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DYNA3D ANALYSIS OF THE DT-20 SHIPPING CONTAINER

R. W. Logan
S. C. Lovejoy

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DYNA3D ANALYSIS OF THE DT-20 SHIPPING CONTAINER

R. W. Logan
S. C. Lovejoy
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Abstract

A DYNA3D model of the DT-20 shipping container was constructed. Impact onto a rigid steel surface at a velocity of 44 ft/sec (30 foot gravity drop) was studied. The orientation of most interest was a side-drop, but end and corner drops were also studied briefly. The assembly for the baseline side impact contained a 150 lb. payload. During this drop, the outer drum sustains plastic strains of up to 0.15, with most of the deformation near the rim. The plywood/Celotex packing is crushed about 3 inches. The inner sealed can sees significant stresses, but barely reaches the onset of yielding in some local areas. Based on hand calculations, the bolts joining the can halves could see stresses near 50 ksi. It is felt that overall, the container should survive this drop. However, detailed modeling of the rim closure and the center bolted joint was not possible due to time constraints. Furthermore, better material models and properties are needed for the Celotex, plywood, and honeycomb in particular.

Introduction / Model Development

The overall design of the DT-20 container is shown in Fig. 1. A stainless steel 146 gal. drum forms the outer shell. Inside, the packing consists of alternating annular rings of Celotex and 3/8" plywood. This provides thermal and shock insulation for the inner stainless can (Fig. 2). The can is elliptical at both ends, representing a change from the design in Fig. 1. At each end, a honeycomb with 500psi initial crush and 150psi subsequent crush is used. The upper and lower halves of this can are joined by a flange that uses 18 1/2x13 bolts (Fig. 3). Inside the can are the payload and support structure shown in Fig. 4.

An overall view of the DYNA3D side-drop model is shown in Fig. 5. The Celotex packing is omitted in these and many other plots for clarity. The outer drum, plywood, and inner can are shown in Fig. 6, with the Celotex packing shown in Fig. 7. All parts are merged, except for the following slide surfaces. These used the sliding with voids model and a friction coefficient of 0.300. Obviously, the drum to impact surface is modeled. In addition, the end Celotex plates are free to slide

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within the drum. The end plywood plates are merged to these Celotex plates. The Celotex annular rings are modeled as a single part, with the plywood rings merged in. This assembly is again free to slide or rattle against the outer drum and inner can. The can is shown in Fig. 8. It is free to rattle inside the Celotex/plywood packing. The 'discrete nodes impacting' feature was used to model sliding on the ends of the pipe portion. Inside the can is the payload and support structure (Fig. 9). The honeycomb ends are merged to the inner can of Fig. 8, but slide against the outer aluminum plates. All four plates slide against the can. The payload is merged to the two inner plates. Joining the plates are beam elements representing the threaded rods. These are modeled as pinned ends rather than fixed ends, and thus their buckling strength may be lower than the real rods. This model contains a total of 22 slide surfaces, about 13000 nodes, and takes about 3 hours on the Cray-YMP to run to 20 milliseconds. Components and their total weights in the model are shown in Table 1 below.

Table 1. Component Weights in the DT-20 DYNA3D Model

Component	Weight (lbs)
Stainless Drum	179
Plywood	29
Celotex	163
Stainless Can	244
Honeycomb	29
Aluminum Plates	121
Rods	16
Payload	150
TOTAL	931

Celotex Properties

Material properties for most of the model are fairly straightforward. One exception is the honeycomb, which is modeled as a 150psi crush 'Model 5' material. A better model is needed for the end and corner drops, but the honeycomb is not critical for the side drop. The major unknown involved good properties and a model for the Celotex packing. Uniaxial crush data from static tests was obtained from Y-12 and also from recent LLNL tests by R. Sanchez from ESD. Summary plots of Sanchez' data are shown in Figs. 10-12. With this information, parameters for Model 5 were developed or estimated. The pressure-volume behavior was taken from Fig. 12. Due to virtually nil Poisson strains during the uniaxial crush tests, the stress-strain behavior shown was converted to true stress-strain and then used directly as the pressure-volume crushing behavior. Note that the high-rate drop tower data is nearly twice as stiff as the static data (Fig. 12 vs. fig. 11). The drop tower levels were used as they were felt to be close to the strain rates the actual container would see.

