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PROJECTILE-IMPACT-INDUCED FRACTURE OF LIQUID-FILLED, FILAMENT-REINFORCED PLASTIC OR ALUMINUM TANKS

by Francis S. Stepka

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Cleveland, Ohio

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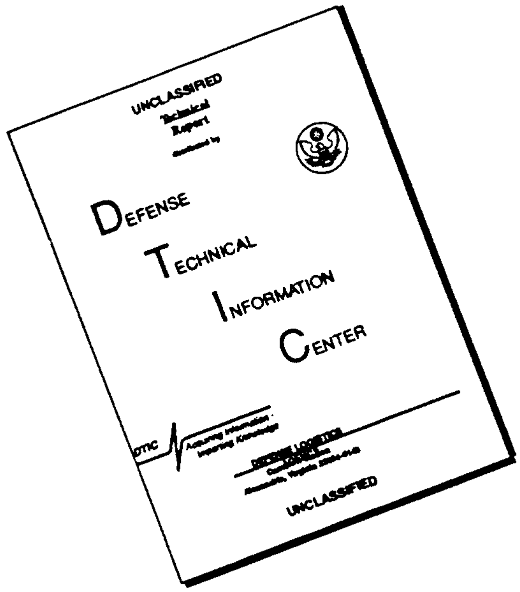

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SUMMARY

An experimental evaluation was made of the impact-fracture characteristics of liquid-filled tanks with walls of several filament-reinforced plastic materials. Comparisons were also made with tank walls made of an aluminum alloy. The materials evaluated were glass-filament-reinforced urethane or epoxy, Dacron-filament-reinforced urethane, steel-wire-reinforced urethane, and 2014-T6 aluminum alloy. The liquid contained in each tank was either water or liquid nitrogen. The impacting projectiles were 7/32-inch-diameter spheres of steel or aluminum, which were accelerated to velocities of 5500 and 6500 feet per second, respectively.

The glass-reinforced plastics were most resistant to impact-fracture damage; the Dacron-reinforced urethane was least resistant. The glass-reinforced plastic walls were also more resistant to fracture than the aluminum alloy walls. Impacts into liquid-nitrogen-filled cylindrical tanks with approximately 1/32-inch-thick walls of these materials resulted in bursting of an aluminum wall stressed prior to impact to only 10 percent of the material ultimate strength, compared with only a puncture and local delamination of the outer filament layer of glass-reinforced epoxy walls stressed prior to impact to as high as 40 percent of the material ultimate strength.

INTRODUCTION

Meteoroid or projectile impacts into thin-walled, liquid-filled tanks can result in fracturing or bursting the walls. Because of these possible hazards to liquid-propellant tanks of space vehicles, liquid-filled model tanks of several filament-reinforced plastics and an aluminum alloy were impacted to determine the wall-fracture characteristics and the static stress levels at which wall fracture would occur for constant projectile impact conditions.

When a high-velocity projectile penetrates a tank wall, the deceleration of the projectile in the liquid can generate high pressures in the liquid (refs. 1 and 2). The results of reference 1 (which were obtained for metal tank walls only) indicated that above a given impact velocity for each projectile size and material the pressures generated in the liquid were sufficiently large to fracture walls of tanks even if there were no internal pressurization prior to impact.

Reinforced plastic materials have demonstrated many desirable characteristics at cryogenic temperatures, and research is being conducted on the application of tanks made of these materials for containing cryogens in space vehicles. These materials have excellent strength-to-density ratios and notch-strength characteristics relative to metals (ref. 3).

Because of their low elastic modulus and laminated construction, reinforced plastic materials may also have particularly good characteristics in resisting fracture from the pulse loadings induced by projectile impacts. The ability of this class of materials in resisting catastrophic rupture from high-speed projectile impact, however, has not been experimentally investigated.

An experimental investigation was conducted, therefore, to obtain a preliminary evaluation of the impact-fracture characteristics of liquid-filled model tanks with walls of glass-filament-reinforced urethane or epoxy, Dacron-filament-reinforced urethane, or steel-wire-reinforced urethane. Another objective was to compare the results with those of metal tanks with walls of 2014-T6, a relatively high-strength aluminum alloy. All test tanks were filled with either water or liquid nitrogen. Impacting projectiles were 7/32-inch-diameter solid spheres of steel and aluminum, which were accelerated to impact velocities of 5500 and 6500 feet per second, respectively.

APPARATUS

Projectile Accelerator

A 22 caliber Swift rifle was used to launch projectiles into test walls of liquid-filled tanks, as shown schematically in figure 1. The rifle was mounted on a table and fired remotely. Projectile velocities were determined from calibration curves of measured projectile velocities for various projectile materials and for various powder charges that were obtained during the investigation of reference 1. Projectiles used were 7/32-inch-diameter solid spheres of either aluminum or steel with impact velocities of 5500 and 6500 feet per second, respectively. These velocities were the maximum attainable with the rifle used.

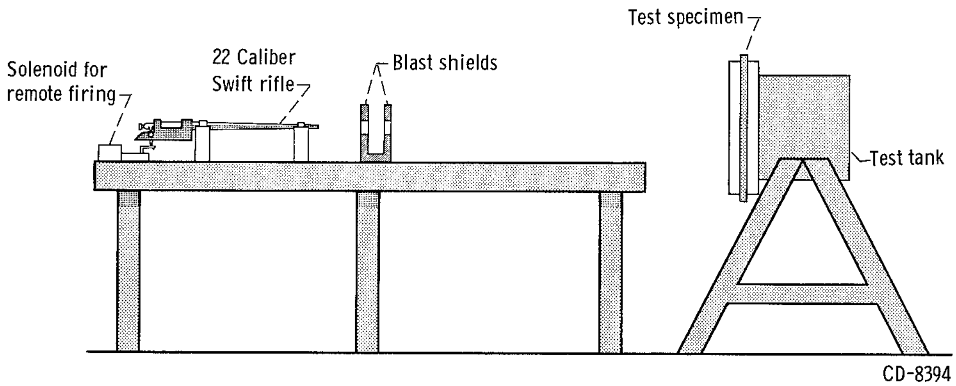

Figure 1. - Projectile accelerator.

