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by C. Robert Morse and Francis S. Stepka

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

High-speed rifles and light-gas guns were used to accelerate projectiles for impact into unpressurized, water-filled tanks having walls of 1/32-inch-thick (0.795-mm-thick) 7075-T6 aluminum. The projectiles were solid spheres of aluminum or steel with diameters of 1/32, 1/16, 1/8, or 7/32 inch (0.795, 1.59, 3.175, or 5.56 mm).

The tank walls were impacted with each projectile material and size at velocities from 4530 to 24 300 feet per second (1.38 to 7.41 km/sec). Threshold values of projectile kinetic energy and velocity were determined above which fractures resulted and below which only punctures occurred.

For a given projectile material, wall fractures were obtained at lower kinetic energy levels for the smaller diameter projectiles. For projectile diameters greater than 1/16 inch (1.59 mm) aluminum projectiles caused wall fracture at substantially lower kinetic energy levels than did the same diameter steel projectiles; however, the reverse was true for projectile diameters less than 1/16 inch (1.59 mm).

The threshold-impact velocity required for wall fracture with steel and aluminum projectiles was found to be inversely proportional to the projectile diameter to about the 0.65 power and 1.15 power, respectively.

The threshold-impact kinetic energy resulting in wall fracture with the steel and aluminum projectiles was directly proportional to the projectile diameter to about the 1.7 power and 0.7 power, respectively.

INTRODUCTION

When a high-velocity projectile, such as a meteoroid, penetrates a liquid-propellant tank wall, high pressures can be generated in the contained liquid as a result of the deceleration of the projectile by the liquid. These pressures can result in fracture or complete blowout of the tank wall. The impact conditions under which fracture occurs needs definition.

This investigation, therefore, was conducted to determine the effects of projectile size, material, and impact velocities on the fracture of metal walls of liquid-filled tanks. The investigation was conducted to determine specifically the threshold velocities and kinetic energies above which fractures of the wall will occur for each projectile and to determine relations of the threshold velocity or energy with projectile size and material.

A preliminary experimental study (ref. 1) established some of the factors responsible for fracture of liquid-filled tanks impacted by high-speed projectiles. Reference 1 indicated that the shock pressure generated in the contained liquid by the impacting projectile was the primary factor affecting wall fracture. The data presented, however, were limited to impacts of projectiles of one size and shape and limited to relatively low impact velocities (less than 7600 ft/sec, 2.32 km/sec). A subsequent investigation (ref. 2) studied characteristics such as shock-wave shape and progress and the projectile progress after impact in a water-filled transparent plastic tank.

Reference 2 suggests that, for a given level of projectile impact kinetic energy, a greater hazard of wall fracture may be present for small, high-velocity, low-density projectiles than with more massive low-velocity projectiles.

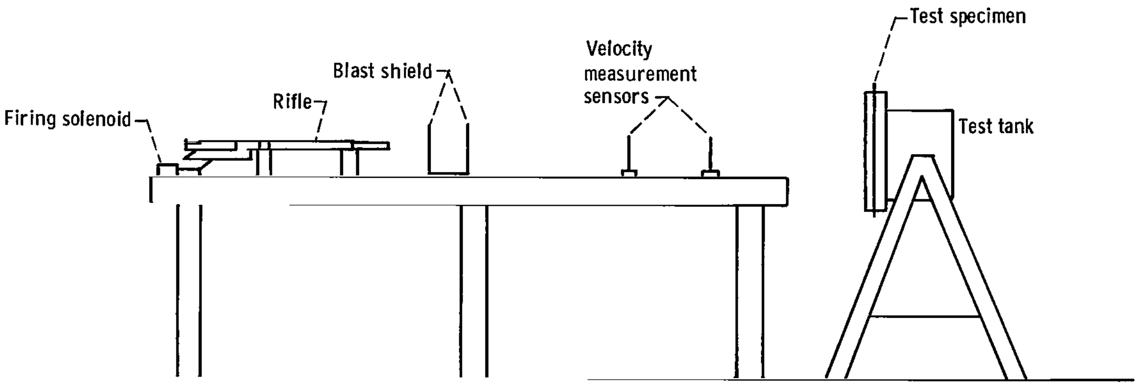
The investigation reported herein determined the effects of projectile size and material. Impacts, therefore, were made into only unpressurized water-filled tanks having walls of the same thickness and material (1/32-inch-thick (0.795-mm-thick) 7075-T6 aluminum). Two projectile materials, aluminum and steel, were investigated. These were selected because of their wide differences in density and hardness. The projectiles were solid spheres with diameters of 1/32, 1/16, 1/8, or 7/32 inch (0.795, 1.59, 3.175, or 5.56 mm). The impact velocities ranged from 4530 to 24 300 feet per second (1.38 to 7.41 km/sec).