From Fig. 10, an approximate bulk unloading modulus of 800000psi was used. With the information available, it was impossible to separate a deviatoric yield component, so this was taken as a very small value (50 psi) with a slight (0.1) linear pressure dependence.

Results: Side-Drop, 150 lb. Payload

Figures 13-17 (a-d) show the results of the DYNA3D side drop at 1 ms intervals. Most notable is the deformation of the drum, the crushing of the Celotex, and the crushing (actually buckling and breaking) of the plywood rings, resulting in a gap between the upper side of the can and the plywood rings. Fig. 18a shows the rigid body displacement (inches) of several materials versus time (seconds). The Celotex (A) decelerates more quickly and is stopped after about 9 ms. The honeycomb (B), plates (C) and payload (D) move together and require about 11 ms to stop. The plot of velocity (inch/sec) vs. time (Fig. 18b) confirms these observations. Acceleration is plotted in G's ("smooth-2" in TAURUS used on data taken each 0.2 ms) in Fig. 18c. The peak G's are clearly on the order of 200 G's.

Figure 19a shows the levels of effective plastic strain in the outer drum. Strains of about 20 percent maximum are observed. These are not dangerously high for annealed stainless, but what is significant is that they are concentrated around the rim of the drum, which must retain a good seal. From this model alone, we cannot predict whether the seal will be maintained. However, comparing the gross deformations with previous container drops, it appears likely that the seal would survive. Fig. 19b shows that the inner stainless can sees only the onset of plastic strain. Even in the areas where the payload support plates impact the can, there is only the onset of plasticity. In Fig. 19c, the extent of volumetric crushing (labelled plastic strain) is shown. The crushing exceeds a volumetric strain of -0.4 in some areas below the can. This means that the Celotex has been crushed to half (or less) of its original thickness. The plywood rings (Fig. 19d) have long since buckled and broken. In DYNA3D, the plywood is modelled as an elastic-plastic material, with a yield of 2 ksi and a strain to 'failure' (Model-24) of 0.002. Essentially, this means that shortly after 'yield', the plywood breaks and loses all its strength.

In Figs. 20-21, longitudinal stresses in the inner can are shown in psi. This stress will tend to pull the bolted joint apart. The areas of maximum tension are about 10000psi. With a can wall of .190", and 18 1/2x13 UNC bolts around the flange, the ratio of wall area to bolt area is calculated to be 11.9/2.55, leading to bolt stresses of 47000psi for a 10000psi wall stress. This should be well within the load carrying capacity of the bolts.

It is clear from the above discussion that although this impact appears survivable, more detailed properties and modeling would allow additional certainty. There is little sense in developing a detailed closure ring or bolt flange model until we have a more accurate loading available. This will come only from additional testing on the Celotex, plywood, and possibly other materials. Data from accelerometers during actual drop tests would be of immense help.

Other Impact Conditions

Two additional side impacts were run. The first had a payload of 300 lbs. Visually, the results are similar to the base impact. The only significant difference appears in the rigid body motion plots (Fig. 22a-c). The Celotex sees a rigid body displacement of about 1.6 inch, as in the base drop. However, the 300 lb. payload results in a displacement of 3.8" for the can and contents, as opposed to only 3.3" with the base payload. The accelerations are nearly the same in magnitude (as are the stresses in the bolt flange), but their duration is longer with the higher payload. This is significant, since it implies that if the drum closure and bolt flange survive the 150 lb. payload, they should also survive the 300 lb. payload.

An additional run was made to test the limits of the side-impact model. This run had a payload of 1500 lb. As expected, the Celotex stopped in about the same distance as before (see Fig. 23a-c), but the can and contents did not stop by the time the model was terminated due to mesh tangling. Given that the Celotex is nearly crushed at this point and the can still has about half its initial momentum, it is unlikely that the assembly would survive this drop.

