APPENDIX 10.4:
F-458 Overpack Tie-Down Test
Tests November 2007

TEST REPORT

Requirements:

The handle openings of the F-458 overpack are assessed with respect to the tie-down loads specified in Table V.2 of the IAEA Safety Guide TS-G-1.1 (ST-2), "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material". Package retention systems of Type B packages being transported in the USA must withstand simultaneous acceleration of 10g in the direction of travel, 5g lateral to the direction of travel, and 2g vertically upwards. Structural components of the package must not yield when subjected to this loading.

The IAEA guidance material provides a method to calculate the resultant load force on the tie-down members for this acceleration condition. Based on the calculated net resultant load, a static test was performed to simulate this loading condition.

Calculation of Resultant Loads:

The heaviest configuration in the F-458 family of transport packages is the F-458/F-251, with maximum gross mass of 171 kg. The F-458 package has nominal dimensions of 400 mm (15.75 in) diameter and 494 mm (19.45 in) height. The center of gravity for the package was determined empirically. An F-458/F-251/F-368 package configuration was assembled. The package was suspended from a single handle by a single chain. A vertical line was projected down from the single chain and marked on the circumference of the F-458 package. This process was repeated for the opposite handle, forming an "X" marking on the side of the package. The point of intersection of the two lines, the center of gravity, was measured at 229 mm (9.0 inches) from the base of the F-458 package.

The analysis follows the example given in Appendix V of the IAEA Advisory Material TS-G-1.1 (ST-2). In the tie-down configuration considered, a pair of ratchet straps are looped through the handles and are attached at four floor locations. The straps make an angle of 45 degrees relative to the floor, and relative to the direction of travel (see Figure 10.4-1). The base of the package is assumed to be chocked.

Considering first the loads in the X and Z directions, assume that the package is on the verge of tipping about the A-A axis. Assume that there are no pre-loads at the moment of the acceleration forces are applied. The F_x and F_z loads will be balanced by tension in tie-downs T1 and T4, and there will be no force in tie-downs T2 and T3. For no movement of the package, the sum of all moments about axis A-A is zero. It is assumed that the reaction forces of T1 and T4 are equal, due to symmetry.

$$\sum M_{AA} = 0$$
$$F_X \cdot Z_{CG} + F_Z \cdot R_{F458} = F_G \cdot R_{F458} + 2T1_X \cdot Z_{Top} + 2T1_Z \cdot D_{F458}$$

where

$$T1_X = T1 \cdot \cos 45 \cdot \cos 45 = 0.5T1$$
$$T1_Z = T1 \cdot \sin 45 = 0.707T1$$
$$F_X = M \cdot 10g, \quad F_Z = M \cdot 2g$$
$$M = 171kg, Z_{CG} = 0.229\ m, Z_{Top} = 0.494m, R_{F458} = 0.2\ m, D_{F458} = 0.4\ m$$

Then solving for T1:

$$171 \cdot 10 \cdot 9.81 \cdot 0.229 + 171 \cdot 2 \cdot 9.81 \cdot 0.2 = 171 \cdot 9.81 \cdot 0.2 + 2 \cdot 0.5T1 \cdot 0.494 + 2 \cdot 0.707T1 \cdot 0.4$$
$$T1 = 3942\ N$$

