Biological Effects of Simulated Micrometeoroid Penetration of a Sealed Chamber Containing Animal Specimens

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CHANCE Vought Corporation, in its in-house research, has been firing aluminum pellets at hypervelocities into a small chamber containing rat specimens. This chamber was located inside a large vacuum tank and the projectiles fired through a vacuum attained velocities of 23,000 fps or approximately 17,000 mph. Evidence of oxidative explosion within the chamber was secured by photography. Animal experiments demonstrated the pathological effect of these explosions on incarcerated rats as ranging from mild to lethal, depending on certain physical factors and the internal environment of the animal chamber.

REVIEW OF THE LITERATURE

Extraterrestrial material in space poses a potential hazard to the crews of space vehicles, particularly on long voyages where the probability of receiving a damaging meteorite hit is enhanced by the long flight time. There is more individual energy in meteoroids than any other type of incident space radiation. Due to their relatively low velocity (11 to 72 km/sec) as compared to high energy corpuscular radiation, meteoroids penetrate only a small distance on impact and release all their energy in this distance.[1,4] Hence the immediate direct effects are much greater than those of cosmic radiation.

The estimated frequency of occurrence of micrometeorites and meteorites entering the earth's atmosphere has varied from 10 tons to 1 million tons per day[3,5] and estimates of their density has varied from 0.05 grams/cubic centimeter dust balls to 8.00 grams/cubic centimeter nickel-iron fragments.[3,5] It is probably safe to assume that the average frequency of occurrence lies somewhere between these values—probably approximately 1000 tons per day. Likewise, it has been accepted practice by several investigators to separate space debris into two categories—the stony and ferrous type meteorites varying in density from 2.8 grams/cubic centimeter to 8.0 grams/cubic centimeter and the dust particle masses of cometary origin having a density of approximately 0.05 to 0.3 grams/cubic centimeter.[2,3,5] Meteoritic debris is generally concentrated in the plane of the ecliptic in the form of streams along the orbits of comets and within the belt of the asteroids.[5] In the near vicinity of the earth, satellite sampling results have indicated millions of micrometeorites of up to pinhead size, in earth orbits from 100 miles altitude to several thousand miles. These particles probably have a density of approximately 2.8 grams/cubic centimeter, that of stone when taken individually. They are trapped by the gravitation field into elongated orbits about the earth, eventually burning up in the atmosphere only to be replaced by other incoming particles.

Of interest, from the standpoint of manned space travel, are the frequency of occurrence and the probability of penetration of the vehicle on impact with this debris, the effects of penetration into pressurized crew compartments, and methods of protection from meteoroid damage. Based on calculated data by Thompson, using Whipple's distribution and Bjork's penetration relationship, it has been estimated that an aver-

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age size space vehicle of 1000 square meter surface area will be penetrated once in 24 hours if it has a .070-inch thick aluminum skin, and once in 120 hours if its skin is 0.1-inch thick. Clearly, the meteoroid risk must be considered for orbiting manned space stations or vehicles enroute to the moon or planets.

As penetration of the space vehicle by meteoroids is a distinct possibility, it is of prime importance to assess the effect of hypervelocity impact into pressurized compartments containing various gas mixtures simulating crew area atmospheres. Undoubtedly, there will be decompression, the rate of which will be dependent upon the hole size and internal pressure. In some designs, the hole size vs. cabin volume may determine compartment size and the need for compartmentation due to rate of decompression considerations.

