
- Radial Impact Position – For the 1-foot drops, the clock position (i.e., 3, 6, 9, and 12) from the drum weld.

- Vertical Rapping – Rapping (for definition of rapping, see above) the closure ring on its top, in a direction approximately perpendicular to the floor.
- 45° (Rapping) – Rapping (for definition of rapping, see above) the outside corner of the closure ring, in a direction approximately at a 45° angle to the floor.

DROP

facility, tools and equipment

- Drop (Test) Pad – The SRS 723-A High Bay drop pad. An evaluation of the SRS 723-A High Bay drop pad has determined that the pad meets the intent of a flat, horizontal surface of such mass and rigidity that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase the damage to the specimen as required by 49 CFR 173.465.
- Choker – Nylon lifting sling used to attach the drum to the drop mechanism and maintain the desired angle. Prior to use must be inspected and approved by SRNS Rigging.

testing, modeling, and analyses

- Balance Angle (BA) – Angle of the drum's longitudinal axis, with the drop test pad when raised to the drop height (immediately before the drop). Using this notation, a BA=0° means a side drop (i.e., drum laying on its side when dropped), and BA=90° implies a normal vertical standing drum when dropped.
- Center-of-Gravity Over Top (CGoT) – When point of impact is directly below the center of gravity of the package. The CGOT orientation is the demarcation line between single and dual impact events. When the BA is between 67.5° and 90°, the top of the drum/closure assembly solely absorbs the incident kinetic energy. When the BA <67.5°, the initial impact is followed by the downward rotation of the system with the initial impact surface acting as pivot, culminating with a secondary impact.
- Concentrated Payload – A payload that results in the package content acting on a small area of the lid during a top-down drop.
- Distributed Payload – A payload that results in the package content acting on a large area of the lid during a top-down drop.
- Drop Height – Distance from the drop pad to lowest point on the drum, immediately prior to release.
- Eccentrically Loaded Concentrated Content Mass – Worst case hypothetical content (for a CGoT drop.
- Maximum Damage – Damage from an eccentrically loaded concentrated content mass that suffers a CGoT drop such that "piston action" occurs and the lid comes off.
- Radial Angle – For the 4-foot drop, the radial angle (distance) from the drum weld.

ABSTRACT

The Savannah River National Laboratory (SRNL) is in the process of developing recommendation for the U.S. Department of Energy contractors and vendors who want to qualify drums as U.S. Department of Transportation (DOT) 7A Type A to meet 49 CFR 173.465 drop testing requirements for fissile and non-fissile material to maintain containment.

Based on the finite element analysis (FEA) models, the safety features suffering the maximum damage that result in loss of containment are identified as the closure ring mechanism (in entirety), the top (mouth area) of the drum, and the lid (including the gasket). The maximum damage is measured in terms of the collective ability of these combined three safety features to maintain containment. As such, both drop testing and FEA were performed to determine the sensitivities of these safety features to drop variations.

As part of this effort, a series of physical drop tests and FEAs were conducted at SRNL. These tests used Skolnik drums, CQ5508L (see Attachment 1), which are open DOT 7A Type A open-head carbon steel 208-liter (55-gallon) drums with 12-gauge bolted closure rings. Variables studied were (1) stress relief methods during closure ring installation, (2) content configurations, and (3) drum orientations during a 4-foot free fall. It should be noted that the Skolnik CQ5508L drums have a closure ring with a "V shaped" cross section.

(1) The closure testing with analysis confirmed that closure stress relief by rapping is necessary to distribute the closure ring tension around the perimeter and to maintain sufficient closure pre-load for lid retention during 4-foot drops of the heavier packages (500 to 1,000 lbs). It was concluded that no specific style of stress relief is preferred (e.g., multi-step rapping/torqueing process, heavy hits vs. light hits, hitting near closure vs. away), as long as no additional change in bolt torque occurs with additional rapping.

(2) (3) Modeling indicated that maximum damage is a result of both: (2) content configuration and (3) drop orientation. The worst-case content configuration is one with an eccentrically loaded concentrated content mass. FEA modeling showed that the center-of-gravity over top (CGoT) with the eccentric content on the high side was the orientation of maximum damage relative to drum lid retention. In this content configuration (i.e., CGoT), FEA modeling showed payloads over 500 lbs were required to contain a load distribution plate between content and lid. Both analysis and testing showed the drum with distribution plate can pass the 4-foot CGoT drop.

1.0 INTRODUCTION

U.S. Department of Transportation (DOT) 7A Type A drums refer to drum type radioactive material packages that have radioactive contents limited to A_1 or A_2 and meet the requirements of Title 49 Code of Federal Regulations (CFR), Section 173.410 and 173.412. Performance requirements of a Type A drum to maintain containment and shielding integrity required under Normal Conditions of Transport (NCT) are demonstrated in the water spray, free drop, stacking, and penetration tests set forth in 49 CFR 173.465 for fissile and non-fissile material. Type A packages are self-certified, and do not require competent authority (i.e., DOT, U.S. Nuclear Regulatory Commission, or U.S. Department of Energy [DOE]) approval per 49 CFR 173.403; therefore, it is the responsibility of the packaging manufacturer to demonstrate compliance with the testing requirements in accordance with 49 CFR 178.350.

A DOT 7A Type A drum must undergo 4-foot regulatory free drop testing such that the test drum “suffers maximum damage to the safety features being tested.” In addition, drums for containing fissile material must be dropped tested from a height of 0.3 m (1 foot) on to each of the quarters of each rim per 49 CFR 173.465(c)(2). With each drum manufacturer responsible for the determination of the drop orientation of the drum and drop testing conditions, drop results could vary.

This report provides recommendations based on the drum drop testing and analyses.

2.0 SCOPE

Skolnik drums, CQ5508L, DOT 7A Type A carbon steel open-head 208-liter (55 gallon) drums with 12-gauge bolted, V-shaped closure rings were selected for drop testing and analysis purposes.

The following three safety features were evaluated in this report to suffer the maximum damage during the drop test that result in loss of containment: the closure ring mechanism (in entirety), the top (mouth area) of the drum, and the lid (including the gasket). The maximum damage is measured in terms of the collective ability of these combined three safety features to maintain containment. In addition to clarification of drop testing parameters, the results of this report also provide recommendations for closure assembly and content configuration.

3.0 METHODOLOGY

49 CFR 173.465 Type A package tests require that the packaging, with contents, must withstand a free drop test. The specimen must drop onto the target so as to suffer maximum damage to the safety features being tested, and the height of the drop measured from the lowest point of the specimen to the upper surface of the target may not be less than the distance specified in Table 1, for the applicable package mass. The target must be as specified in 49 CFR 173.465(c)(5). For purposes of this evaluation, the maximum drop height of 4 feet, typical of that required for drum style packages, was used.

Table 1. Free Drop Distance for Testing Packages for Normal Conditions of Transport

Package mass	Free drop distance	
Kilograms (pounds)	Meters	Feet
< 5000 (11,000)	1.2	4
5,000 (11,000) to 10,000 (22,000)	0.9	3
10,000 (22,000) to 15,000 (33,000)	0.6	2
>15,000 (33,000)	0.3	1

For fissile content packages, 49 CFR 173.465(c)(2) requires that the required Table 1 drop test be preceded by a free drop from a height of 1 foot on each corner, or in the case of cylindrical packages, onto each quadrant of the drum.

Since DOE/RL-96-57, Rev. 0-F, Vol. 1, addresses material form no. 1 solids – any particle size, it is important to note that the payload was chosen to be consistent with the FEA model maximum damage determination (vs. the commonly tested DOE/RL-96-57, Rev. 0-F, Vol. 1, Hanford test content).

For the test phase of this study, 7A drums are loaded with an array of large solid contents and subjected to 4 ft drops. The amount of weight added will bring the total drum weight to just under the 1000 lbs target. Drum orientations will be those that result in Slap-down and CGoT impacts. The analysis phase of this study will simulate the same package contents and drop conditions as tested. The analysis will also simulate eccentrically loaded concentrated content masses such that "piston action" occurs during CGoT orientation drops. Cases of insufficient preload and/or insufficient rapping will also be investigated through analysis.

3.1 PREVIOUS STUDIES

DOE previously supported an extensive program that qualified Type A radioactive material packagings. As part of that effort, the Type 7A standard 208-liter (55-gallon) drum with a standard 12-gauge bolted closure ring was tested. A typical 55-gallon drum is shown in Figure 1.

From the 1970s through 1990s, DOE conducted evaluations and testing to qualify Type A radioactive material packagings per DOT Specification 7A (DOT-7A) of 49 CFR 178.350. The program was administered by the DOE Division of Transportation and Packaging Safety, DOE/EH-33.3, of DOE-Headquarters (DOE-HQ) in Germantown, Maryland. The program was known as the U.S. DOE DOT-7A Program. Drum style packages represented a significant portion of the testing and qualification.

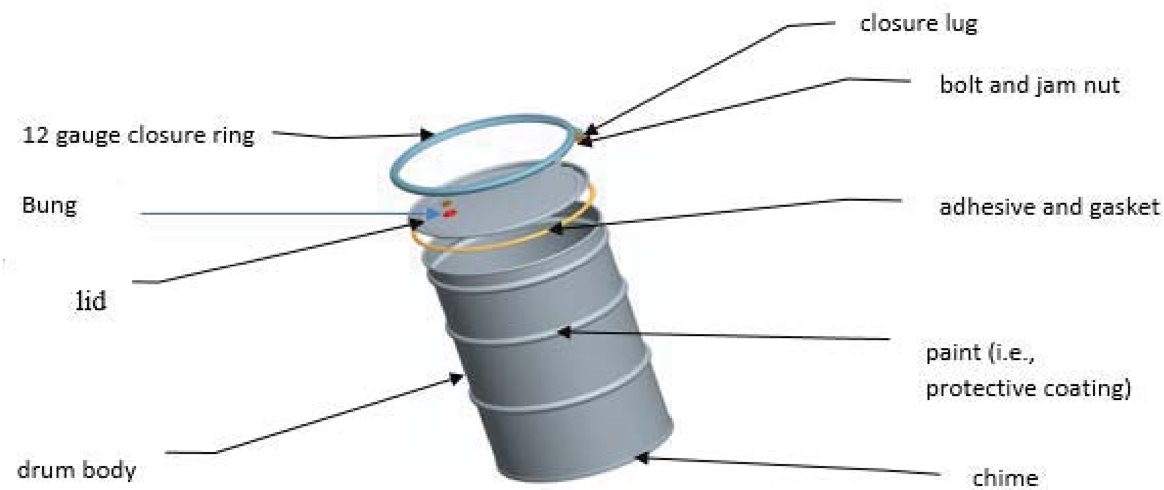


Figure 1. Standard 55-gallon Drum with 12-gauge Bolted Closure Ring

The evaluation and testing program that qualified the packages as DOT 7A packages was documented in the "DOE 7A Blue Book." Work was published in 1987 (MLM-3245) for the DOE Security Evaluation Program (DP-4) and later in 1996 (DOE/RL-96-57).

General drop test orientations were considered in evaluating the performance of a drum: (1) top-down, (2) bottom-down, (3) side, and (4) CGoT.

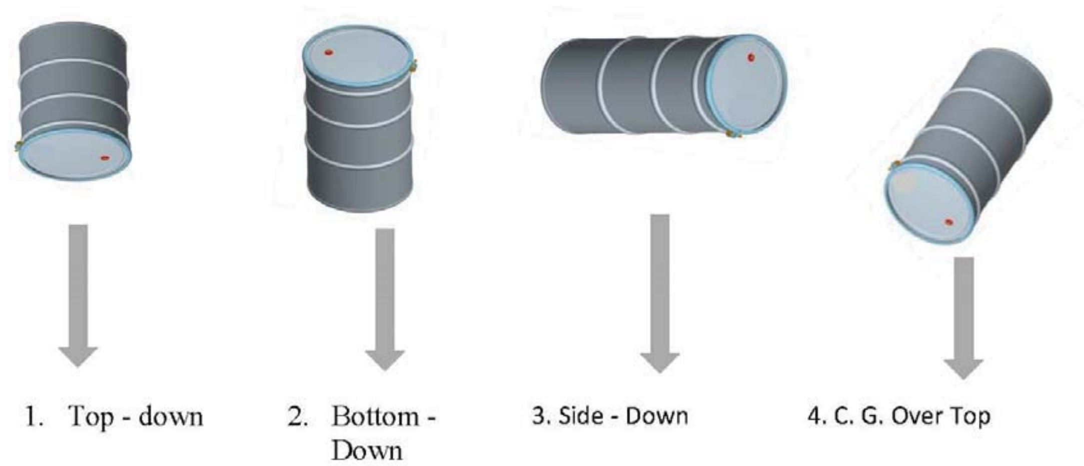


Figure 2. Historic Drop Testing Orientations

DOT commercial specification drums 6C, 17C, 17H, and military drums were commonly used for transporting Type A quantities of radioactive material. Use of 12-gauge closure rings, dropped–forged lugs, and jam nuts was standard.

For the DOT 17C 55-gallon drum the closure torque was specified at 40 $\pm$ 4 ft-lb, with closure was achieved by rapping of the drum closure ring while tightening the closure bolt. A jam nut was also used to prevent unintentional loosening during transport (DOE/RL-96-57 Rev.0-F, Vol 1, Section 2.7.3).

4.0 CLOSURE ANALYSIS AND TESTING

Based on the FEA models, the safety features suffering the maximum damage are identified as the closure ring mechanism (in entirety), the top (mouth area) of the drum, and the lid (including the gasket). The maximum damage is measured in terms of the collective ability of these combined three safety features to maintain containment. As such, both drop testing and FEA were performed to determine the sensitivities of these features to drop variations.

Since the worst damage package failure modes involve the lid coming off, this study begins by evaluating the drum closure process. Bolt installation torque and closure ring stress relief methods (rapping with varying hammer size and strike orientations) are examined relative to drum lid gasket compression and the amount of closure ring stretch (measured from the surface of the bolt head to the back of the opposite lug).

4.1 CLOSURE TESTING ON TORQUE AND STRESS RELIEF VARIATIONS

The performance of the drum closure process is quantified in part by recording deflections of the closure ring (assembly) during the closure ring bolt torqueing process. These deflections were recorded using a FaroArm® coordinate measuring machine (CMM), which is a mechanical system that moves a coordinate measuring probe around a workpiece.

- Accuracy: The 6-foot arm calibrated FaroArm® Gage Arm with Bluetooth accuracy specifications are defined in terms of a single point articulation test (SPAT) of 18 microns (0.0007 inch) and volumetric maximum deviation of +/- 25 microns (+/- 0.001 inch with a single point articulation test of 18 microns (0.0007 inch).

4.1.1 Equipment

The following equipment was used during the closure testing:

- DOT 7A Type A 55-gallon open head carbon steel drums with 12-gauge bolted closure rings and lids, specifically Skolnik CQ5508L drums
- A calibrated 0 to 100 ft-lb torque wrench
- A 6-foot arm calibrated FaroArm® (Gage Arm with Bluetooth) CMM.
- A 0.67-kg (1.5-lb) and a 1.4 kg (3-lb) dead blow hammer

Figure 3 shows the use of the FaroArm® during the closure testing.

Figure 3. Picture of FaroArm® and Drum During the Closure Testing

Figure 4 shows an example of a typical dead blow hammer.

Figure 4. Picture of Dead Blow Hammer

4.1.2 Closure Testing Procedure Overview

1. Assign a unique identification number to each drum package and mark the drum body, lid, and closure ring assembly with this identification number.

2. On each drum, fully remove lid and closure ring assembly. Inspect lid and closure ring gasket for any damage and note as required. If acceptable, replace lid and closure ring assembly on drum.

    a. Torque drum closure bolt to finger tight, then tighten to a baseline torque of 20 ft-lb (27 N-m). Using CMM, record coordinate measurements at 16 locations (shown in Figure 5) around lid perimeter.

    b. Torque closure bolt to 35 ft-lb (47 N-m).

    c. Stress relieve the closure ring by striking with the applicable hammer, using one hit per each of the four quadrants.

    d. Torque closure to 35 ft-lb (or confirm no bolt rotation at 35 ft-lb).

    e. Using CMM, record coordinate measurements at 16 locations around lid perimeter.

    f. Torque closure bolt to 45 ft-lb (61 N-m).

    g. Stress relieve the closure ring by striking with the applicable hammer, using one hit per each of the four quadrants.

    h. Torque closure to 45 ft-lb (or confirm no bolt rotation at 45 ft-lb).

    i. Use CMM to take coordinate measurements at 16 locations around the lid perimeter.

3. Fully remove lid from drum, inspect seal, and allow seal to expand for at least 30 minutes before use in subsequent drum closure gasket compression testing.

The top of the three drum lids, immediately adjacent to the closure ring, were marked with the sixteen-vertical gasket compression measurement points as shown in Figure 5. The bottom picture in Figure 5 shows the location on the lid where the actual vertical gasket compression measurement points were taken. Table 2 shows the test matrix used. The amount of closure ring stretch was also measured with the CMM, by recording displacement between the surface of the bolt head to the back of the lug.

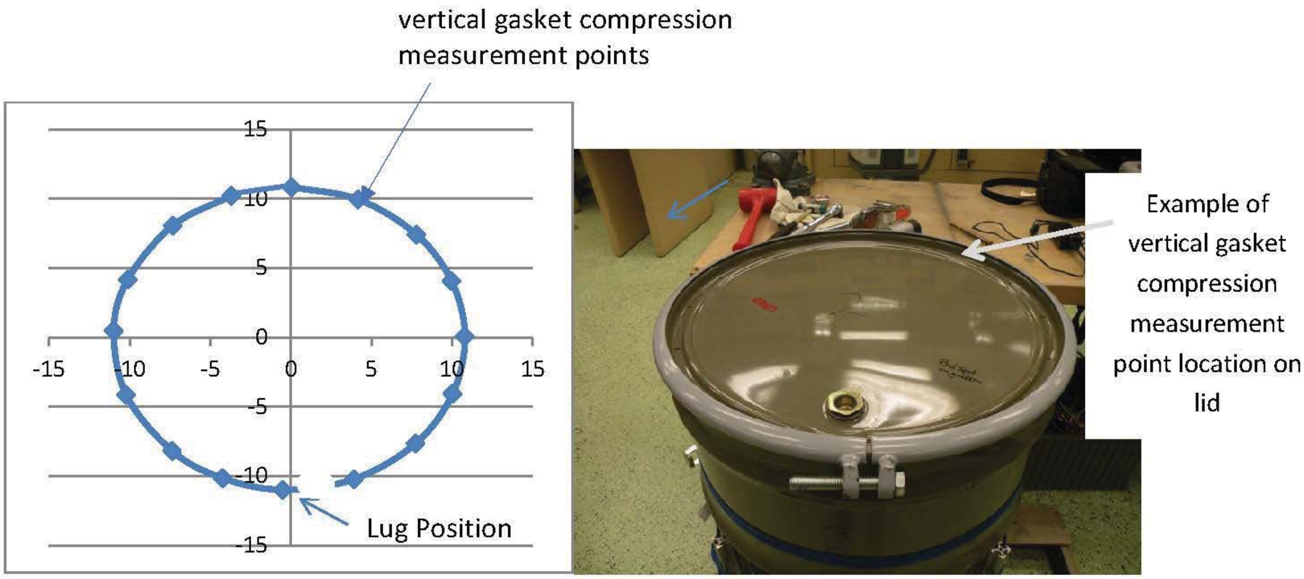


Figure 5. Location of Vertical Gasket Compression Measurement Points

Table 2. Test Matrix Impact of Torque and Stress Relief on Gasket Compression and Bolt Closure Distance

Activity	Drum 1	Drum 2	Drum 3	Drum 4	Drum 5	Drum 6
Rapping with Dead Blow Hammer	1.4 kg (3 lb)	1.4 kg (3 lb)	1.4 kg (3 lb)	0.67 kg (1.5 lb)	0.67 kg (1.5 lb)	0.67 kg (1.5 lb)
Stress Relief Impact Angle	parallel	90°	45°	parallel	90°	45°
Torque	27 N m (20 ft-lb) (no stress relief-baseline)					
	47 N m (35 ft-lb) (before and after stress relief) with applicable mallet					
	61 N m (45 ft-lb) (before and after stress relief) with applicable mallet					

4.2 CLOSURE FORCE ANALYSIS

Standard practice with the single bolt closure ring is to tighten the bolt to the specified torque in stages. Between stages (i.e., at intermediate torques), a 1.5- or 3-lb dead blow hammer is used for rapping the closure ring to equalize the tension over the entire closure ring length, as illustrated in Figure 6. The premise is that the closure ring to drum friction causes the closure ring tension to be initially focused in the area next to the lugs/closure bolt. Rapping vibrates the closure ring, temporarily reducing contact between the closure ring and lid, distributing the closure ring tension around the full circumference of the closure ring. This provides a uniform vertical compressive force on the gasket and the overall drum closure. Both testing and modeling exhibit the advantages of rapping.

