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Containment Devices for Small Terrorist Bombs for Law Enforcement

FINAL REPORT

97 DT-CX-K001

Jaycor Report J4039-99-100

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1. Introduction

Jaycor, under NIJ Contract No. 97-DT-CX-K001, has designed, built and tested a lightweight, relatively low cost, blast resistant container for bomb squads to store and transport pipe bombs containing at least 1 lb of black powder explosive.

The Jaycor container is designed to augment the present bomb containment vessels. The present method of protecting against a suspected bomb, once it has been discovered and cannot be disarmed, is to place it in a steel container for detonation. The majority of these containers are vented at the top, where the detonation gases and fragments are directed upward in the air. There are several disadvantages of the present containers. They are expensive: with the total containment vessel costing one-half a million dollars. The raining down of the fragments from the vented containers could prove hazardous in populated areas. The containers are extremely heavy, with the vented and total containment vessels weighing 5000 lb and 8000 lb respectively, necessitating their transport to the bombsite by a heavy truck. Furthermore, bomb disposal in enclosed areas, such as airport terminals, with these vessels is problematic due to the difficulty in transporting them.

In contrast to the present steel containment vessels, the Jaycor container was designed so that it can be transported in a pick-up truck or sport utility vehicle, and can be carried by one or two members of the bomb squad. The container has dimensions of 2 ft × 2 ft × 2 ft, and weighs about 55 lbs. The Jaycor vessel is designed to contain the blast and fragments of a pipe bomb containing at least 1 lb of black or smokeless powder.

If greater protection against fragments is desired the container is designed so that panels of varying degrees of thickness can be inserted and removed depending on the perceived threat.

The Jaycor design is based on the lightweight, blast-resistant cargo container Jaycor has developed for the Federal Aviation Administration to contain the force of the blast and fragments from a bomb placed in checked luggage.

To achieve the required blast containment and low weight the Jaycor container design utilizes the superstrong, man-made fibers found in ballistic armor. The theoretical blast containment of a closed container made of such material is considerable. However, putting an ordinary opening on the container negates most of the strength of these materials. To overcome this liability, Jaycor has developed an innovative design that allows the container to be built with nearly the optimum blast resistant capacity allowed by the material, while maintaining a fully functioning opening.

To design the NIJ prototype containers Jaycor has used state-of-the-art engineering analysis tools. First, the internal blast loading was estimated from Computational Fluid Dynamics (CFD) simulations. The structural response of the proposed prototype to the blast was then determined with a finite element structural analysis simulation. Two prototypes were then built and tested for their blast resistance. A third prototype will be delivered to NIJ for independent testing.

As part of the design effort, Jaycor contacted the San Diego Sheriff's Department and Los Angeles Police Department bomb squads during the requirements phase of the project. It was during this phase that the goal of protection was set at a 1-lb pipe bomb.

This project has been a cost-shared effort by Jaycor and the Allied Signal Corporation. Jaycor is presently undertaking an internally funded research and development project to build and test additional cargo containers with increased strength, reduced weight, different materials and construction techniques, at the same time reducing the overall cost of production. Allied Signal Corporation has contributed Spectra composite material.

2. Container Design

In arriving at the final size of the NIJ container, a number of factors were considered. The larger the containment vessel, the lower the blast and final pressures, and thus the thinner the walls. On the other hand the transportability of a small container was considered. Also the door design in a smaller container is less challenging than in a larger one. The final size was selected by the practicality of transporting the container in a pick up truck and carried by one or two persons through doors into and out of buildings.

Once the size was selected, the container had to be designed to withstand the force of the blast. This implies selecting its thickness and shape. First, the internal blast loading was estimated from published data that the explosive strength of black powder ranges from 10-50% of TNT. Estimated blast pressures were obtained from the INBLAST[1] code using explosive charge of 50% TNT.

The effect of fragments was estimated by assuming a reasonable fragment size, imparting an initial velocity to the fragments based on the impulse supplied by the expanding gases, and calculating the momentum of the fragments.