APPARATUS AND PROCEDURE

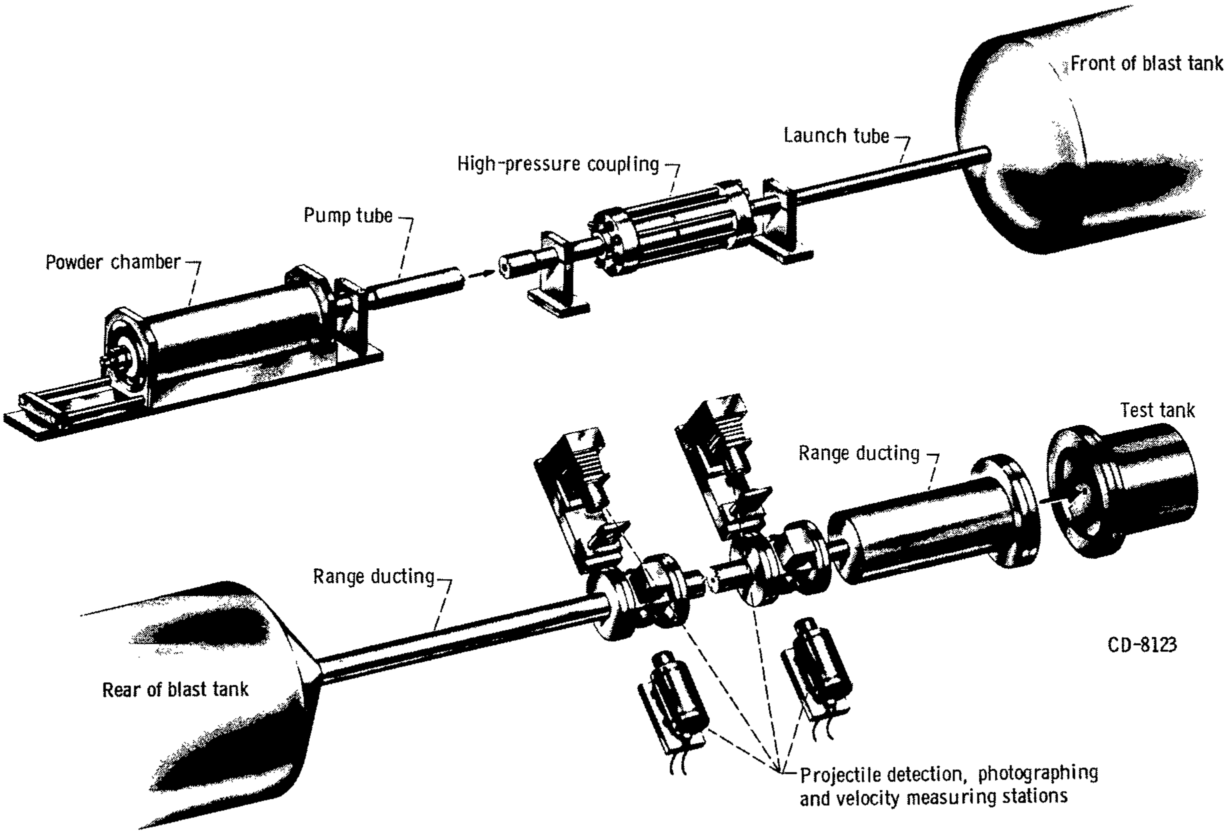
The test apparatus consisted of the projectile accelerators, test tanks, and associated instrumentation for determining the impact-fracture threshold of walls of water-filled tanks.

Projectile Accelerators

220 Swift rifle. - A 220 Swift rifle was used to accelerate the 7/32-inch-diameter (5.56-mm-diam) steel projectiles for impacts at velocities of less than 7000 feet per



(a) 220 Swift rifle facility.



(b) Accelerated reservoir light-gas gun facility.