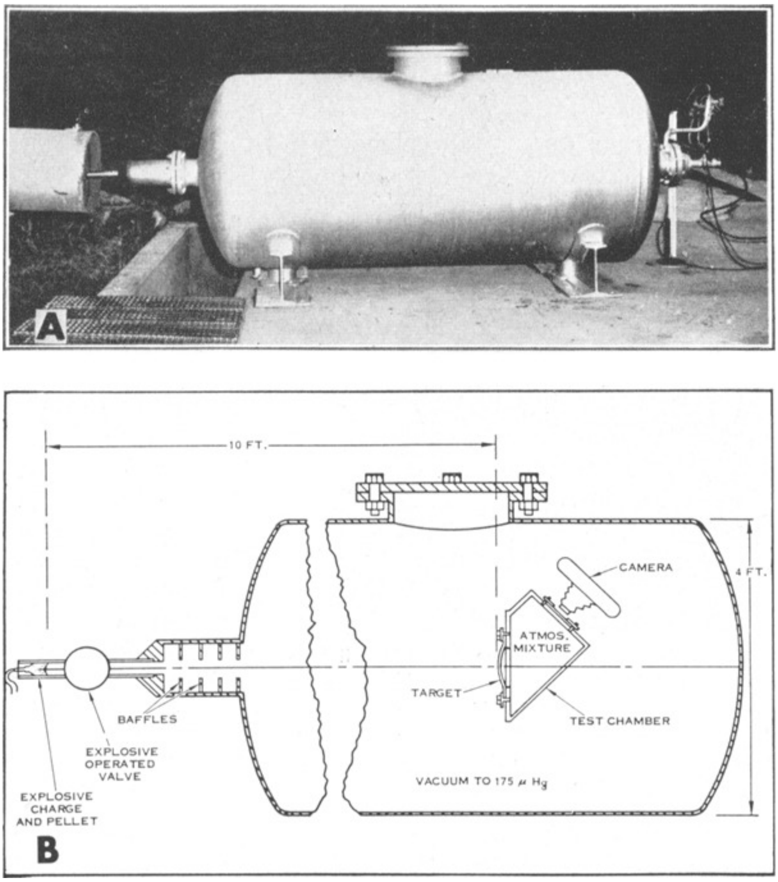

Fig. 1. Hypervelocity impact test facility for simulated meteoroid penetration investigations.

METHOD AND RESULTS

To determine the more unique effects of hypervelocity impact into pressurized crew compartments, a series of tests were conducted by Vought Astronautics in a hypervelocity test facility shown in Figure 1. By means of a special shaped double-density explosive charge, particles were accelerated to hypervelocities in a vacuum and impacted into a number of small vessels containing various atmospheric mixtures. The penetration wall used was .070-inch thick aluminum and the impacting particles were 2S aluminum, varying in diameter from around 10 microns to approximately 2 millimeters. Velocities obtained were in the order of 8 km/sec. for the larger particles and 20 km/sec. for the very small particles.

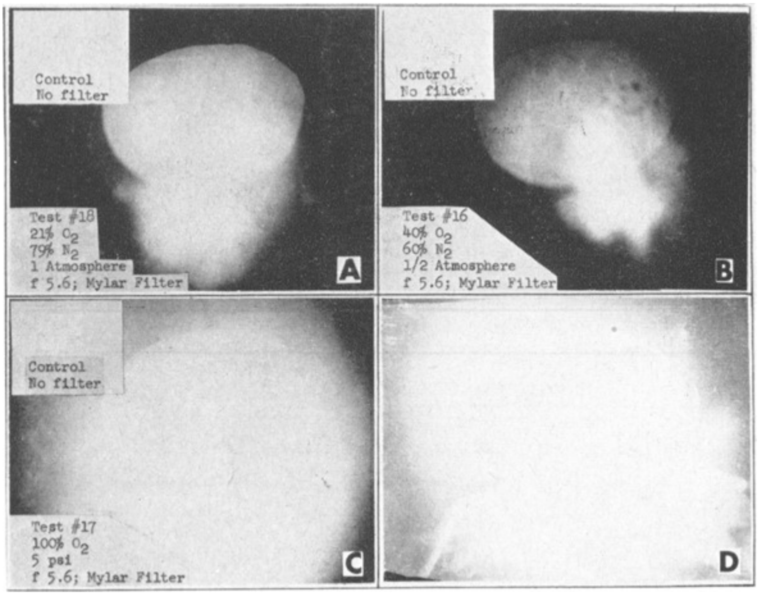

Fig. 2. Oxidative flash occurring in test cell from hypervelocity pellet penetration.—(a) Sea level atmosphere. (b) ½ atmospheric pressure with sea level pp O_2. (c) 1/3 atmospheric pressure with 100 per cent O_2. (d) 100 per cent O_2 with animal specimen. (All exposures through approximately 0.1 per cent transmissibility filter).

When the particles with their very high kinetic energy strike the target surface, the impact produces a very high heat which melts and/or vaporizes the impacting particle and a significantly large volume of the target material producing craters or holes.

If the crater is deep enough to completely penetrate the vehicle wall, the remains of the particle and melted or vaporized target material enter the atmosphere, and a very rapid, almost explosive, oxidation occurs. An intense flash of light is evidenced for a period of .8 to 1.2 milliseconds. Open shutter photographs were taken of the flash in the test chamber through an aluminum coated Mylar filter having a transmissibility of approximately 0.1 per cent. Figure 2 (a, b, and c) shows the flash occurring in various atmospheres of oxygen and nitrogen at the pressures proposed for typical space vehicle systems. The peak flash intensity varies from a low of about 3 million lumens for a standard atmospheric composition at sea level pressure to approximately 20 million lumens for a pure oxygen atmosphere at 5 psia. As a comparison, a standard General Electric Number 5 flashbulb reaches a peak intensity of only 1.2 million lumens. Temperature measurements taken in free air at a distance of 1 inch from the flash indicate temperatures in excess of 1500° F.