The response of the container to the blast pressure and fragments was then determined with the LS-DYNA structural analysis code. The stress analysis yielded the maximum charge that the container could tolerate before failing. Figure 2-1 shows the mesh used in the finite element analysis. Only one-quarter of the container needed to be simulated owing to the design symmetry. The material properties of the composite material used in the stress analysis are given in Table 1. These properties are based on material testing done by Jaycor for the FAA cargo container project.[2] Figure 2-2 shows a result of a structural analysis of the container after the pressure loads from the explosion has been applied. Comparing Figures 2-1 and 2-2, the container tries to attain a spherical shape from a more square shape as a result the blast pressure loads. Figure 2-2 shows that the maximum loads are along the edges. The maximum stress that can be tolerated by the composite material is about 60,000 psi. By increasing the radius of curvature of the edges the maximum stress could be reduced to acceptable levels.

The Jaycor door design calls for a stiff door that will not deform during the blast event and a face on the container that will not break as a result of the door opening and the localized stress of the door pushing on the panel. Figure 2-3 shows stress contours from the finite element analysis of the door and front panel. The door is curved at the edges to conform to the curvature of the box. The finite element analysis suggested the thickness of the door and panel.

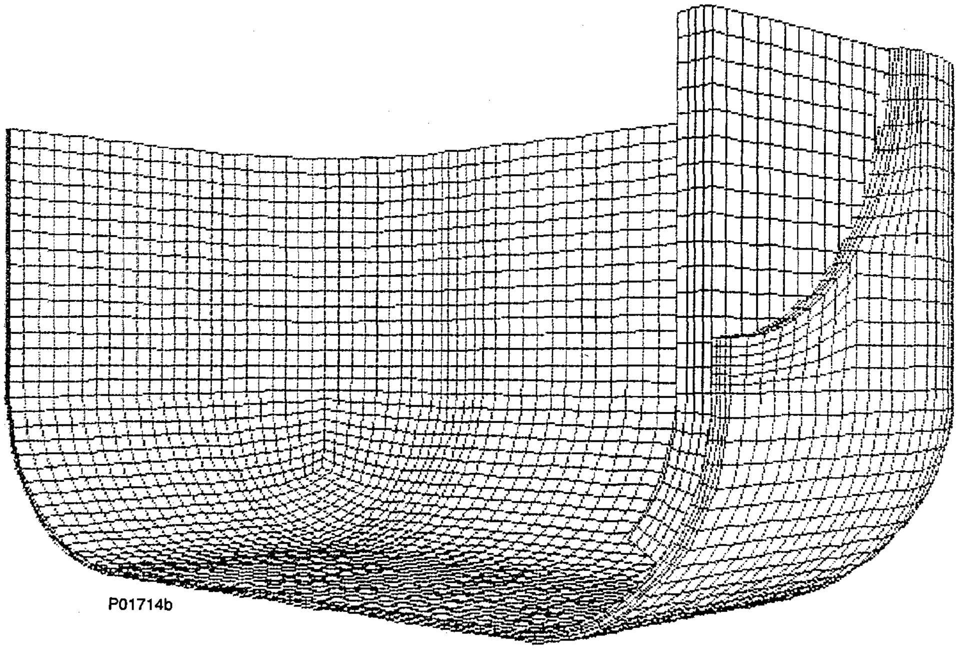

Figure 2-1. Finite Element Model of NIJ Container.

Table 1. Orthotropic Material Properties of Composite Material.

Property	**Value**
Specific gravity	1.1
Young's modulus Warp and Fill (E1 and E2) Thickness (E3) †	 1.8 mpsi 0.26 mpsi
Shear modulus G12 G23=G13 †	 0.26 mpsi 0.26 mpsi
Poisson's ratios v12 v23=v13=v12*E3/E1 †	0.3
Tensile strength, Xt, (Warp and Fill)	61 kpsi
Compressive strength, Xc (Warp and Fill)	-7.5 kpsi
Shear strength, Xs, (warp/fill)	17 kpsi