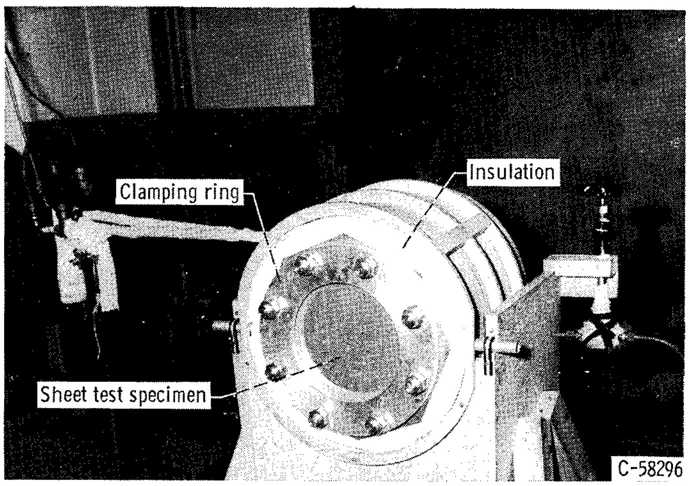

Figure 2. - Cylindrical liquid-filled tank used for investigation of impact-fracture sheet wall specimens.

Test Specimens

Two types of wall specimen were investigated. One was a flat sheet of test material about 16 inches wide, mounted at the open end of a cylindrical liquid-filled container (fig. 2). The other type of specimen was a cylindrical tank, 6 or $7\frac{1}{2}$ inches in diameter and about 18 inches long (fig. 3). The flat specimens were impacted close to the center, and the model cylindrical tanks were impacted approximately midway between the end closures.

Flat-sheet specimens. - The flat-sheet specimens were used for a preliminary evaluation of the impact-fracture performance of several filament-reinforced plastics. The open-end container onto which these specimens were mounted was made of aluminum and was about 12 inches in diameter and 9 inches deep. Bolts and an aluminum ring (fig. 2) held the test specimens to the container. A 3-inch-thick layer of foam insulation was used over the external surface of the liquid container to prevent excessively rapid boiloff when liquid nitrogen was used.

Specimens investigated were 0.125-inch-thick glass-filament-reinforced epoxy, 0.020- and 0.023-inch-thick glass-fiber-reinforced urethane, 0.063- and 0.067-inch-thick Dacron-filament-reinforced urethane, and 0.026- and 0.032-inch-thick steel-wire-reinforced (about 0.005-in. diam.) urethane. The fibers of these specimens were placed at 90° angles to each other, and there were an equal number of fibers in each direction.

Cylindrical-model-tank specimens. - The cylindrical model tank specimens were

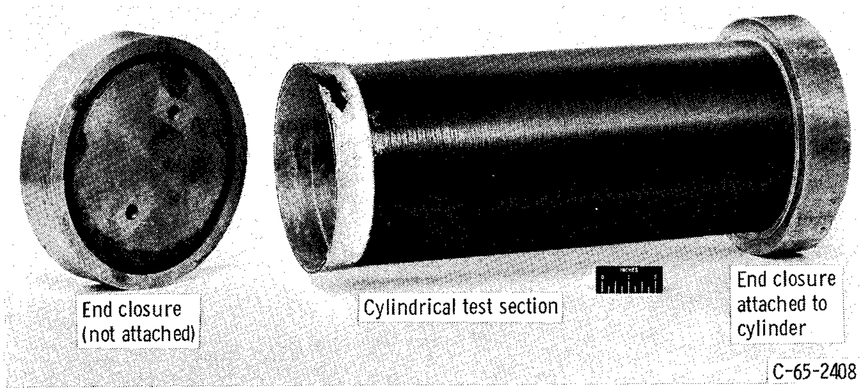

Figure 3. - Cylindrical tank specimen.

used to simulate impact into a wall with a stress field of a cylindrical liquid-filled tank and to test the specimens at higher stress levels than those attainable with the flat-sheet specimens. Heavy aluminum end closures were attached to a hollow cylinder of the test wall material to form a closed tank (fig. 3). A seal and bond at the junction of the cylinder and the end closures was provided by a low-melting-temperature metal alloy, as described in reference 4.

Tank walls investigated were 0.012-, 0.033-, and 0.040-inch-thick glass-filament-reinforced epoxy and 0.032-, 0.063-, 0.081-, and 0.084-inch-thick 2014-T6 aluminum alloy. The filaments of the reinforced plastic cylinders were either helically wound at angles of $\pm 54.7^{\circ}$ to the cylinder axis (this winding angle results in a circumferential-longitudinal-strength ratio of 1), or with circumferential and longitudinal filaments at 90° angles to each other with twice as many circumferential as longitudinal filaments. The aluminum cylinders were rolled from sheet material, and the longitudinal joints were butt-welded.

PROCEDURE

Impacts into Specimens

Individual projectiles were fired into water or liquid-nitrogen-filled tanks with walls of the specimen materials, and the resulting damage was observed. The specimen tank walls were impacted both with and without an initial static stress. Pressurization of the liquid in the tank with gaseous nitrogen induced the desired initial static stress in the walls.

The criterion used to compare the various materials was based on the amount of prestressing (prepressurization) that could be imposed on the specimen walls before fracturing would occur for a single projectile impact condition of size, material, and velocity.

For the sheet specimens, the amount of prestress to which a given material was subjected was expressed only as the actual preload stress value, because the ultimate strengths of these specimen materials were not available. For the model tank specimens, the static stress loading was expressed as the ratio of the preload stress to the ultimate static strength of the material.