The results of the foregoing experiments demonstrated a potentially dangerous situation to man in space should his space craft be penetrated by a meteoroid and an oxidative explosion occur. Generally, it has been assumed that small meteoroid punctures in a space ship would be accompanied by relatively slow leakage. It was presumed that the crew, protected by full pressure suits could conduct damage control and repair the damage. The possibility of intense heat, light and blast introduced a dire possibility. In view of the above information, it was considered highly desirable to conduct some animal studies to assess this danger. A series of tests were conducted wherein single, 300 gram white rats were placed inside the chamber and exposed to the oxidative explosion following penetration by the ultra-high velocity pellet. Six rats were thus exposed. Figure 2-d shows a rat in the chamber at the time of the explosion due to penetration. In the first five rat tests, the atmosphere in the chamber was of near normal atmospheric pressure and composition. All of these rats demonstrated hair and skin burns of varying degrees and extent (Fig. 3—a, b, c, and d). Minor injuries were demonstrated and in most cases subjective symptoms of shock were present. In two cases, there were fractured backs with total paralysis of the lower extremities. None of these animals succumbed in the test, but postmortem studies were made. In the final test, a rat was exposed to oxidative explosion in 100 per cent oxygen. The result was catastrophic with instant death to the rat (Fig. 4—a, b, c, and d). There was total charring of the body. Microscopic damage involved second and third degree burns of the skin and extensive lung damage.

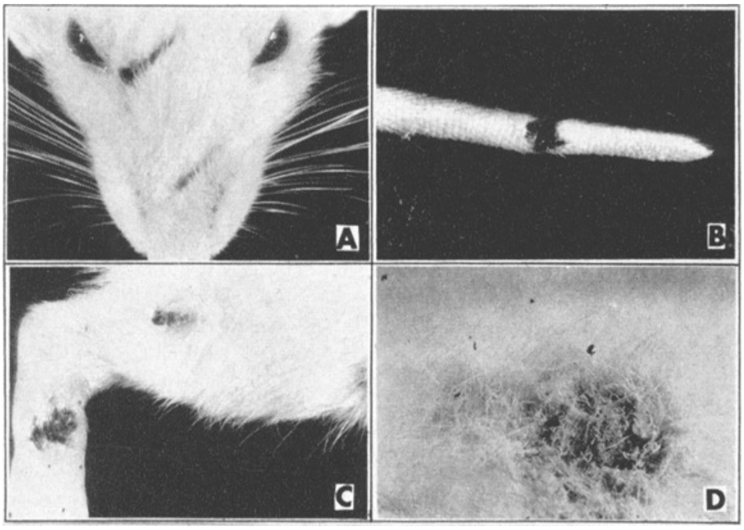

Fig. 3. Various minor injuries sustained by specimen due to hypervelocity pellet penetration of test cell wall. (a), (b), (c) Shrapnel damage to head, tail and leg from spalled wall and pellet materials. (d) Blast damage to back.

DISCUSSION

The significance of these experiments indicate the necessity for further study in the effects of oxidative explosion relative to potential penetration of space vehicles by meteoroids. If man is to have a fair modicum of safety in space flight, we must understand fully the factors that promote the internal explosion accompanying the oxidative effect and attempt to alter them in his favor. Under sea level atmospheric conditions, the animals survived the flash and heat of the explosion, but suffered various superficial injuries, burns, and possible diminution in visual acuity. They also demonstrated evidence of shock and had they been human, their performance capabilities undoubtedly would have been severely reduced during and for an undetermined time after the exposure. At the other extreme, with 100 per cent oxygen at sea level pressure, the animal died instantly from blast and burns. There are apparently a number of factors that vary the possibility of the maximum explosion potential. With the evidence presented to us, we have determined that these factors are:

(a) The cubic volume of the test cell.

(b) The total atmospheric pressure and partial pressure of O_2 in the test cell.

(c) The rate of decompression.

(d) The ignition temperature generated by projectile and wall vaporization.

(e) The total amount of combustible material in the test cell.

In assessing the effects of meteoroid penetration into occupied crew compartments, it may be concluded that certainly decompression will occur; some portion of the oxygen will be used in oxidation of the wall and/or pellet material; and under certain conditions the entire cabin atmosphere can "flash" with catastrophic results to the crew. In less severe cases, the flash may temporarily blind the crew members and delay repair of the damage; and if a crew member is near the penetration area, severe burns may result. In any work in free space outside the parent vehicle, due to the inherent dangers and ease of penetration by very small meteoroids, standard full-pressure suits will probably be unacceptable for repair and maintenance functions.