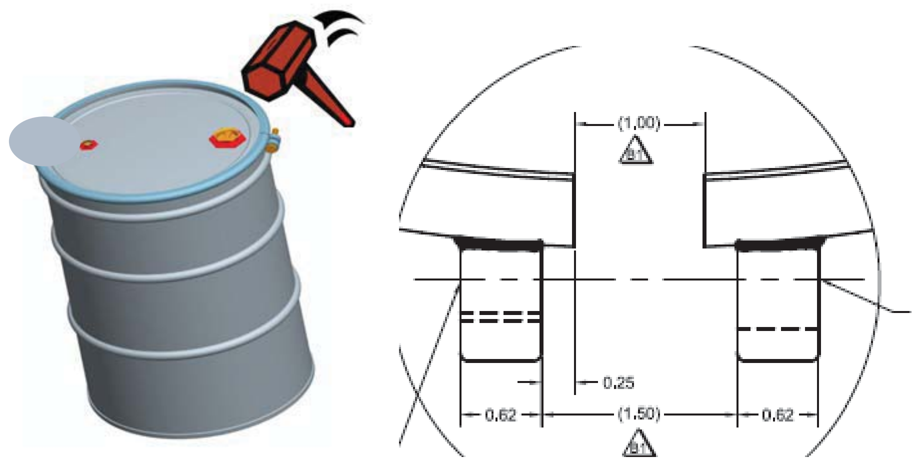


Figure 6. Drum Rapping Showing Nominal As-Built Dimensions of Closure Ring Gap and Lugs

4.2.1 Modeling Inputs

Bolt size = 5/8 inch-11 UNC

ASTM A307 (Yield = 33 ksi typical, Spec minimum tensile strength = 60 ksi)

Torque = 40 ft-lb, +/- 4 ft-lb Use 45 ft-lb	(Test and evaluation document for DOT Specification 7A Type A packaging is based on DOE/RL-96-57. When the torque exceeds 40 ft-lb there are diminishing returns on additional torque being converted to additional band tension. Closure lugs start to bend, which causes very high friction on the bolt; this friction absorbs most of the additional torque.)

Bolt tensile loads from the applied bolt torque are established by the Equation 1 (*Handbook of Bolts and Bolted Joints*).

$$Q = \frac{F_a \cdot D_b}{2}\left(\frac{f\pi D_b + L\cos\alpha_n}{\pi D_b \cos\alpha_n - fL}\right) + \frac{F_a \cdot f_c \cdot D_c}{2} \qquad \text{(Eq. 1)}$$

where:

f = bolt thread friction = 0.15 (typical)

fc = bolt head contact friction = 0.2 (typical)

L = lead angle = 1/11 for 11 threads/inch = 0.0909 inch

α_n = thread angle = 30 degree (ASME B1.1)

Dc = mean diameter of bolt head contact surface (1.0 - 5/8)/2 = 0.82 inch

Fa = pre-load axial force (calculated below)

Q = applied torque = 45 ft-lb (540 in-lb)

Db = nominal bolt diameter = major diameter = 5/8 inch

4.2.2 <u>Calculation of Bolt Axial Force (at 45 ft-lb)</u>

Using the parameters identified above, the tensile force in the closure ring is computed:

$$Q = \frac{F_a \cdot D_b}{2}\left(\frac{f\pi D_b + L\cos\alpha_n}{\pi D_b \cos\alpha_n - fL}\right) + \frac{F_a \cdot f_c \cdot D_c}{2}$$

$$= \frac{F_a \cdot 0.625}{2}\left(\frac{0.15\pi 0.625 + 0.0909\cos 30}{\pi 0.625\cos 30 - 0.15 * 0.0909}\right) + \frac{F_a \cdot 0.20 \cdot 0.82}{2}$$

$$540 = \frac{F_a \cdot 0.0691}{1} + \frac{F_a \cdot 0.0820}{1} = F_a \cdot 0.151$$

Fa = 3,600 lbs

4.2.2.1 Upper/Lower Bound Values:

The 3,600 lbs of clamp load is computed based on 45 ft-lbs torque, which is the upper end of the 40 +/- 5 ft-lbs. Considering the +/- 5 lb torque specification tolerance and a +/- 20% friction coefficient variation, the upper and lower bound clamping forces are approximated as:

Lower Bound = 3,600 lbs × (35/45) × 80% = 2,240 lbs

Upper Bound = 3,600 lbs × (45/45) × 120% = 4,320 lbs

4.3 CLOSURE MODELING

A drum model was created using the ABAQUS® FEA structural analysis program (ABAQUS® 6.6). The FEA model includes the drum body, drum lid, gasket, closure ring, lugs, and bolt. The closure ring, lug, and lug bolt assembly were modeled in sufficient detail to allow the analysis to include simulation of the lid assembly closure process. With the drum model (closure ring lug/bolt assembly), variations in preloading, as well as rapping were evaluated. The solid body representation of the FEA model is shown in Figure 7, and details of the closure ring assembly are shown in Figure 8.

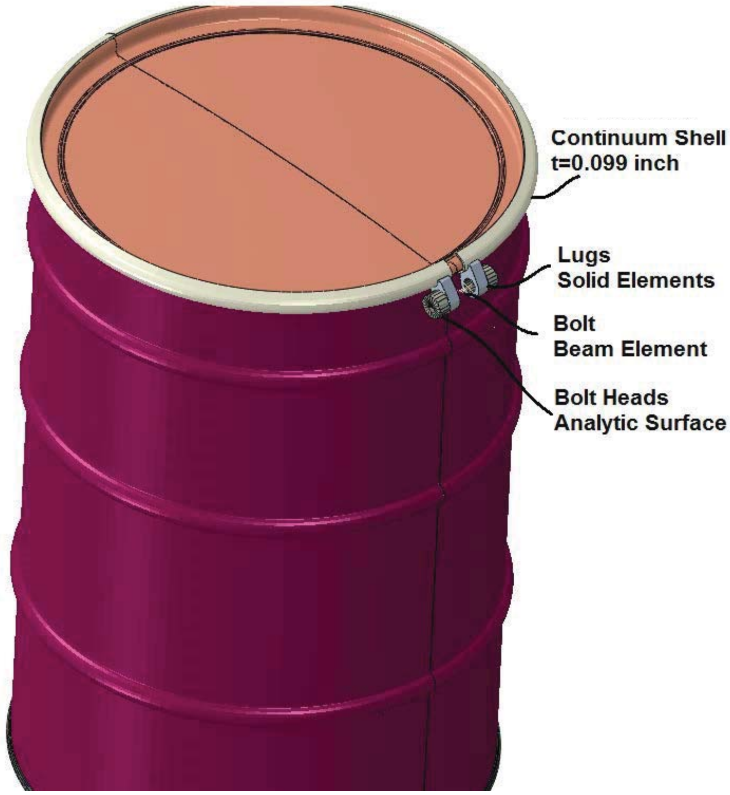


Figure 7. FEA Model of Drum Assembly (Body, Lid, and Closure Assembly)

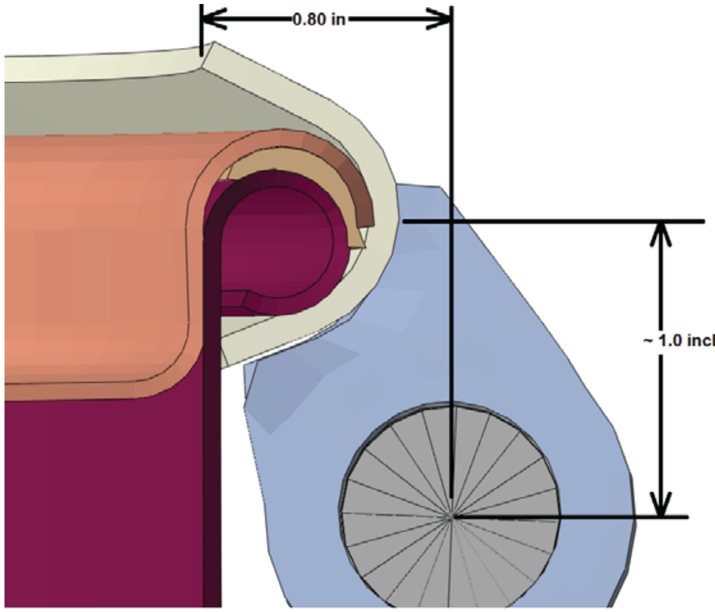


Figure 8. FEA Model Geometry of Drum Closure Lug

4.3.1 <u>Clamping Force Simulation</u>

The clamping force is simulated by prescribing displacements to the two lugs to move them closer together, and then locking the new lug position to the bolt. The clamping force is monitored by tracking the bolt axial load. The clamping simulations were performed varying the preload from 2,240 lbs to 4,320 lbs to cover the range of clamping forces computed in Section 4.2. In the baseline simulation, only a preload is applied to the bolt. In subsequent closure simulations, rapping of the closure ring is simulated by applying a force impulse to the closure ring during the preload application.

4.3.1.1 Rapping

Common practice for tightening the closure ring involves applying the specified torque in stages and rapping the closure ring with a dead blow hammer during these stages. In addition to the strain gage testing (9975 closure ring per TESRF-1) and the deflection measurements (by the CMM), the effects of rapping were evaluated analytically. The impulse simulated both 1.5- and 3-lb hammers at 8 mph (since 1.5- to 3-lb hammers were used for testing). The rapping was directed in three directions: vertically, laterally, and tangentially with respect to the closure. The simulated rapping occurred three times during the tightening of the bolt. Figure 9 shows the three pairs of locations in which a force impulse was applied.

Rapping at points on the lid directly opposite the bolt were not simulated analytically. The first reason for this was the premise stated in Section 4.2 that the closure ring to drum friction causes the tension to be initially focused in the area next to the lugs/closure bolt. Therefore, analytical rapping was initially focused in the area of "trapped" friction. A second reason is that the analysis did not show a strong location dependency on the effectiveness of the rapping. It is believed that rapping at any location causes a vibrational wave felt at the full circumference of the closure ring. Therefore, the analytical simulation of rapping was not expanded to the full circumference. As previously stated, it is still recommended that rapping be applied in all quadrants around the closure ring, because (1) there are likely additional complexities in actual lid-to-gasket-to-closure ring frictional behaviors and sticking behavior compared to the FEA simple friction model, and (2) rapping was shown to be equally effective at the locations evaluated.

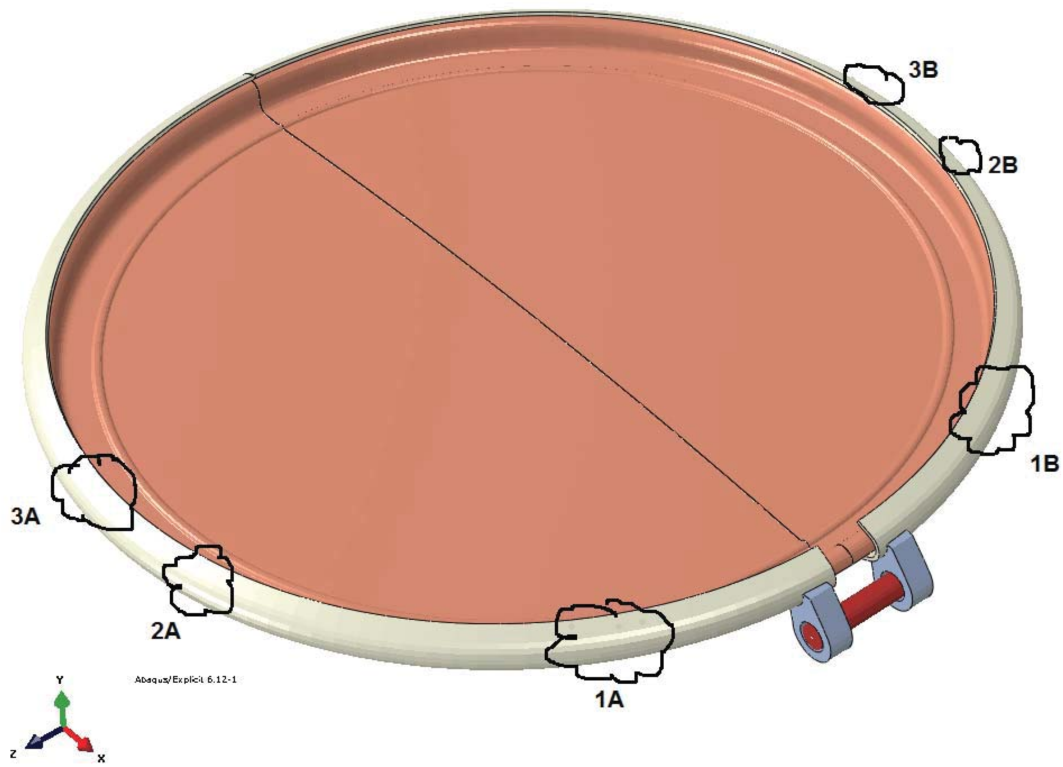


Figure 9. Locations of Simulated Closure Ring Rapping

4.3.1.2 Closure Simulations

Six different closure conditions were simulated. The preload was varied from a minimum expected to a maximum expected. The amount and style of rapping were varied from no rapping, light rapping (i.e., using the 1.5-lb dead blow hammer), to heavy rapping (i.e., using 3-lb hammer). The direction of the hammer blow was also varied. Table 3 summarizes the FEA simulations for closure.

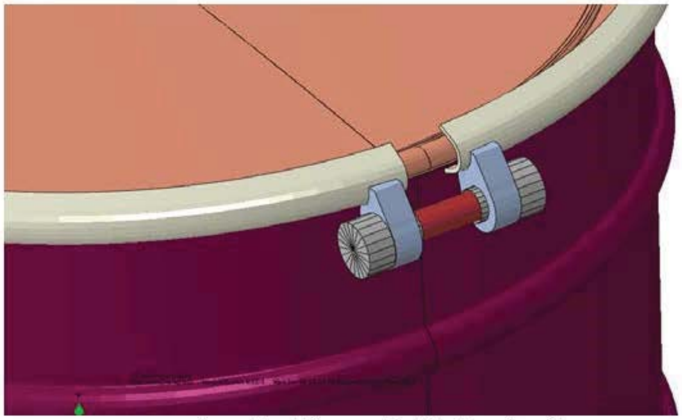
Table 3. FEA Test Matrix Impact of Torque and Stress Relief on Gasket Compression and Bolt Closure Distance

Purpose of Model	Model Name	Targeted Closure Load Magnitude	Rapping Style
Baseline, No Rapping	Drum_norap2	3,000 lbs (~ 40 ft-lb torque)	No rapping
Effects of Rapping	Drum_norap	4,000 lbs (~ 45 ft-lb torque)	No rapping
	Drum_lrap	Same bolt displacement as Drum_norap	Vertical rapping with 1.5-lb hammer
	Drum_hrap	Same bolt displacement as Drum_norap	Rapping with 3-lb hammer (parallel to floor) and tangentially away from lugs
	Drum_brap	Same bolt displacement at Drum_norap	Rapping with 3-lb hammer (vertical to floor) and tangentially away from lugs
Baseline for 4-foot Drops	Drum_brap2	Same as Drum_brap, except preload increased during rapping to bring preload back up to target torque	Rapping with 3-lb hammer (vertical to floor) and tangentially away from lugs

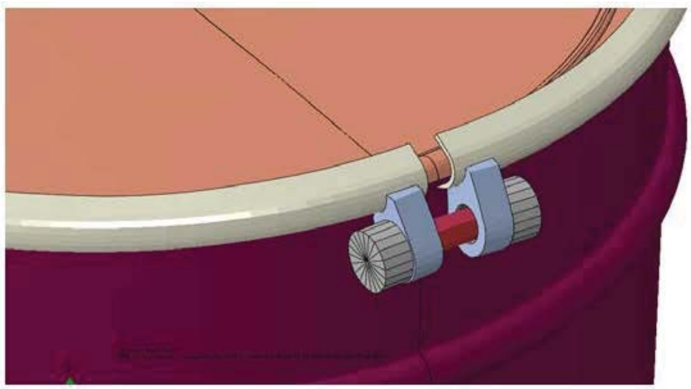
4.4 CLOSURE ANALYSIS RESULTS

The FEA closure simulations show that rapping the closure ring relieves the tension/force on the lug bolts.

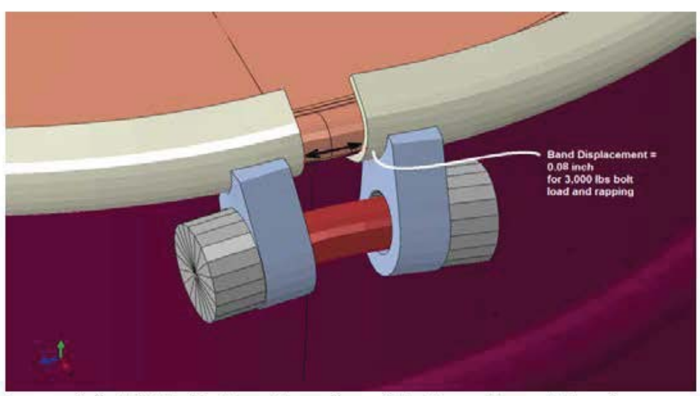
Figure 10 shows the FEA model (1) before clamp /torqueing, (2) with 3,000 lbs tension but no rapping, and (3) with 3,000 lbs tension and effective rapping during the closure process. The analysis shows that the closure ring stretch was increased by 0.08 inch when rapping was applied with the same final bolt tension (i.e., torque). Figure 10 shows the bolt deforming, which is essentially elastic with a small degree of plasticity. It is not uncommon to see some degree of lug rotation and bolt bending at high torque. This was not seen on the actual drums during closure tests.



Lug Position with No Pre-load



Lug Position with 3000 lb Pre-Load, No Rapping



Lug Position with 3000 lb Pre-Load, with Rapping, Displacement = 0.08 inch

Figure 10. FEA Model of Drum Closure, Before and After Pre-load

Figure 11 compares the tension history (in terms of axial force) during torqueing with and without rapping. The history illustrates the build-up in force torqueing and the lug bolt force reduction that occurs from rapping. Because there is no change in the lug's relative displacement during rapping, the force reduction that occurs directly equates to additional bolt turns necessary to reach the final bolt torque.

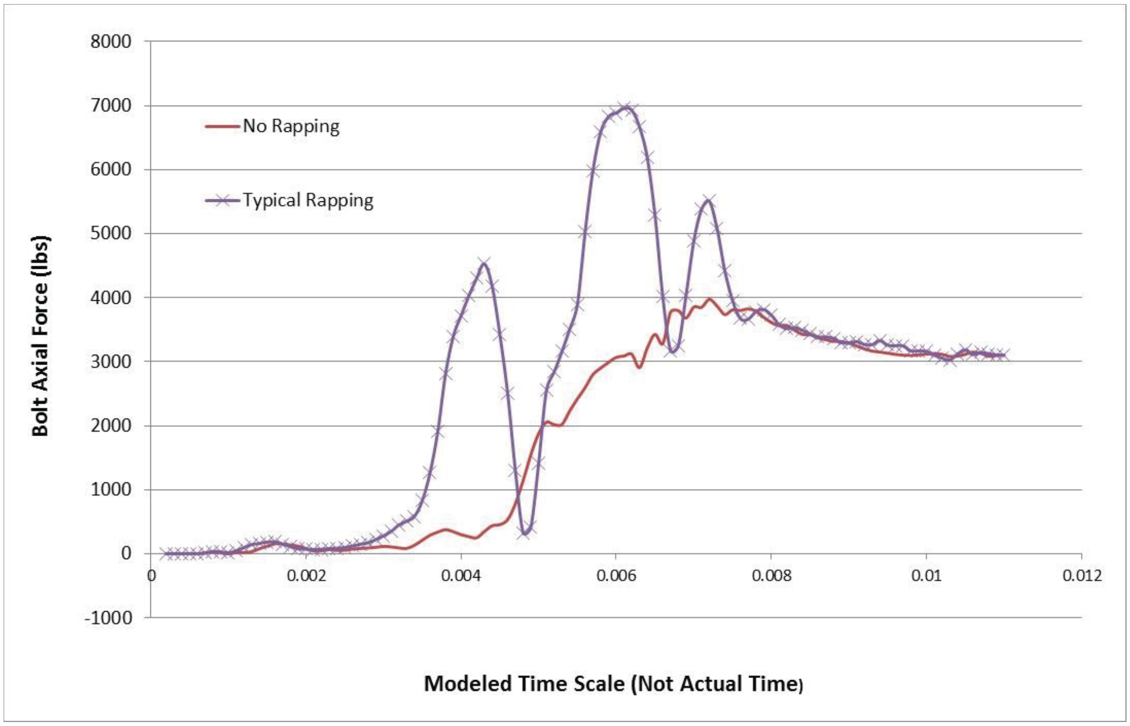


Figure 11. Comparison of Lug Bolt Tension With and Without Rapping (Same Final Bolt Torque)

Figure 12 shows the bolt tension results for a fixed amount of lug displacement (e.g., bolt turns) and four different levels of rapping:

- Baseline of no rapping: Force builds to 4,000 lbs (equal to ~ 45 ft-lbs)
- Rapping with 1.5-lb hammer: Vertical direction, at locations 1A, 1B, 2A, 2B, force reduced to 3,800 lbs
- Rapping with 3-lb hammer: Vertical direction, at locations 1A, 1B, 2A, 2B: final bolt force = 3,000 lbs (~ 38 ft-lbs)
- Rapping with 3-lb hammer: Lateral direction and tangential direction in six locations (1AB, 2AB, 3AB): resulting force = 2,000 lbs (~ 33 ft-lbs)

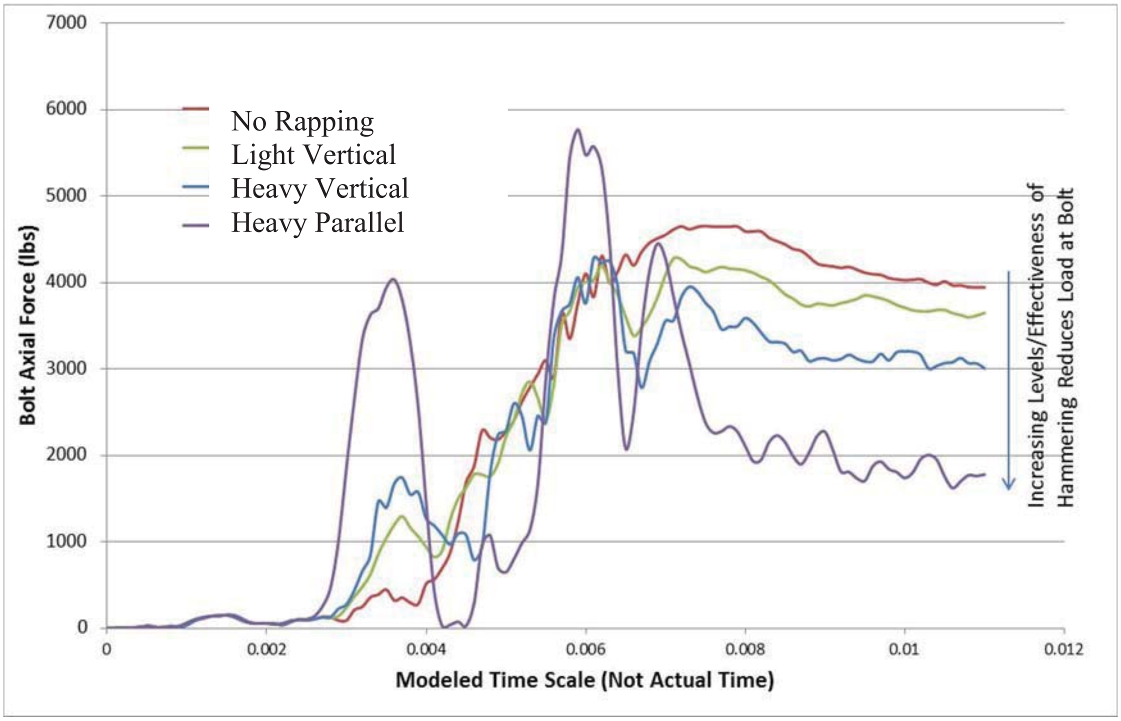


Figure 12. Lug Bolt Tension for Four Different Levels of Rapping (Fixed Amount of Prescribed Lug Movement)

In the above results, the reduction in bolt load is indicative of tension being relieved at the closure end of the closure ring and transferred to the opposite section. Therefore, the analysis shows that lateral and tangential hammering is most effective at equalizing closure ring tension.