An end-drop was run with the 150-lb. base payload, even though an actual test in this orientation is not currently planned. The goal was to test the robustness of the DYNA3D model in this type of impact. Figures 24a-27b show the results of this run at 1 ms intervals. There is a slight buckling of the outer drum, and crushing of the end plywood and Celotex. At a time of 13.5ms, the discrete-nodes-impacting slide surface between the outer end of the can and the plywood plate has become confused. As a result, these elements are becoming distorted and tangled (Fig. 27d) to a point where the time step essentially grinds to a halt. Fig. 28a shows the displacement along the container axis (z-direction). By the time the run was terminated, the Celotex (A) and honeycomb (B) have stopped and rebounded. However, the aluminum plates (C) and payload (D) are still moving downwards. This is because the threaded rods have buckled in the model (Fig. 27c). We suspect that in reality, the rods would behave as fixed-end rather than pinned-end beams, and this problem would likely be avoided. Velocities (in/sec) are shown in Fig. 28b and show a similar trend. Decelerations (in G's) are shown in Fig. 28c. Internally, these reach on the order of 150 G's. With the fixed-end beam model, the internal G levels might be somewhat higher. Figure 29a-d shows the damage to some of the components. The outer drum (a) sees only minimal plastic strain and would be expected to survive. The inner can (b) sees some plastic strain in the regions where the rods tie into the lower plate. Also, extremely high strains are indicated in the tangled mesh area along the bottom edge, but these are likely spurious due to the slide surface problems. The Celotex sees a high level of crushing on the end. The 'clear' areas have a volumetric strain of below -0.4. Under uniaxial conditions, this corresponds to a reduction in height of over 33%. In the honeycomb (d), strains in the axial direction are plotted. These are small for the most part, but we must remember that the plates and payload have not yet stopped.

For similar purposes, we also ran a corner drop model. The orientation is such that a line from the container c.g. through the corner of the drum is perpendicular to the

ground. Figures 30-34 (a-d) show the results of this run at 1 ms intervals. The gradual crushing of the drum and Celotex make this a relatively benign drop for the inner can and contents. However, buckling of the outer drum becomes so severe (Fig. 34c-d) that the drum-to-ground slide surface becomes toast, making the run rather meaningless at this point. Special measures will be needed to carry the run beyond this point and to completion... In any case, at a time of 18.5ms (before the slide surface problems), the inner can and contents (Fig. 35a-b) seem to be intact. Displacements in the y-direction (radially outward from the drum center) and the z-direction (axis of the drum) are shown in Fig. 35c-d. These and the velocity plots (Fig. 36a-b) show that motion has almost stopped in the y-direction, but that the can and contents (B-D lines) are still moving in the z-direction at nearly half of the initial velocity. The y and z decelerations (Figs. 36c-d, 37a-b) are quite low (under 100 G's), but again we must remember that the can contents have not been stopped yet. Regarding the deformations and survivability, Fig. 38a-d provides some insight. Plastic strains in the drum (Fig. 38a) show local regions with over 0.4 strain. These plots are shown at t=16ms, before any major slide surface problems. It is open to debate as to whether the container rim seal would survive this level of deformation. The inner can (Fig. 38b) sees only minimal plastic strains. The corner of the Celotex (Fig. 38c) is highly crushed, accompanied by buckling and breaking of the lower plywood plate (Fig. 38d). Note that in the plywood, none of the plastic strains exceed 0.002, since this value was specified as the failure cutoff. Figure 39a-d shows the axial stresses in the inner can at times of 4, 8, 12, and 16ms. The stresses reach local values of over 12000psi, but not at the bolt flange. Only a few thousand psi are observed there. From the side-drop bolt analysis, we would expect the bolted joint to survive this impact, assuming the stresses would not worsen if the run could be continued to completion.

Conclusions and Future Needs

The DYNA3D model of the DT-20 side drop indicates a probable survival with either the 150 lb. base payload or a 300 lb. payload. As stated above, there are three factors which contribute enough uncertainty that a 'probable' survival is as strong a statement as we can make. The first of these factors is the possible opening of the drum closure due to buckling of the ends of the drum. Without a separate model of the rim and closure assembly it is only possible to speculate. Crushing of the Celotex is quite severe, and although this does not affect the impact survivability, it could impair the container's subsequent fire resistance. The third uncertainty is the analysis of the bolted joint. Based on observed stresses in the can wall in the DYNA3D model, stresses in the bolts could be as high as 50000psi. Additional loading components such as shear could put the stainless bolts on the verge of yielding. Further, a high desired safety factor could have the same effect. Again, analysis of a more detailed bolt joint model using stresses from the large DYNA3D model could help.