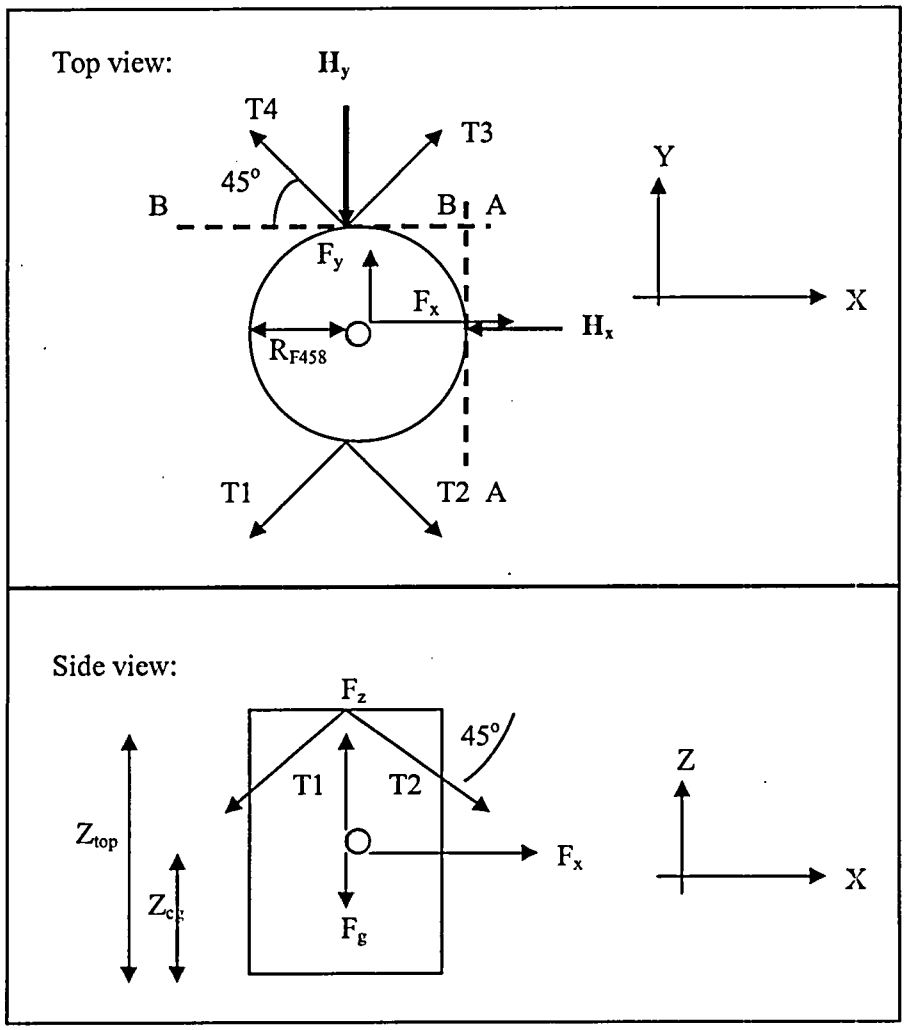

Figure 10.4-1 — F-458 Tie-down configuration

Therefore the reaction force in tie-down T1 due to the forces in the X and Z direction is 3942 N.

Similarly, considering the loads in the Y and Z directions, assume that the package is on the verge of tipping about the B-B axis. Assume that there are no pre-loads at the moment of the acceleration forces are applied. The F_y and F_z loads will be balanced by tension in tie-downs T1 and T2, and there will be no force in tie-downs T3 and T4. For no movement of the package, the sum of all moments about axis B-B is zero. It is assumed that the reaction forces of T1 and T2 are equal, due to symmetry.

$$\sum M_{BB} = 0$$
$$F_Y \cdot Z_{CG} + F_Z \cdot R_{F458} = F_G \cdot R_{F458} + 2T1_Y \cdot Z_{Top} + 2T1_Z \cdot D_{F458}$$

where

$$T1_Y = T1 \cdot \cos 45 \cdot \cos 45 = 0.5T1$$
$$T1_Z = T1 \cdot \sin 45 = 0.707T1$$
$$F_Y = M \cdot 5g, \quad F_G = M \cdot 2g$$
$$M = 171\,kg, Z_{CG} = 0.229\ m, Z_{Top} = 0.494\,m, D_{F458} = 0.4\ m$$

Then solving for T1:

$$171 \cdot 5 \cdot 9.81 \cdot 0.229 + 171 \cdot 2 \cdot 9.81 \cdot 0.2 = 171 \cdot 9.81 \cdot 0.2 + 2 \cdot 0.5T1 \cdot 0.494 + 2 \cdot 0.707T1 \cdot 0.4$$
$$T1 = 2129\ N$$

Therefore the reaction force in tie-down T1 due to the forces in the Y and Z direction is 2129 N.

The total load in tie-down T1 is the sum of the X and Y components (which is conservative, since the vertical Z component is counted in both values). Therefore

$T1_{total} = 3942 + 2129$ N = 6071 N.

The maximum tie-down force is therefore 6071 N. Since the assumed ratchet strap is continuous, the tension in member T2 is the same as in member T1 (T1 = T2).