Static Stresses in Walls Due to Pressurization

The method used to determine the relation between static wall stresses and container pressure for the sheet wall specimens consisted of measuring the curvature of the test sheet specimen over a range of container pressures and using the equation

$$S = \frac{P\left(R - \frac{t}{2}\right)}{2t}$$

where

P pressure in container or test tank, psi

R radius of external wall, in.

S wall stress, psi

t thickness of wall, in.

This equation determines only the membrane stresses. Bending stresses were neglected because their effect on the results with these specimens was not expected to be large.

For the cylindrical-model-tank specimens, only the hoop stresses due to static liquid pressurization were determined. These stresses were evaluated from the equation

$$S = \frac{P\left(R - \frac{t}{2}\right)}{t}$$

RESULTS AND DISCUSSION

Tabulations of the filament-reinforced plastic materials and the aluminum alloy investigated, along with impact conditions and the resulting condition of the materials after impact, are presented in tables I and II.

TABLE I. - IMPACTS INTO SHEET SPECIMEN WALLS ON LIQUID-FILLED CONTAINER

[Impacting projectiles, 7/32-in.-diam metal spheres.]

Test	Tank wall		Liquid	Tank pressure prior to impact, psig	Wall membrane stress, psi	Projectile		Condition of wall after impact
	Material	Thickness, in.				Material	Velocity, ft/sec	
1	Glass-filament-reinforced epoxy	0.125	Water	0	0	Aluminum	6500	(a)
2	Glass-filament-reinforced urethane	.020	Water	0	0			(a)
3	Dacron-filament-reinforced urethane	.063	Water	50	3 900			(a)
4		.063	Nitrogen	50	8 000	Steel	5500	(a)
5		.063		100	12 800			(b)
6		.067		100	12 800			(b)
7	Steel-wire-reinforced urethane	.032		100	29 000			(a)
8		.026		150	28 500			(a)
9		.026		175	30 000			(a)
10		.032		175	37 000			(c)
11	Glass-filament-							
12	reinforced urethane	.020		50	26 700			(a)
13		.020		100	38 000			(a)
14		.023		125	39 800			(a)
		.023		150	43 500			(d)

[a]Hole plus local delamination of outer filament layer.
[b]Large fracture or bursting of wall.
[c]Hole plus extreme delamination.
[d]Hole plus small crack near hole and local delamination.

Sheet Wall Specimens

The initial investigation of the reinforced plastics was made by impacting a high-velocity projectile into flat-sheet specimens bolted to the front face of a water- or a liquid-nitrogen-filled container. The results with these specimens are summarized in table I.

Specimens on water-filled containers. - Impacts were initially made into unstressed specimens on a water-filled container. Impacts with a 7/32-inch-diameter aluminum sphere at a velocity of about 6500 feet per second into 0.125-inch-thick glass-filament-reinforced epoxy and 0.020-inch-thick glass-filament-reinforced urethane sheet speci-

TABLE II. - IMPACTS INTO LIQUID-NITROGEN-FILLED CYLINDRICAL TEST TANKS

[Impacting projectiles, 7/32-in.-diam steel spheres; velocity, 5500 ft/sec.]

Test	Tank wall				Tank diameter, in.	Tank pressure prior to impact, psig	Ratio of wall stress to ultimate strength	Condition of wall after impact
	Material	Thickness, in.	Type	Ultimate hoop strength, psi				
15	Glass-filament-	0.040	(a)	112 000	7.5	1040	0.80	(b)
16	reinforced epoxy					780	.60	
17						650	.50	
18						585	.45	
19						455	.35	(c)
20						500	.38	
21		.040	(d)	115 000		615	.50	
22		.033	(e)	204 000		720	.40	
23		.012	(e)	156 000		100	.20	(b)
24	Aluminum alloy,	.032	(f)	92 000		78	.10	(b)
25	2014-T6	.032				0	0	(g)
26		.063				458	.30	(h)
27		.081			6.0	830	.33	
28		.081			6.0	1180	.48	
29		.084			6.0	1500	.58	(b)

[a]Filaments helically wound at angle of ±54.7° with cylinder axis; glass roving E-801.
[b]Large fracture or bursting of wall.
[c]Hole plus local delamination of outer filament layer.
[d]Circumferential and longitudinal filaments wound 90° to each other; glass roving E-801.
[e]Circumferential and longitudinal filaments wound 90° to each other; glass roving E-HTS.
[f]Solid metal.
[g]Hole plus small crack near hole.
[h]Hole only

mens (tests 1 and 2, respectively, table I) resulted in only a penetration of the specimens and delaminations of the outer filament layer of the specimens in the vicinity of the impact. The results of the impact into the 0.125-inch-thick specimen are shown in figure 4. Before a photograph of the complete specimen was made, a portion of the specimen material had been removed after the impact for use in another investigation. An outline of the portion removed is shown with dashed lines.

Because no fracturing of the initially unstressed specimens was obtained, impacts were initiated into stressed specimens. Impact into a 0.063-inch-thick sheet specimen of a Dacron-filament-reinforced urethane pressurized to 50 pounds per square inch gage (initial static membrane stress, about 3900 psi) also resulted in only a penetration and delamination of the outer fibers.