The end-drop model also indicates that the container should survive, although as stated above the run would not go to a complete stop due to mesh difficulties. Further development is needed on this model before any definitive statements are made. Similar conclusions hold for the corner-drop. However, in that case, it appears much more likely that the integrity of the outer drum closure could be lost.

To resolve any of the above issues, more DYNA modeling will be required. This will necessitate better material properties and models, particularly for the Celotex and honeycomb. Accelerometer data from actual drop tests would help to verify the code's impact calculations. After these steps have been taken, it would be worthwhile to develop DYNA or NIKE models of the rim closure, bolt flange, or other local areas of the container.

Distribution:

D. S. Bretl
A. B. Copeland
B. E. Knapp
R. W. Logan (8)
R. R. Sandberg
D. A. Schauer
F. J. Tokarz (2)
J. J. West (1)
R. G. Whirley

DT-20 Container

Inner Container
OD 20.00
ID 19.62
20" SCH 5S Pipe, 304L

Outer Container
ID 30.00
16 gauge 304 Stainless Steel
 $\Delta x = 0.0635$ " galvanized sheet
2.65 lb/ft²

Air Gap:
Between inner and Celotex: $7/32$ in.
Between outer and Celotex: $5/16$ in.

Figure 1. General sketch of the DT-20 container.

DT-20 Container Dimensions

Figure 2. Outline of the stainless inner can.

Figure 3. Bolted flange holding the two halves of the can, with O-ring seals.

Figure 4. Inner can contents and payload area.

izshsc 122290 rwl/sc1 DT-20 side v=528ips pay=
time = 0.

Figure 5. Overall DYNA3D model of the DT-20 with rigid impact surface.
Celotex packing omitted for clarity.

izshsc 122290 rwl/sc1 DT-20 side v=528ips pay=
time = 0.

Figure 6. Shell model of the outer drum, plywood, and inner can.

izshsc 122290 rwl/sc1 DT-20 side v=528ips pay=
time = 0.

Figure 7. The Celotex packing for the DYNA3D model using brick elements.

```
izshsc 122290 rwl/sc1 DT-20 side v=528ips pay=  
time = 0.
```

Figure 8. The inner can, constructed of a stainless pipe section, with elliptical ends welded (merged in DYNA) onto the pipe. Shell elements are used.

izshsc 122290 rwl/scI DT-20 side v=528ips pay=
time = 0.

Figure 9. The can contents. Brick elements are used for the honeycomb, aluminum plates, and payload. Beam elements with pinned ends are used for the threaded rods.

Celotex Fiber Board

Figure 10. Engineering stress-strain behavior of the Celotex at low strain rates. Loading and unloading behavior is shown.

Figure 11. Expanded area of Fig. 10 showing the low-stress behavior.

Figure 12. High strain-rate data on the Celotex. Comparison to Fig. 11 shows rate effect.

lzanad 122290 rwi/sci DT-20 slide v=5281ps pay=
time = 0.

lzanad 122290 rwi/sci DT-20 slide v=5281ps pay=
time = 9.99455e-04

disp. scale factor = 1.000e+00 (default)

lzanad 122290 rwi/sci DT-20 slide v=5281ps pay=
time = 1.99972e-03

disp. scale factor = 1.000e+00 (default)

lzanad 122290 rwi/sci DT-20 slide v=5281ps pay=
time = 2.99947e-03

Figure 13. Side impact of the container at time=0, 1, 2, 3 ms.

lzahad 12290 rwl/sci DT-20 side v=528ips poy=
time = 3.99976e-03

a)

lzahad 12290 rwl/sci DT-20 side v=528ips poy=
time = 4.99940e-03

b)

disp. scale factor = 1.000e+00 (default)

lzahad 12290 rwl/sci DT-20 side v=528ips poy=
time = 5.99997e-03

c)

disp. scale factor = 1.000e+00 (default)

lzahad 12290 rwl/sci DT-20 side v=528ips poy=
time = 6.99981e-03

d)

Figure 14. Side impact of the container at time=4, 5, 6, 7 ms.