The net load on the handle is calculated from the T1 and T2 loads applied simultaneously; it is then the vector sum of loads $T1_{total}$ and $T2_{total}$. The net load on the handle acts at an angle to the ground of

$\tan\theta = \sqrt{2}$, or $\theta = 54.7$ degrees. The net load on the handle is then

$$P_{net} = 2 \times \frac{T1_{total} \cdot \sin 45 \cdot \cos 45}{\cos 54.7} = 10{,}514 \text{ N.}$$

Each F-458 package tie-down point must therefore withstand **10,514 N (2364 lb) acting at an angle of 54.7 degrees from the ground** (and radial from the center of gravity), without yield, to satisfy the tie-down requirements for Type B packages in the USA. This forms the acceptance criterion for the subsequent tie-down tests.

Test Equipment:

- F-458 overpack, no serial number, selected randomly from inventory before entering service.
- F-168 container, including skid, gross mass 5445 kg.
- Porta-Weigh scale, model MSI 3400, MDSN tool number 13531 (calibrated).
- Overhead crane, lifting straps, attachment hardware.

Test Procedure:

The following test procedure was performed for the tie-down configuration assessed.

1. Measure the F-458 package diameter and height at the tie-down points before the test. Inspect the package in the region of the tie-down points for damage and distortion.
2. Place the F-458 package in the middle of the modified steel plate (2" thick mild steel plate with lifting rings and fully-rounded edges).
3. Lift the steel plate in a "basket" configuration using lifting straps using the overhead crane.
4. Zero the scale on the overhead crane.
5. Attach the F-458 tie-downs to a second pair of lifting straps. The angle of attachment to the F-458 package shall be as close as possible to 35 degrees relative to the package (54.7 degrees to ground). Connect these straps to an F-168 package (or similar) sitting underneath. Use appropriate clevis hardware.

6. Raise the crane slowly until the scale reading is greater than 5000 lb. Note that the straps will stretch and therefore the reading will decrease slowly with time. Do not raise the F-168 package off the ground.

7. After taking photos of the test, and noting the maximum sustained load on the scale, lower the crane and disassemble.

8. Measure the F-458 package diameter and height at the tie-down points after the test. Inspect the package in the region of the tie-down points for damage and distortion.

A test was performed on November 9, 2007. Figure 10.4-2 shows the test schematic.

Results:

A photo of the test in progress is shown in Figure 10.4-3, with the projectile shield removed for clarity. The angle of the tie-down strap relative to the package was approximately 40 degrees. In the tie-down configuration (see Figure 10.4-5), straps were passed through each of the handle openings to apply load to the handles.

The diameter at the top of the F-458 overpack was measured in several locations prior to testing, and was uniformly round at 398 mm. The height at each handle was measured at 492 mm. The lid on the package was in place but without any screws installed. There was no damage or distortion of the rim.

The scale was zeroed with the F-458 sitting on the steel plate. After attaching the F-458 to the F-168 (dead weight), the crane raised the steel plate. The straps passing over the rounded edge of the steel plate (see Figure 10.4-4) transmitted the load from the dead weight. The total load applied exceeded 6200 lb (27.6 kN) temporarily, and gradually fell as the straps stretched. The total applied load stabilized at 5670 lb (25.22 kN) after several minutes (see Figure 10.4-6).

After releasing the load and removing the lifting straps, the F-458 package was re-measured. There was no change to the diameter of the top of the package, and the shape remained circular. The height of the F-458 package also did not change for either handle. There did not appear to be any local deformation, cracking, or crushing of the package at the contact areas or surrounding rim.

The test was performed by William Allin, with assistance from Jason Brydges and Paul St. Gelais. The test was witnessed by Scott McGhee.

Discussion:

The load applied to the F-458 tie-down points was transmitted by the lifting straps passing over the rounded edge of the steel plate (see Figure 10.4-4). This rounded edge was ground smooth to reduce the friction of the strap over the edge. Due to the relatively large radius of curvature (approximately 2 inches) and the smoothness of the surface, the friction of the lifting strap on the steel plate would be small. Therefore it is reasonable to conclude that the tension in the lifting strap was approximately uniform throughout its length.