† denotes estimated properties

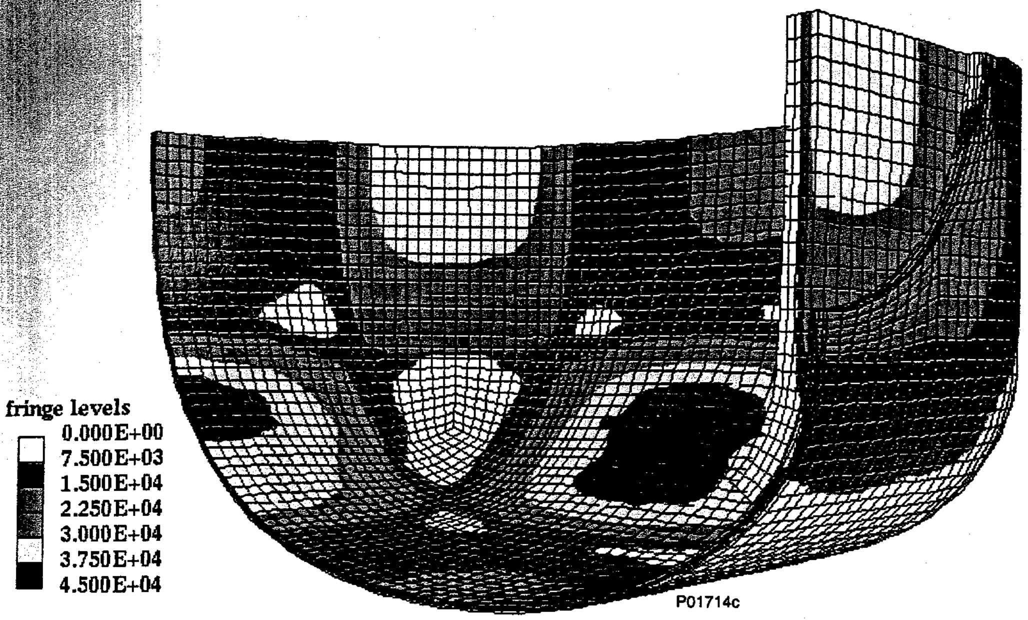

Figure 2-2. Maximum principal stress at 325 psi load.

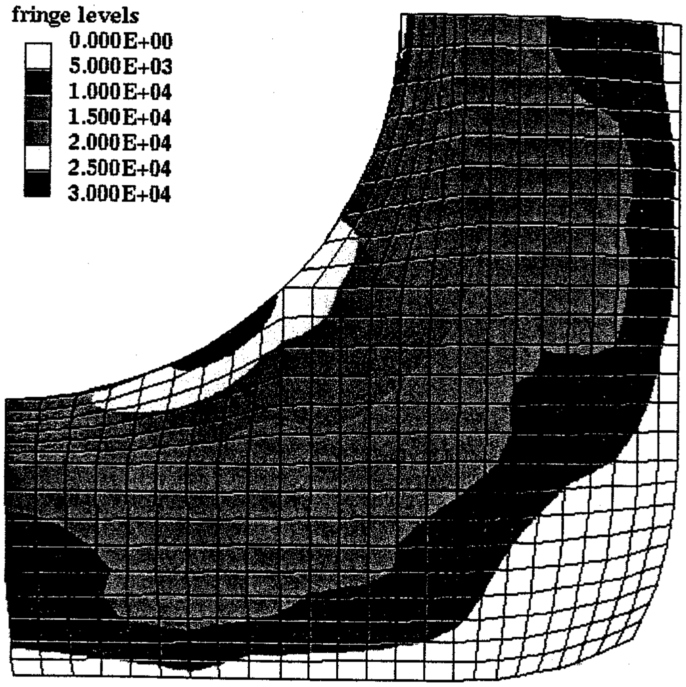

Figure 2-3. Stress on the front door panel at a 325 psi load.

The target design was for about 300 psi internal pressures. Figure 2-4 plots the maximum principal stress on the edges of the container, at the edge of the door opening, and the aluminum door as function of the applied load. The figure indicates that the stresses are well below the maximum at a pressure of 300 psi.