Figure 1. - Schematic drawings of projectile accelerators and facilities for investigation of projectile impact damage of liquid-filled tanks.

second (2.13 km/sec) and for all impacts with the 7/32-inch-diameter (5.56-mm-diam) aluminum projectiles. The rifle was mounted on a stand (fig. 1(a)) and located about 7 feet (2 m) from the target tank. A solenoid was used to operate the trigger mechanism so that the rifle could be fired remotely. Blast shields were located about 6 inches (15 cm) from the muzzle of the rifle to protect the velocity measuring sensors from damage when the rifle was discharged. Two velocity measuring sensors were located 12 inches (30.48 cm) down range from the blast shields. Each sensor consisted of a 0.25-mil (0.064-mm) Mylar sheet with a layer of vapor-deposited aluminum approximately 1000 angstroms thick (0.1 μ thick) on each side of the Mylar. Penetration of a sensor by a projectile resulted in the shorting of the two layers of aluminum of the sensor, which permitted a capacitor to discharge. The time interval between successive discharges was recorded by an electronic event timer. The projectile velocities were determined by using the intervals and the distance between the sensors. The velocities were varied by hand loading cartridges with specific amounts of gun powder.

Accelerated reservoir light-gas guns. - The impacts by 7/32-inch-diameter (5.56-mm-diam) steel spheres above 7000 feet per second (2.13 km/sec) and all impacts with smaller projectiles were made with a light-gas gun. The guns were located at the Lewis Research Center or at the Denver Research Institute, where some of the tests were performed under NASA contract.

Figure 1(b) shows a schematic drawing of the Lewis accelerated reservoir light-gas gun facility; the main components of the gun are the powder chamber, a 25-foot-long (7.62 m long) pump tube with an 0.8-inch-diameter (20.32-mm-diam) bore; a high-pressure coupling; and a 48-inch-long (1.22 m long) launch tube with 0.22-inch-diameter (5.59-mm-diam) bore. For those tests involving projectiles of diameters smaller than that of the launch tube bore, it was necessary to use a sabot to provide a seal for the driving gases and to hold the projectile during its travel in the launch tube. The sabot was a Lexan or Nylon cylinder 0.22 inch (5.59 mm) in diameter and length. The sabot was separated from the launched projectile as described in reference 2 and deflected from the projectile flight path so that only the projectile impacted the tank wall.

The velocity measurements for the projectiles accelerated by the gun were obtained through the use of a two-station projectile-detector system. This system, described in reference 2, consisted essentially of a mercury-vapor light source, a photoelectric detector at each station, and an electronic timer for recording the time of flight between the two stations. Projectile velocities were determined from the known distance and the time of flight between the detector stations. The test range was evacuated to less than 200 microns of mercury prior to each test in order to minimize the deceleration and the deterioration of the projectile in flight.

A Kerr cell shadowgraph system was used to obtain a short-exposure (50 nsec) photograph of the projectile in flight. It consisted primarily of a light pulse generator, a Kerr cell shutter, and a camera, which were used in conjunction with each of the two stations of the projectile-detector system. The shadowgraph verified the integrity of the projectile.

The Denver Research Institute light-gas gun was essentially the same as the Lewis facility with the exception that the pump tube was 60 inches (1.52 m) long and had a 20-millimeter-diameter (0.7874-in. diam) bore and the launch tube was 60 inches (1.52 m) long and had a 0.30-inch diameter (7.62-mm-diam) bore. The sabot and sabot stripping method were similar to those described in reference 2. The range was 40 feet (12.19 m) long and was evacuated to a pressure of less than 1 millimeter of mercury.

The Denver Research Institute facility velocity measurement system consisted of two silicon photocells; one photocell viewed the muzzle of the launch tube, and the other viewed the test specimen. The output of the two photocells was displayed on a single trace on the screen of an oscilloscope with the velocity calculated from the time between signal excursions and the known distance between the photocells.

The outlet of both Denver Research Institute and Lewis range tanks was sealed with a 0.005-inch-thick (0.127-mm-thick) Mylar diaphragm. The projectile left the evacuated range through this seal and impacted the test tank, located about 1 foot (30.5 cm) from the seal. The decay in the projectile velocity in this distance was negligible. The perforated plastic diaphragm after impact provided a visual verification of the integrity of the impacting projectile.