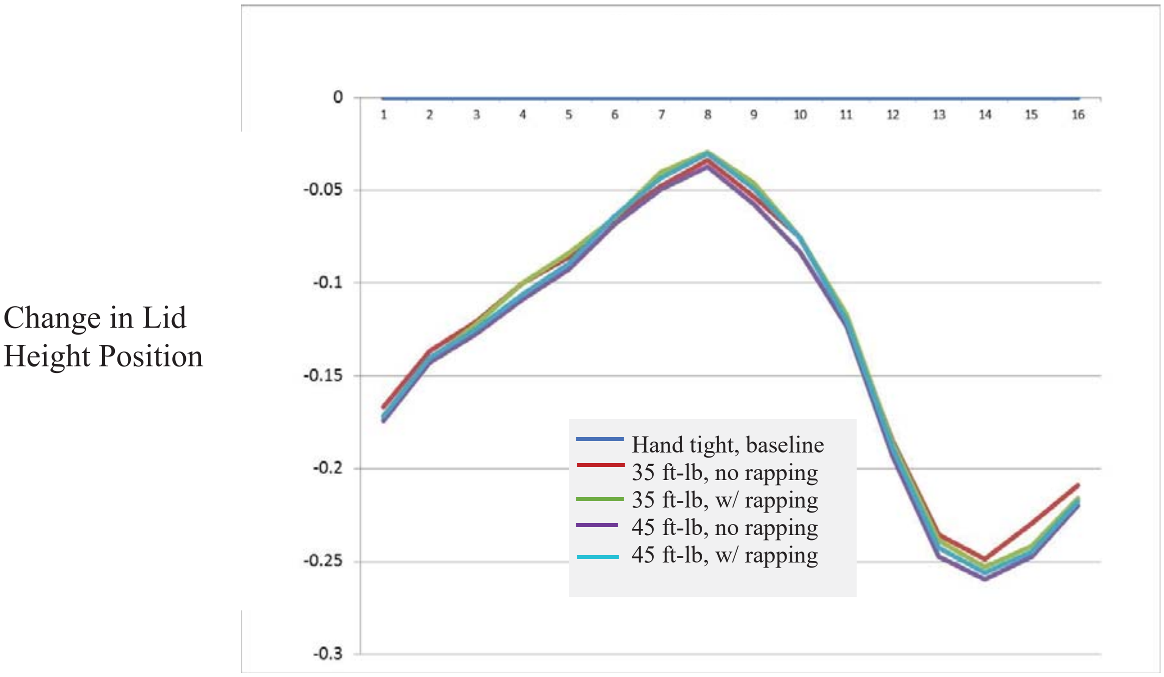
Note: An additional finding illustrated by the FEA study is the importance of the lug-to-closure ring connection. If this welded joint is weak, the lugs could bend excessively, further increasing friction on the bolt threads, resulting in a condition where the bolt torque is not effectively converted into closure ring tension.

4.5 CLOSURE TESTING

The amount of vertical gasket compression occurring during tightening of the closure ring bolt was estimated by measuring the vertical movement of the drum lid at 16 points around the outer circumference of the lid. As was previously shown in Figure 5, the measurement is made on the lid, not the closure ring, with results made at different closure torques as also previously described in Table 2.

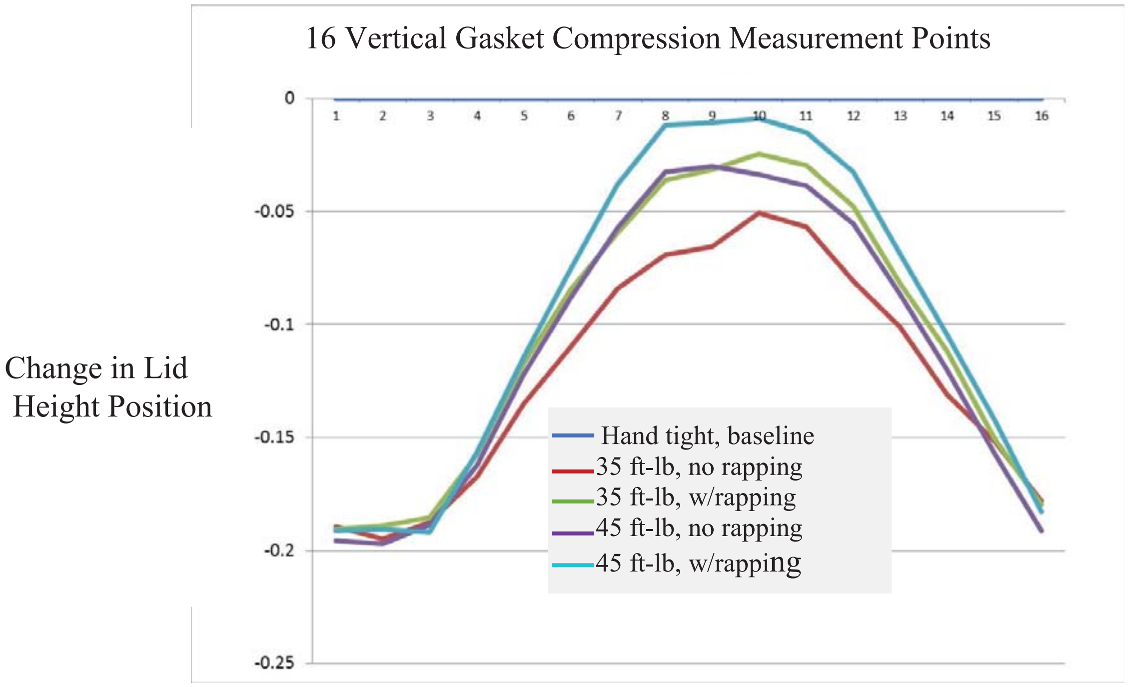
The actual testing was performed using six different drums, varying the size (weight) of the dead blow hammer and the direction of impact. The individual closure results are shown in Figure 13 through Figure 15 showing closures using the 3-lb hammer, and Figure 16 through Figure 18 showing closures which used the 1.5-lb hammer. Figure 19 shows the final measurement for all six lid installation tests.

Note 1: It is important to understand that when interpreting Figure 13 through Figure 19, the changes in the vertical height of the lid for its 16 gasket compression measuring points largely varies as a legacy associated with using a CMM, with the true significance only shown by the vertical distance between the colored lines (with each of the colored lines representing the different applied closure techniques) at each specific gasket compression measuring point.



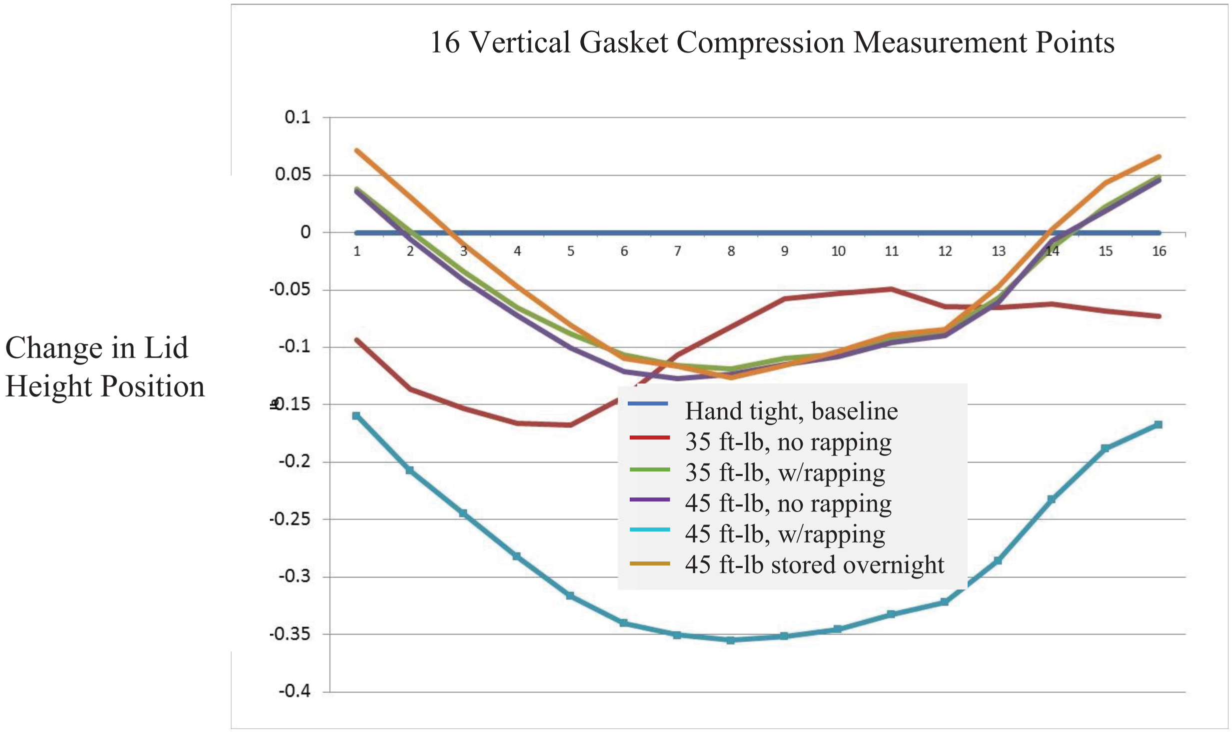
See Note 1 on pg. 30 before interpreting graph

Figure 13. Lid Deflection for Drum #1 Test, 3-lb Hammer, Parallel Rapping



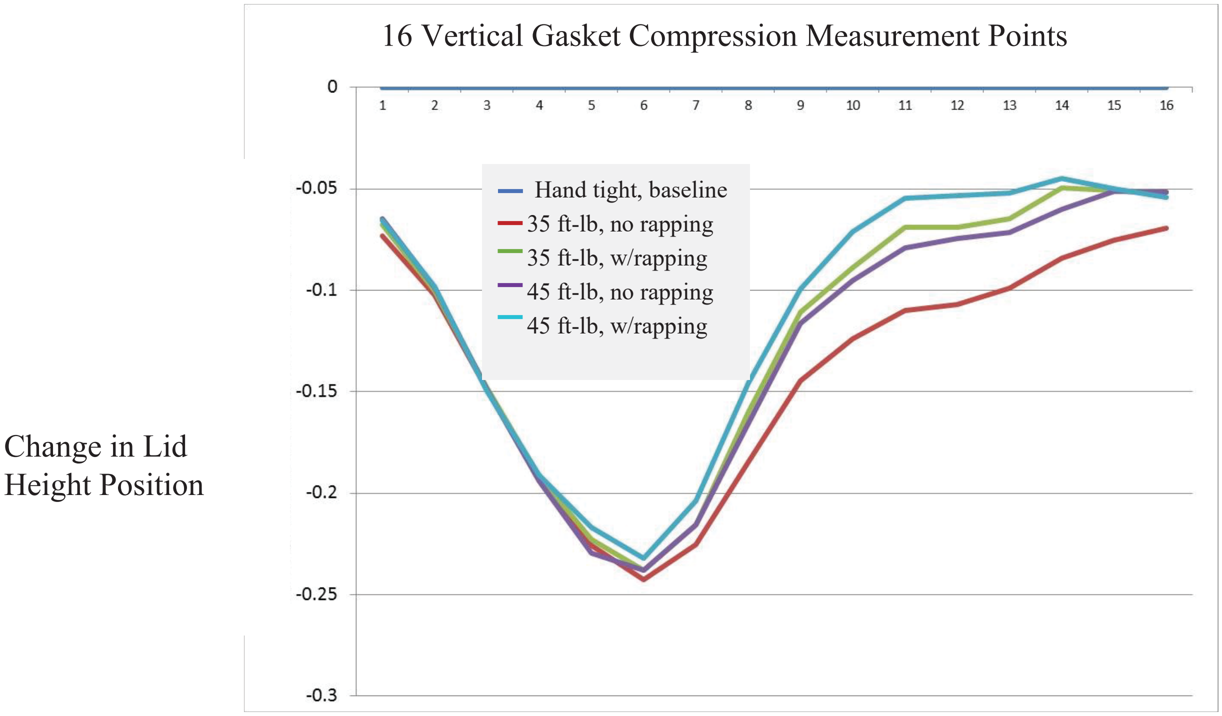
See Note 1 on pg. 30 before interpreting graph

Figure 14. Lid Deflection for Drum #2 Test, 3-lb Hammer, Vertical Rapping



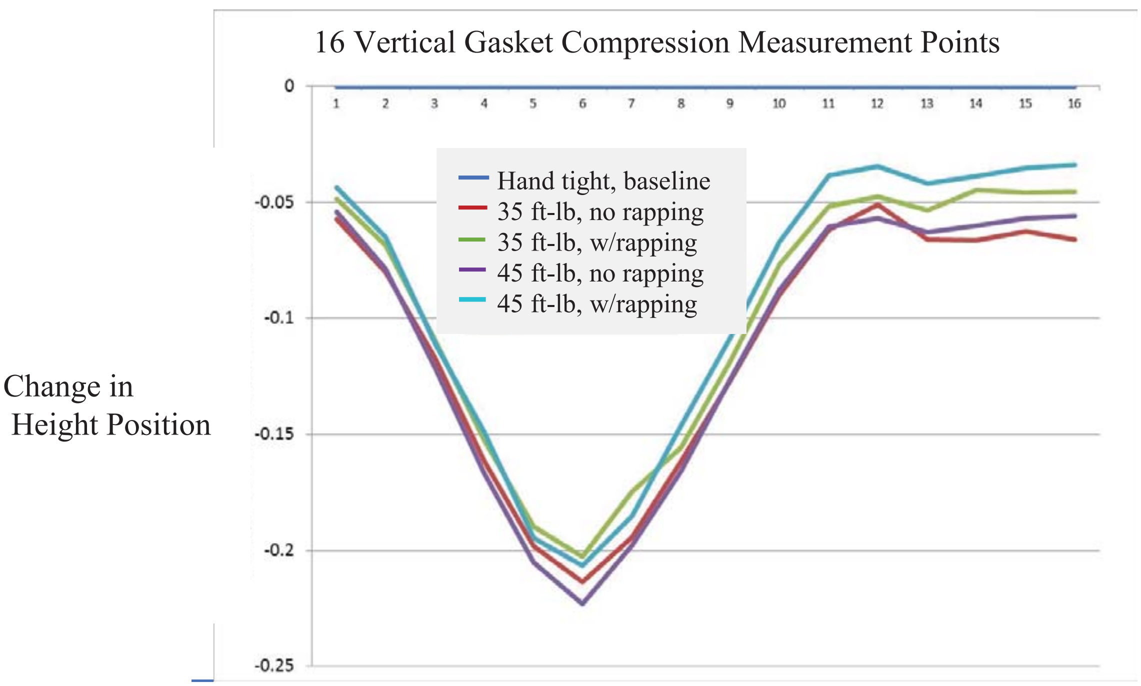
See Note 1 on pg. 30 before interpreting graph

Figure 15. Lid Deflection for Drum #3 Test, 3-lb Hammer, 45° Rapping



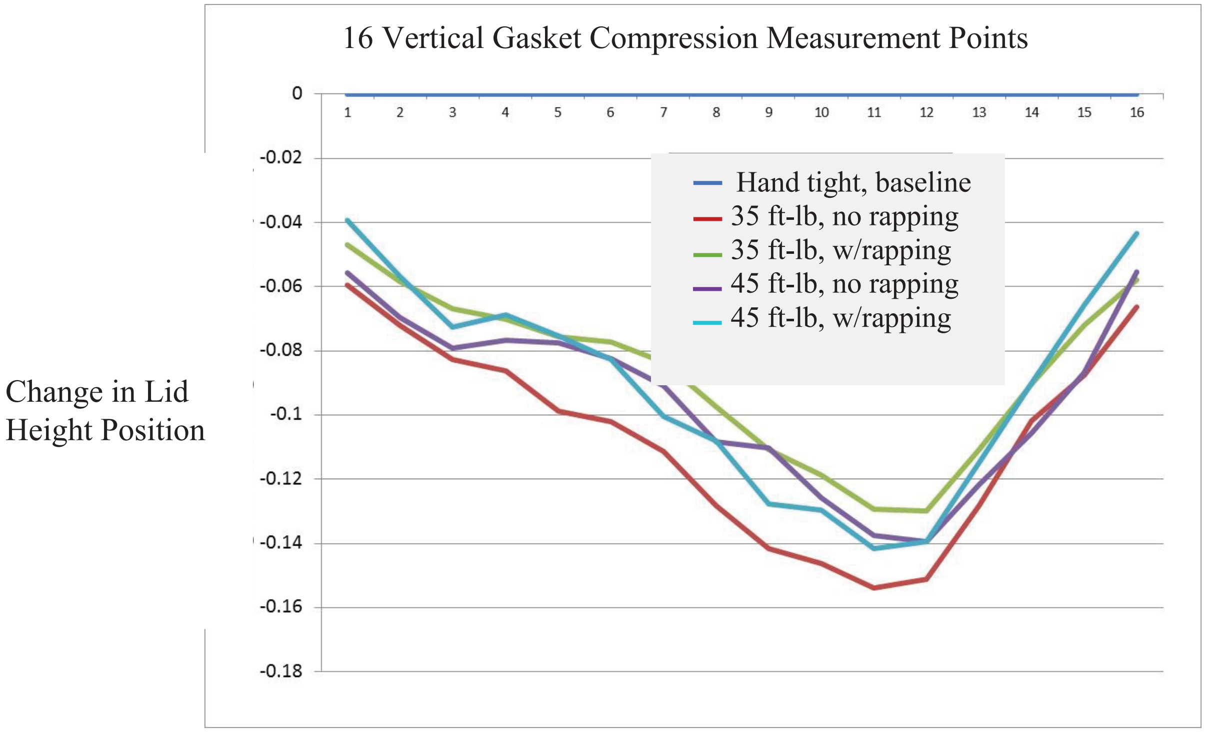
See Note 1 on pg. 30 before interpreting graph

Figure 16. Lid Deflection for Drum #4 Test, 1.5-lb Hammer, Parallel Rapping



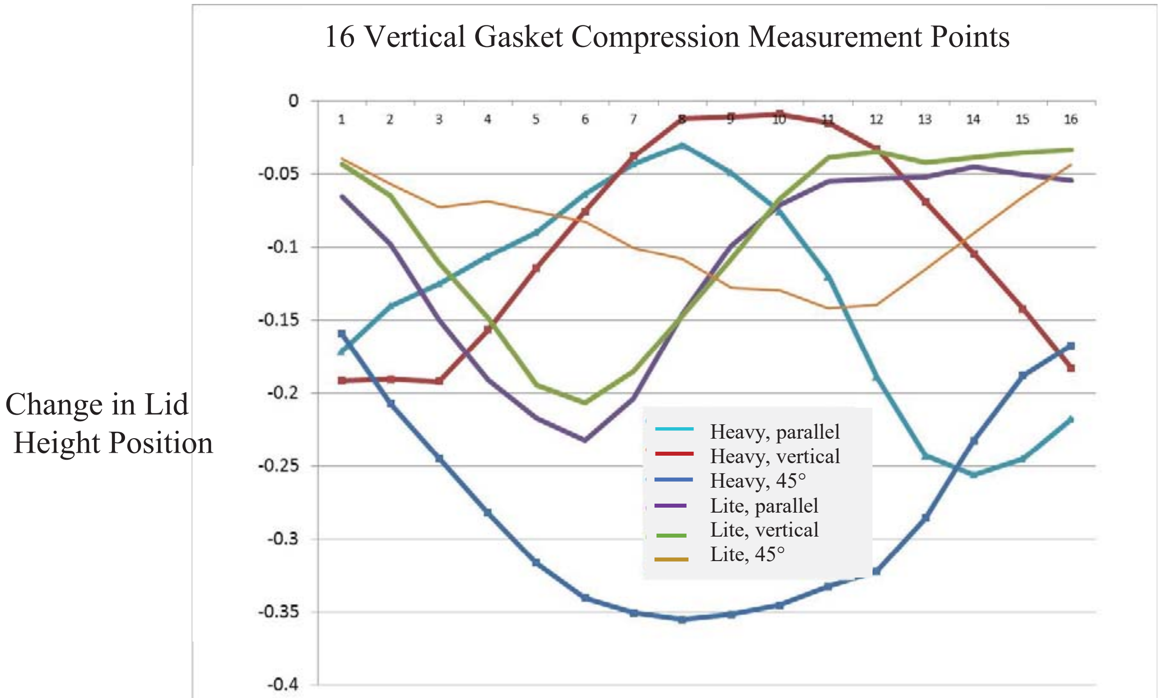
See Note 1 on pg. 30 before interpreting graph

Figure 17. Lid Deflection for Drum #5 Test, 1.5-lb Hammer, Vertical Rapping



See Note 1 on pg. 30 before interpreting graph

Figure 18. Lid Deflection for Drum #6 Test, 1.5-lb Hammer, 45° Rapping



See Note 1 on pg 30 before interpreting graph

Figure 19. Lid Deflection Final Measurements, All Six Tests

Except for the first test identified in Table 2 (drum #1, 3-lb hammer, parallel rapping), the CMM measurements showed clear compression of the lid based on before and after rapping. The tests showed that there was more movement at locations away from the lug, than at the lug, suggesting that closure ring tension was being equalized around the circumference.