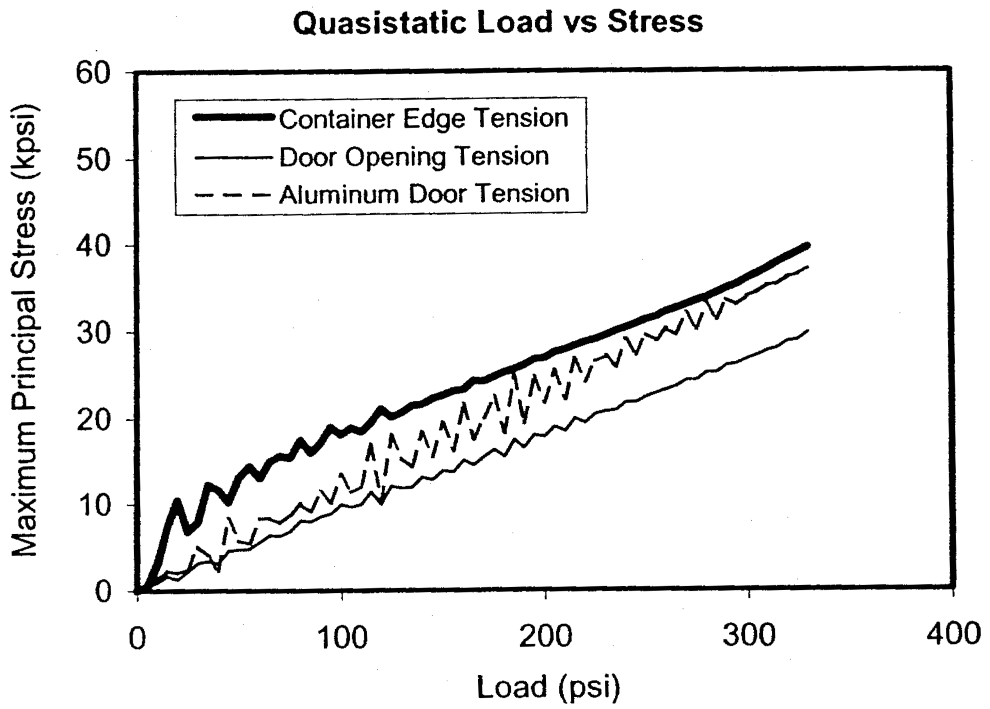

Figure 2-4. Peak stresses vs. load.

Our final design called for the container walls to be 0.2 in. thick, the panel holding the door to be 0.4 in. thick, and the aluminum door to be 0.5 in. thick. Guides fabricated from fiberglass material are secured inside the container to guide the door during opening and closing.

3. Blast Tests

The first container was constructed based on the engineering design analysis. Our fabricator, Composiflex Corporation, in Erie, PA, manufactured the container. Kevlar fabric, impregnated with an epoxy resin, was chosen as the construction material. This was based on Kevlar's relatively low cost compared to other composite materials.

The container was fabricated by laying up the fabric over a fiberglass mold. A fabric's strength can vary in the warp and fill directions, so, for that reason, the direction of the fabric layers was alternated in a 0-90° pattern to give the maximum overall strength. Once all of the layers were in place, a vacuum bag was placed over the container, and it was placed in an autoclave under 100 psi pressure and increased temperature for curing. Figure 3-1 shows the container before blast testing.

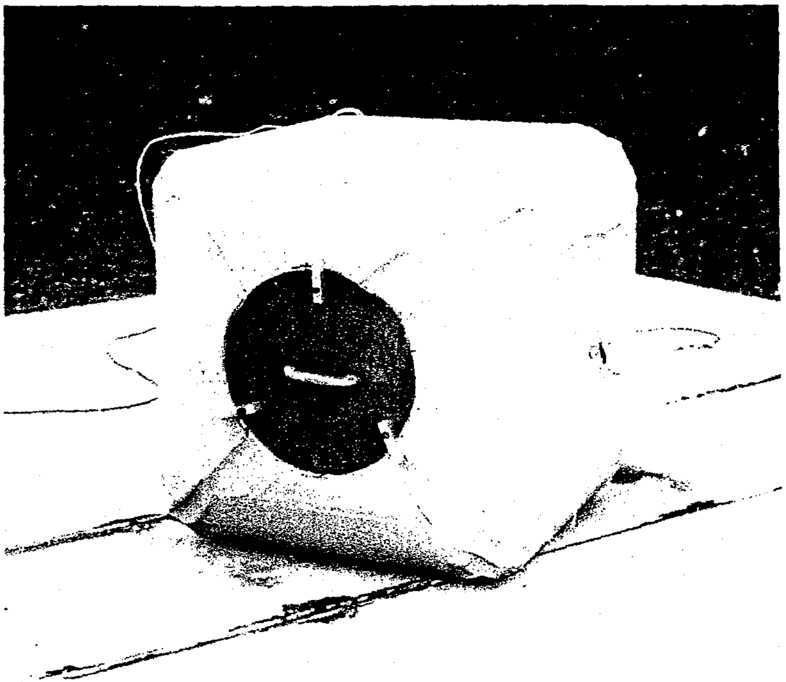

Figure 3-1. First container before testing.