Test Tanks

The test tanks used in this investigation (fig. 2) were cylindrical metal tanks with one

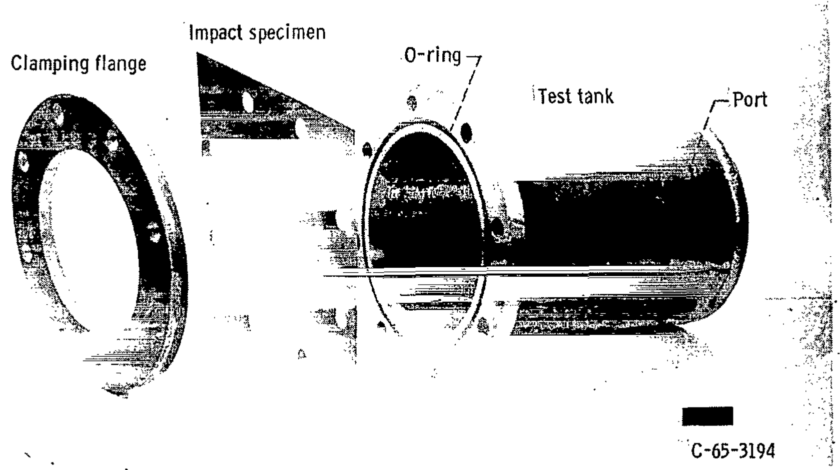


Figure 2. - Test specimen and tank used in investigation of impact damage by spherical projectiles.

removable end. This removable end constituted the test specimen for each impact. The tanks had an inside diameter of about 12 inches (30. 5 cm) and were about 9 inches (22. 9 (22. 9 cm) deep.

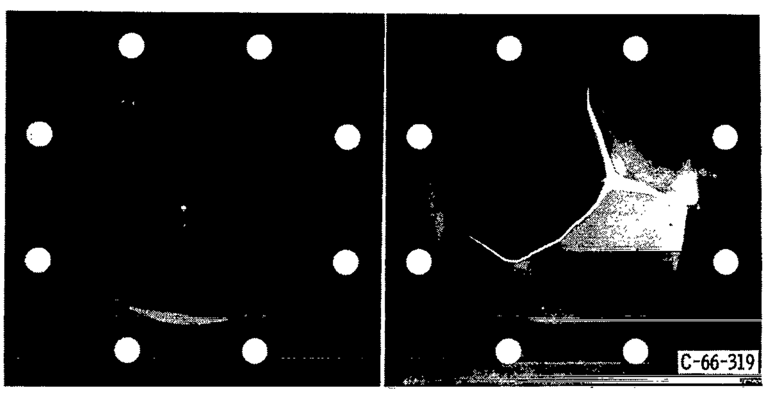
Test Specimen Material

The test specimens were sheets of 1/32-inch-thick (0. 795-mm-thick) 7075-T6 aluminum with a circular test section 11 inches (27. 9 cm) in diameter. The specimens were attached to the end of the test tank by bolts and a 1-inch-thick (2. 54-cm-thick) clamping flange. Sealing was accomplished by use of an O-ring (fig. 2).

The tank was completely filled with water. No internal static pressure was applied. The individual projectiles were impacted into the specimens, and the resulting damage was observed. All impacts made in this investigation were within a 2-inch (5. 08-cm) radius from the center of the specimen.

RESULTS AND DISCUSSION

The design of liquid-propellant tanks that are safe from meteroid penetration or fracture requires extensive knowledge of the effects of a number of variables. Although many impact investigations have been conducted, a correlation is not yet apparent that can include the effects of all the factors such as: projectile size, shape, and material; tank wall thickness, material, and stress; contained liquid; and tank wall protective structures. Therefore, minimizing the variables to be investigated by testing specific



(a) Simple puncture; velocity, 10 000 feet per second (3.05 Km/sec).

(b) Fracture; velocity, 10 800 feet per second (3.29 Km/sec).

Figure 3. - Typical impacts by 1/8 inch-diameter (3.175-mm-diam) steel spheres.

TABLE I. - SUMMARY OF TEST FIRINGS FOR IMPACTS INTO 1/32-INCH-THICK (0. 795-mm-THICK) 7075-T6 ALUMINUM SPECIMENS ON UNPRESSURIZED WATER-FILLED TANK