lzhad 122290 rwi/sci DI-20 side v=528ips poym
time = 7.99930e-03

lzhad 122290 rwi/sci DI-20 side v=528ips poym
time = 8.99991e-03

disp. scale factor = 1.000e+00 (default)

lzhad 122290 rwi/sci DI-20 side v=528ips poym
time = 9.99940e-03

disp. scale factor = 1.000e+00 (default)

lzhad 122290 rwi/sci DI-20 side v=528ips poym
time = 1.09994e-02

Figure 15. Side impact of the container at time=8, 9, 10, 11 ms.

lzahad 127290 rwi/sci DT-20 side vm5281ps pay=
time = 1.19999e-02

a)

lzahad 127290 rwi/sci DT-20 side vm5281ps pay=
time = 1.19999e-02

b)

disp. scale factor = 1.000e+00 (default)

lzahad 127290 rwi/sci DT-20 side vm5281ps pay=
time = 1.19999e-02

c)

d.sp. scale factor = 1.000e+00 (default)

lzahad 127290 rwi/sci DT-20 side vm5281ps pay=
time = 1.19999e-02

d)

Figure 16. Side impact of the container at time=12, 13, 14, 15 ms.

lzahad 122290 rwl/sci DT-20 side v=5281ps pay=
time = 1.59996e-02

a)

lzahad 122290 rwl/sci DT-20 side v=5281ps pay=
time = 1.69993e-02

b)

disp. scale factor = 1.000e+00 (default)

lzahad 122290 rwl/sci DT-20 side v=5281ps pay=
time = 1.79997e-02

c)

disp. scale factor = 1.000e+00 (default)

lzahad 122290 rwl/sci DT-20 side v=5281ps pay=
time = 1.91996e-02

d)

Figure 17. Side impact of the container at time=16, 17, 18, 19.2 ms.

a)

b)

c)

Figure 18. Rigid-body motion vs. time (sec) for the Celotex (curve A=7), honeycomb (curve B=9), plates (curve C=10), and payload (curve D=11).
a) Displacement (inch). b) Velocity (in/sec). c) Deceleration (G's).

izshsd 122290 rwl/scf DT-20 side v=528ips pay=
time = 1.91996e-02
fringes of effective plastic strain
min=-4.205e-01 in element 75
max=1.752e-03 in element 3284

fringe levels
1 1.000e-01
2 2.000e-01
3 3.000e-01
4 4.000e-01
5 5.000e-01
6 6.000e-01
7 7.000e-01
8 8.000e-01
9 9.000e-01
10 1.000e+00

izshsd 122290 rwl/scf DT-20 side v=528ips pay=
time = 1.91996e-02
fringes of effective plastic strain
min=-4.205e-01 in element 75
max=1.752e-03 in element 3284

fringe levels
1 1.000e-01
2 2.000e-01
3 3.000e-01
4 4.000e-01
5 5.000e-01
6 6.000e-01
7 7.000e-01
8 8.000e-01
9 9.000e-01
10 1.000e+00

disp. scale factor = 1.000e+00 (default)

disp. scale factor = 1.000e+00 (default)

izshsd 122290 rwl/scf DT-20 side v=528ips pay=
time = 1.91996e-02
fringes of effective plastic strain
min=-4.205e-01 in element 75
max=1.752e-03 in element 3284

fringe levels
1 1.000e-01
2 2.000e-01
3 3.000e-01
4 4.000e-01
5 5.000e-01
6 6.000e-01
7 7.000e-01
8 8.000e-01
9 9.000e-01
10 1.000e+00

izshsd 122290 rwl/scf DT-20 side v=528ips pay=
time = 1.91996e-02
fringes of y-strain
(green-st. venant)
min=-2.087e+00 in element 1366
max=4.772e-01 in element 1457

fringe levels
1 1.000e-01
2 2.000e-01
3 3.000e-01
4 4.000e-01
5 5.000e-01
6 6.000e-01
7 7.000e-01
8 8.000e-01
9 9.000e-01
10 1.000e+00

Figure 19. a) Plastic strain in the drum. at 19.2 ms. b) Plastic strain in the can. c) Volumetric strain in the Celotex. d) Y-strain (crushing direction) in the plywood.