In the first test the container was tested against a charge of 0.5 lb of black powder. The charge was hung in the center of the box. The box suffered no damaged from this blast. Figure 3-2 shows the box prior to the second test along with the charge hanging in the center. The absence of damage is evident from the figure. The second test was carried out using a charge of 1 lb of black powder. During the second blast test the container split along

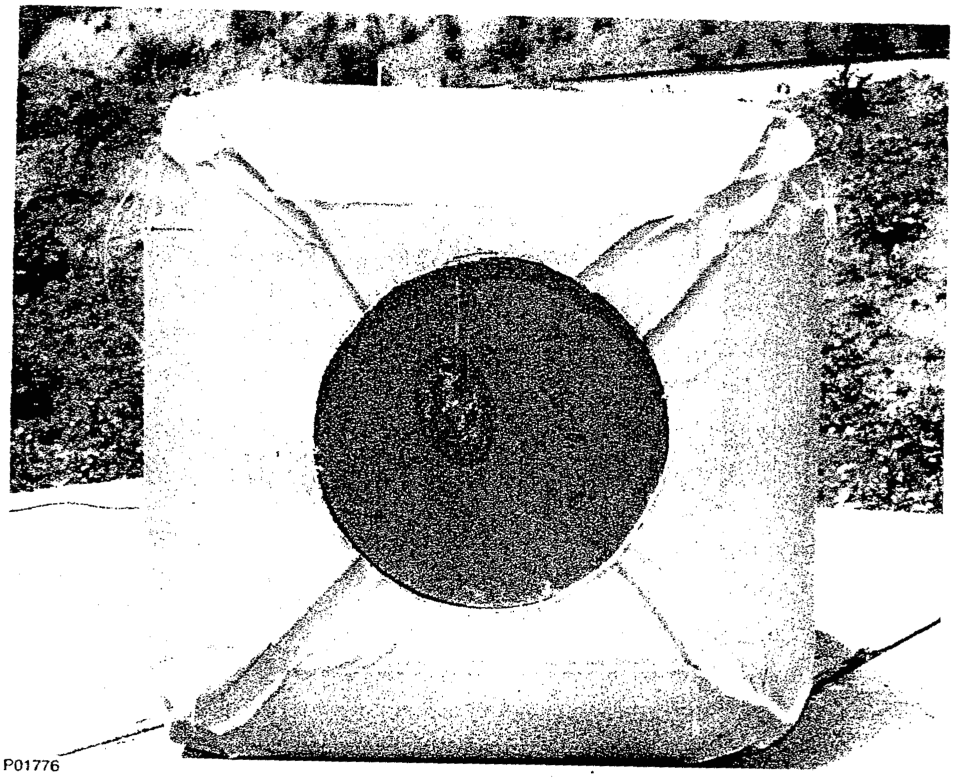

Figure 3-2. First container before second test with charge placed in center of container.

the edges and along a 45° line in the door panel, as shown in Figure 3-3. The container failed at the locations where the finite element analysis predicted the maximum stresses would occur, as seen in Figure 2-2. Close examination of the pieces of the container after the test suggested that the bonding along the edges where failure occurred was incomplete, giving a failure stress below the one obtained from test panels in laboratory tests. The finite element analysis assumed the laboratory failure stress in predicting failure.