The CMM measurements showed 45° rapping to result in the most vertical movement of the lid (thus stress relief), lateral rapping to result in the least vertical movement of the lid, and vertical rapping to be in between these two. The analytical simulations showed lateral rapping as more effective in relieving (e.g., equalizing) load. To address these apparent differences, some artifacts of test versus analysis are noted:

(1) The FEA simulation applied vertical rapping at the mid-span of the upper half of the closure ring (see Figure 19). During physical testing, the size of the hammer tip causes contact to occur at the top edge of the closure ring during vertically directed rapping.

(2) The FEA simulation of lateral rapping was also angled to have the hammer impulse directed circumferentially into the closure ring, which would be expected to be more effective.

(3) The difference in lid movement recorded by the CMM for the three rapping orientations were small, such that overall effect of equalization was large compared to the minor

differences between the three hammer directions (e.g., testing showed differences, but not sufficient to claim a clear trend between vertical and lateral).

In all six tests, the measured deflections indicated that the torqueing of the closure ring not only lowers the lid, but also changes a net lid tilt, as the lid seats more squarely with the drum rim after torqueing. This implies that the lid is initially tilted relative to the drum body, until the torque is applied.

Although, the modeling simulated tangential rapping, directed away from the lugs, may be effective, it was not performed during the actual testing due to replication and safety issues. In lieu of tangential rapping, rapping the closure ring at 45° was included in the actual testing. Results between the modeled tangential rapping and the actual test 45° rapping showed similarity (i.e., resulting in the biggest change in equalization of compression).

As indicated by Figure 19, the testing showed there is no clear trend in lid movement as a function of hammer size or direction of rapping other than the 45° rapping using the 3-lb hammer is best. It was also observed during the tests that the closure torque at the lug bolt may be reduced by approximately 15% after the 3_ lb hammer rapping. For example, after torqueing to 35 ft-lb, and then rapping closure ring at 45°, a reduced torque of approximately 30 ft-lb would then turn the lug bolt.

In summary, the closure ring tightening tests demonstrate that rapping of the closure ring alters the tension load at the lug bolt (by indication of bolt torque), as well as alters the lid compression around the perimeter.

5.0 DROP TEST TESTING

5.1 DROP TESTING METHODS

For each drum tested, a free drop was performed from a height of 1 foot onto each quarter rim of the bottom drum chime and closure ring followed by a free drop through the distance of 4 feet onto a flat, unyielding, horizontal surface, striking the surface in an orientation for which maximum damage is expected. For drop testing, the total (loaded) drums weighed 980 lbs ±10 lbs per Savannah River Site (SRS) field procedure FP-1121.

Pre-condition drops may alter the likelihood of piston action failure. However, piston action in CGoT orientation is the worst case failure drop scenario as analyzed in the report.

The drop test involved the following equipment and instrumentation:

- Fifteen 55-gallon Type A drums with lids, specifically Skolnik CQ5508L.
- Calibrated torque wrench with range of 0 to 100 ft-lb.
- Calibrated dynamometer capable of weighing a fully loaded drum.
- Blacklight.

- Fluorescent powder/flour mix.

- Electro-mechanical drop mechanism: illustrated in Figure 20.

- Choker approved by SRNS Rigging used to attach the drum to the drop mechanism and maintain the desired angle.

- Angle finder used to confirm that the angle of the package is within the tolerance range for the desired drop angle.

- Rigging equipment: Shepherd hooks and similar instruments used to pull the locating and safety pins from the drop mechanism.

- Drop (test) pad: 49 CFR 173.465 requires that the test specimen must drop onto a flat, horizontal surface of such mass and rigidity that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase the damage to the specimen. The impact pad within the 723-A High Bay is designed as shown in SRS drawing S5-7-2520. Previous evaluation of this test pad has determined that it meets the intent of a flat, essentially unyielding, horizontal surface as required by the regulations.

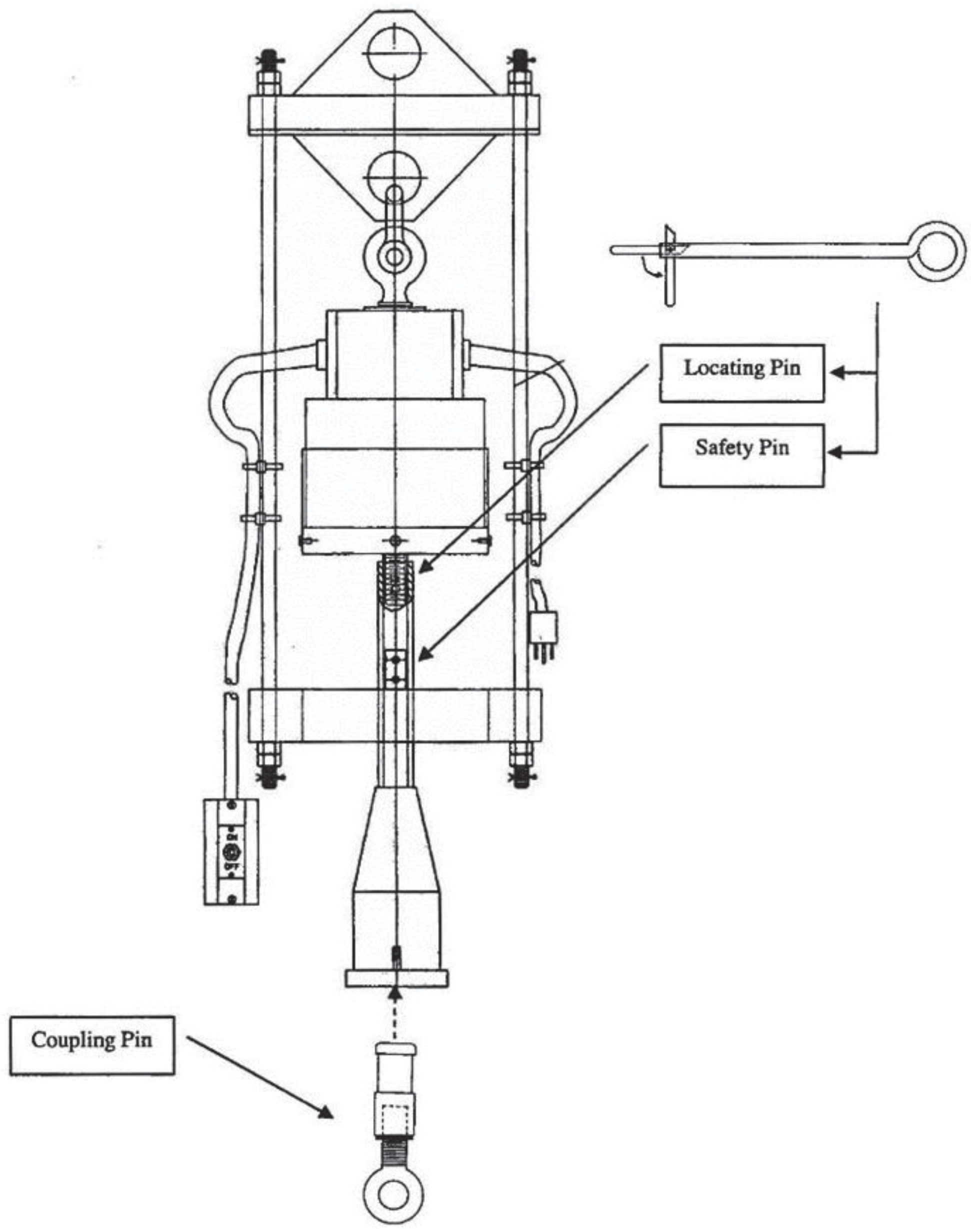


Figure 20. Electro-Mechanical Drop Mechanism

- Backdrop: A contrasting vertical surface behind the drop area, marked with a square grid, used to confirm the drum height, angle of the drum directly before impact, and distances travelled per unit time.

- Watch used to record the time the drop mechanism has been energized, due to a duty cycle requiring that it cannot be continuously energized for more than 10 minutes.

The drum weights and orientations used for the drop testing are summarized in Table 4. Pictures associated with the drops and drum closure evaluations are shown in Appendix 1.

Figure 21 shows a simplified schematic of how the desired angle was measured/confirmed, while Figure 22 shows the same for the radial impact position and radial angle (RA).

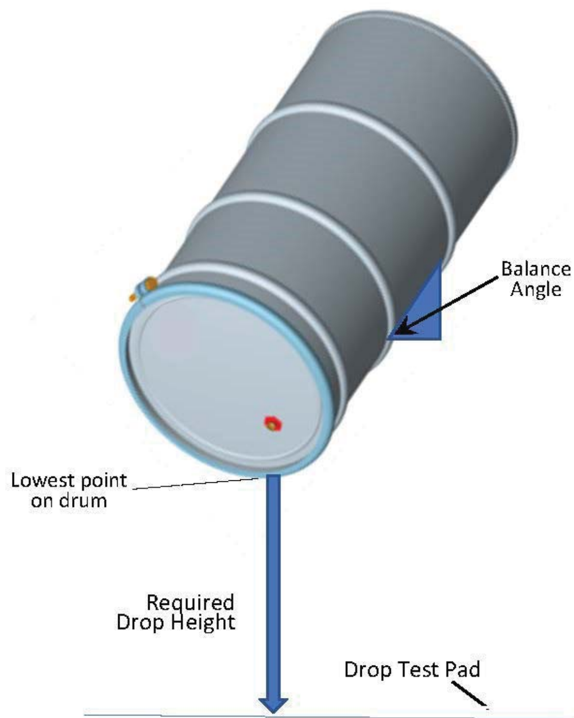


Figure 21. Simplified Schematic Showing Measurement/Confirmation of BA

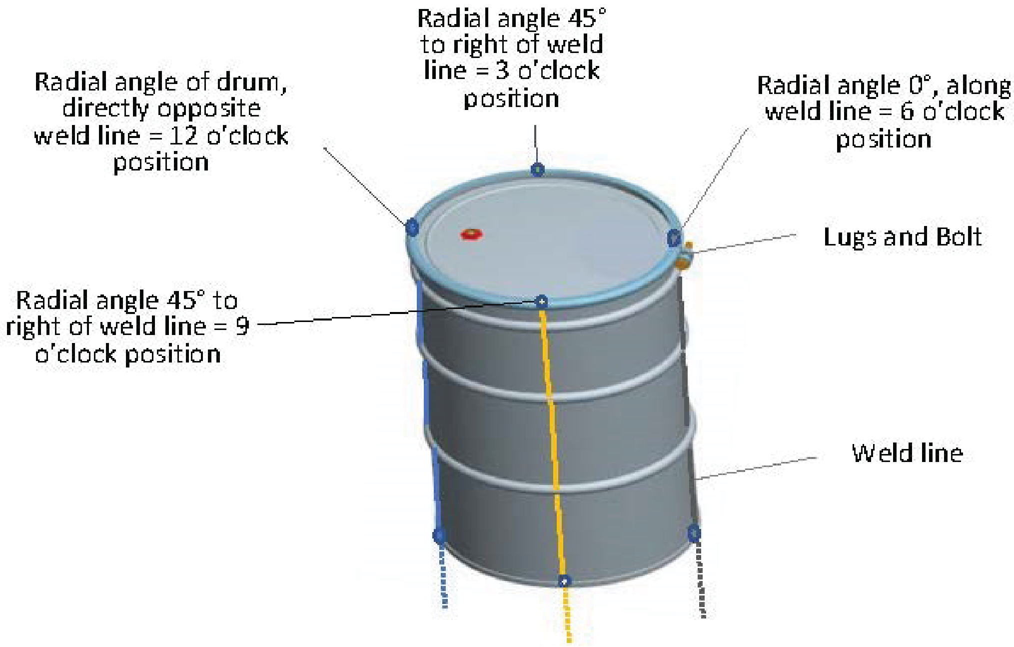


Figure 22. Simplified Schematic Showing Angle Nomenclature for Radial Impact Position and RA

Table 4. Free Drop Testing – Drum Weight and Orientation

Drop Test	Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	Historic Nomenclature for Drop Orientation Family	4-foot Drop Radial Angle (°)
		1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)			
1	980	45	12, 3, 6, 9	45	12, 3, 6, 9	5	side-shallow angle	0
2	980	45	12, 3, 6, 9	45	12, 3, 6, 9	5	side-shallow angle	15
3	982	45	12, 3, 6, 9	45	12, 3, 6, 9	10	side-shallow angle	15
4	992	45	12, 3, 6, 9	45	12, 3, 6, 9	60	CGoT	5
5	982	45	12, 3, 6, 9	45	12, 3, 6, 9	60	CGoT	30
6	989	45	12, 3, 6, 9	45	12, 3, 6, 9	10	side-shallow angle	90
7	987	45	12, 3, 6, 9	45	12, 3, 6, 9	45	approaching CGoT	0

Drop Test	Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	Historic Nomenclature for Drop Orientation Family	4-foot Drop Radial Angle (°)
		1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)			
8	987	35	12, 3, 6, 9	35	12, 3, 6, 9	10	side-shallow angle	90
9	986	15	12, 3, 6, 9	15	12, 3, 6, 9	5	side-shallow angle	15
10	999	30	12, 3, 6, 9	30	12, 3, 6, 9	10	side-shallow angle	15
11	980	45	3, 6, 9, 12	45	3, 6, 9, 12	30	side-shallow angle	30
12	987	60	3, 6, 9, 12	60	3, 6, 9, 12	0	side- Shallow angle	0
13	990	60	3, 6, 9, 12	60	3, 6, 9, 12	20	side- shallow	0
14	988	60	3, 6, 9, 12	60	3, 6, 9, 12	45	approaching CGoT	0
15	987	na	na	na	na	60	CGoT	0

Note: all angles within ±5°

5.2 DROP TESTING RESULTS

The drop tests shown in Table 4 were completed with drum angle tolerances set at ±5°. The 12, 3, 6, and 9 clock position refers to 0°, 90°, 180°, and 270° from the vertical weld line on the drum wall, respectively. For drop testing, the 4-foot balance angles (BAs) and RAs were varied in an attempt to identify the orientations that result in maximum damage. The input from the FEA model was used to ensure testing included the BA associated with the 4-foot drop that would result in maximum damage. Appendix 1 includes photographs of drop test conditions and results. No test drum failed at the drum closure because of or during the actual drop testing.

The testing showed that for the angles tested at the 1-foot drop condition, damage to the bottom chime and lid were not significantly different. Similar severity of buckling damage across the drum closure lid and drum bottom was observed, which can be attributed to the weight loading configuration of the drums. A comparative example can be observed between drum #3 after all bottom drops and drum #7 after all top drops (Appendix 1).

The 4-foot drop onto the drum closure bolt or lugs was observed to produce the greatest local damage to the closure lid. Severity of the local damage observed varied between the CGoT (45-60° angle) to the shallow angle (~10°) drops; although no lid failures were experienced in any of the drops.

5.3 DROP ANALYSIS MODELS

For modeling, 13 different package conditions were subjected to 4-foot drop simulations, as shown in Table 5. Eight of the simulations pertain to the CGoT orientation, with variations made in closure effectiveness, content weight, and content weight distribution. The two side down simulations were performed with minimum closure ring torqueing and without rapping. Since the lid always stayed on, no other side down configurations were investigated. Three slap-down drop configurations were simulated.

Table 5. FEA Free Drop Analysis – Drum Orientation and Content Weight Distribution

Purpose of Simulation(s)	File Name	Closure Preload Condition	Drum Orientation	Content Description	Result
Evaluate extreme eccentrically placed point source content, placed in a most damaging location	Drumcg_t	45 ft-lb*, no rapping	CGoT, with closure bolt at bottom	950 lbs total, point source rigid mass Eccentrically placed	Lid comes off
	Drumcg_t_rap	Same, but w/ rapping			Lid Comes off
Evaluate effects of distribution plates between payload and lid	Drumcg_d	45 ft-lb, no rapping	CGoT, at Bolt	Same eccentric pt. mass, but ½ inch plate between content and lid	Lid and closure ring come off
	Drumcg _d_rap	Same, but w/ rapping	CGoT, at Bolt		Lid stays on
Evaluate a typical bounding distributed content, with and without rapping	Drumcg_n	45 ft-lb no rapping	CGoT, with closure bolt at bottom	950 lbs total, contents distributed @ 24 equal parts	Lid stays on
	Drumcg_n_rap	45 ft-lb w/ rapping			Lid stays on
Evaluate performance based on payload mass	Drumcg _tl	45 ft-lb, no rapping	CGoT, with closure bolt at bottom	500 lbs point mass	Lid stays on
	Drumcg_dl			With distribution plate	Lid stays on
Evaluate side down orientation	Drum _side	45 ft-lb, no rapping	Side drop onto closure, tilted ~ 2°	950 lbs contents distributed over multi-parts	Lid stays on
	Drum _side_L	45 ft-lb, no rapping		Same, but 500 lbs	Lid stays on
Evaluate slap down onto closure	Drum_ slap_low	<15 ft-lb w/ rapping	10° slap	950 lbs, distributed	Slight seal breach

Purpose of Simulation(s)	File Name	Closure Preload Condition	Drum Orientation	Content Description	Result
	slap_norap	45 ft-lb, no rapping	10° slap	950 lba, distributed	Lid stays on
	slap_rap	45 ft-lb w/ rapping	10° slap	950 lba, distributed	Lid stays on

*45 ft-lb equates to 3,000 to 4,300 lb tension in closure ring, dependent upon thread friction, gasket friction.

5.3.1 CGoT Simulations – Point Source Eccentric Mass

The effects of content weight distribution on drum closure performance were investigated by simulating a single point source content of maximum mass, with the mass positioned with extreme eccentricity (see Figure 23). The content consisted of:

- A lightweight dunnage assembly that partitions the drum cavity (~ 50 lbs)
- A 900-lb cylindrical, rigid concentrated content placed in the partition created by the dunnage

The drum was oriented in a CGoT condition, with the lug side down and the 900-lb point source content positioned on the high side of the tilted drum. In this configuration, the initial impact with the rigid floor would result in a piston effect inside the drum, in which the content impacts the drum lid at the upper end of the drum lid.

Figure 23 shows the post-drop deformed shape of the drum for the simulated case of 45 ft-lb pre-load with no rapping. Figure 24 shows the same simulation, except stress-relief by rapping was simulated during the bolt preload application. In both cases, the closure ring failed to retain the lid across a 90°segment. The piston effect of the concentrated, eccentric mass was too severe of a load, causing the lid to deflect outward.

Because the lid did not remain on in either of the two simulations (one without rapping, second with rapping), two additional variations of the CGoT orientation were evaluated, as discussed in the next two sections.