Furthermore, the load applied to either side of the F-458 package must be very close to equal, since any inequality in tension would cause the F-458 package to shift in its position on the plate (it was not fixed to the plate). Differences in the lengths of the two lifting straps on opposing sides are negated when the crane lifts the plate. The hanging steel plate will be forced to shift laterally until the load is balanced between the two lifting straps.

Therefore the tension in each strap is approximately equal to half of the measured load, as indicated on the crane's scale.

Conclusions:

The F-458 package handles were tested with respect to the IAEA Safety Guide TS-G-1.1 (ST-2) guidelines for packages being transported through the USA. The resultant load for a simultaneous 10g, 5g, 2g acceleration for the heaviest F-458 package configuration was calculated. The required net load on the handle was determined to be **2364 lb (10.51 kN)** at an angle 35-degrees downward from the tie-down point.

Physical tests of an F-458 package were performed. The package was selected randomly from the stock of F-458 overpacks prior to entering service (not yet serialized). The applied load on each tie-down point was greater than **3100 lb (13.79 kN)** for a brief time, applied at an angle of approximately 40 degrees to the package. The load stabilized at 2835 lb (12.61 kN) after several minutes. The temporary and stabilized loads were significantly higher than the calculated required net load.

The diameter and height of the F-458 package was measured before and after all tests, and was found to be unchanged. No deformation or damage was observed. It is therefore concluded that the F-458 package satisfies the requirements for tie-down for Type B packages in the USA.