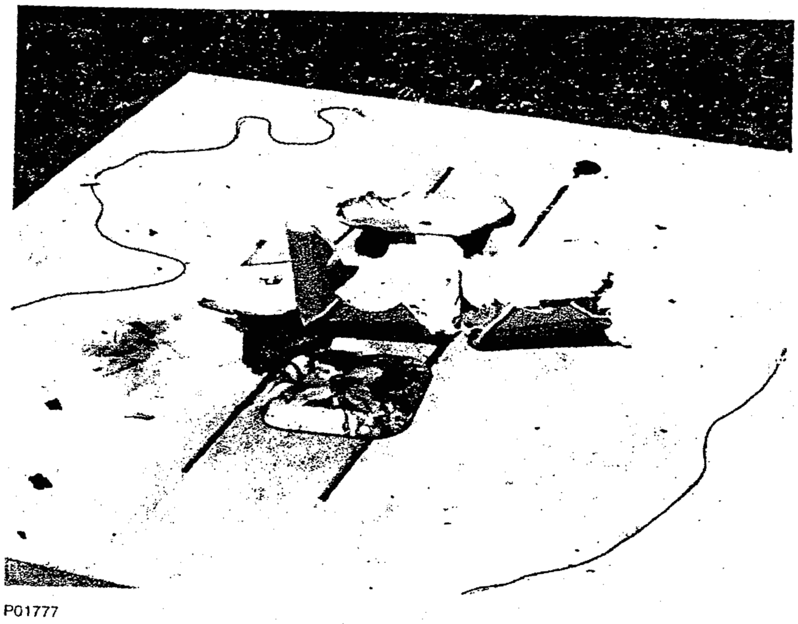

Figure 3-3. First container after blast with 1 lb of black powder.

As a result of the first test a number of design modifications were made for the second container. The first box was cured in a single stage, and the cured fabric exhibited wrinkles that can be seen in Figures 3-1 and 3-2. This would lead to incomplete bonding and lower strength. Thus the second container was cured in two stages in order to achieve better bonding, especially along the edges where the highest stress occurs. A second modification included using Spectra composite material instead of Kevlar due to Spectra's higher strength-to-weight. In addition, extra layers were placed along the edges for increased strength there. Along the front panel layers of fabric were laid up in a 0-45-90° pattern to prevent the breaking that occurred along the 45° lines in the first box. Finally the door opening was made smaller in order to decrease the maximum stresses on the door panel. Composiflex also fabricated this container.

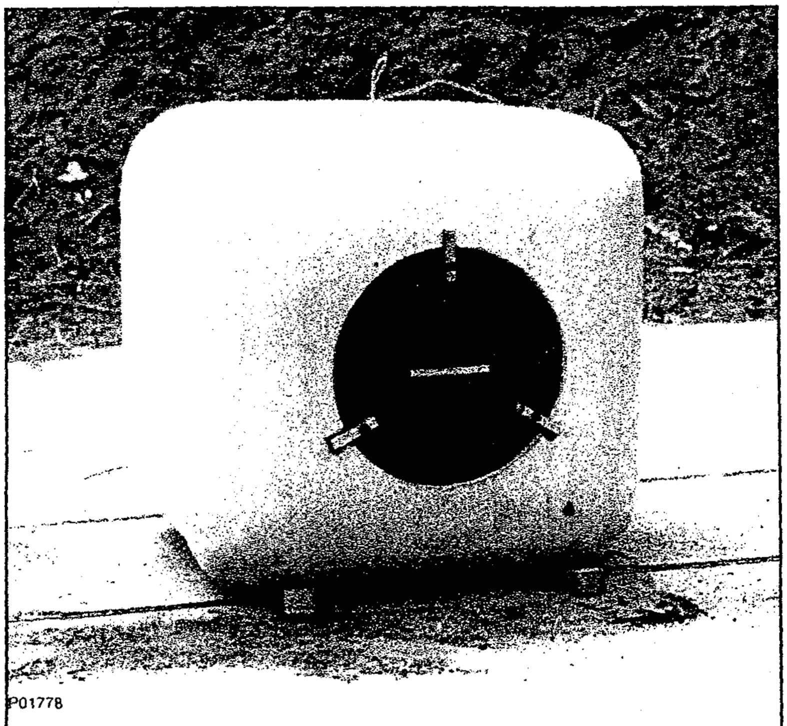

Figure 3-4. Second container before testing

Figure 3-4 shows the second box before the test. The container exhibits no wrinkles as the first box and has a much smoother surface, which can be attributed to the two-cure cycle. The box was tested with 0.75 lb of black powder. The charge was again hung in the center, shown in Figure 3-5. Figure 3-6 shows that the box after the test and that it was relatively undamaged by the charge. Close inspection of the container did exhibit small burn holes through the material, shown in Figure 3-7. Figure 3-8 shows the interior after the test and the charring which took place in the inside layers. Spectra is a flammable material, but the fiberglass mold upon which the Spectra was laid was removed after the curing to reduce the overall weight. Fiberglass will withstand much higher temperatures, and in future designs an option will be to let the fiberglass remain in place to prevent the burn through.