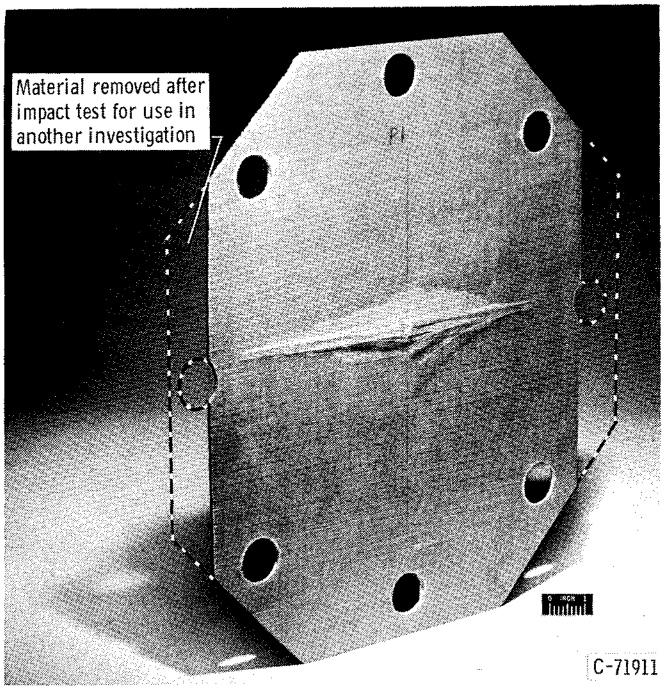

Figure 4. - Impact into unstressed 0.125-inch-thick glass-reinforced epoxy specimen wall on water-filled tank (test 1). Impacting projectile, 7/32-inch-diameter aluminum sphere; velocity, 6500 feet per second.

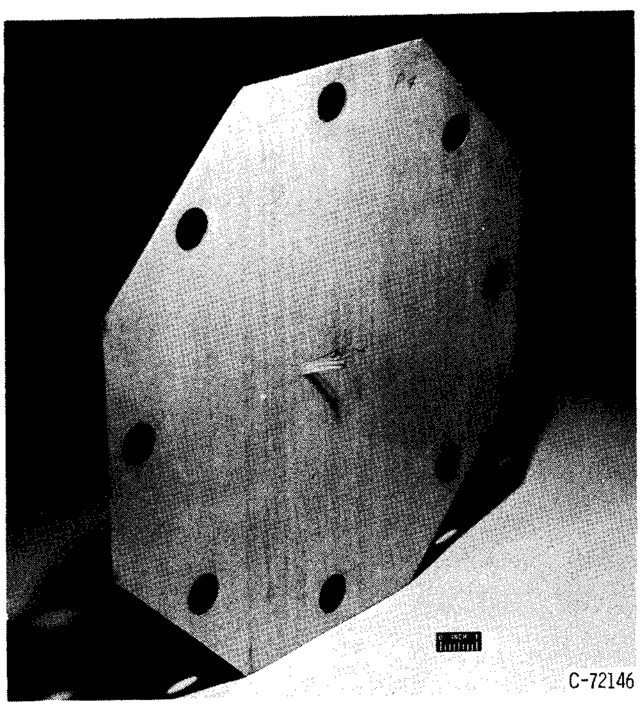

Figure 5. - Impact into 0.063-inch-thick Dacron-reinforced urethane specimen wall on liquid-nitrogen-filled tank pressurized to 50 pounds per square inch gage (test 4). Impacting projectile, 7/32-inch-diameter steel sphere; velocity, 5500 feet per second.

No further testing was conducted with water as the liquid because of large yielding in the vicinity of the bolt holes of the specimens as the static pressure was increased. This yielding was due to the low modulus of elasticity of the specimen material at the temperature of the water.

Specimens on liquid-nitrogen-filled containers. - The use of liquid nitrogen reduced the yielding near the bolt holes in the specimens and represented a better simulation of the environment to which reinforced plastic tank material might be subjected in actual applications.

Dacron-filament-reinforced urethane specimens: An impact made with a 7/32-inch-diameter steel sphere at a velocity of about 5500 feet per second into a 0.063-inch-thick sheet specimen of Dacron-reinforced urethane pressurized to 50 pounds per square inch gage (wall stress, about 8000 psi) resulted in a puncture and a local delamination of the outer filament layer (test 4), as shown in figure 5. When the initial stress before impact in two other Dacron-reinforced specimens (tests 5 and 6) was increased to about 12 800 pounds per square inch (by a liquid pressure of 100 psig), impact by a projectile resulted in catastrophic fracturing of the specimens, as shown in figure 6 for test 5.

Steel-wire-reinforced urethane specimens: Impacts into three of the four specimens of the 0.026- to

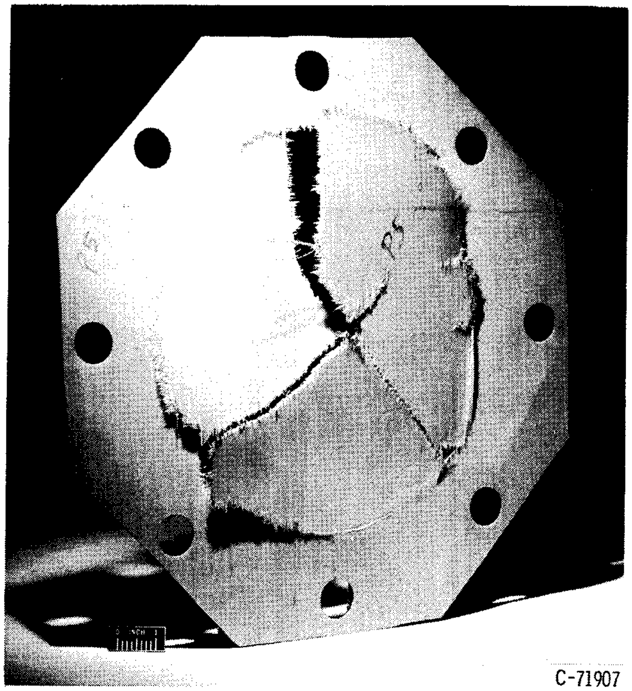

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Figure 6. - Impact into 0.063-inch-thick Dacron-reinforced urethane specimen wall on liquid-nitrogen-filled tank pressurized to 100 pounds per square inch gage (test 5). Impacting projectile, 7/32-inch-diameter steel sphere; velocity, 5500 feet per second.