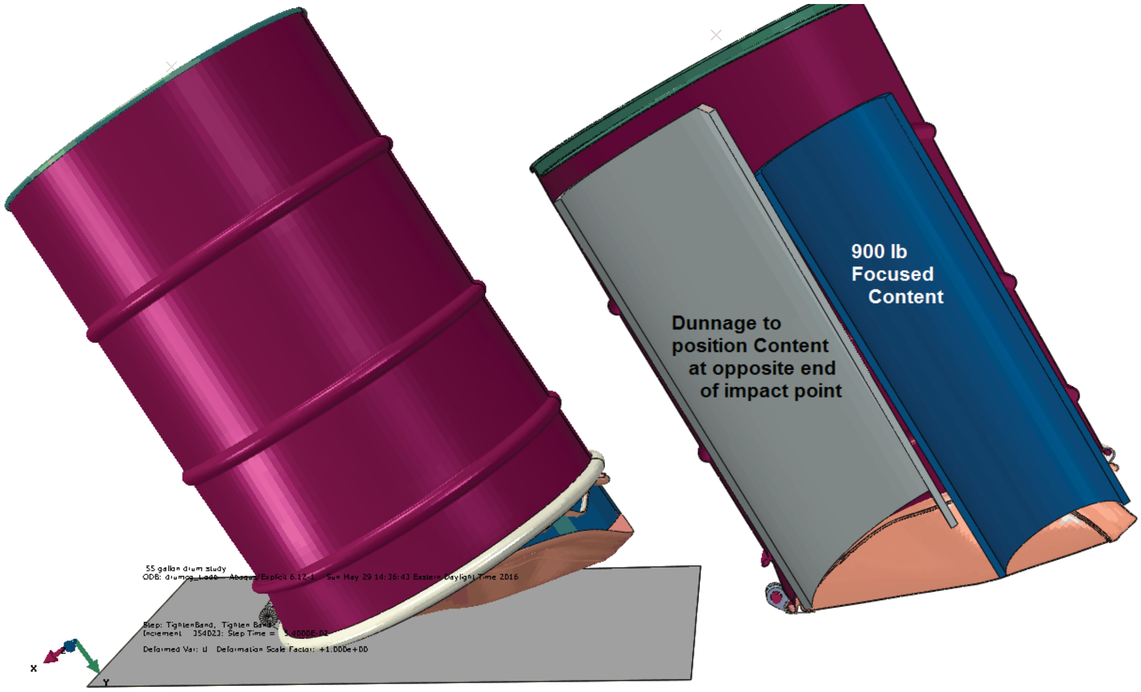


Figure 23. Deformed Shape after 4-foot Free Fall Simulation, Concentrated Content, No Rapping During Closure

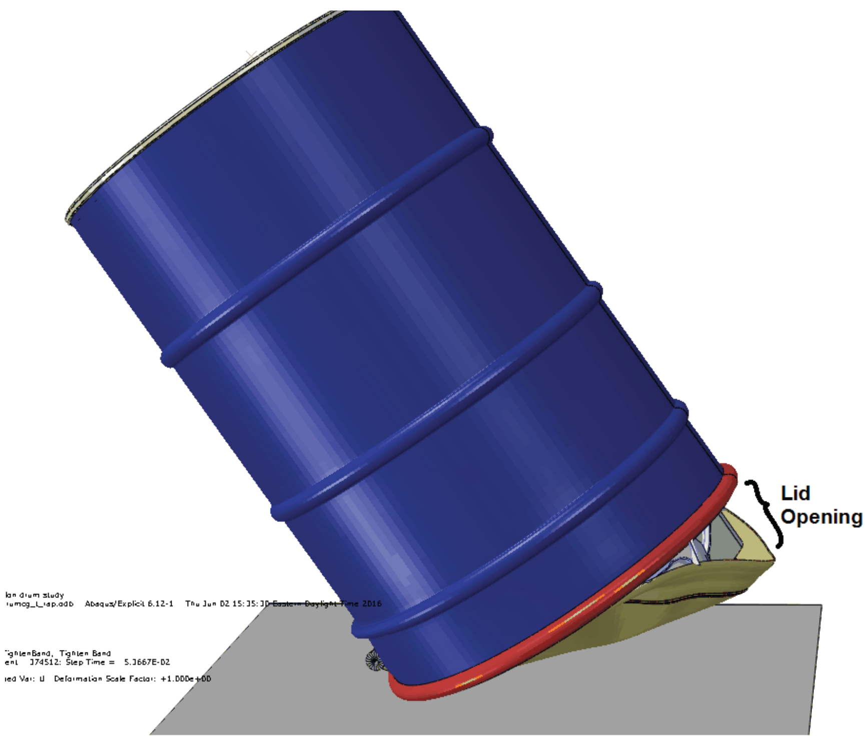


Figure 24. Deformed Shape after 4-foot Free Fall Simulation, Concentrated Content, With Rapping During Closure

5.3.2 CGoT Simulations – Eccentric Point Mass with Distribution Plate

Note: This modeling was performed using 40 ft-lb of torque because it is the minimum value needed to keep the lid on.

Based on the results of the eccentric point mass contents, simulations were performed where the simulated content was modified to include a top plate that would act to distribute the concentrated content mass over a larger area of the lid. The modeled distribution plate was 1/2-inch thick steel and 21 inches in diameter. Two variations of this model were used:

- Normal preload (~ 40 ft-lb), achieved without rapping (e.g., insufficient closure)
- Normal preload (~ 40 ft-lb), achieved with rapping (e.g., normal closure)

The simulation results show that the lid comes off for the no-rapping condition (Figure 25) but the lid stays on when rapping is incorporated (Figure 26). The lug bolt tension histories are shown in Figure 27 and Figure 28. The loss of lug tension is evident in Figure 27 at the end of the simulation time history. Figure 28 confirms the maintenance of lug tension for the case of a properly tightened closure ring.

This simulation concludes that the incorporation of a distribution plate on a properly closed drum (40 ft-lbs, rapping) would survive the 4-foot drop. It is also concluded that the CGoT is the most challenging configuration when the contents are an eccentric point mass.

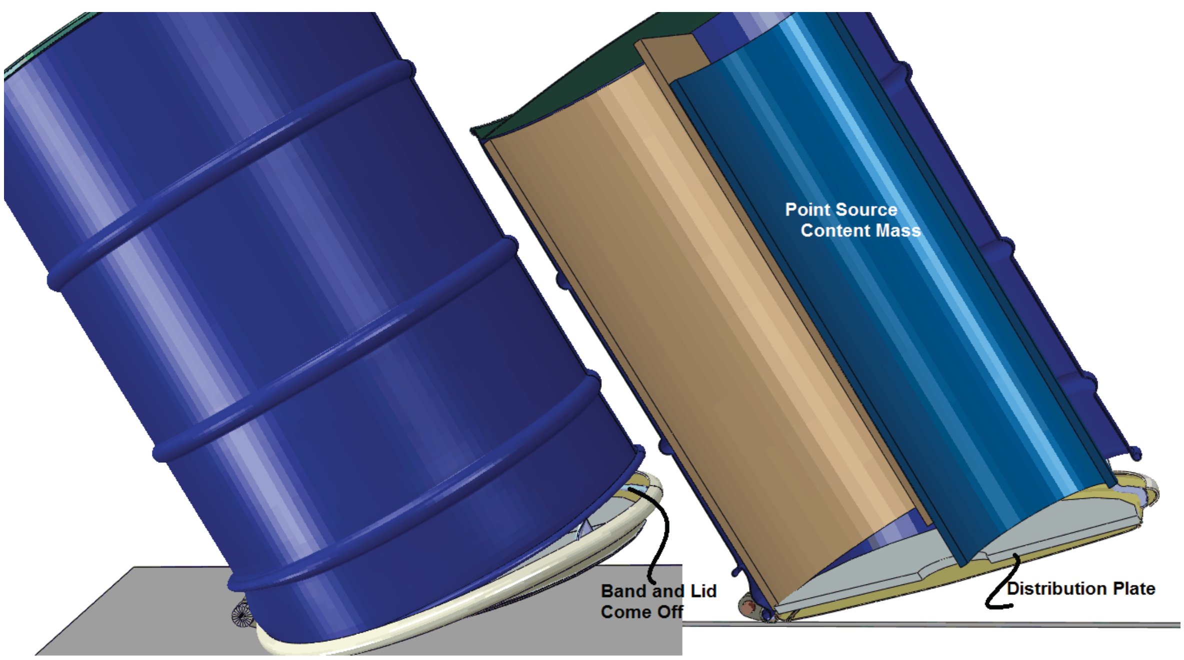


Figure 25. Deformed Shape after 4-foot Free Fall Simulation, Distribution Plate Over Concentrated Eccentric Content, without Rapping During Closure

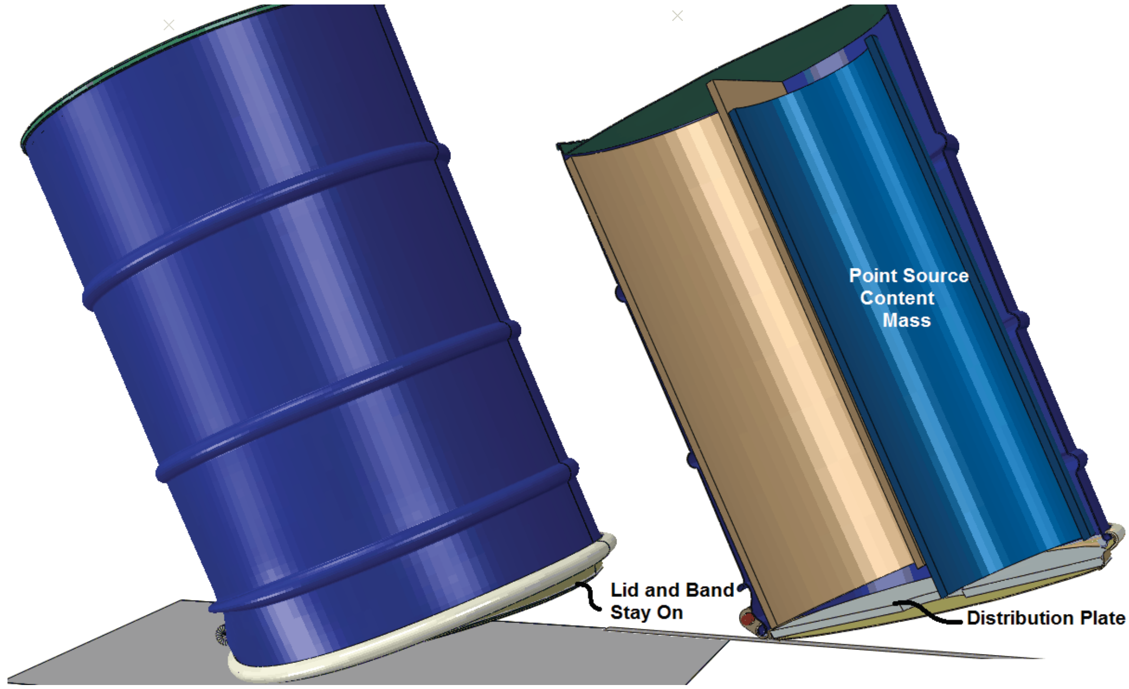


Figure 26. Deformed Shape after 4-foot Free Fall Simulation, Distribution Plate Over Concentrated Eccentric Content, with Rapping During Closure

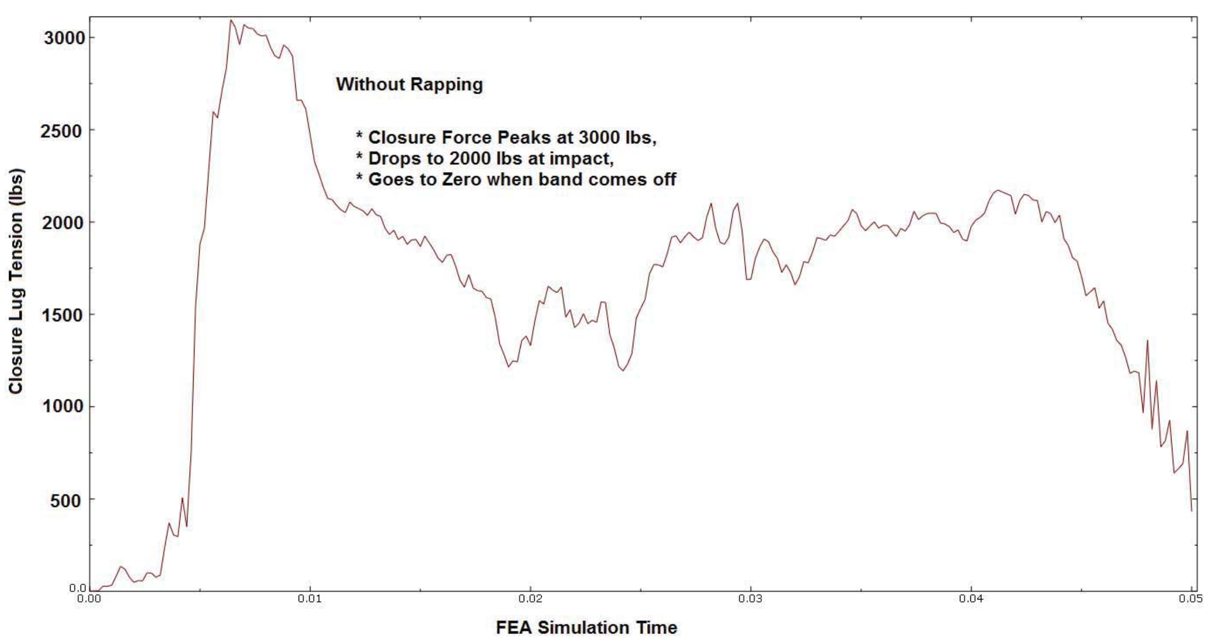


Figure 27. Closure Bolt Force History During Preload and 4-foot Free Fall Simulation, CGoT with Distribution Plate, without Rapping. Lid comes off.

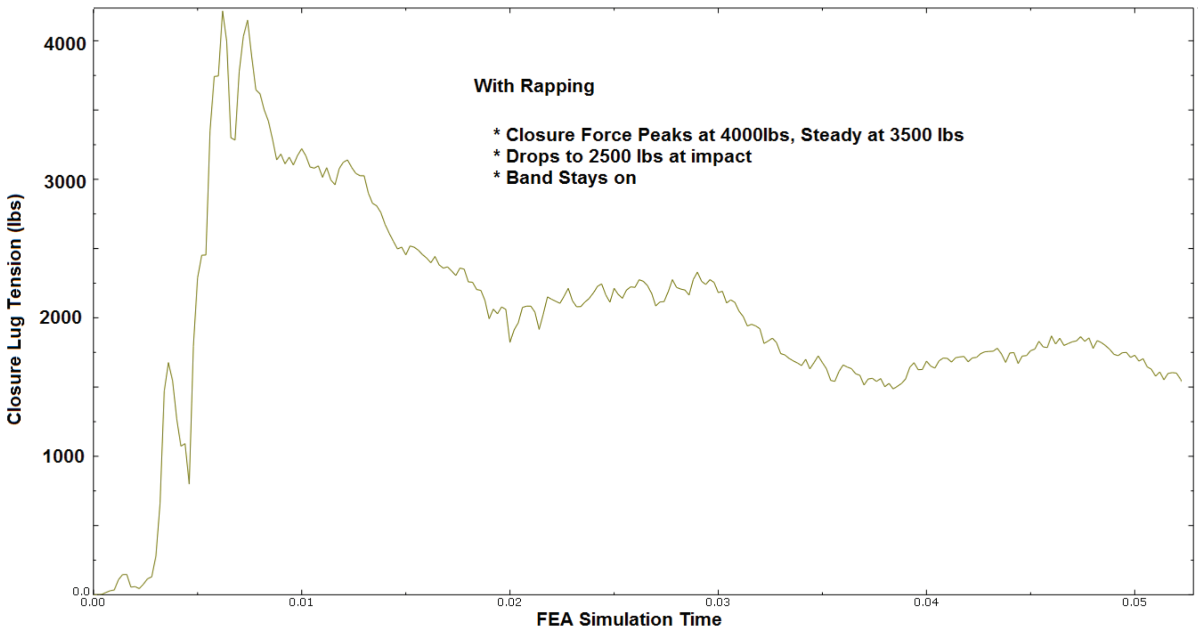


Figure 28. Closure Bolt Force History During Preload and 4-foot Free Fall Simulation, CGoT with Distribution Plate with Rapping. Lid stays on.

5.3.3 CGoT Simulations – Realistic Distributed Bounding Content

The previous sections simulated an extreme point mass, eccentrically positioned within the drum. Simulation of that focused, heavy, eccentric content required modeling a long (31-inch), small diameter (9.5-inch) solid cylindrical mass with a density 30% greater than steel. Therefore, this section looks at more realistic content mass distributions.

Figure 29 shows the FEA model and post-impact deformation for the drop simulation with a typical bounding content. Compared to the concentrated eccentric content weight of the previous model (Section 5.3.1, 5.3.2), this model simulated the content mass distributed over multiple components. The components were modeled as rigid, thus non-energy absorbing, for maximum energy transfer to the lid and with the weight spread over 24 components, similar to the actual drop test portion of this study. As with the single eccentric point mass simulation, two simulations are performed, one without rapping and one with rapping. The results show that the drum lid and closure ring stay on the drum in both closure condition cases (Figure 29).

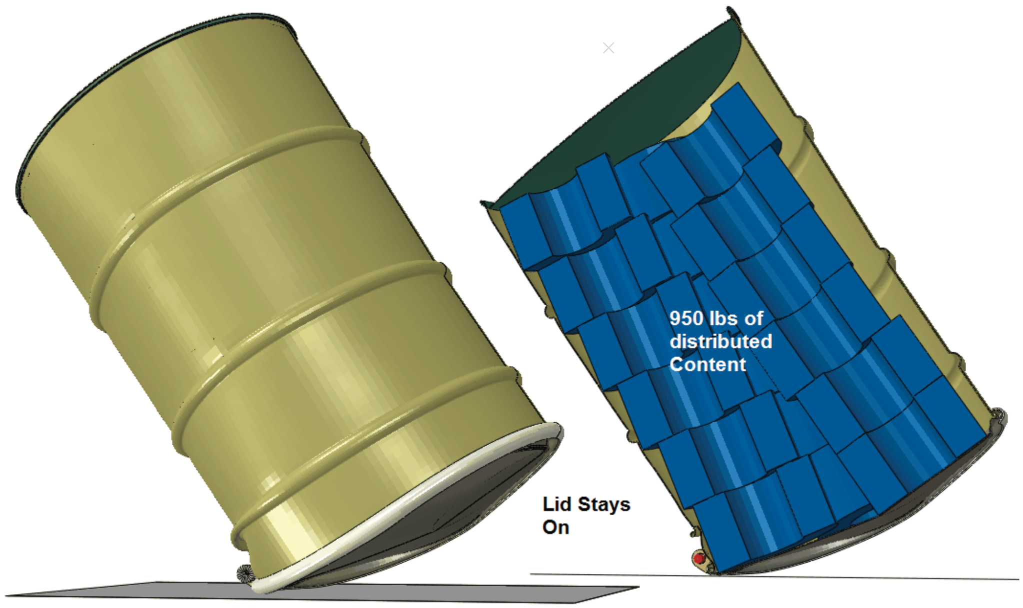


Figure 29. Deformed Shape after 4-foot Free Fall Simulation, Distributed Content, with or without Rapping During Closure

5.3.4 CGoT Simulations – At Reduced Content Mass

In this section, the drum lid retention capacity for less than maximum weight content was investigated. Using the two-drum content and closure configurations from Section 5.3.1 and 5.3.2 (concentrated eccentric mass, minimal closure force, no rapping, with and without a content top distribution plate), but with the content mass reduced to 500 lbs total, the CGoT were simulated. In this condition with 500 lbs content mass, the drum lid was retained in all simulations. Without the distribution plate, the deformed shape of the drum after the simulation clearly shows that the lid was near its limit of retention (Figure 30), but the lid was retained and no loss of gasket seal was evident. With the distribution plate, the lid was retained without challenge (Figure 31).

Therefore, this section also shows that the CGoT is a drop orientation that is most challenging to the safety feature of lid retention. The content distribution plate is shown to add benefit to the safety feature when the content is an eccentric mass, even at 500 lbs.