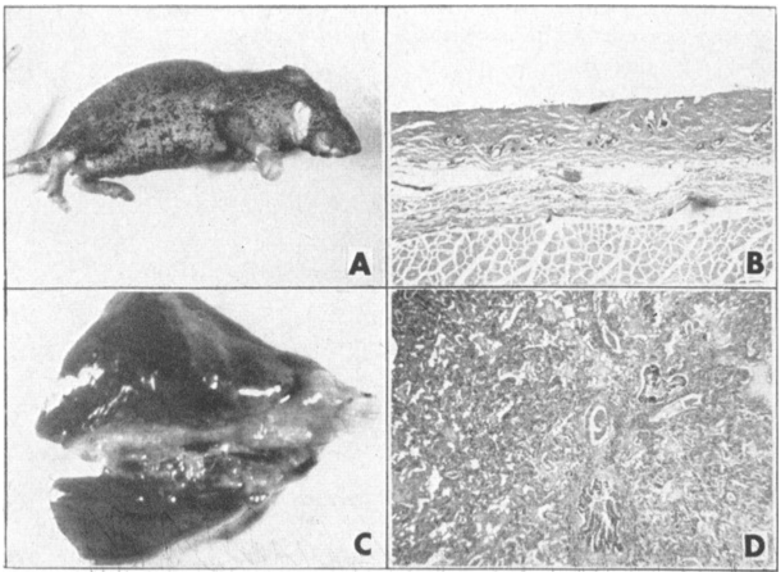

Fig. 4. Extent of injuries to specimen from atmospheric flash caused by hypervelocity pellet penetration of test cell. (a) External burns. (b) Photomicrograph of burned skin tissue. (c) Gross lung. (d) Photomicrograph showing edema in lung tissue.

A metallic hard-shell type will likely be the minimum protection consistent with desired safety criteria. A standard full-pressure suit would give little protection to human tissue from the effects of the intense heat generated by the hypervelocity penetration if it occurs in actual space. An example of impact into a sandwich of sponge-like material, simulating human tissue in water volume and density, is shown in Figure 5-a. Pressure buildup caused by vaporization of super-heated fluids, even though one end of the panel was vented, resulted in violent rupture of this structure. Of interest to the study of meteor bumpers are those limited tests also conducted by this facility. A meteor bumper consists of a thin skin located 1 inch to 2 inches from the vehicle surface. Upon meteoroid impact the pellet is shattered into a large number of minute, and probably fluid, particles with substantially less penetrating power (Fig. 5-b).

RECOMMENDATION

It is apparent that to insure man's safety in prolonged and extensive space trips an exhaustive study should be conducted to evaluate the factors which create the optimum configuration for oxidative explosion if a space ship is penetrated by a meteoroid. With a knowledge of the optimum configuration, engineering design can create the necessary protective alternatives in bumpers and/or other safety devices.

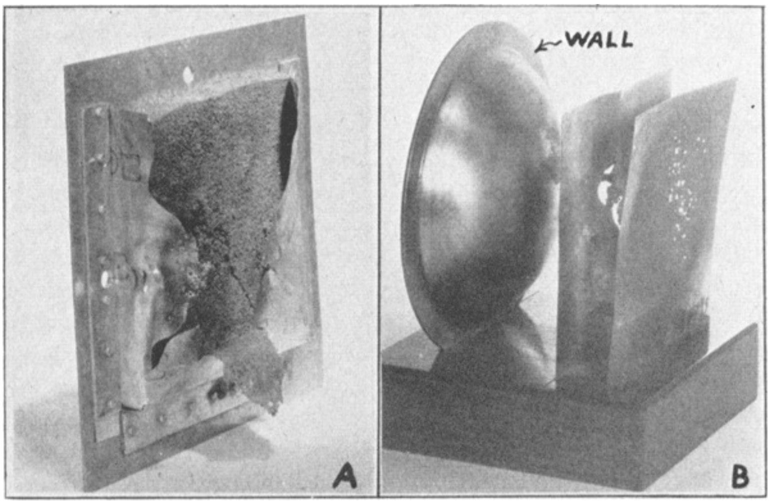

Fig. 5. Hypervelocity impact effects. (a) Explosive effect on outer skin when penetration made into material simulating living tissue (92 per cent liquid semi-solid). (b) Complete protection afforded by double bumper of 0.012-inch thick aluminum.

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