0.032-inch-thick sheets of steel-wire-reinforced urethane (tests 7 to 9) resulted in only a hole and local delaminations of the outer layer of the wire in the vicinity of the hole. Prior to impact, these specimens were pressurized internally to values of 100 to 175 pounds per square inch gage, which resulted in wall stresses of 28 500 to 30 000 pounds per square inch, respectively. Impact into the remaining specimen with a 0.032-inch-thick wall that was pressurized to 175 pounds per square inch gage (test 10) resulted in large areas in which the wire layers were delaminated. The results of impact into two of these specimens (tests 7 and 10) are shown in figure 7 and 8, respectively.

Glass-filament-reinforced urethane specimens: Three of the glass-filament-reinforced urethane specimens of 0.020- to 0.023-inch thickness (tests 11 to 13) that were impacted after the wall had been initially stressed to levels of 26 700 to 39 800 pounds per square inch (liquid pressures 50 to 125 psig) resulted in only a hole and local delamination of the outer filament layer. Impact into a specimen 0.023 inch thick and pressurized to 175 pounds per square inch gage to induce a wall stress of about 43 500 pounds per square inch (test 14) resulted in local delamination of the outer filament layer and a tearing of the wall extending about 3/4 inch from the edge of the hole (fig. 9). Further testing of the sheet specimens at higher stress levels was impossible because of yielding in the specimen material surrounding the bolt holes.

Comparison of reinforced plastic sheet specimens. - The evaluations of the sheet specimen materials indicated that the glass-reinforced plastic generally exhibited the best resistance to catastrophic rupture from the impulsive pressure loading induced in the liquid by a decelerating projectile. The steel-wire-reinforced urethane also had a good resistance to fracture, but, because of the high density of the reinforcing wires, it would not be so desirable a tank wall material as the glass-reinforced resin on a strength-to-weight basis. In addition, a development problem may exist in obtaining an adequate bond between the wires and the matrix to prevent the large delaminations of areas of the wall such as those obtained on one of the specimens tested. The Dacron-reinforced urethane had poor resistance to rupture due to impact.

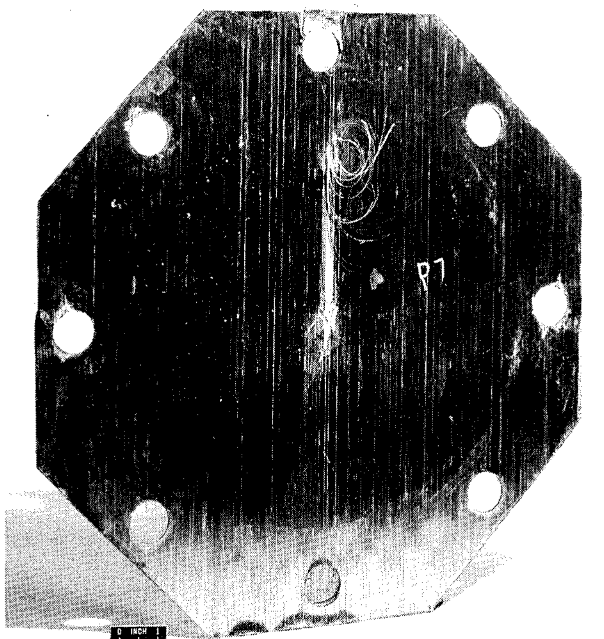


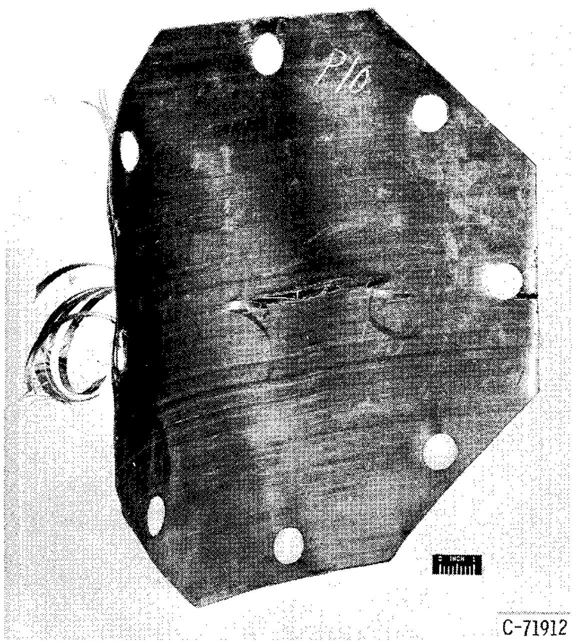
Figure 7. - Impact into 0.032-inch-thick steel-wire-reinforced urethane specimen wall on liquid-nitrogen-filled tank pressurized to 100 pounds per square inch gage (test 7). Impacting projectile, 7/32-inch-diameter steel sphere; velocity, 5500 feet per second.

Cylindrical Test Tanks

The results of the preliminary evaluation of the aforementioned sheet materials suggested that glass-reinforced plastic materials should be evaluated further, particularly at higher stress levels than those attainable with the sheet specimens. The specimens for this additional evaluation were cylindrical tanks of glass-reinforced epoxy of the type and size described in APPARATUS. Cylindrical tanks of 2014-T6 aluminum alloy were also evaluated to compare their relative resistance to fracture with that of filament-reinforced plastic tanks. The tanks were filled with liquid nitrogen and were so pressurized internally that various static wall stresses were induced prior to impact. The tanks were impacted with 7/32-inch-diameter steel spheres at a velocity of about 5500 feet per second. The results with these specimens are summarized in table II (p. 7).