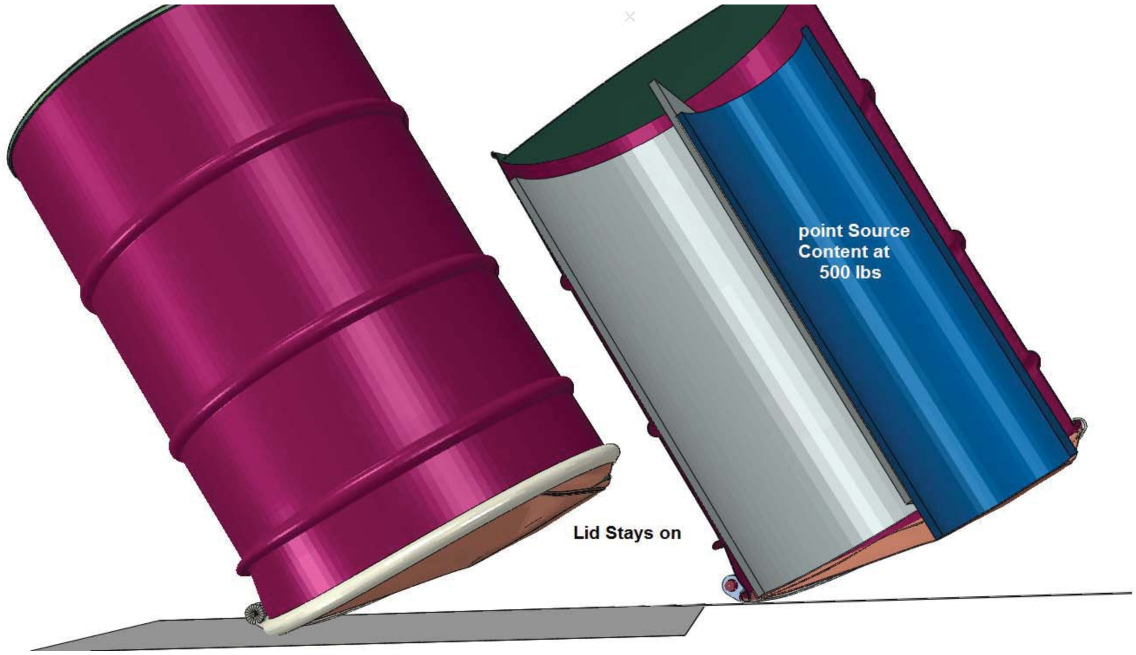


Figure 30. Deformed Shape after 4-foot Free Fall Simulation, Point Source Content at 500 lbs with or without Rapping During Closure

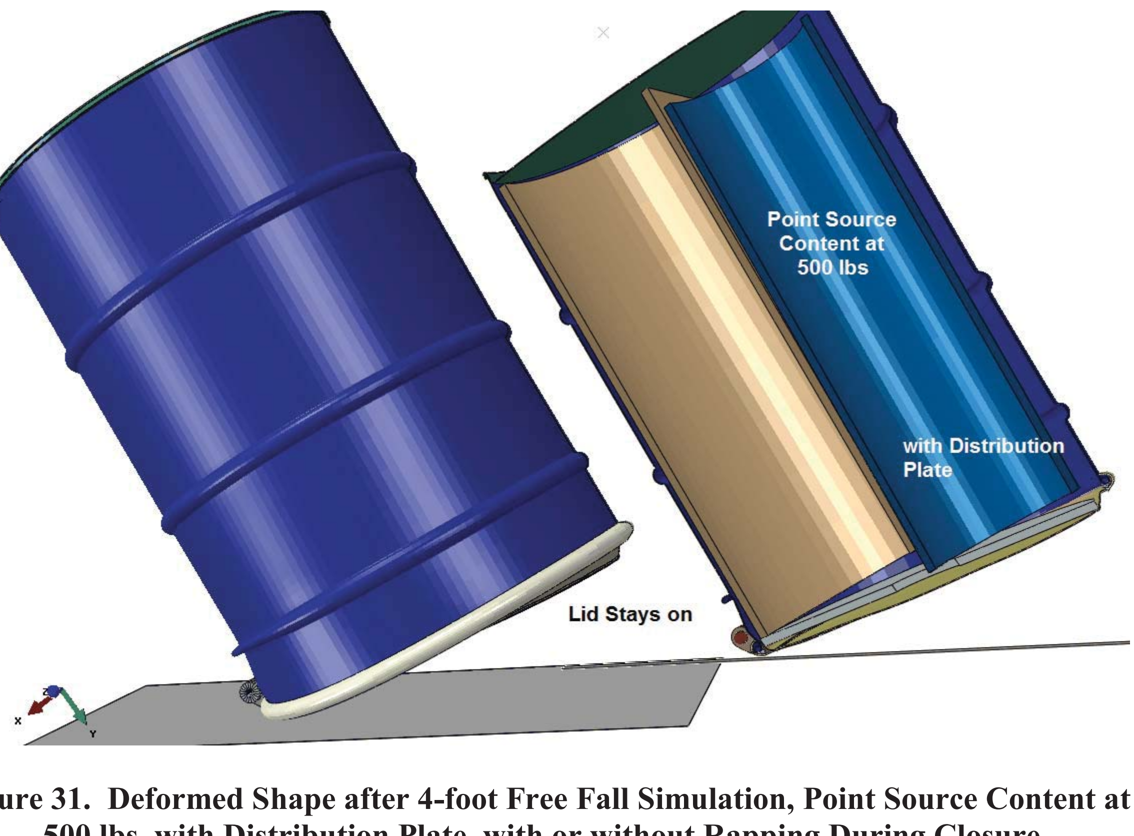


Figure 31. Deformed Shape after 4-foot Free Fall Simulation, Point Source Content at 500 lbs, with Distribution Plate, with or without Rapping During Closure

5.3.5 Side Down Simulations

Two drum variations were modeled for the side down free drop: (1) a full weight content condition, the payload of 24 discretized parts (950 lbs), and (2) the same content configuration with content mass reduced to 500 lbs. For the side drop, the multi-segmented content was selected rather than using the single-piece content, as the multi-segmented contents would be more inclined to move around and put outward pressure on the lid. Figure 32 shows the initial position of the drum, just before impact. The drum was tilted just enough such that the lug and lower chime would contact the ground simultaneously. Figure 33 shows the deformed shape, with a detail of the lid seal, showing the lid to be well retained. Figure 34 shows the lug bolt tension history, also showing that a significant percentage of the lug tension is retained.

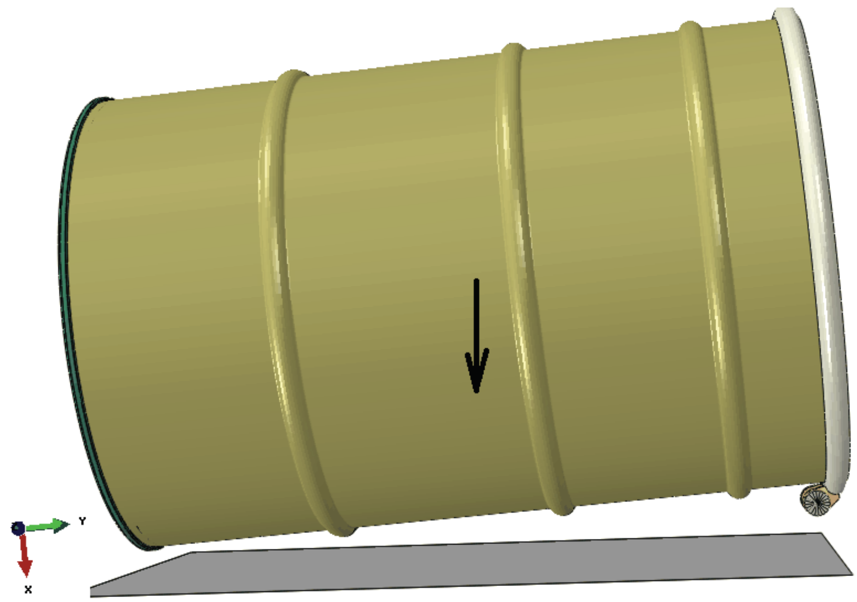


Figure 32. Initial Position of Drum Prior to Side Down Impact

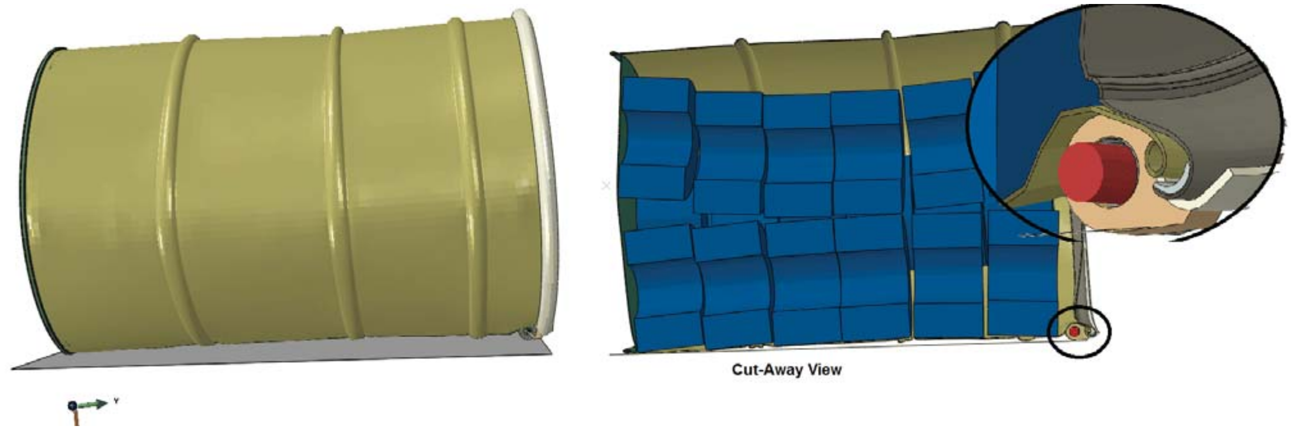


Figure 33. Deformed Shape after 4-foot Free Fall Simulation, Side Down, with or without Rapping During Closure

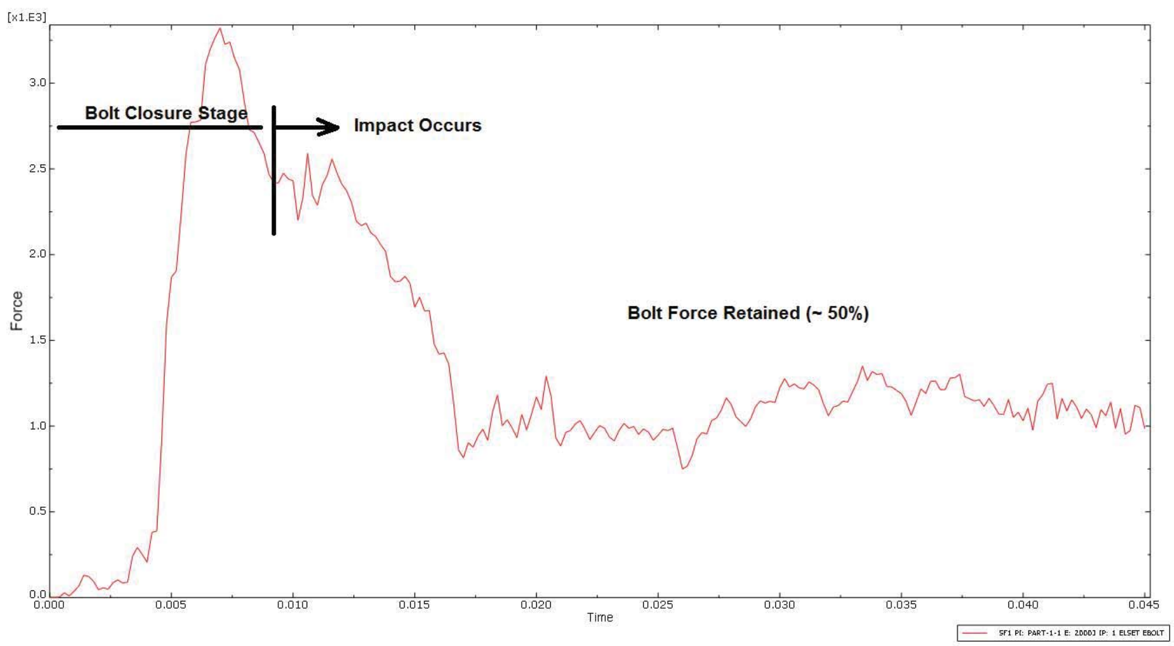


Figure 34. Closure Bolt Force History During Preload and 4-foot Free Fall Simulation (Side Down, Maximum Load, with or without Rapping – Lid Stays On)

5.3.6 <u>Slap Down Simulation</u>

The slap down drop condition describes when the drum is oriented at a shallow angle (5° to 15°) from a true side down orientation. The initial contact at the lower end acts to speed the opposite end into the impact surface. By tilting the drum so that the closure end is slightly elevated, that ends gets a speed increase and strikes the impact surface at a higher velocity than occurs in the 4-foot free fall. The speed increase can be a factor of two higher than the net free drop velocity, depending on the rigidity of the drum (ASME PVP2010-26067). Three simulations were performed for the slap down at an angle of 10° due to the drum angle tolerance set at ±5°:

- 950 lbs content, at low closure ring torque (~ 15 ft-lb), with rapping
- 950 lbs content, at a normal closure ring torque, but with no rapping
- 950 lbs content, with normal closure ring torque, with rapping

The drum orientation for these three cases, just prior to impact, is shown in Figure 35.

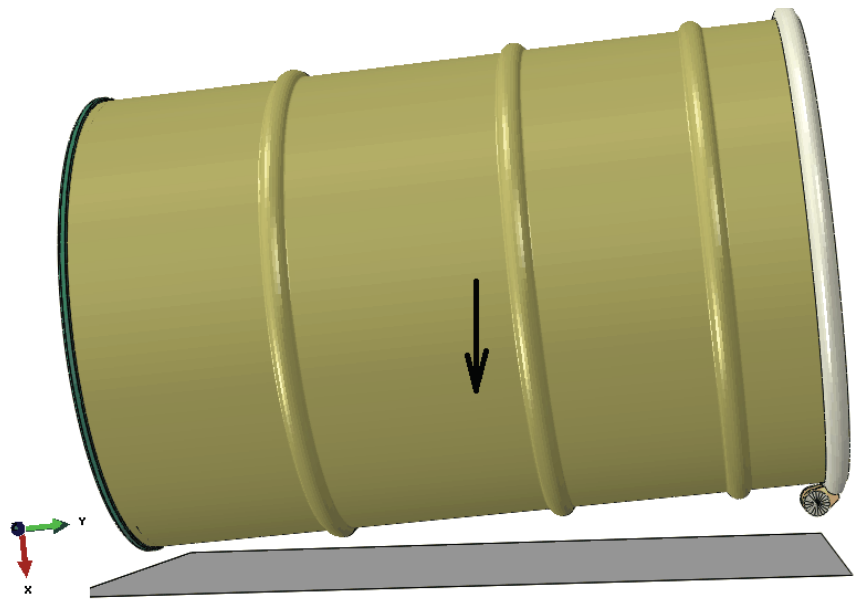


Figure 35. Initial Position of Drum Prior to Slap-down

Figure 36 through Figure 38 illustrate the modeled results from the condition of insufficient torque. For these cases, a slight opening in the drum closure less than a 1-inch span occurred at the impact point between the lid gasket and drum rim. The analysis in the next section shows that with proper torque there is no breach in the drum closure as confirmed with testing.

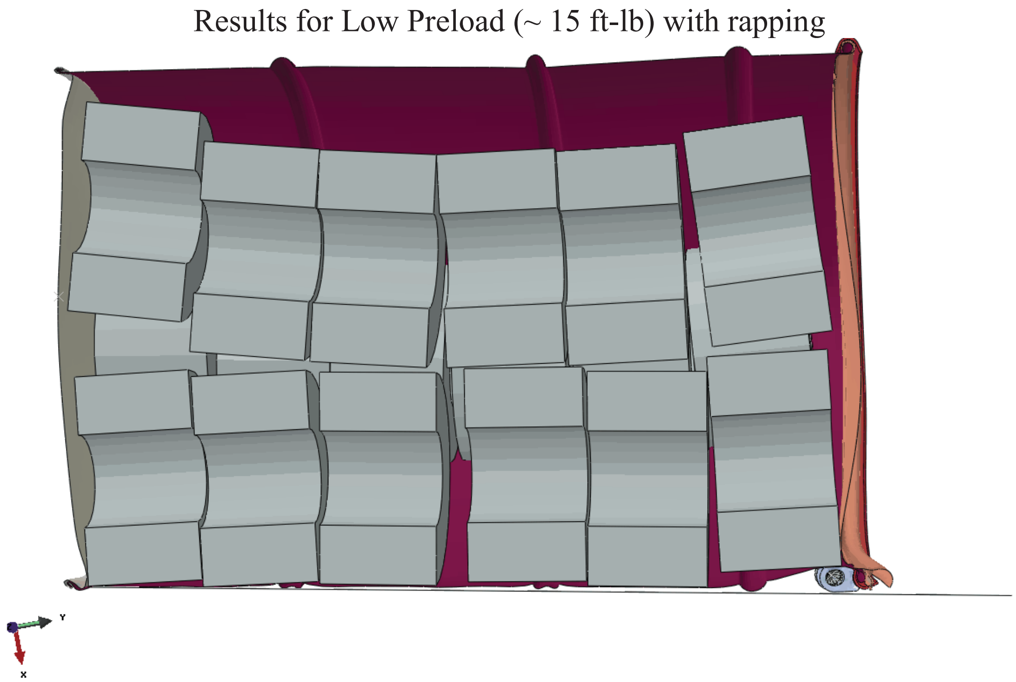


Figure 36. Deformed Shape after 4-foot Free Fall Simulation, Slap Down, with Insufficient Bolt Torque with Rapping

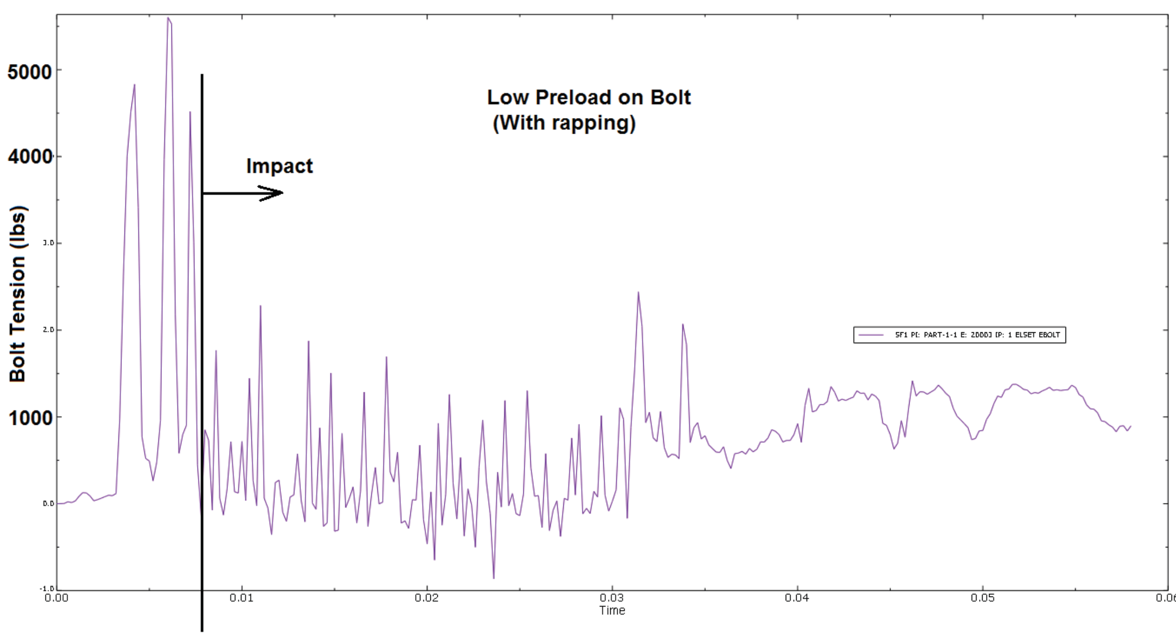


Figure 37. Closure Bolt Force for 4-foot Free Fall Simulation, Slap Down, with Insufficient Bolt Torque, with Rapping

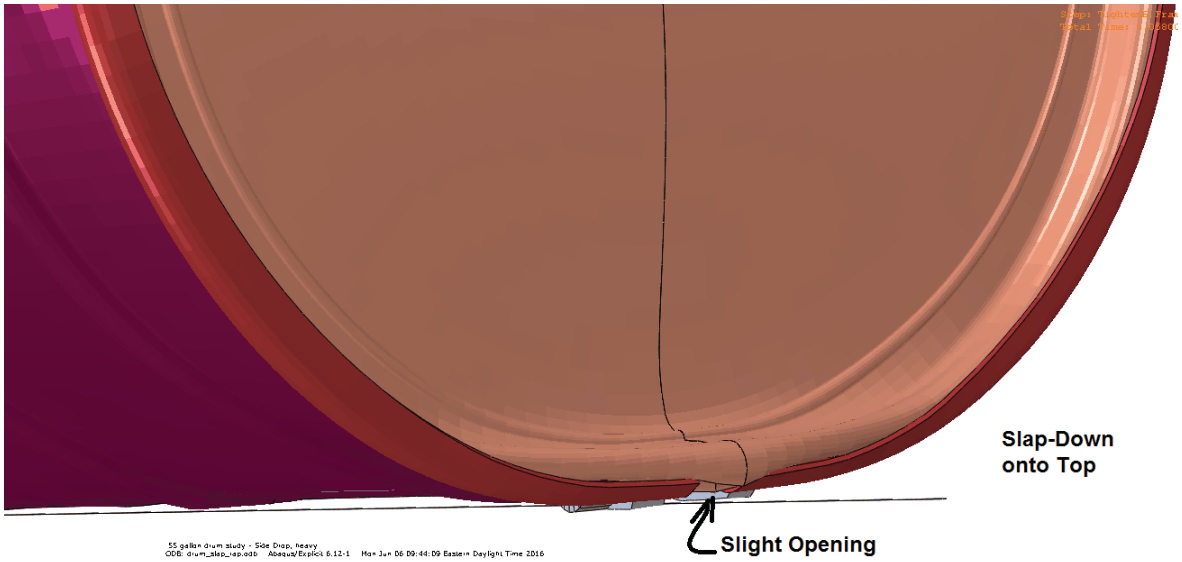


Figure 38. Detail of Deformed Shape after 4-foot Free Fall Simulation, Slap Down, with Insufficient Bolt Torque (with Rapping), Displaying Small Opening at Impact Point

Figure 39. Detail of Deformed Shape after 4-foot Free Fall Simulation, Slap Down, with Insufficient Bolt Torque, with Rapping, Showing Bottom Chime Stays Intact

