NAVSEA INDIAN HEAD

TECHNICAL MEMORANDUM

NAVAL PHST CENTER

NAVAL SURFACE WARFARE CENTER, INDIAN HEAD DIVISION
DETACHMENT EARLE
PHST CENTER

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SUBJECT: LIGHTWEIGHT EXPLOSIVE BLAST CONTAINMENT CONTAINER DESIGN AND MATERIAL SELECTION REPORT

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1. ABSTRACT

1-1. This report details the analysis, evaluation methods and progressions that were considered by Naval Surface Warfare Center, Indian Head Divison (NSWCIHD), Detachment Earle, PHST Center, in determining a proposed design and material selection for a lightweight explosives blast containment container. The evolution of this process took place over a relatively short period of approximately six months.

The initial work on the project started with a cooperative Research and Development Agreement (CRADA) between the PHST Center and Galaxy Scientific Corporation. Dr. Edward Weinstein of Galaxy Corporation had designed and tested a number of blast resistant airline luggage containers. Dr. Weinstein pointed us in the direction of using composite materials for the container shell. He also informed us of various energy absorbing materials to lessen the effects of the explosive blast.

The PHST Center began work on some concepts using technology from synthetic slings made from continuous strands of aramid fiber to contain the effects of an explosive blast. Out of those early concepts came the idea for a concept that we call a “box in a box in a box”. Each section or “box” of the concept container would be constructed from filament wound aramid fiber in an epoxy matrix.

Naval Surface Warfare Center’s (NSWC) Carderock Division informed the PHST Center of Igor Paley’s work at Honeywell Corporation on a surprisingly similar design to the “box in a box in a box” concept. They also informed us that Honeywell made several successful prototypes.

NSWCIHD Detachment Earle, PHST Center, has decided to pursue the “box in a box in a box” container concept using Honeywell’s Spectra fiber.

2. INTRODUCTION

2-1. The Naval PHST Center recognized the potential need for a lightweight container that could fully contain the effects of relatively small explosives initiating devices, such as detonators and fuzes. These small, generally easily initiated explosives devices, cannot be safely shipped or stored with larger explosives devices such as bombs. Having the ability to ship and store initiating explosives with larger explosives devices would greatly improve the logistics of ammunition and explosives in the Navy.

At the time, Dr. Edward Weinstein with Galaxy Scientific Corporation was developing an airline luggage container that could safely contain the effects of one to two pounds of C4 explosives. Initial tests of their prototype container looked promising. The container was made from a combination of formed aluminum edges and flat panels of a material called Glare. Glare is a lamination of thin aluminum sheets and unidirectional S2 fiberglass. The aluminum edges were bolted to the Glare panels. A proprietary door fastening system kept the door in place.

The container was approximately 50% successful in testing. Most of the failures occurred in the formed aluminum edges that joined the Glare panels. Any major breach in the container was considered a failure. Dr. Weinstein realized that in order to make the luggage container marketable, he had to reduce the high cost of materials and manufacturing that he was currently using. A totally composite container was designed using a proprietary method of fastening the panels together. Initial testing proved that the panel fastening method was still the weak link and further development was needed.

The PHST Center recognized the blast mitigation expertise of Dr. Weinstein, and Dr. Weinstein recognized the packaging technical expertise that the PHST Center had to offer. A CRADA was created between Galaxy Scientific Corporation and the PHST Center to benefit both parties. Dr. Weinstein would perform most of the analytical work, and the PHST Center would perform most of the technical work to jointly develop a lightweight explosives blast containment container.

In an effort to get funding, a proposal was submitted to the Office of Naval Research (ONR) under BAA 01-025. The objective was to prove that a lightweight container, approximately 50 pounds and 8 cubic feet in size, could fully contain the effects of one pound of C4 explosives. Dr. Weinstein believed that a similar method that was developed for fastening the luggage container composite panels could be used for the creation of a lightweight explosives blast containment container.

Soon after the CRADA was created, Dr. Weinstein left Galaxy Scientific in pursuit of other endeavors. The PHST Center soon found Galaxy Corporation had little to offer without Dr. Weinstein, except software called INBLAST which is used to predict the pressure loading inside a known volume. The PHST Center decided to continue the effort without Galaxy Corporation's help and obtain INBLAST for it's own use.

About this time, the PHST Center was working with synthetic slings made from continuous strands of aramid fiber. The slings were being used in the development of a forklift truck lift beam. The high strength to weight ratio of the slings is a property we were looking for in a lightweight explosives blast containment container. Concepts using this sling technology led us to our final concept, the “box in a box in a box” concept.