Impacts into glass-filament-reinforced epoxy. - The fiber-glass tanks that were investigated can be divided into two groups. One group consisted of six tanks of 0.040-inch-thick walls, which had filaments helically wound at an angle of $\pm 54.7^{\circ}$ with the cylinder axis, and the other group consisted of three tanks with 0.040-, 0.033-, and 0.012-inch-thick walls, which had circumferential and longitudinal filaments wound at 90° angles to each other. Because the reinforced plastics were not completely impermeable to the liquid under pressure, a 0.005-inch-thick inner liner of aluminum was placed in the tanks. The ultimate burst pressure of each of these groups of tanks filled with liquid nitrogen was obtained as part of the investigation reported in reference 5. These tests indicated material ultimate strengths of 122 000 and 115 000 pounds per square inch for the 0.040-inch-thick wall tanks of the first and the second groups, respectively, which were wound with glass roving E-801 (an amino silane), and material ultimate strengths of 156 000 and 204 000 pounds per square inch, respectively, for the 0.012- and the 0.033-inch-thick walls of the tanks in the second group, which were wound with a higher strength glass roving E-HTS (an epoxy resin and amino silane). Part of the differences in the strengths may also be attributed to variables in the fabrication of the tanks.

Impacts into four tanks of the first group, pressurized prior to impact to produce



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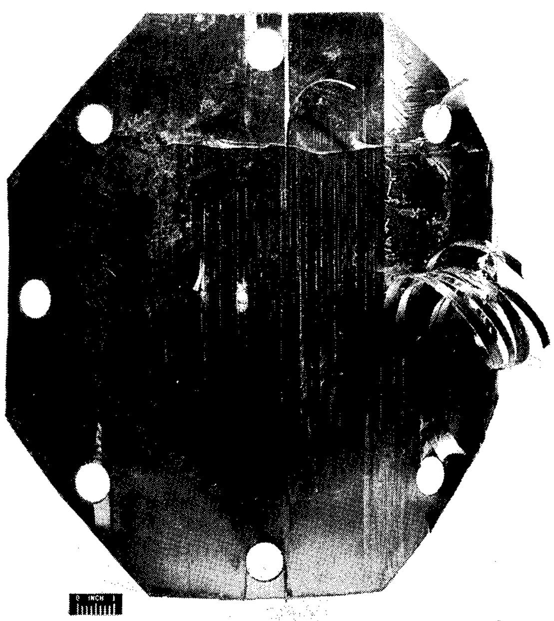
(a) Impact side.



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(b) Rear side.

Figure 8. - Impact into 0.032-inch-thick steel-wire-reinforced urethane specimen wall on liquid-nitrogen-filled tank pressurized to 175 pounds per square inch gage (test 10). Impacting projectile, 7/32-inch-diameter steel sphere; velocity, 5500 feet per second.

wall-stress - ultimate-strength ratios of 0.8, 0.6, 0.5, and 0.45 (tests 15 to 18), resulted in fracture of the walls in respectively decreasing extent. The results of impact into the tanks with the wall-stress - ultimate-strength ratios of 0.8 and 0.5 (stress of 80 and 50 percent of ultimate stress) are shown in figures 10(a) and (b), respectively. When the internal pressure in the tanks of this group was reduced to produce a ratio of wall stress to ultimate strength of 0.35 and 0.38 prior to impact (tests 19 and 20), only a hole with local delamination of the outer filament layer was obtained as a result of impact. The results of impact for the tank with the ratio of wall stress to ultimate strength of 0.38 and shown in figure 10(c). The results obtained with the first group of tanks indicated that the critical ratio of wall stress to ultimate strength prior to impact for fracture at the imposed impact conditions was between 0.38 and 0.45

The tank with the 0.040-inch-thick wall in the second group was pressurized prior to impact to produce a wall-stress - ultimate-strength ratio of 0.5 (test 21). Although catastrophic fracture of the tank was expected, based on the results of the first group of tanks tested, only a hole was obtained with delamination of the outer filament layer around the tank in the vicinity of the puncture. Although one data point is not sufficient for a conclusion, the result obtained might imply that the winding of the filaments in layers 90° to each other provides a better resistance to fracture from impulsive loading compared with a helically wound glass-filament-reinforced epoxy tank. Impact into the 0.033-inch-thick wall tank at a wall-stress -

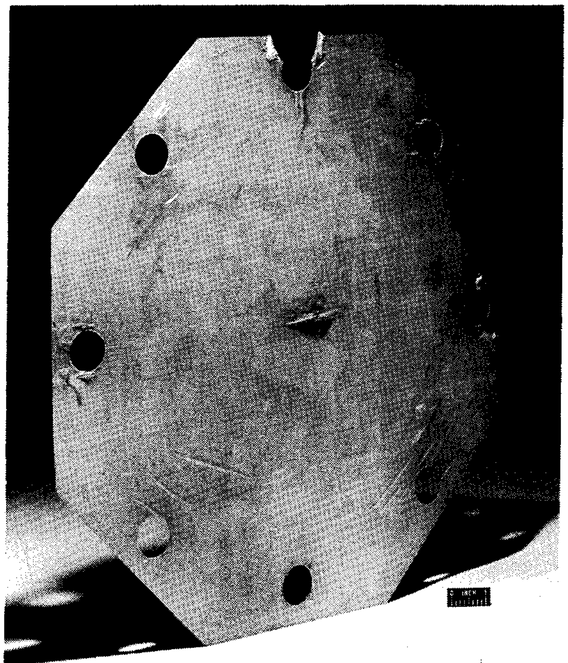

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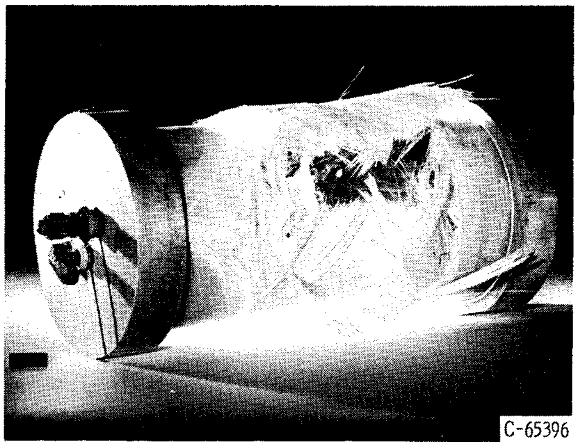
Figure 9. - Impact into 0.023-inch-thick glass-reinforced epoxy specimen wall on liquid-nitrogen-filled tank pressurized to 150 pounds per square inch gage (test 14). Impacting projectile; 7/32-inch-diameter steel sphere; velocity, 5500 feet per second.