Projectile diameter, in.	Projectile diameter, mm	Material	Mass, lb	Mass, g	Velocity, ft/sec	Velocity, km/sec	Kinetic energy, ft-lb	Kinetic energy, joules	Gun (a)	Result
7/32	5. 56	Steel	1.54×10^{-3}	0. 699	9 450	2. 88	2137. 8	2898. 5	L	Fracture
					8 150	2. 48	1590. 1	2155. 9	L	Fracture
					7 290	2. 22	1272. 0	1724. 6	L	Fracture
					6 435	1. 96	991. 4	1344. 2	S	Puncture
					6 057	1. 85	878. 4	1191. 0	S	
					6 020	1. 83	867. 6	1176. 3	S	
					5 780	1. 76	799. 8	1084. 4	L	
					5 507	1. 68	726. 1	984. 5	S	
					4 530	1. 38	491. 2	666. 0	S	
		Aluminum	5.53×10^{-4}	0. 251	8 084	2. 46	561. 0	760. 6	S	Fracture
					7 825	2. 39	525. 7	712. 8		
					6 878	2. 10	406. 1	550. 6		
					6 750	2. 06	391. 1	530. 3		
					6 600	2. 01	374. 0	507. 1		Puncture
					6 456	1. 97	357. 8	485. 1		Fracture
					6 447	1. 965	356. 8	483. 8		Puncture
					6 435	1. 96	355. 5	482. 0		Fracture
					6 158	1. 88	325. 5	441. 3		Puncture
					5 995	1. 83	308. 5	418. 3		
					5 565	1. 70	265. 9	360. 5		
					5 447	1. 66	254. 6	345. 2		
					5 362	1. 63	246. 8	334. 6		
1/8	3. 175	Steel	2.87×10^{-4}	0. 130	13 100	3. 99	765. 2	1037. 5	D	Fracture
					12 600	3. 84	707. 9	959. 8		
					12 200	3. 72	663. 7	899. 9		
					11 400	3. 47	579. 5	785. 7		
					11 000	3. 35	539. 5	731. 5		
					10 800	3. 29	520. 0	705. 0		
					10 000	3. 05	445. 9	604. 6		Puncture
					9 650	2. 94	415. 2	562. 9		
					8 900	2. 71	353. 2	478. 9		
					7 500	2. 29	250. 8	340. 0		

[a]220 Swift rifle, S; NASA Lewis light gas gun, L; Denver Research Institute light gas gun, D.

TABLE I. - Concluded. SUMMARY OF TEST FIRINGS FOR IMPACTS INTO 1/32-INCH-THICK (0.795-mm-THICK) 7075-T6 ALUMINUM SPECIMENS ON UNPRESSURIZED WATER-FILLED TANK

Projectile diameter, in.	Projectile diameter, mm	Material	Mass, lb	Mass, g	Velocity, ft/sec	Velocity, km/sec	Kinetic energy, ft-lb	Kinetic energy, joules	Gun (a)	Result
1/8	3.175	Aluminum	1.03×10^{-4}	0.047	16 522	5.04	437.3	592.9	L	Fracture
					15 300	4.66	375.0	508.4	D	Fracture
					13 500	4.11	292.0	395.9	D	Fracture
					13 300	4.05	283.4	384.2	D	Fracture
					13 100	3.99	274.9	372.6	D	Fracture
					12 564	3.83	252.8	342.8	L	Fracture
					11 500	3.51	211.9	287.3	D	Puncture
					10 500	3.20	176.6	239.4	D	Puncture
					8 100	2.47	105.1	142.5	D	Puncture
1/16	1.59	Steel	3.57×10^{-5}	0.016	18 300	5.58	185.7	251.8	D	Fracture, 3 cracks 1/2 to 3/4 in. long (1.27 to 1.91 cm)
					16 800	5.12	156.5	212.2	D	Fracture, 2 cracks 1/8 in. long (0.32 cm)
					15 900	4.85	140.2	190.1	D	Fracture, 2 cracks 1/2 in. long (1.27 cm)
					15 300	4.66	129.8	176.0	D	Puncture
					12 700	3.87	89.5	121.3	D	Puncture
					12 700	3.87	89.5	121.3	D	Puncture
		Aluminum	1.38×10^{-5}	0.0063	24 300	7.41	126.6	171.6	D	Puncture
					22 900	6.98	112.5	152.5	D	Puncture
					17 000	5.18	62.0	84.1	D	Puncture
1/32	0.795	Steel	4.46×10^{-6}	0.002	24 300	7.41	40.9	55.5	D	Puncture
					22 900	6.98	36.4	49.4	D	Puncture

[a]220 Swift rifle, S; NASA Lewis light gas gun, L; Denver Research Institute light gas gun, D.

design configurations is the more effective method of evaluating the impact-fracture hazard.

This investigation was limited to providing relations for predicting fractures of a water-filled tank with walls of a given thickness and material impacted by two different projectile materials of various diameters.