It was felt that the people that deal with blast hardening ships at the NSWC Carderock Division should look at our concepts before we continued any further. They immediately recognized the “box in a box in a box” concept as Igor Paley’s. Carderock informed us that we had unknowingly copied Igor Paley’s design, which was patented with Honeywell Corporation.

The PHST Center then visited Igor Paley at Honeywell Corporation and he showed us his work on the project. His work culminated in many successful prototypes of various types, all based on the “box in a box in a box” concept. All of the Honeywell boxes are constructed from Spectra fiber. Spectra is Honeywell’s trademark name for one of their Ultra High Molecular Weight Polyethylene (UHMWPE) fibers.

3. DISCUSSION

3-1. The initial concept work focused on the guidance provided by Dr. Weinstein. His concept for a lightweight explosives blast containment container was based on his work with aircraft luggage containers. The concept, Figure 1, involved making panels by wrapping prepreg composite fabric around thin wall aluminum tubing at the outermost edges. The wrapped assembly would then be placed in an autoclave to cure under heat and pressure. The resultant panel would then be machined so that the adjoining panels create a piano hinge like edge. Since half of the material is machined away at the edges, extra material has to be added to the edges to make up for the loss of strength.

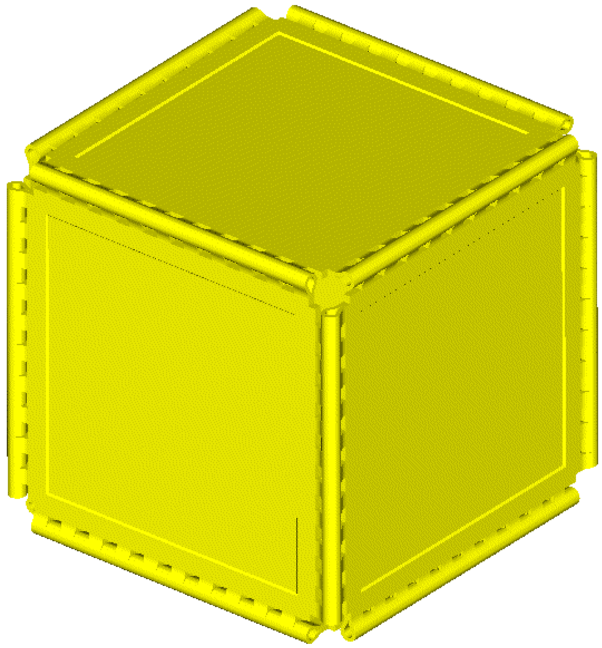

FIGURE 1.

The PHST Center contacted Sioux Manufacturing, located at Fort Totten, North Dakota, about manufacturing the panels. Dr. Dana Grow of Sioux Manufacturing said it would be in our best interest to try another approach, since they had an extremely difficult time making the panels for the aircraft luggage container. The panels were made from a phenolic S-2 glass composite in accordance with MIL-PRF-64154. He did not believe that other materials would improve the manufacturability.

This concept does not take full advantage of the composite material, since the machined edges cut through the composite fibers. The extra material placed around the edges was needed not only to increase the strength of the piano hinge edges, but to also distribute the load to the rest of the panel. In addition, testing of prototype aircraft luggage containers consistently failed at the piano hinge edges.

3-2. Another approach that was looked at briefly consisted of composite panels joined together with metallic piano hinge edges. This concept, Figure 2, is essentially the same as above, but uses metallic piano hinge joining features riveted to the composite panels. This way, the composite panels could simply be flat composite sheets. The metallic edges could be made from high strength aluminum or steel. The concept was not pursued after a few calculations were made concerning the necessary weight of the metallic edges.

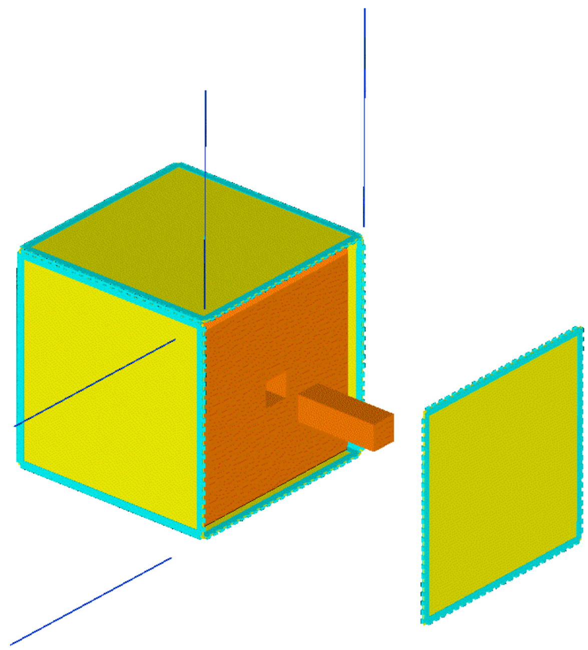

FIGURE 2.