izshsd 122290 rwl/sci DT-20 side v=528ips pay=
time = 5.99975e-03
fringes of z-stress
min=-1.954e+04 in element 2177
max=1.038e+04 in element 2197

fringe levels
-1.000e+03
-5.000e+02
0.
5.000e+02
1.000e+03

izshsd 122290 rwl/sci DT-20 side v=528ips pay=
time = 7.99950e-03
fringes of z-stress
min=-1.357e+04 in element 2209
max=1.050e+04 in element 2213

fringe levels
-1.000e+03
-5.000e+02
0.
5.000e+02
1.000e+03

disp. scale factor = 1.000e+00 (default)

izshsd 122290 rwl/sci DT-20 side v=528ips pay=
time = 1.19999e-02
fringes of z-stress
min=-8.572e+03 in element 2193
max=4.840e+03 in element 2213

fringe levels
-1.000e+03
-5.000e+02
0.
5.000e+02
1.000e+03

izshsd 122290 rwl/sci DT-20 side v=528ips pay=
time = 1.59996e-02
fringes of z-stress
min=-4.004e+03 in element 2137
max=2.708e+03 in element 1976

fringe levels
-1.000e+03
-5.000e+02
0.
5.000e+02
1.000e+03

Figure 20. Axial stresses in the can (psi), at t=4, 8, 12, and 16 ms.

izshsd 122290 rwl/sci DT-20 side v=528ips pay=
time = 5.99976e-03
fringes of z-stress
min=-1.954e+04 in element 2177
max=1.0584e+04 in element 2197

fringe levels
-8.000e+03
-4.000e+03
0.
4.000e+03
8.000e+03

izshsd 122290 rwl/sci DT-20 side v=528ips pay=
time = 7.99930e-03
fringes of z-stress
min=-1.337e+04 in element 2177
max=1.0509e+04 in element 2197

fringe levels
-8.000e+03
-4.000e+03
0.
4.000e+03
8.000e+03

a)

b)

disp. scale factor = 1.000e+00 (default)

disp. scale factor = 1.000e+00 (default)

izshsd 122290 rwl/sci DT-20 side v=528ips pay=
time = 1.19999e-02
fringes of z-stress
min=-8.572e+03 in element 2193
max=4.640e+03 in element 2213

fringe levels
-8.000e+03
-4.000e+03
0.
4.000e+03
8.000e+03

izshsd 122290 rwl/sci DT-20 side v=528ips pay=
time = 1.59996e-02
fringes of z-stress
min=-4.004e+03 in element 2137
max=2.708e+03 in element 1976

fringe levels
-8.000e+03
-4.000e+03
0.
4.000e+03
8.000e+03

c)

d)

Figure 21. Axial stresses as in Fig. 20, but with expanded scale.

a)

b)

c)

Figure 22. Rigid body motions for the side-drop with 300 lb. payload. Compare to Fig. 18.

Figure 23. Rigid body motions for the side-drop with 1500 lb. payload. Compare to Figs. 18 and 22.

Figure 24. End-drop impact of the container at t=0, 1, 2, and 3 ms.

lzhed 122290 rwi/sci DT-20 end v=5281ps pay=
time = 3.99947e-03

a)

lzhed 122290 rwi/sci DT-20 end v=5281ps pay=
time = 4.99923e-03

b)

disp. scale factor = 1.000e+00 (default)

lzhed 122290 rwi/sci DT-20 end v=5281ps pay=
time = 5.99924e-03

c)

disp. scale factor = 1.000e+00 (default)

lzhed 122290 rwi/sci DT-20 end v=5281ps pay=
time = 6.99958e-03

d)

Figure 25. End-drop impact of the container at t=4, 5, 6, and 7 ms.

lzshd 12290 rwl/sci DI-20 end v=528ips pay=
time = 7.99999e-03

a)

lzshd 12290 rwl/sci DI-20 end v=528ips pay=
time = 9.00000e-03

b)

displ. scale factor = 1.000e+00 (default)

lzshd 12290 rwl/sci DI-20 end v=528ips pay=
time = 9.99992e-03

c)

displ. scale factor = 1.000e+00 (default)

lzshd 12290 rwl/sci DI-20 end v=528ips pay=
time = 1.09998e-02

d)

Figure 26. End-drop impact of the container at t=8, 9, 10, and 11 ms.

lashed 122290 rwi/sci DT-20 end v=5281ps pay=
time = 1.19998e-02

a)

lashed 122290 rwi/sci DT-20 end v=5281ps pay=
time = 1.34998e-02

b)

disp. scale factor = 1.000e+00 (default)

lashed 122290 rwi/sci DT-20 end v=5281ps pay=
time = 1.34998e-02

c)

disp. scale factor = 1.000e+00 (default)

lashed 122290 rwi/sci DT-20 end v=5281ps pay=
time = 1.34998e-02

d)