Typical examples of impacted test specimens which resulted in simple puncture or fracture are shown in figure 3. The only exceptions to the typically fractured specimens shown in figure 3(b) were the fractures with the 1/16-inch-diameter (1.59-mm-diam) steel projectiles, where the fracture cracks were less than 3/4 inch (1.91 cm) long. A summary of the relation between the projectile kinetic energy and the projectile velocity for each impact in this investigation is listed in table I and shown in figure 4. The fracture threshold velocities and corresponding kinetic energy values for steel and aluminum projectiles are listed in table II.

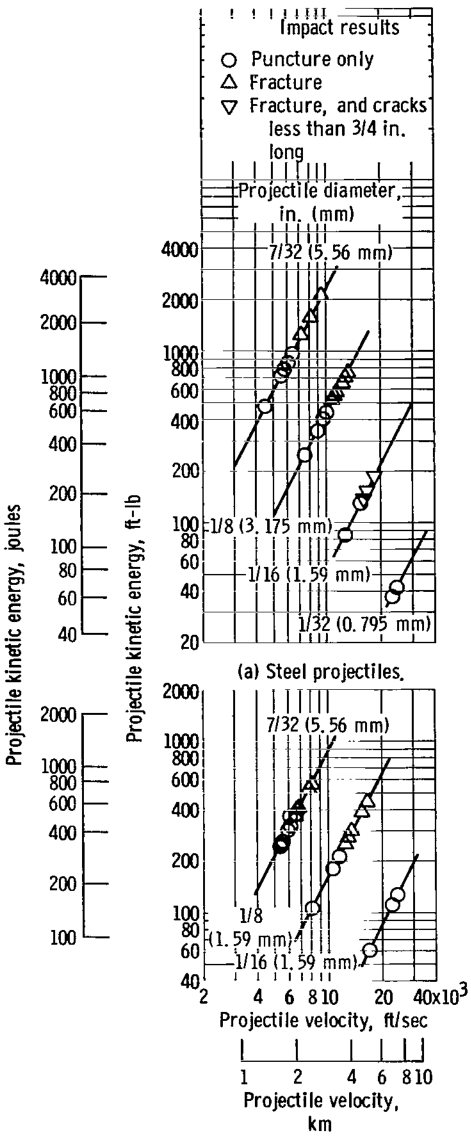


Figure 4. - Summary of projectile velocity as a function of projectile kinetic energy for impacts into 1/32-inch-thick (0.795-mm-thick) 7075-T6 aluminum specimens on unpressurized water-filled tank.

Figure 5 is a plot of projectile velocities and diameters which defined the impact wall-fracture threshold range of this investigation. The points plotted in the figure represent, for each size and material of projectile, the lowest velocity at which fracture occurred and the highest velocity at which only a puncture was obtained. The data indicate that, for steel projectiles, the fracture threshold velocity can be represented by the relation

$$V = \frac{2600}{D^{0.65}}$$

where velocity V is in feet per second, and projectile diameter D is in inches, or

$$V = \frac{6.49}{D^{0.65}}$$

TABLE II. - FRACTURE THRESHOLD PROJECTILE IMPACT VELOCITIES AND KINETIC ENERGY VALUES FOR TANK WALL FRACTURE

Projectile diameter		Lowest level for fracture				Highest level for puncture			
		Velocity		Kinetic energy		Velocity		Kinetic energy	
in.	mm	ft/sec	km/sec	ft-lb	joules	ft/sec	km/sec	ft-lb	joules
Spherical steel projectiles									
7/32	5.56	7 290	2.22	1272.0	1724.6	6 435	1.96	991.4	1344.2
1/8	3.175	10 800	3.29	520.0	705.0	10 000	3.05	445.9	604.6
1/16	1.59	15 900	4.85	140.2	190.1	15 300	4.66	129.8	176.0
1/32	0.795	(a)	(a)	(a)	(a)	24 300	7.41	40.9	55.5
Spherical aluminum projectiles									
7/32	5.56	6 456	1.97	357.8	485.1	6 158	1.88	325.5	441.3
1/8	3.175	12 564	3.83	252.8	342.8	11 500	3.51	211.9	287.3
1/16	1.59	(a)	(a)	(a)	(a)	24 300	7.41	126.6	171.6

[a]No fracture within capability of apparatus.