ultimate-strength ratio of 0.4 (test 22) also resulted in only a hole and delamination of the outer layer of filaments around the tank (fig. 10(d)). Impact into the 0.012-inch-thick wall tank with an initial wall-stress - ultimate-strength ratio of 0.2 (test 23) resulted in catastrophic bursting of the wall. This result, obtained with the relatively low-stressed thin-walled tank, indicates that as the tank walls become thinner (1) the transient stresses produced in the wall by the pressure pulse generated in the contained liquid by the decelerating projectile become the dominant factor influencing the fracturing of the tank wall and (2) fracture becomes less dependent on the initial static stress level in the walls.

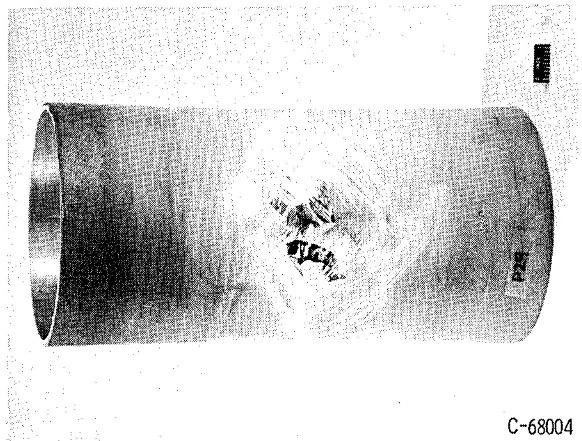
Impacts into aluminum tanks. - Impacts were made into six 2014-T6 aluminum alloy tanks with wall thicknesses of 0.032 to 0.084 inch. The ultimate strength of the tank walls, 92 000 pounds per square inch, was obtained from burst tests of 2014-T6 aluminum tanks filled with liquid nitrogen (ref. 6).

Impacts into one of the tanks with a 0.032-inch wall thickness with an initial static tank wall-stress - ultimate-strength ratio of 0.1 (test 24) resulted in a catastrophic bursting (fig. 11(a)). The result of impact into the same thickness tank without any initial pressurization (test 25) resulted in a hole and a small crack (about 3/8-in. long) at the edge of the hole (fig. 11(b)). Impacts into the tank with a 0.063-inch-thick wall stressed to 30 percent of the material ultimate strength prior to impact (test 26) and into the two tanks with the 0.081-inch wall thickness stressed to 33 and 50 percent of the material ultimate strength (tests 27 and 28) resulted only in holes in the tank walls. Increasing the wall stress to 58 percent of the ultimate for the tank with the 0.084-inch-thick wall (test 29) resulted in catastrophic bursting of the wall as a result of projectile impact.

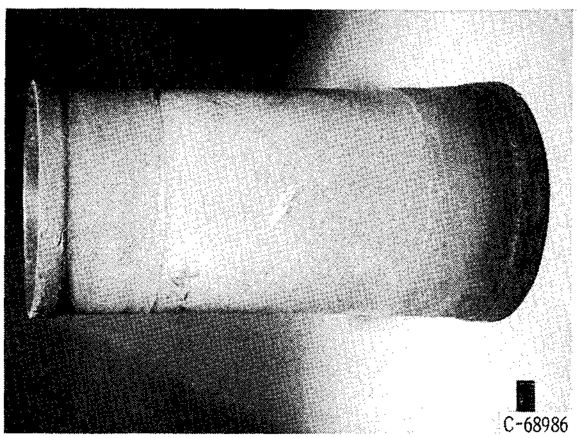
In addition to providing information on the initial wall static stress levels at which impact results in fracture of aluminum tanks, the results illustrate (as did those with the reinforced plastic tanks) that as the walls become thinner, the transient stresses induced in the walls by the pressure pulse in the liquid become the dominant factor influencing fracture. Not only is the thinner wall less able to absorb a given pressure loading without fracture, but as the thickness of the wall is reduced less of the projectile energy is



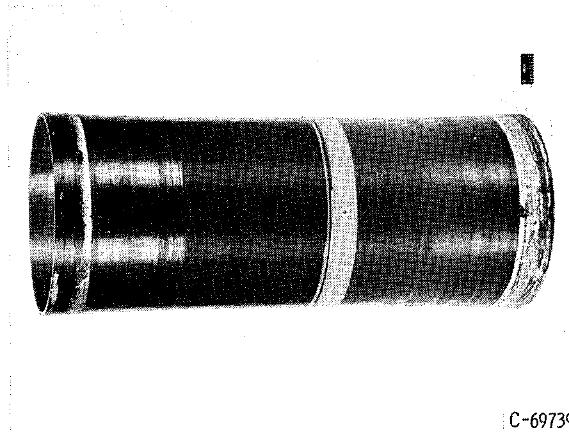
(a) 0.040-Inch-thick, 7.5-inch-diameter tank pressurized to 80 percent of ultimate stress before impact (test 15).



(b) 0.040-Inch-thick, 7.5-inch-diameter tank pressurized to 50 percent of ultimate stress before impact (test 17).



(c) 0.040-Inch-thick, 7.5-inch-diameter tank pressurized to 38 percent of ultimate stress before impact (test 19).