A third box was constructed using the same design and fabrication techniques as the second box. This box will be turned over to NIJ for independent testing.

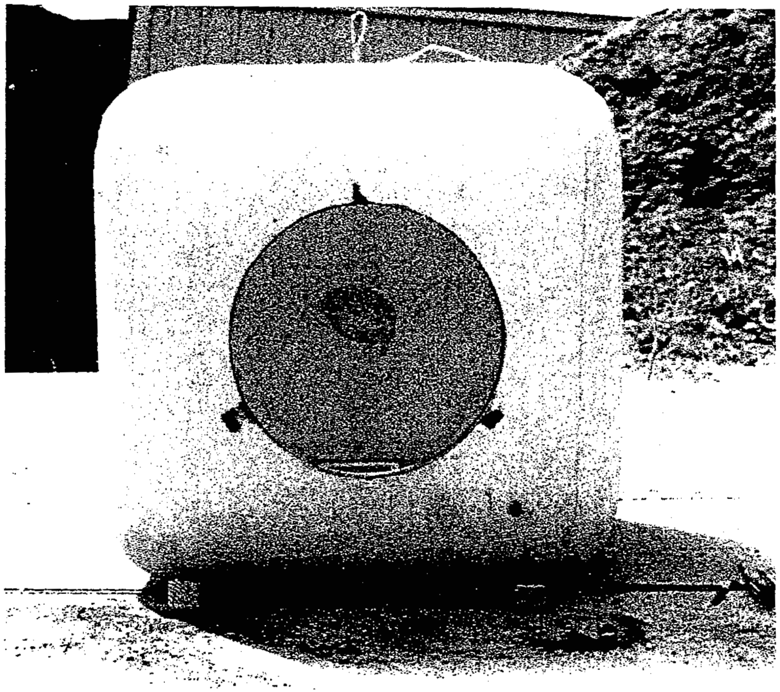
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Figure 3-5. Second container before testing with charge placed in center.

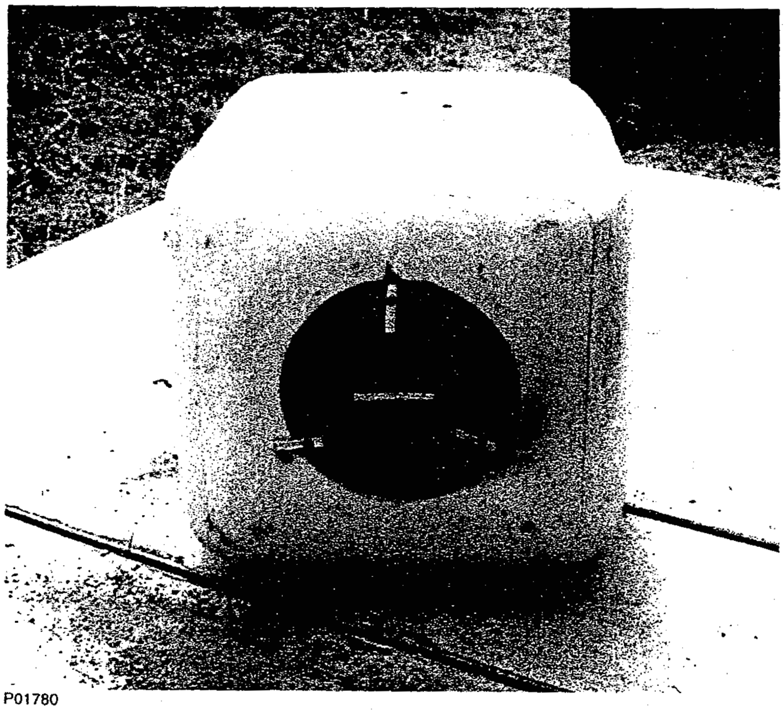
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Figure 3-6. Second container after test with ¾ lb of black powder.