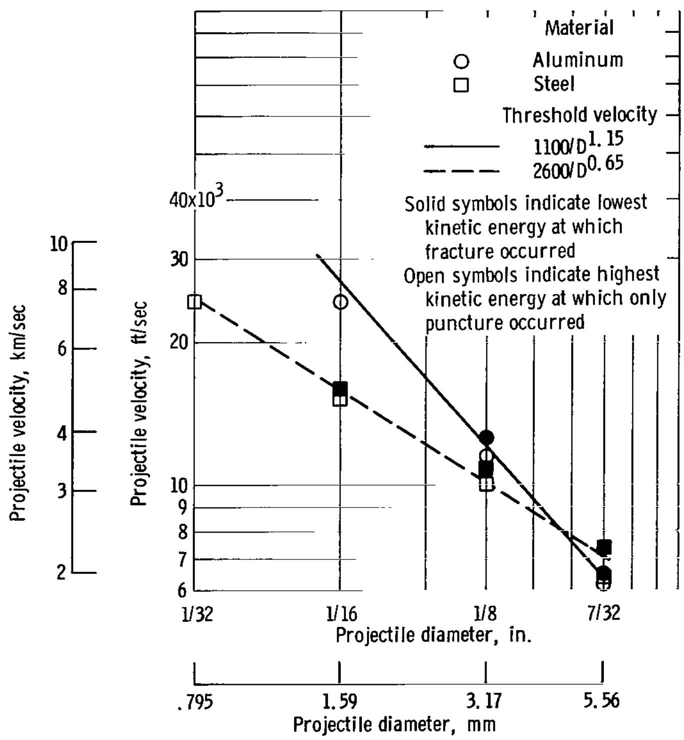


Figure 5. - Projectile velocity and diameter which indicate impact-fracture threshold range for impacts into 1/32-inch-thick (.795-mm-thick) 7075 T-6 aluminum specimens on unpressurized water-filled tank.

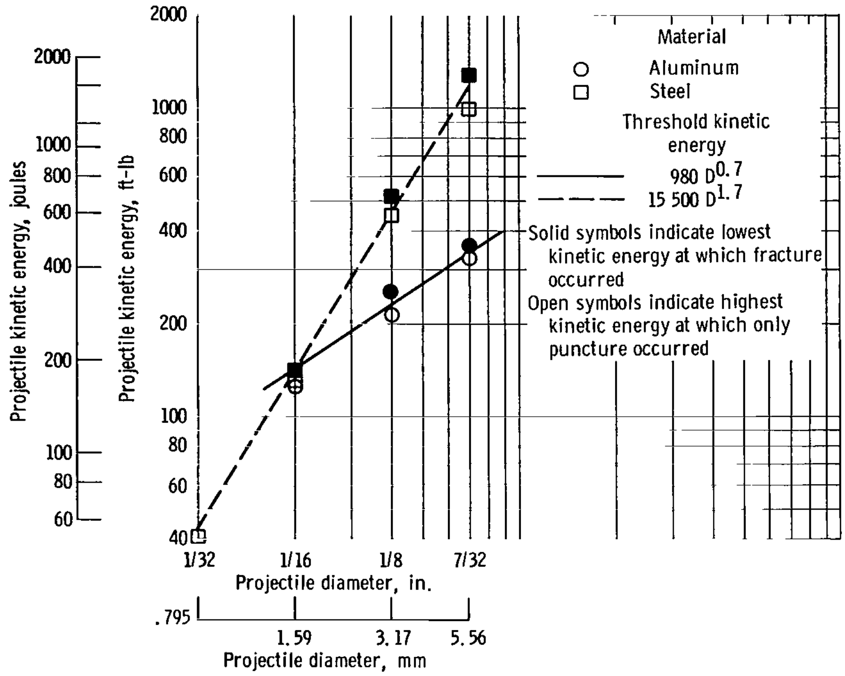


Figure 6. - Projectile kinetic energy and diameter which define impact-fracture threshold range for impacts into 1/32-inch-thick (0.795-mm-thick) 7075 T-6 aluminum specimens on an unpressurized water-filled tank.

where V is in kilometers per second, and D is in millimeters. For aluminum projectiles the relation is

$$V = \frac{1100}{D^{1.15}}$$

where V is in feet per second, and D is in inches, or

$$V = \frac{13.8}{D^{1.15}}$$

where V is in kilometers per second, and D is in millimeters.