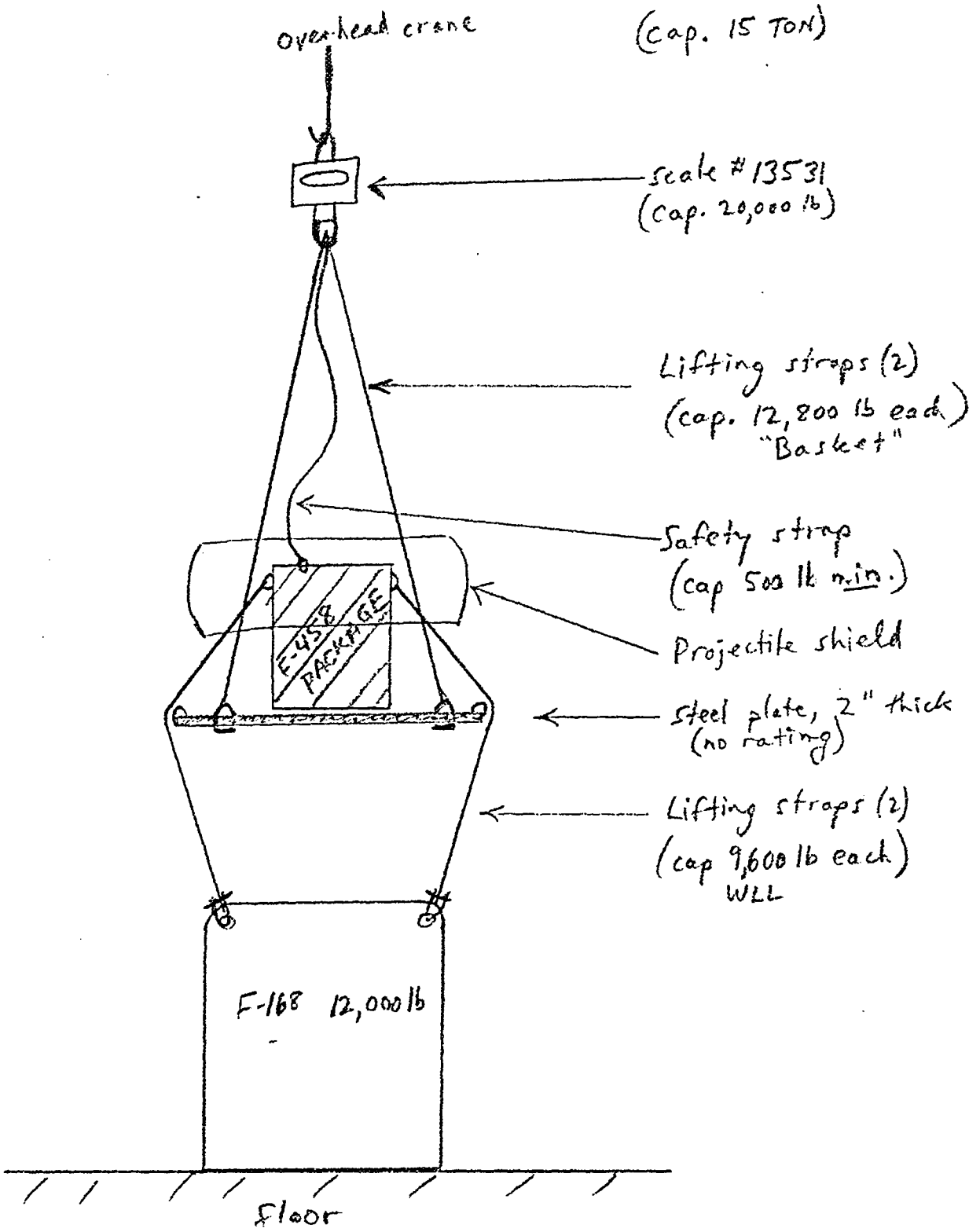

Figure 10.4-2 — F-458 Tie-down test schematic

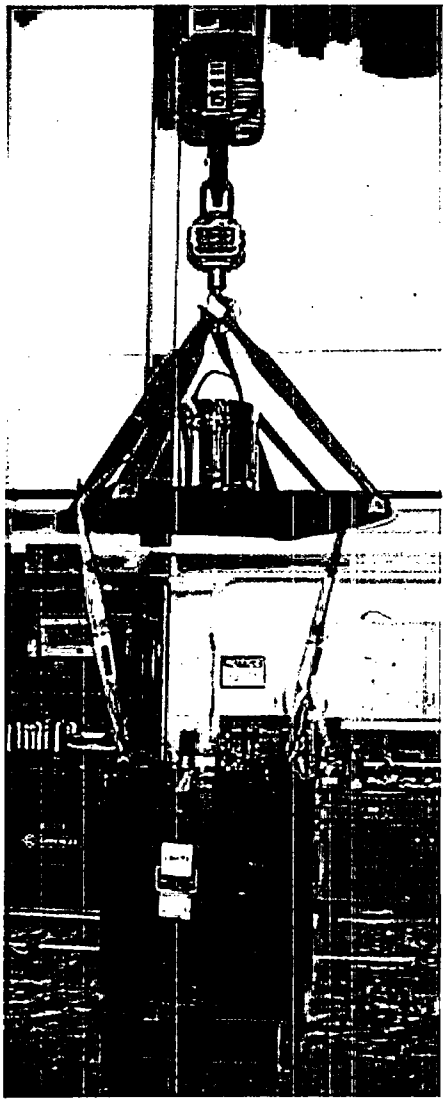

Figure 10.4-3 — F-458 Tie-down Test in Progress

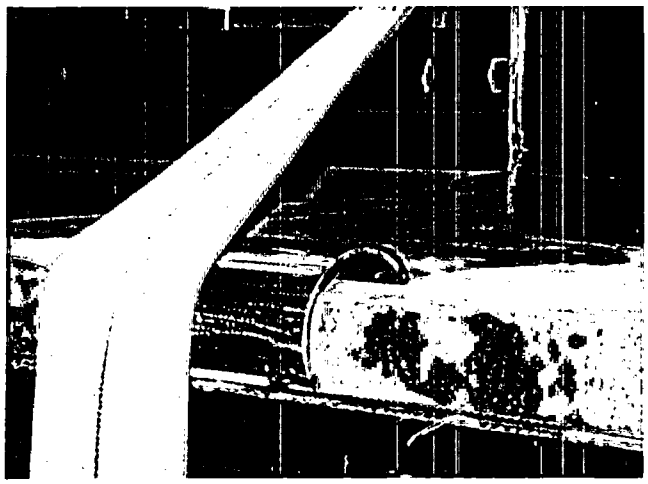

Figure 10.4-4 — Rounded edge of Steel Plate (Straps pulled aside)