3-3. The problem of making a lightweight composite explosives blast containment container now focused on an effective method of joining the composite panels together. We were looking for a method that would take advantage of a composite material's high strength properties. The previous concepts use a similar method of joining the panels together. The problem with these concepts is that the composite fibers are cut and are not continuous. In the first concept, half the fibers are cut at the edges so half of the fibers are stressed higher under load. In the second concept, we switched to metallic edges that do not come near the strength to weight ratio of composites. In theory, both of these concepts could work if a sufficient quantity of material is used, but this would not result in a lightweight design.

3-4. Synthetic slings made from high strength yarns take advantage of continuous fibers. Actually, the yarns are a combination of aramid and polyethylene fibers. The polyethylene fibers act as a lubricant so that the aramid fibers are stressed evenly under load. Commercially available synthetic slings with a breaking strength of 1,000,000 pounds weigh only 4.37 pounds per foot. Aramid fiber has one of the highest specific strengths of the man-made fibers, being 410 (specific strength = tensile strength x 10^3/specific gravity). Only the latest types of Ultra High Molecular Weight Polyethylene (UHMWPE) fibers, such as Spectra 1000 have a slightly higher specific strength of 435. However, UHMWPE fibers are not recommended for use above 200°F and burn readily. Aramid fiber properties, on the other hand, do not change up to 266°F and do not burn readily. In addition, the UHMWPE fibers do not bond well with thermoset resins, such as epoxy, and must be treated. From this basis, we decided to focus our fiber choice on aramid.

3-5. Our next set of concepts looked into incorporating synthetic sling technology into the design of the container. The first iteration, Figure 3, consisted of two, formed phenolic/aramid shells held together with a synthetic sling-like wrap. The aramid/phenolilc was to be made in accordance with MIL-DTL-62474, Type 2, a well-known armor material. Dana Grow from Sioux Manufacturing did not see a problem in the manufacture of the shells.

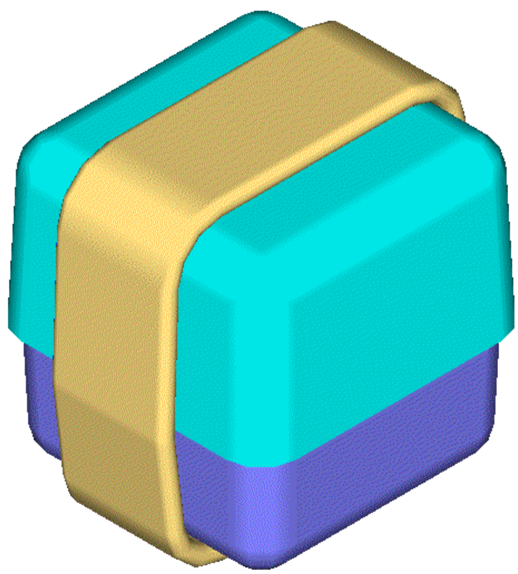

FIGURE 3.

This concept looked promising, however, it was obvious that we still had a situation where many of the aramid fibers used in the construction of the shells are not stressed evenly under load. Inefficient use of material results in a heavier than desired container.

3-6. Our next iteration based on this concept turned to the filament winding process. We believed that with a filament would cylinder, we could more evenly distribute the load to all of the fibers. Plugs made from composite armor would be used at both ends to contain the effects of the explosive blast. A synthetic sling-like wrap would be used to keep the whole assembly together.

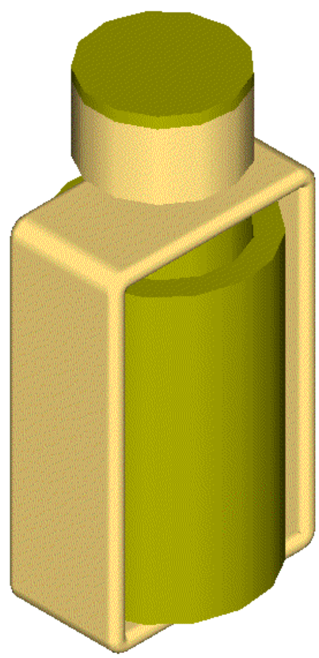

FIGURE 4.