Figure 27. a,b)End-drop impact of the container at t=12 and 13.5 ms. c) condition of the can at t=13.5ms.

a)

b)

c)

Figure 28. Rigid body motions for the end-drop with 150 lb. payload.

```

finished 122290 rwl/sci DT-20 and v=528ips pay=
time = 1.34998e-02
fringes of eff plastic strain
min=-9.674e-01 in element 139
max=-3.864e-04 in element 2548

```

a)

disp. scale factor = 1.000e+00 (default)

```

fringe levels
-4.000e-01
-3.000e-01
-2.000e-01
-1.000e-01
-1.332e-15

```

```

finished 122290 rwl/sci DT-20 and v=528ips pay=
time = 1.34998e-02
fringes of z-strain
(green-st. venant)
min=-2.951e-02 in element 3953
max=-5.564e-04 in element 4366

```

```

fringe levels
2.000e-02
1.500e-02
1.000e-02
5.000e-03
0

```

b)

disp. scale factor = 1.000e+00 (default)

```

finished 122290 rwl/sci DT-20 and v=528ips pay=
time = 1.34998e-02
fringes of eff plastic strain
min=-9.674e-01 in element 139
max=-3.864e-04 in element 2548

```

c)

```

fringe levels
-4.000e-01
-3.000e-01
-2.000e-01
-1.000e-01
-1.332e-15

```

```

finished 122290 rwl/sci DT-20 and v=528ips pay=
time = 1.34998e-02
fringes of z-strain
(green-st. venant)
min=-2.951e-02 in element 3953
max=-5.564e-04 in element 4366

```

```

fringe levels
2.000e-02
1.500e-02
1.000e-02
5.000e-03
0

```

d)

Figure 29. a) Plastic strain in the drum. b) Plastic strain in the can. Very high maxima are in the tangled mesh area. c) Volumetric strain in the Celotex. d) Z-strain (axial direction) in the honeycomb.

Figure 30. Corner-drop impact of the container at t=0, 1, 2, and 3 ms.

lzhcd 122290 rwi/sci DT-20 corner=528lps pay=

time = 3.99967e-03

a)

lzhcd 122290 rwi/sci DT-20 corner=528lps pay=

time = 4.99955e-03

b)

displ. scale factor = 1.000e+00 (default)

lzhcd 122290 rwi/sci DT-20 corner=528lps pay=

time = 5.99940e-03

c)

displ. scale factor = 1.000e+00 (default)

lzhcd 122290 rwi/sci DT-20 corner=528lps pay=

time = 6.99975e-03

d)

Figure 31. Corner-drop impact of the container at t=4, 5, 6, and 7 ms.

Figure 32. Corner-drop impact of the container at t=8, 9, 10, and 11 ms.

izahcd 122290 rwl/sci DT-20 corner=538lps pay=
time = 1.19998e-02

izahcd 122290 rwl/sci DT-20 corner=538lps pay=
time = 1.29995e-02

disp. scale factor = 1.000e+00 (default)

izahcd 122290 rwl/sci DT-20 corner=538lps pay=
time = 1.39997e-02

disp. scale factor = 1.000e+00 (default)

izahcd 122290 rwl/sci DT-20 corner=538lps pay=
time = 1.49998e-02

Figure 33. Corner-drop impact of the container at t=12, 13, 14, and 15 ms.

lzhcd 12290 rwi/sci DT-20 corner=528ips pay=
time = 1.59998e-02

a)

lzhcd 12290 rwi/sci DT-20 corner=528ips pay=
time = 1.69999e-02

b)

disp. scale factor = 1.000e+00 (default)

lzhcd 12290 rwi/sci DT-20 corner=528ips pay=
time = 1.79998e-02

c)

d sp. scale factor = 1.000e+00 (default)

lzhcd 12290 rwi/sci DT-20 corner=528ips pay=
time = 1.85000e-02

d)

Figure 34. Corner-drop impact of the container at t=16, 17, 18, and 18.5 ms.