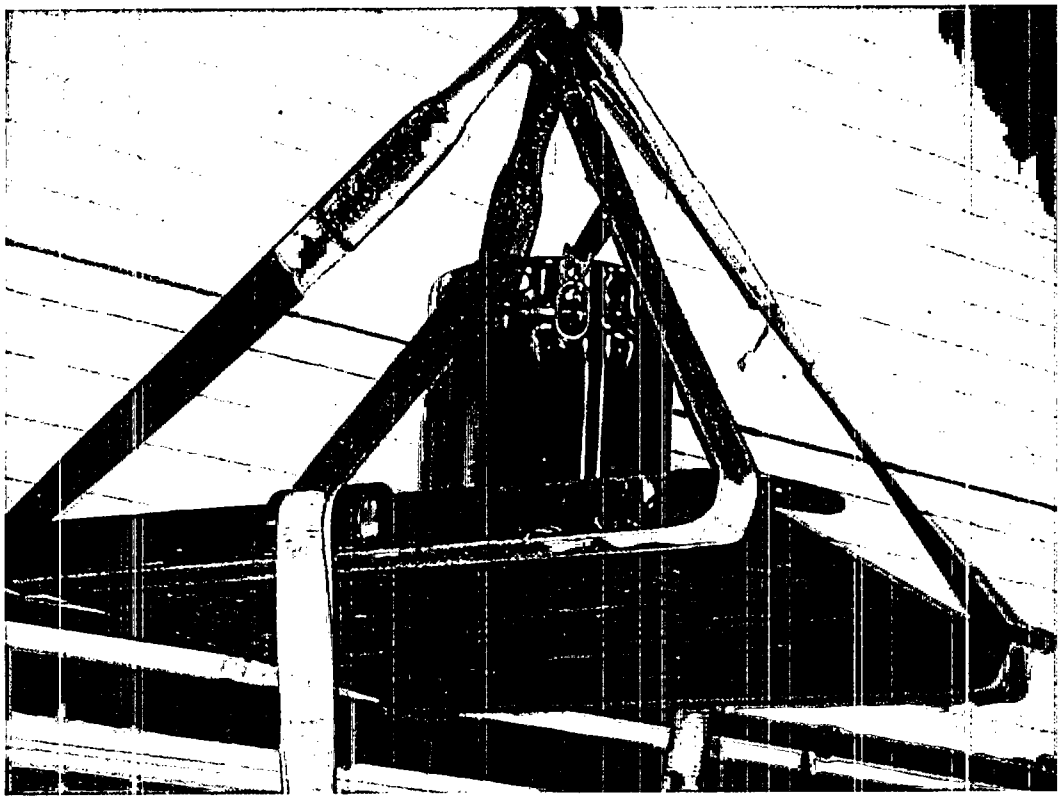

Figure 10.4-5 — F-458 package Tie-down test, Handle

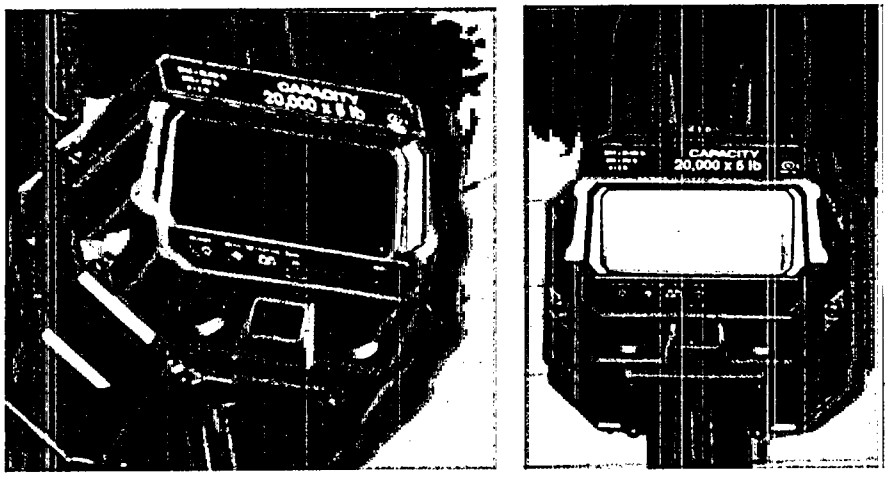

Figure 10.4-6 — Scale during Tie-down test, Transient (6245 lb) and Stabilized (5670 lb)