The concept of the filament wound cylinder, Figure 4, is shown with one of the end plugs removed above the synthetic sling-like wrap. The end plug is shown with a cylinder of high-density polyurethane energy absorbing foam, bonded to a composite disk of aramid/epoxy. C-K composites, a company that manufactures filament wound cylinders, informed us that making the cylinder could easily be done.

3-7. At the same time, another concept was being developed, Figure 5, that uses three-square tubes that slid over one another to form a closed container. The tubes can each be made using the filament winding process around a square mandrel of required size. The pressure tape winding process could also be used to make them. Either method of manufacture would use a low modulus aramid fiber in an epoxy matrix. The low modulus fiber has higher elongation and is better at absorbing impact energy. This concept became known as the “box in a box in a box”.

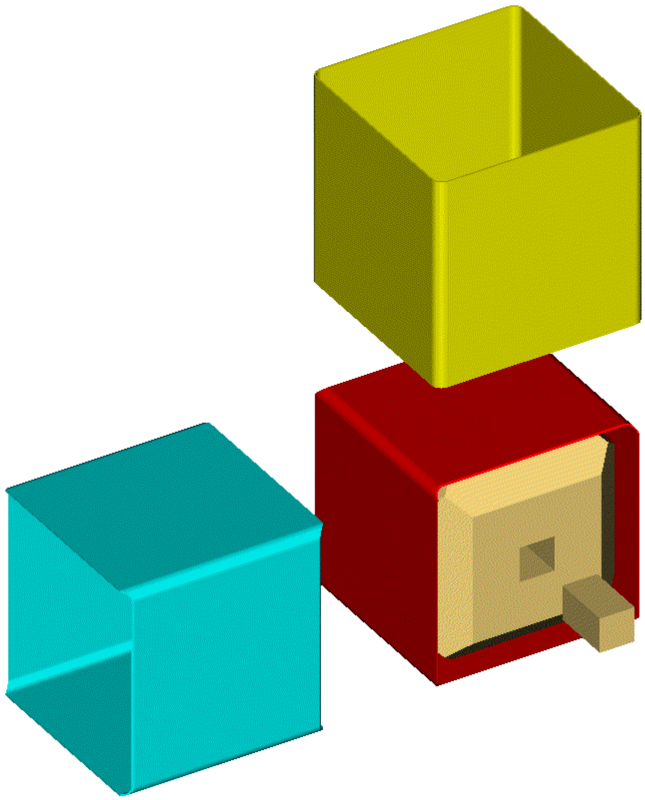

FIGURE 5.

The filament or pressure tape winding process would allow the continuous aramid fibers to be used in their most efficient orientation for each tube or box. Each side of the assembled box had two layers of composite material oriented 90° to each other. The design would in effect mimic three bands or slings acting as a high-pressure vessel. We believed this design offered the most promise to evenly distribute the resultant loads to the aramid fibers.

3-8. Igor Paley's container differs in that it uses Honeywell's UHMWPE fiber called Spectra and a thermoplastic resin. Semi-unidirectional fabric or approximately 75% in one direction is wrapped around a square mandrel. A thin sheet of thermoplastic resin separates each layer of fabric. A heated platen then fuses each side together under pressure.

Explosive testing of Paley's containers proved very positive. In fact, one of the successful tests involved containing the effects of one pound of C4 in a container than measures 18" x 18" x 27" and weights 82 lbs. The container dimension and weight were very close to our goal as written in the ONR proposal. We believe Igor Paley has a very good understanding of the science involved in the container, and testing confirms this. We also believe there is more valuable information to be learned.

4. CONCLUSION

4-1. It is obvious that a container made and constructed from Spectra fiber, the way Igor Paley has done, offers several advantages over a filament wound aramid/epoxy container. First, Spectra 1000 fiber possesses a higher specific strength over aramid. Secondly, the way the box is constructed allows the edges to remain flexible, thereby reducing stress concentration along the edges. This in effect is acting more like a sling, distributing the stress to all the fibers. In fact, one of Igor's successful prototypes is a soft-sided container. It is also apparent from the testing of Igor's containers that the transient nature of an explosive blast does not have an appreciable effect on the properties of the material, as was once feared. Thirdly, the manufacturing method used to construct the container is rather simple. It is for these reasons the PHST Center has moved from an aramid/epoxy container to a Spectra/thermoplastic container. The PHST Center believes that this approach hold the most promise to deliver a lightweight explosives blast containment container.