Figure 40 through Figure 43 illustrate the results of closure ring torque with and without rapping for the slap down impact. For these cases, the lid closure was not compromised

Results for Normal Preload (Without Simulated Rapping)

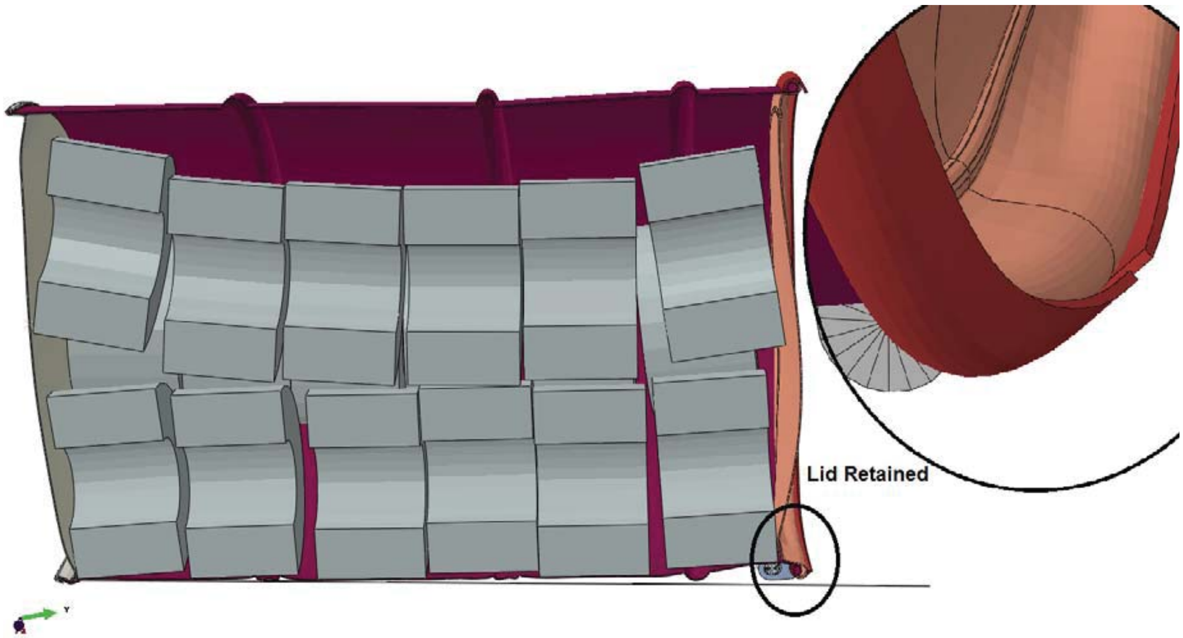


Figure 40. Deformed Shape after 4-foot Free Fall Simulation, Slap Down, Normal Bolt Torque without Rapping

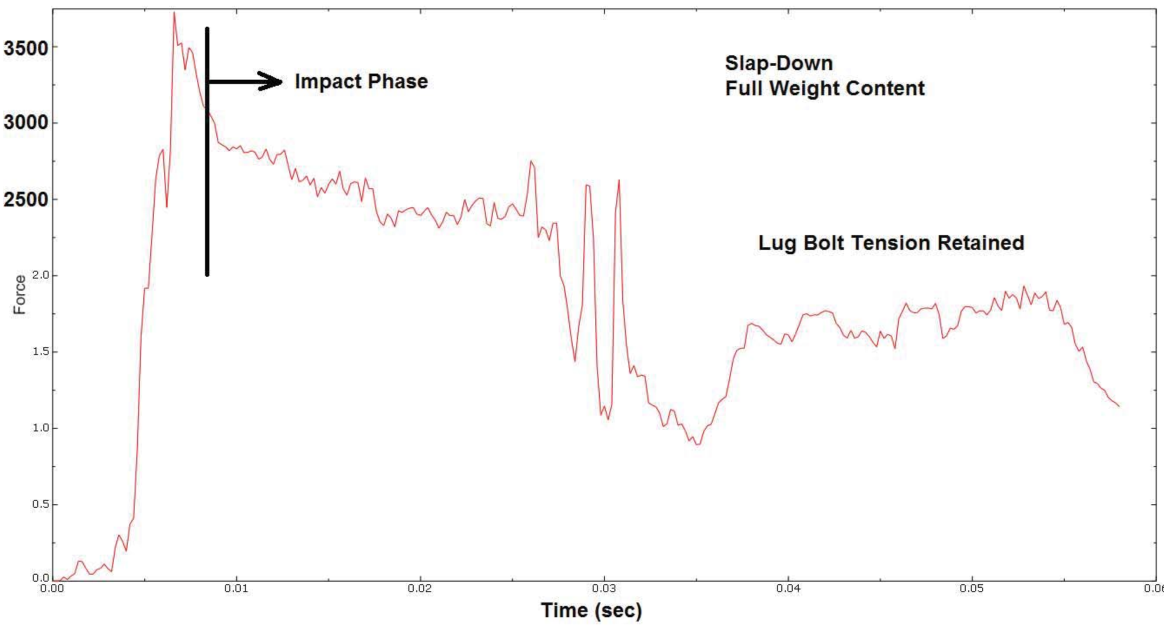


Figure 41. Closure Bolt Force for 4-foot Free Fall Simulation, Slap Down, with Normal Bolt Torque Without Rapping

.

Results for Normal Preload with Simulated Rapping

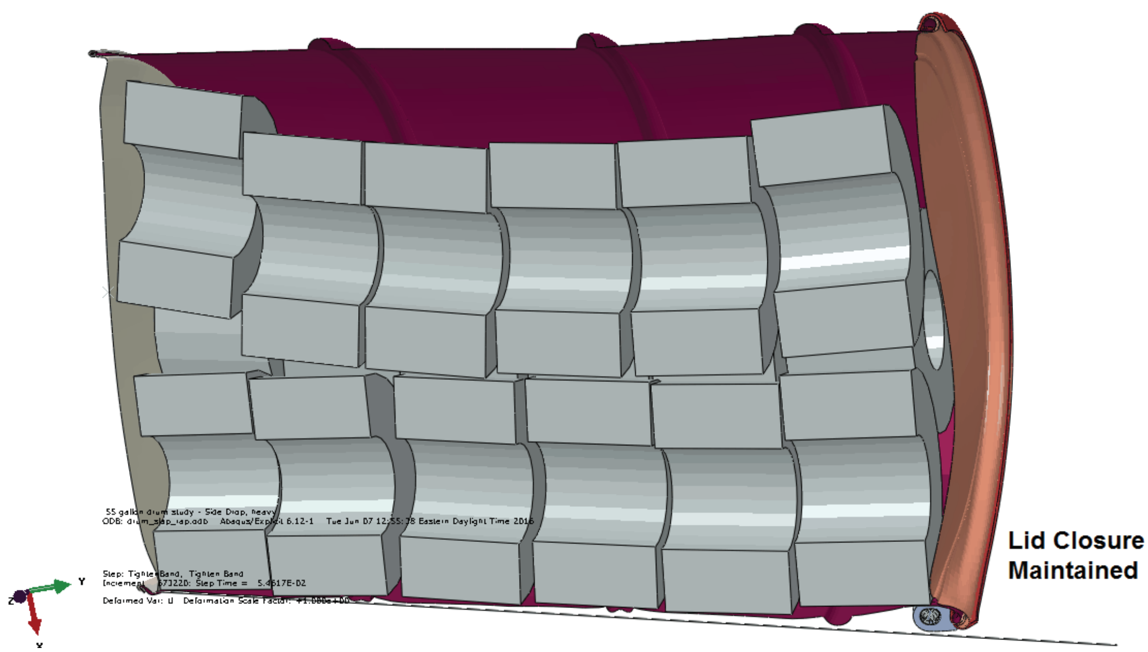


Figure 42. Deformed Shape after 4-foot Free Fall Simulation, Slap Down, Normal Bolt Torque Achieved with Rapping

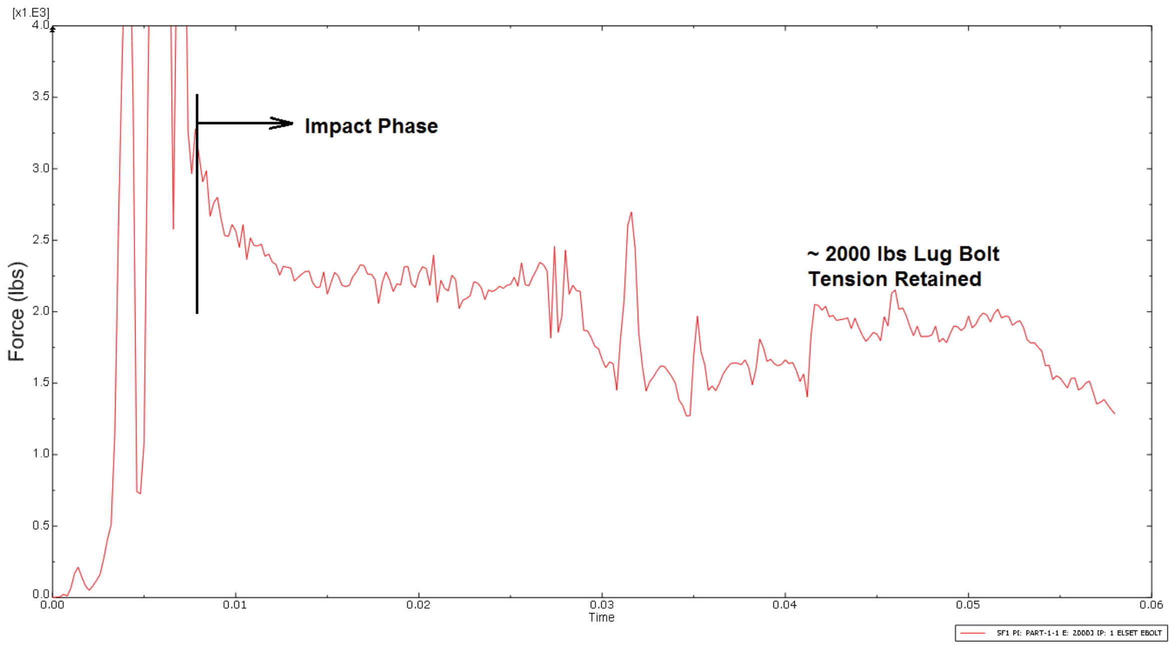


Figure 43. Closure Bolt Force for 4-foot Free Fall Simulation, Slap Down, with Normal Bolt Torque Achieved with Rapping

As previously stated, the slap down drop condition describes when the drum is oriented at a shallow angle (5° to 15°) from a true side down orientation. The initial contact at the lower end acts to speed the opposite end into the impact surface. By tilting the drum so that the closure end is slightly elevated, that ends gets a speed increase and strikes the impact surface at a higher velocity than occurring in the 4-foot free fall (Figure 44). The speed increase can be a factor of two higher than the net free drop velocity, depending on the rigidity of the drum (ASME PVP2010-26067). The lid opening is partly attributed to the increased acceleration and lack of sufficient closure restraint force of the lid due to the slap down effect.

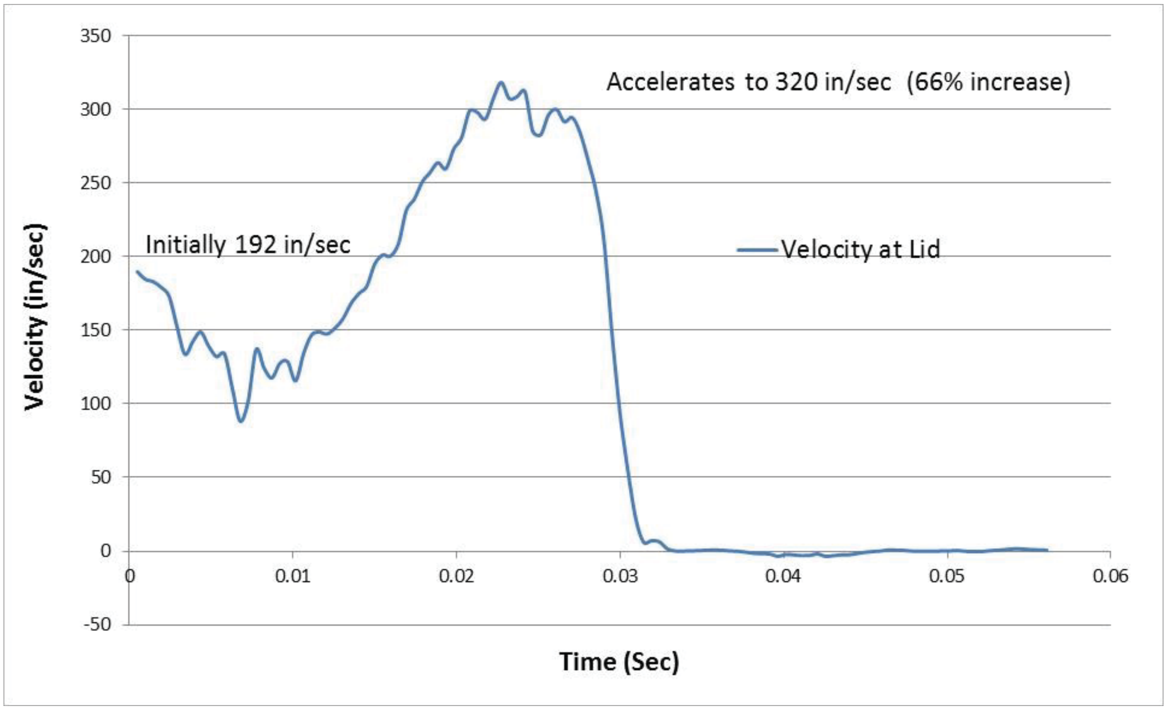


Figure 44. Velocity of Lid During Slap Down Showing Velocity Increase Occurring from the Slap Down Effect, Resulting in Impact at 166% of the Original Free-Fall Speed

6.0 OVERALL RESULTS AND CONCLUSION

A matrix of 15 free-drop tests was performed on DOT 7A Type A packages containing the same nominal content weight. The drop tests resulted in a breach of the side wall on a single drum due to puncture from sharp objects inside the drum; however, the drum closures remained sealed. The analysis was performed on drums with concentrated payloads with and without distribution plates. The analysis concluded that a concentrated payload of over 500 lbs unrestrained (without the distribution plates) would cause lid seal failure.

Also, to prevent breach in the side wall due to sharp, brittle objects inside of the drum, a secondary structure/barrier should be considered to distribute the impact forces.

Testing and computer FEA modeling showed that rapping of the closure ring during the installation does act to distribute closure ring tension. In the FEA simulations, this was shown by a reduction in bolt tension after a torque/rapping cycle. In the physical testing, the redistribution was shown by lid displacements moving back toward the baseline hand-tight values over some regions. Both testing and analysis showed minor differences between hammer weights and rapping direction. The biggest difference was always between no rapping and rapping. Sufficient testing and analysis were performed to conclude that as long as the closure process ends with a rapping process and re-check of lug torque, a sufficient closure condition will be achieved. The weight of the hammer, direction of rapping, and number of locations rapped will influence how many final cycles the installer goes through before the lug bolt closure torque reaches a steady value. Using rubber mallets in the 1.5- to 3-lb range, rapping at 45°, and striking at all quadrants with forceful blows, will result in the final closure condition being achieved as efficiently as possible.

Analytical simulations of the drop tests showed that the drum lid is retained better when the closure is performed to a minimum 45 ft-lb torque (plus or minus tolerance) and when the torque is achieved with the stress-relief of the closure ring through rapping.

Specific modeling findings include:

- The drum lid was not retained during 4-foot drops for the 900-lb point source contents, eccentrically located, with drum in CGoT orientation, unless both:
  - The distribution plate was placed between content and drum lid, and
  - Closure involved rapping and 40 ft-lb or more of bolt torque.
- The drum lid was retained during 4-foot drops for 500-lb point source, eccentrically located contents. A distribution plate was shown to enhance the subjectively assessed safety margin, but lid retention was achieved with or without the distribution plate.
- For uniformly distributed contents, a shallow angle slap down, with the drum tilted 10° to cause the bottom to be lower than the top FEA showed small breach of lid retention for simulated condition of low preload, as would occur with no rapping or inadequate bolt torque.

Overall modeling findings were:

- For a concentrated mass payload, the center-of-gravity over the top (lug positioned at impact point) is the condition most likely to cause a lid failure.
  - For point source contents above 500 lbs, use of a distribution plate (for example, any structure that is 10 times stiffer than the drum lid in bending, e.g., ¼-inch steel, or ½-inch wood) and a properly torqued closure ring is effective in maintaining lid retention (e.g., containment).
  - For contents weighing less than 500 lbs, the distribution plate is still beneficial, but analysis shows it is not required.
- For uniformly distributed contents, a shallow angle slap down, with the drum tilted 10° to cause the bottom to be lower than the top, is most likely to reveal a lid seal failure. Closure ring torque and rapping were shown to be essential.

Actual drop testing showed that for the various tests performed (see Appendix 2 Section 3 for the detailed lists), no lid or chime failure occurred.

7.0 RECOMMENDATIONS

7.1 RECOMMENDATIONS FOR CLOSURE INSTALLATION

- Closure rings should be torqued to the final torque specification in stages (1/3, 2/3 and full torque).

- Between each stage, the closure ring should be rapped with a dead blow hammer.

- Hammer rapping should be directed onto the closure ring, at an angle between vertical and 45° to vertical.

- Strike locations should start near the closure lug, on each side, and progress to cover all four quadrants of the closure perimeter (e.g., five locations).

- Closure is completed when final cycle of rapping and torqueing occurs when no additional bolt rotation occurs at final torque specification.

7.2 RECOMMENDATIONS FOR TESTING

- It is recommended that (1) the drum manufacturer states the content configuration in which the drum is qualified (payload configuration used for self-certification) and (2) the user ensures that the content meets this condition.

- Shallow angle and slap-down tests at approximately 10° should be performed in addition to the historically standard tests to ensure package integrity.

- The maximum damage drop determined in this report, based on modelling, was the lug side facing down and hitting the ground first.

- Content packing should be avoided that result in eccentric, concentrated payloads. As determined from FEA, this content is defined as a content having a single weight exceeding 500 lbs with a size less than half the diameter of the drum. If such a content is required, a distribution plate should be placed between the content and the drum lid.

8.0 REFERENCES

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ASME PVP2010-26067, *Effect of Package Content Position on Slap-Down Angle*, 2010.

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FP-1121, Revision 0, *Drop Test of 7A Drum*, Savannah River Site, Aiken, SC, February 18, 2015.

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S5-7-2520, Revision 3, *Impact Pad Plan and Details*, Savannah River Site, Aiken, SC, September 1980.

TESRF-1, *Drop Test Data for the 9975 Package, Rev. 0*, Savannah River Site, Aiken, SC, March 2000.

Title 49, Code of Federal Regulations, Part 173.403, “Definitions,” Washington, DC, October 2015.

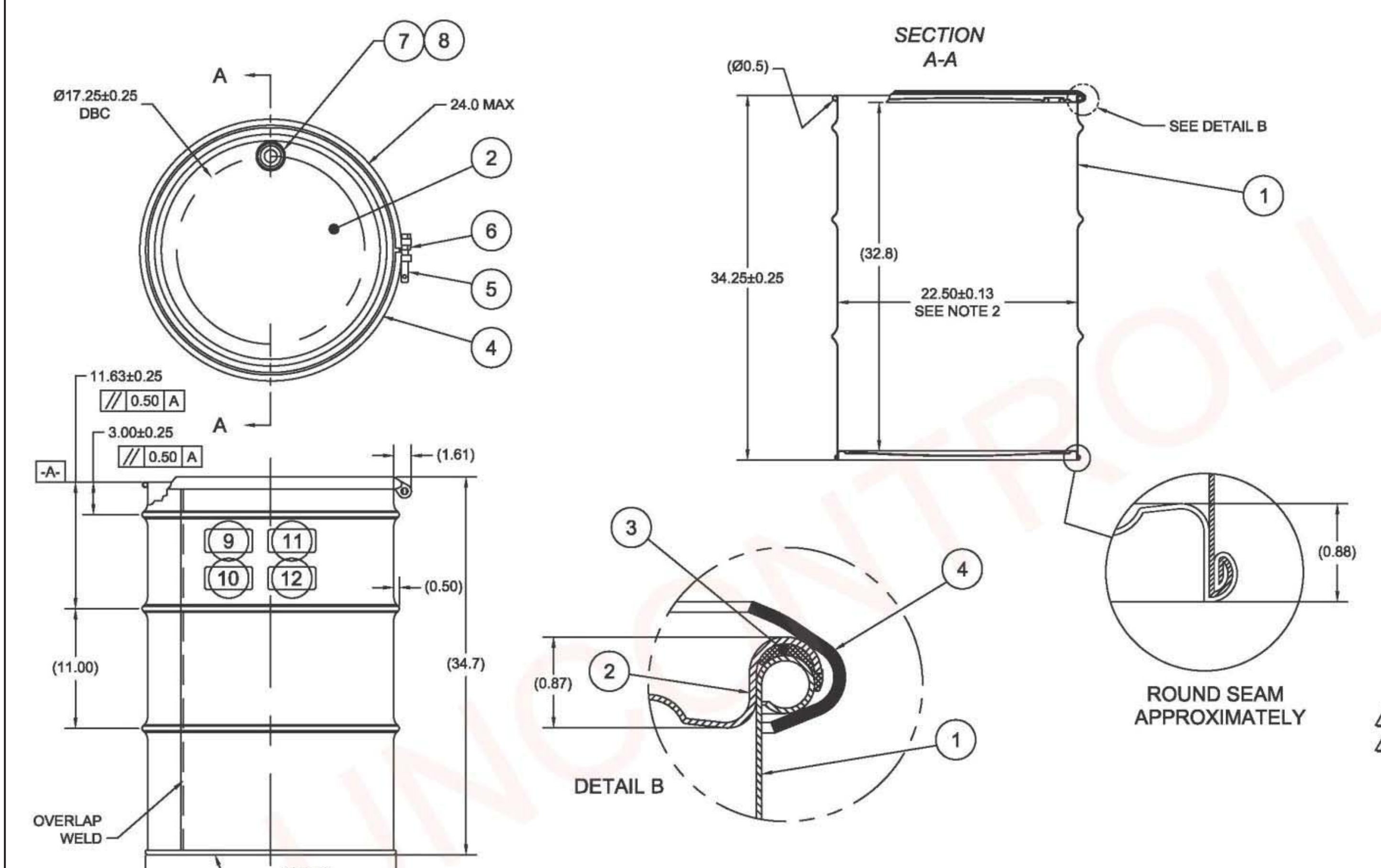
Title 49, Code of Federal Regulations, Part 173.465, “Type A Packagings Tests,” Washington, DC, October 2015.