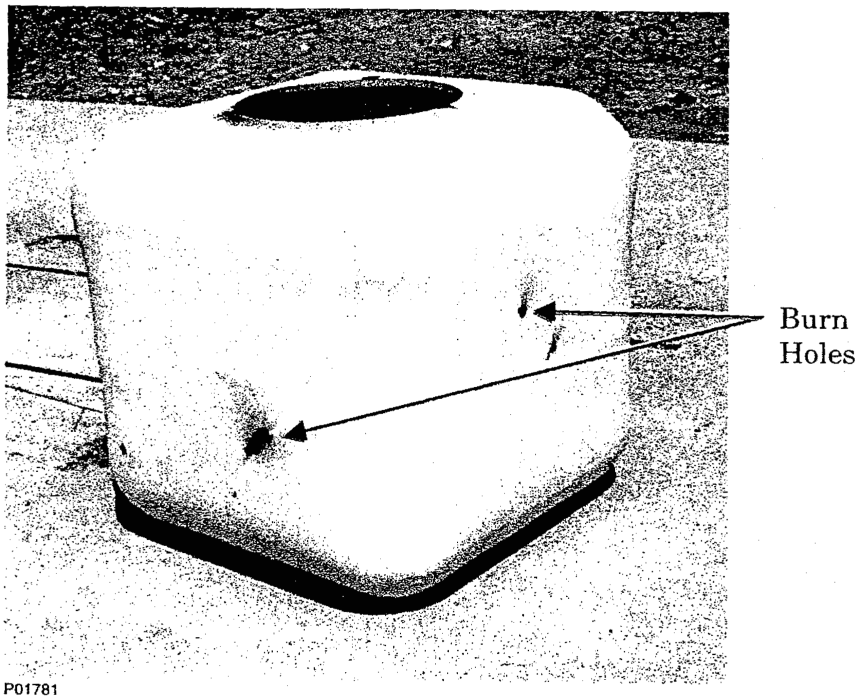

Figure 3-7. Second container after testing showing burn holes in side.

Figure 3-8. Interior of the second container showing charring of the inside layers of fabric.

4. Conclusions

Jaycor, under NIJ Contract No. 97-DT-CX-K001, has designed, built and tested a lightweight, relatively low cost, blast resistant container for bomb squads to store and transport pipe bombs containing at least 1 lb of black powder explosive.

In contrast to the present steel containment vessels, the Jaycor container was designed so that it can be transported in a pick-up truck or sport utility vehicle, and can be carried by one or two members of the bomb squad.. The container has dimensions of 2 ft × 2 ft × 2 ft, and weighs about 55 lbs. The Jaycor vessel is designed to contain the blast and fragments of a pipe bomb containing 1 lb of black or smokeless powder.

The project has demonstrated the feasibility of containing bomb blasts and will result in a design that can be developed into a commercially available, cost-effective product for law enforcement.

Future improvements include modifying the design to make the container more spherical since the optimum container shape for blast containment is spherical. The Jaycor design approaches the spherical shape as shown by the finite element analysis in Figure 2-2. Making the container more spherical will increase its strength.

Another design improvement would be to incorporate thermal absorbing material on the inside surfaces of the container to lower the overall pressure and prevent burn-through of the material. In its work for the to develop a hardened cargo container JAYCOR has shown that the presence of luggage and clothing material in the container strongly attenuates shock and gas pressure loading and acts as an energy sink for the explosive. Placing energy absorbing material in the inside surfaces would also greatly increase the amount of explosive charge that can be contained.

5. References

1. Swisdak, Michael M. Jr. and Montanaro, Paul E., "INBLAST – A New and Revised Computer Code for the Prediction of Blast Inside Closed or Vented Structure," Minutes of the 23rd Explosive Safety Seminar, Aug. 1991.
2. Neubert, H.D., Klein, H.H., and Stuhmiller, J.H., "Material Design Allowables Test Report," Jaycor Rpt.J4036-00-98/065 under Contract No. DTFA03-97-C-00015, Mar. 1998.