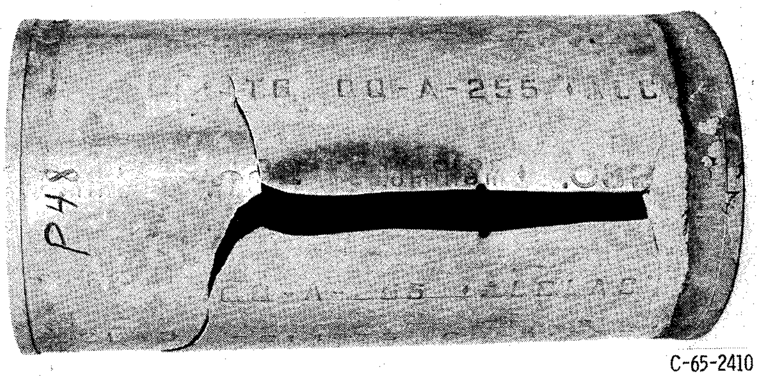
(d) 0.033-Inch-thick, 7.5-inch-diameter tank pressurized to 40 percent of ultimate stress before impact (test 22).

Figure 10. - Results of impact into glass-reinforced epoxy tanks filled with liquid nitrogen. Impacting projectile, 7/32-inch-diameter steel sphere; velocity, 5500 feet per second.

absored in penetrating the wall, and a higher pressure pulse is generated in the liquid and transferred to the wall.

Impact-Fracture Resistance of Reinforced Plastic and Aluminum Tanks

The results of the impact into the sheet specimen of 0.020-inch-thick glass-reinforced urethane on an unpressurized water-filled tank (test 2) indicated a superior performance compared with the catastrophic bursting of an even thicker wall (0.032-in.) of 2014-T6 aluminum obtained in the investigation of reference 1 at the same conditions of impact. Although these results indicated that a filament-reinforced plastic wall, about half the weight of an aluminum wall, better resisted the transient stresses imposed by the impact, the results do not have much significance for space applications, when a tank



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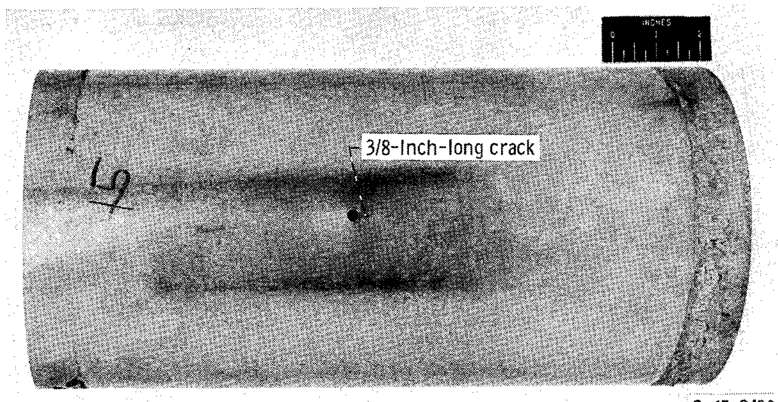
(a) Tank pressurized to 10 percent of ultimate stress before impact (test 24).



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(b) Tank without any initial pressurization prior to impact (test 25).

Figure 11. - Results of impact into 0.032-inch-thick, 7.5-inch-diameter 2014-T6 aluminum tanks filled with liquid nitrogen. Impacting projectile, 7/32-inch-diameter steel spheres; velocity, 5500 feet per second.

is filled with a cryogenic liquid. The reinforced urethane walls at the 70° temperature of the water would be expected to have particularly good impact-fracture resistance because of the low elastic modulus of the wall material. This property permits the reinforced plastic to yield and to absorb the transient pressures to a greater extent than the higher modulus aluminum.

The impacts into liquid-nitrogen-filled cylindrical tanks of glass-filament-reinforced epoxy and 2014-T6 aluminum with about the same wall thickness (1/32 in.) also indicated the superior impact-fracture resistance of the reinforced plastic material. An aluminum tank wall with an imposed initial static wall-stress - ultimate-wall-strength ratio of only 0.1 burst catastrophically when impacted (test 24). The reinforced plastic tank was able to resist impact fracture even though the ratio of wall stress to ultimate strength of the wall was 0.4 (test 22). After impact, this tank wall had only a puncture with local delamination of the outer layer of filaments.

SUMMARY OF RESULTS

The following results were obtained when reinforced plastic or aluminum alloy tanks filled with either water or liquid nitrogen were impacted by small high-velocity projectiles:

1. Walls of glass-filament-reinforced urethane on tanks containing liquid nitrogen were more resistant to damage from the pressure pulse induced in the liquid by projectile impact than the other reinforced plastics evaluated, namely, Dacron-filament-reinforced and steel-wire-reinforced urethanes. Impacts into the walls of the glass-reinforced urethane and the steel-wire-reinforced urethane generally resulted in only a hole with a local delamination of the outer fiber layer in the vicinity of the impact. A greater area of delamination was obtained with the wire-reinforced plastic than with the glass-reinforced plastic. Impacts into the Dacron-reinforced urethane walls resulted in a bursting of the walls.

2. The resistance to impact fracture of the glass-reinforced urethane walls on a water-filled tank was greater than that of a 2014-T6 aluminum alloy wall. Impacts into initially nonstressed walls resulted in only a puncture and a local delamination of the outer layer of the wall of a 0.020-inch-thick glass-reinforced urethane compared with a bursting of a 0.032-inch-thick 2014-T6 aluminum wall.

3. Impacts into pressurized tanks filled with liquid nitrogen also indicated that glass-reinforced epoxy walls resisted fracture to a greater extent than did walls of 2014-T6 aluminum. Impacts into test tanks with approximately 1/32-inch-thick walls of these materials resulted in bursting of an aluminum wall stressed to only 10 percent of the material ultimate strength compared with only puncturing and locally delaminating the outer filament layer of a glass-reinforced plastic wall stressed to as high as 40 percent of the material ultimate strength.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, March 1, 1966.

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