lzhcd 122290 rsl/sci DT-20 corner=528ips pay=

time = 1.85000e-02

a)

lzhcd 122290 rsl/sci DT-20 corner=528ips pay=

time = 1.85000e-02

b)

disp. scale factor = 1.000e+00 (default)

lzhcd 122290 rsl/sci DT-20 corner=528ips pay=

c)

disp. scale factor = 1.000e+00 (default)

lzhcd 122290 rsl/sci DT-20 corner=528ips pay=

d)

Figure 35. a) Condition of the stainless inner can at t=18.5ms. b) Condition of the can contents. c) Rigid body displacement in the y-direction. d) Rigid body displacement in the axial or z-direction

Figure 36. Rigid body velocities and accelerations for the corner drop.

Figure 37. Rigid body accelerations for the corner drop.

izshd 122290 rwl/sci DT-20 corner=528ips pay=
time = 1.59998e-02
fringes of eff. plastic strain
min= 0. in element 1805
max= 5.15e+00 in element

fringe levels
1.000e-03
1.010e-01
2.010e-01
3.010e-01
4.010e-01

a)

disp. scale factor = 1.000e+00 (default)

izshd 122290 rwl/sci DT-20 corner=528ips pay=
time = 1.59998e-02
fringes of eff. plastic strain
min= 0. in element 2640
max= 3.280e-02 in element 1905

fringe levels
5.029e-03
1.070e-02
1.640e-02
2.210e-02
2.780e-02

b)

disp. scale factor = 1.000e+00 (default)

izshd 122290 rwl/sci DT-20 corner=528ips pay=
time = 1.59998e-02
fringes of eff. plastic strain
min= -9.099e-01 in element 2640
max= 3.128e-04 in element 2412

fringe levels
-1.000e-01
-5.000e-01
-2.000e-01
-1.000e-01
-1.332e-15

c)

izshd 122290 rwl/sci DT-20 corner=528ips pay=
time = 1.59998e-02
fringes of eff. plastic strain
min= 0. in element 1632
max= 2.00e-03 in element 791

fringe levels
1.000e-04
5.000e-04
1.000e-03
1.450e-03
1.900e-03

d)

Figure 38. a) Plastic strains in the drum at t=16ms. b) Plastic strains in the can. c) Volumetric strain in the Celotex. d) Plastic strain in the plywood; values of 0.002 and greater indicate failure.

izshd 122290 rwl/sci DT-20 cornerv=528ips pay=
time = 5.99967e-03
fringes of z stress
min=-1.367e+03 in element 2071
max=2.113e+03 in element 2001

a)

fringe levels
-1.000e+03
-5.000e+02
0.
5.000e+02
1.000e+03

izshd 122290 rwl/sci DT-20 cornerv=528ips pay=
time = 7.99921e-03
fringes of z stress
min=-3.540e+03 in element 1972
max=3.537e+03 in element 1969

b)

fringe levels
-1.000e+03
-5.000e+02
0.
5.000e+02
1.000e+03

disp. scale factor = 1.000e+00 (default)

izshd 122290 rwl/sci DT-20 cornerv=528ips pay=
time = 1.19998e-02
fringes of z stress
min=-7.700e+03 in element 1969
max=2.404e+03 in element 1955

c)

fringe levels
-1.000e+03
-5.000e+02
0.
5.000e+02
1.000e+03

disp. scale factor = 1.000e+00 (default)

izshd 122290 rwl/sci DT-20 cornerv=528ips pay=
time = 1.59998e-02
fringes of z stress
min=-1.692e+04 in element 1969
max=1.261e+04 in element 1971

d)

fringe levels
-1.000e+03
-5.000e+02
0.
5.000e+02
1.000e+03

Figure 39. Axial stresses in the can at t=4, 8, 12, and 16ms.

LLNL Codes Offer Vehicle/Barrier Impact Simulation

- Complex models can be developed with INGRID
- Non-linear large deformation analysis with DYNA3D for impact simulation and NIKE3D for longer time post crash monitoring

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Existing hardware provides enhanced ability to model regions of impact

2D and 3D elements provide greater accuracy than 1D beam models

Large deformation capability useful for post impact vehicle monitoring

Nonlinear soil and structural material constitutive libraries available

Failure surfaces useful for extreme impact conditions

- Post processing with TAURUS offers time history as well as state variable processing

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