Title 49, Code of Federal Regulations, Part 178.350, “Specification 7A; general packaging, Type A,” Washington, DC, February 2017.

APPENDIX 1 – DRUM DRAWING

CQ5508L-SRNL99

ECN # or INIT	REV	DESCRIPTION	DATE
	A	RELEASED	17-JUN-2011
OE-003	A1	REMOVED LABEL & LINING TO BE STD THK	06-SEP-2011
OE-010	A2	SEE ECN #OE-010 (NEW PART NUMBER)	02-OCT-2012



UN NUMBER EMBOSSED ON BOTTOM OF DRUM
½" CHARACTERS READING:
UN/1A2/X430/S/YR
1.5 *

(YR = YEAR OF MANUFACTURE)

TARE WEIGHT:
60 lbs

NOTES:

1. THIS DIMENSION REPRESENTS DRUM AFTER BEING PROPERLY ASSEMBLED AND CLOSED PER SKOLNIK CLOSING INSTRUCTIONS
2. TO DETERMINE GREATER ACCURACY OF ANY DIAMETRIC DIMENSION, MEASURING OF CIRCUMFERENCE IS REQUIRED
3. CONSTRUCTION per 49 CFR §178.504 (b)

MATERIAL:

1. DRUM BODY AND COVER CRCQ CARBON STEEL PER ASTM A1008 OR ASTM A568 OR EQUIVALENT
2. MATERIAL THICKNESS 1.5mm (0.0543 - 0.0590; 16 GAUGE)
3. GASKET MAT'L PER ASTM D1056

FINISH:

1. DRUM BODY & COVER EXTERIOR PAINTED BASE BEIGE #619 (LQ10001)
2. INTERIOR DRUM BODY AND COVER LINED W/EPOXY PHENOLIC COATING 0.6 MIN MIL DFT (LQ50007)

ITEM	P/N	DESCRIPTION	QTY
12		DURABLE LABEL "GROSS MASS TEST WEIGHT: 430 KG (946 lbs)"	1
11		DURABLE LABEL, "PO Number"	1
10		DURABLE LABEL, "USA DOT 7A TYPE A"	1
9		UN DURABLE LABEL	1
8	PR3041	PLUG 3/4 RIEKE VGII EP/PH EPDM GASKET	1
7	FR3010	FLANGE 3/4 RIEKE VGII EP/PH	1
A2 6	NT5800NQA	5/8-11UNC HEX JAM NUT	1
A2 5	BT5840.3NQA	HEX HEAD BOLT, 5/8-11UNC x 4", STEEL W/ Ø5/16 @ 1/2 FTE	1
4	RBH2212	55 GAL BOLT RING 12 GA 5/8 LUG	1
3	GE5500	GASKET, EPDM IN-COVER D	1
2	P2215L	COVER, Ø22.5 DRUM, CRCQ STEEL	1
1		55 GALLON DRUM BODY AND BOTTOM	1

UNCONTROLLED ✓ CONTROLLED

PRELIMINARY APPROVAL X
APPROVED FOR FABRICATION SB
REVISED FOR FABRICATION ___
10/04/2012 DATE SB INITIALS

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X° ± 3°
X.X ± 0.2
X.XX ± 0.10
X.XXX ± 0.030
3RD

SKOLNIK INDUSTRIES, INC.
4900 SOUTH KILBOURN AVENUE, CHICAGO, IL 60632

DESCRIPTION
55 GALLON OPEN HEAD DRUM
1.5 - 1.5 - 1.5 CRCQ STEEL
1A2/X430/S

REL. DATE 17-JUN-2011 | PART NUM. / FILENAME CQ5508L-SRNL99 | REV A2

BEST PRINTED ON B-SIZE PAPER

APPENDIX 2 - DROP TEST PICTURES AND SUPPORTING DATA

A2.1 TEARS IN LID GASKETS

Prior to beginning the testing, the drums, lids including the gasket, and the closure rings were inspected. Two of the drums (i.e., 2/15) had torn gaskets prior to beginning the testing.

A2.2 GENERAL CONTENT, LOADING PICTURES, AND ASSOCIATED NOTES

Notes:

1). Diameter of drum = 23 inches (per CQ5508L-SRNL99, Rev. 2)
2). Diameter of CAP 45-lb barbell plates with 2-inch hole = Nominally 16.5 inches per Amazon product details

A2.3 SUMMARY OF DROP TESTS PERFORMED

All tolerances are ±5 °

12, 3, 6, and 9 clock positions are 0°, 90°, 180°, and 270° from the weld line

BA = Balance Angle

RA = Radial Orientation

All drop tests done at a drum closure torque of 45 ft-lb

Drop Test	Test Weight (lb)	1-foot Bot BA (°)	Bot RA 1	Bot RA 2	Bot RA 3	Bot RA 4	1-foot Top BA (°)	Top RA 1	Top RA 2	Top RA 3	Top RA 4	4-foot drop BA (°)	4-foot drop RA (°)
# 1	980	45	12	3	6	9	45	12	3	6	9	5	0
# 2	980	45	12	3	6	9	45	12	3	6	9	5	15
# 3	982	45	12	3	6	9	45	12	3	6	9	10	15
# 4	992	45	12	3	6	9	45	12	3	6	9	0	5
# 5	982	45	12	3	6	9	45	12	3	6	9	60	5
# 6	989	45	12	3	6	9	45	12	3	6	9	10	10
# 7	987	45	12	3	6	9	45	12	3	6	9	45	0
# 8	987	35	12	3	6	9	30	12	3	6	9	10	90
# 9	986	15	12	3	6	9	15	12	3	6	9	5	15
# 10	999	30	12	3	6	9	30	12	3	6	9	10	15
# 11	980	45	12	3	6	9	45	12	3	6	9	30	30
# 12	987	60	3	6	9	12	60	3	6	9	12	0	0
# 13	990	60	3	6	9	12	60	3	6	9	12	20	0
# 14	988	60	3	6	9	12	60	3	6	9	12	45	0
# 15	987	NA	NA				NA	NA				60	0

A2.4 DROP TEST 1 RESULTS

	Bottom		Top			
Test Weight (lb)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
980	45	12, 3, 6, 9	45	12, 3, 6, 9	5	0
4-foot drop angle referred to as being:					shallow side, slap down	hitting lugs

Note: 4-foot drop resulted in a "direct" hit to bolt, but 4-foot drop was at a shallow angle (i.e., commonly called a slap-down).

Drop Test 1 drum being closed

Drop Test 1 drum prior to initiating test drops

Drop Test 1 drum after first 1-foot bottom drop

(drum stood up as final part of final part of inspection)

Drop Test 1 drum during fourth 1-foot bottom drop

Notes from completed Drop Test 1 procedure:

1). Drop Test 1 was performed on December 16, 2014, and completed at approximately 11:10 am.
2). 1-foot bottom drops showed damage to bottom, but no indications of leak.
3). 1-foot top drops showed slight damage to lid with no indications of leak.
4). 4-foot drop (shallow, slap down) showed significant damage with bolt bent into drum.
5). There was no evidence of loss of containment.

A2.5 DROP TEST 2 RESULTS

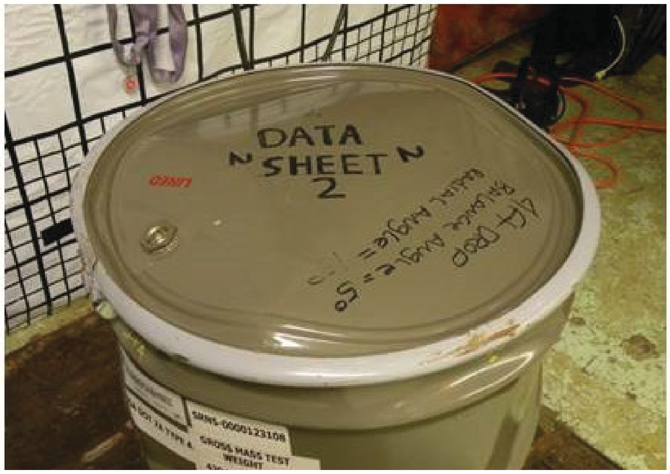
	Bottom		Top			
Test Weight (lb)	**1-foot Drop Balance Angle (°)**	**Radial Impact Positions (Clock Position)**	**1-foot Drop Balance Angle (°)**	**Radial Impact Positions (Clock Position)**	**4-foot Drop Balance Angle (°)**	**4-foot Drop Radial Angle (°)**
980	45	12, 3, 6, 9	45	12, 3, 6, 9	5	15
4-foot drop angle referred to as being:					shallow side, slap down	

Drop Test 2 drum immediately before first

1-foot bottom drop

Drop Test 2 drum after 1-foot bottom drops

(drum stood up as final part of inspection)



Drop Test 2 drum after all drops

(drum stood up as final part of post drop inspection)

Another picture of Drop Test 2 drum after all drops

(drum stood up as final part of post drop inspection)

Notes from completed Drop Test 2 procedure:

1). Drop Test 2 was performed on December 16, 2014, and completed at approximately 3:26 pm.
2). 1-foot bottom drops resulted in hole at 6 o'clock position.
3). Bottom was significantly bulged after 1-foot drops.
4). After completion of 1-foot drops, lots of "waving" seen on the drum.
5). Other "hole" noted near seam after 4-foot drop (slap down).
6). Although a "hole" occurred, there was no evidence of loss of containment from the drum closure area based on absence of fluorescent powder. Determining the cause of the holes is outside the scope of this report because they did not occur on the safety features being tested.

A2.6 DROP TEST 3 RESULTS

	Bottom		Top			
Test Weight (lb)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
982	45	12, 3, 6, 9	45	12, 3, 6, 9	10	15
4-foot drop angle referred to as being:					shallow side, slap down	

Drum at start of Drop Testing 3 drop testing

Drum raised for first 1-foot bottom drop

Drop Test 3 drum after first bottom drop

Drop Test 3 drum after all bottom drops

Drop Test 3 drum after first 1-foot top drop

Drop Test 3 drum being raised for 4-foot drop

Notes from completed Drop Test 3 procedure:

1). Drop Test 3 was performed on December 16, 2014, and completed at approximately 3:11 pm.
2). 1-foot bottom drops resulted in panning out on bottom of drum and crease in side of drum near the bottom.
3). 1-foot top drops resulted in moderate denting.
4). 4-foot slap down only resulted in minor damage to drum.
5). There was no evidence of loss of containment.

A2.7 DROP TEST 4 RESULTS

Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)		
992	45	12, 3, 6, 9	45	12, 3, 6, 9	60	5
4-foot drop angle referred to as being:					approx. CGoT	hitting bolt

Drop Test 4 drum after first 1-foot bottom drop

(drum stood up as final part of post drop inspection)

Drop Test 4 drum after second 1-foot bottom drop

Drop Test 4 drum after first 1-foot top drop

Drop Test 4 drum during 4-foot regulatory drop

Drop Test 4 drum after all drops

(drum stood up as final part of post drop inspection)

Notes from completed Drop Test 4 procedure:

1). Drop Test 4 was performed on February 3, 2015, and completed at approximately 1:10 pm.
2). The bottom drops resulted in slight dents from each drop with the third drop resulting in puncture from weight fragments.
3). The bolt was impacted during the first 1-foot top drop.
4). After the 4-foot drop (CGoT), lid was significantly bulged.
5). There was no evidence of loss of containment, but clearly heard the drum vent.

A2.8 DROP TEST 5 RESULTS

	Bottom		Top			
Test Weight (lb)	**1-foot Drop Balance Angle (°)**	**Radial Impact Positions (Clock Position)**	**1-foot Drop Balance Angle (°)**	**Radial Impact Positions (Clock Position)**	**4-foot Drop Balance Angle (°)**	**4-foot Drop Radial Angle (°)**
982	45	12, 3, 6, 9	45	12, 3, 6, 9	60	30
4-foot drop angle referred to as being:					CG over Top	

Drop Test 5 drum after third 1-foot bottom drops

Drop Test 5 drum during first 1-foot drop

Notes from completed Drop Test 5 procedure:

1). Drop Test 5 was performed on February 3, 2015, and completed at approximately 1:30 pm.
2). The 1-foot second bottom drop resulted in a significant impact to the drum, worsening through the fourth drop.
3). The second 1-foot top drop resulted in body waving.
4). The 4-foot drop (CGoT) did not result in loss of containment.

A2.9 DROP TEST 6 RESULTS

Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)		
989	45	12, 3, 6, 9	45	12, 3, 6, 9	10	15
4-foot drop angle referred to as being:					shallow, slap down	

Drop Test 6 drum during first 1-foot drop

Drop Test 6 drum during second 1-foot drop

Drop Test 6 drum during 4-foot drop

Notes from completed Drop Test 6 procedure:

1). Drop Test 6 was performed February 3, 2015, and completed at approximately 3:21 pm.
2). The 1-foot bottom drops resulted in a significant bulge in the bottom of the drum. The other drops showed minor dents.
3). The second and third 1-foot top drops resulted in a significant bulge on top.
4). The 4-foot drop (shallow, slap down) did not result in significant damage.
5). There was no evidence of loss of containment.

A2.10 DROP TEST 7 RESULTS

Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)		
987	45	12, 3, 6, 9	45	12, 3, 6, 9	45	0
4-foot drop angle referred to as being:					Slap down, approaching CGoT	Direct hit to lugs

Drop Test 7 drum after all four 1-foot top drops completed

(drum stood up as final part of post drop inspection)

Drop Test 7 drum after 4-foot 45° drop

(drum stood up as final part of post drop inspection)

Notes from completed Drop Test 7 procedure:

1). Drop Test 7 was performed on February 4, 2015, and completed at approximately 9:20 am.
2). The 1-foot bottom drops resulted in increased denting to the bottom of the drum.
3). The 1-foot top drops resulted in very minor damage, including slight dents to the top of drum/lid.

4). The 4-foot drop (slap down approaching a CGoT) resulted in a direct hit to lugs.
5). There was no evidence of loss of containment.

A2.11 DROP TEST 8 RESULTS

	Bottom		Top			
Test Weight (lb)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
987	35	12, 3, 6, 9	35	12, 3, 6, 9	10	90
4-foot drop angle referred to as being:					shallow, slap down	

Drop Test 8 drum post second 1-foot bottom drop

Notes from completed Drop Test 8 procedure:

1). Drop Test 8 was performed on February 4, 2015, and completed at approximately 10:30 am.
2). The first two 1-foot bottom drops resulted in denting to the bottom of the drum, with other two drops resulting in no noticeable difference to the drum.
3). The 1-foot top drops resulted in little damage to the top of the drum.
4). The 4-foot drop (shallow, slap down) resulted in significant damage to side.
5). There was no evidence of loss of containment from the lid, top of drum area.

A2.12 DROP TEST 9 RESULTS

Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)		
986	15	12, 3, 6, 9	15	12, 3, 6, 9	5	15
4-foot drop angle referred to as being:					shallow, slap down	

Drop Test 9 drum at the completion of 4-foot drops

(shallow, slap down)

Notes from completed Drop Test 9 procedure:

1). Drop Test 9 was performed on February 4, 2015, and completed at approximately 1:26 pm.
2). The first two 1-foot bottom drops resulted in slight denting to the bottom of the drum, with other two drops resulting in almost no difference to the drum.
3). The 1-foot top drops resulted in little damage to the top, with the third resulting in folds developing in the middle height region of the drum.
4). The 4-foot drop (shallow slap down) resulted in drum looking like a bottom hit.
5). There was no evidence of loss of containment.

A2.13 DROP TEST 10 RESULTS

Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)		
999	30	12, 3, 6, 9	30	12, 3, 6, 9	10	15
4-foot drop angle referred to as being:					shallow, slap down	

Drop Test 10 drum after first 1-foot bottom drop

Drop Test 10 drum after 1-foot bottom drops complete

Drop Test 10 drum after all drops complete

Notes from completed Drop Test 10 procedure:

1). Drop Test 10 was performed on February 4, 2015, and completed at approximately 3:00 pm.
2). All drops result in slight damage to the top drum closure area except for the 4-foot drop, which showed no additional sign of damage.
3). Overall drum appears to have significant damage to side of drum (based on the other drops, the damage is representative of that expected from shallow slap down drops).
4). There was no evidence of loss of containment.

A2.14 DROP TEST 11 RESULTS

Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)		
980	45	12, 3, 6, 9	45	12, 3, 6, 9	30	30
4-foot drop angle referred to as being:					Slap down	

Drop Test 11 drum impacting test pad during 4-foot drop

Notes from completed Drop Test 11 procedure:

1). The Drop Test 11 was performed on February 3, 2015, and completed at approximately 10:15 am.
2). Each of the 1-foot bottom drops resulted in small dents on the bottom of the drum, while each of the top drops and 4-foot drop (30° slap down) resulted in very little damage.
3). There was no evidence of loss of containment.

A2.15 DROP TEST 12 RESULTS

Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)		
987	60	3, 6, 9, 12	60	3, 6, 9, 12	0	0
4-foot drop angle referred to as being:					(completely flat), side down	

Drop Test 12 drum impacting test pad during third 1-foot bottom drop

Drop Test 12 drum impacting test pad during second 1-foot top drop

Drop Test 12 drum immediately prior to 4-foot (completely flat, side drop)

Notes from completed Drop Test 12 procedure:

1). Drop Test 12 was performed on February 19, 2016, and completed at approximately 11:15 am.
2). First 1-foot bottom drop resulted in slight damage to drum ring, while the third drop resulted in the bottom flanging out. The fourth bottom drop resulted in the crinkling on the weld.
3). The first through third 1-foot top drops resulted in little damage, with the weld hit for the fourth drop.
4). There was no evidence of loss of containment.

A2.16 DROP TEST 13 RESULTS

Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)		
990	60	3, 6, 9, 12	60	3, 6, 9, 12	20	0
4-foot drop angle referred to as being:					shallow side, slap down	

Drop Test 13 drum after 4-foot (shallow side, slap down) drop

Notes from completed Drop Test 13 procedure:

1). Drop Test 13 was performed on February 19, 2015, and completed at approximately 2:15 pm.
2). The 1-foot bottom drops resulted in noticeable good dents, with incremental damage from the 1-foot drop while each of the top drops and 4-foot drop resulted in very little damage.
3). There was no evident of loss of containment.

A2.17 DROP TEST 14 RESULTS

Test Weight (lb)	Bottom		Top		4-foot Drop Balance Angle (°)	4-foot Drop Radial Angle (°)
	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)	1-foot Drop Balance Angle (°)	Radial Impact Positions (Clock Position)		
988	60	3, 6, 9, 12	60	3, 6, 9, 12	45	0
4-foot drop angle referred to as being:					Considered part of the CGoT family	Direct hit to lugs

Drop Test 14 drum immediately before last 1-foot bottom drop

Notes from completed Drop Test 14 procedure:

1.) Drop Test 14 was performed on February 19, 2015, and completed at approximately 3:26 pm.

2.) The 1-foot drops resulted in slight damage, while after the 4-foot drop the top and bottom bulged, with the lid becoming difficult to remove.
3.) There was no evidence of loss of containment.

A2.18 DROP TEST 15 RESULTS

	Bottom		Top			
Test Weight (lb)	**1-foot Drop Balance Angle (°)**	**Radial Impact Positions (Clock Position)**	**1-foot Drop Balance Angle (°)**	**Radial Impact Positions (Clock Position)**	**4-foot Drop Balance Angle (°)**	**4-foot Drop Radial Angle (°)**
987	NA	NA	NA	NA	60	0
4-foot drop angle referred to as being:					CGoT	Direct hit to lugs

It should be noted that only the 4-foot drop test was performed (i.e., no 1-foot top and bottom drops performed) thus Drop Test 15 is a Type A drop test requirement only.

Drop Test 15 drum immediately prior to 4-foot (CGoT) drop bottom drop

Notes from completed Drop Test 15 procedure:

1.) Drop Test 15 was performed on February 19, 2015, and completed at approximately 3:41 pm.
2.) Only the 4-foot drop test was performed (i.e., no 1-foot top and bottom drops) thus representing the Type A requirement only.
3.) The 4-foot drop approximates a CGoT with the drop force applied directly to the bolt.
4.) Although the bolt area was significantly dented, there was no evidence of loss of containment.