Figure 6 is a plot of projectile kinetic energies and diameters which define the impact fracture threshold range of this investigation. The data points in the figure represent, for each projectile size and material, the lowest kinetic energy at which fracture occurred and the highest kinetic energy at which only a puncture was obtained. The data indicate that for steel projectiles the fracture threshold kinetic energy can be represented by the relation

$$KE = 15\,500\ D^{1.7}$$

where kinetic energy KE is in foot-pounds, and projectile diameter D is in inches, or

$$KE = 86.0\ D^{1.7}$$

where KE is in joules, and D is in millimeters. For the aluminum projectiles the relation is

$$KE = 980\ D^{0.7}$$

where KE is in foot-pounds, and D is in inches, or

$$KE = 138\ D^{0.7}$$

where KE is in joules, and D is in millimeters.

The threshold kinetic energy for fracture by the 7/32- and 1/8-inch-diameter (5.59- and 3.175-mm-diam) aluminum projectiles was less than that for the steel projectiles of corresponding diameter. The reason for this for the larger diameter projectiles which were not significantly decelerated by the tank wall is that the less dense and more deformable aluminum projectiles, after entry into the water, decelerated more rapidly than the higher density steel projectiles. Also, based on the results of reference 2, a greater portion of the impact kinetic energy of an aluminum projectile at a given time after impact would be expected to be deposited in the liquid and transferred to the tank wall than with a steel projectile. Other results of reference 2 which determined the pressure at the wave front in water by measurement of the shock-wave-front velocity indicated that the shock-front pressure was primarily influenced by projectile kinetic energy and time and was not significantly influenced by the separate effects of projectile material, size, or velocity. These results in combination with the data reported herein would indicate that wall fracture is influenced not only by the magnitudes of the shock-front pressures, but also by the shape and duration of the pressure pulse behind the fronts.

The difference in the threshold kinetic energies between the steel and aluminum projectiles (fig. 6) was largest for the 7/32-inch-diameter (5.56-mm-diam) projectile. The threshold kinetic energies diminished as the projectile diameter decreased, but at a diameter of about (1.59 mm) the fracture kinetic energies for the steel and aluminum projectiles were approximately the same. Then, as the projectile size decreased further, the aluminum projectiles required a higher impact energy than steel projectiles to cause fracture. The apparent reason for this is that, as the projectile mass is reduced, the wall thickness has a significant effect in reducing the projectile velocity (ref. 3). The residual energies of the aluminum projectiles after penetrating the wall and entering the liquid are expected to be proportionately less than those of the steel projectiles; hence, lower pressures would be generated in the water, and the probability of wall fracture would be reduced.

SUMMARY OF RESULTS

The following results were obtained from an investigation of impacts by spherical steel and aluminum projectiles of various sizes into unpressurized water-filled tanks with 1/32-inch-thick (0.795-mm-thick) 7075-T6 aluminum alloy walls:

1. For a given projectile material, tank wall fracture occurred at lower impact kinetic energies for smaller diameter projectiles.

2. For the larger projectiles, which were not significantly decelerated by the tank wall, aluminum projectiles caused wall fractures at lower impact kinetic energies than those of the same size steel projectiles.

The reverse occurred, however, for the smaller diameter projectiles, which were significantly decelerated by the tank wall.

3. The impact velocity that caused wall fracture with steel projectiles was inversely proportional to the diameter to about the 0.65 power. The impact velocity with aluminum projectiles was inversely proportional to diameter to about the 1.15 power.

4. The impact kinetic energy that caused wall fracture with steel projectiles was proportional to the diameter to about the 1.7 power. The impact kinetic energy with aluminum projectiles was proportional to diameter to about the 0.7 power.

5. Although the results of this and other investigations of impact fractures of tank walls have provided an understanding of the influence of a number of variables, a correlation is not yet apparent that can include the effects of all the variables such as: projectile size, shape, and material; tank wall thickness, material, and stress; contained liquid; and tank wall protective structures.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, May 20, 1966,
124-08-01-36-22.

REFERENCES

1. Stepka, Francis S.; and Morse, C. Robert: Preliminary Investigation of Catastrophic Fracture of Liquid-Filled Tanks Impacted by High-Velocity Particles. NASA TN D-1537, 1963.

2. Stepka, Francis S.; Morse, C. Robert; and Dengler, Robert P.: Investigation of Characteristics of Pressure Waves Generated in Water Filled Tanks Impacted by High-Velocity Projectiles. NASA TN D-3143, 1965.

3. Malik, Donald: An Empirical Study on Residual Velocity Data for Steel Fragments Impacting on Four Materials. Proc. Third Symposium on Hypervelocity Impact, Vol. II, Chicago Ill., Oct. 7-9, 1958. Armour Res. Foundation, Feb. 1959, pp. 5-32.

NASA-Langley, 1966 E-3384

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