STRUCTURES AND MATERIALS

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HIGH-TEMPERATURE STRUCTURES

You are in the structures research laboratory where research is underway to advance the technology of structures and materials for all types of flight vehicles, ranging from supersonic aircraft to interplanetary spacecraft. In this work, we generate data for the design of lightweight structures that can withstand, with high reliability, the aerospace environments of launch, descent, spaceflight, entry, and landing. From this work we have selected high-temperature problems of atmospheric flight and the structural design of manned space cabins for discussion today.

CHART I

The high-temperature environment of aerospace vehicles is summarized on this chart. The maximum surface temperature experienced by the vehicle during flight in the earth's atmosphere is plotted as a function of the total flight time of the vehicle. Note that the time scale is logarithmic. The temperatures and times of several vehicles are shown by the sketches indicating a supersonic transport, a hypersonic airplane, and three manned entry vehicles; orbital missions with Mercury-Gemini type vehicles and with lifting bodies and the lunar mission of Apollo. In addition, the chart is divided into two parts; in the lower blue area metallic surfaces can be employed and the vehicles may be used for many flights. In the upper red area, metallic outer surfaces can not be used at these high temperatures and we must resort to ablative materials. In this case, the outer surfaces are consumed during entry, thus, the times shown are for a single flight. Ablative materials, which are generally plastic composites, can absorb large quantities of heat through thermal decomposition and removal of material.

Although the temperatures encountered by the supersonic transport are modest compared with those experienced by the other vehicles, the commercial feasibility of this airplane requires a long, successful service life. A high-strength material that does not deteriorate with long exposure to high temperature must be used if a lightweight, reliable structure is to be built. NASA has been investigating prospective materials for several years.

Tests in real time under load and temperature cycles that duplicate the 4 years of actual flight time are underway. Future tests, again in real time, must be conducted on representative components of the actual design, culminating in tests of the complete airplane.

Hypersonic aircraft must operate near the maximum usable temperature of metallic materials. The structural problems of these vehicles will be discussed at another stop. We have on display here, however, some samples of our materials research for both supersonic and hypersonic aircraft.

CHART II

Consider next ablation heat shields for entry vehicles, particularly manned spacecraft. This chart shows one of the newest heat shield materials before and after exposure to a simulated entry environment. It is a combination of silicone elastomer, hollow glass spheres, and hollow plastic spheres embedded in a plastic honeycomb matrix that provides mechanical strength. This material has high thermal efficiency because it has been tailored to produce just the right combination of physical and chemical properties. Its low density provides good insulation characteristics and prevents the surface heat from reaching the internal structure. During the process of thermal decomposition, enough gases of the required composition are generated to block incoming convective heat and a tough carbonaceous char layer is formed that reradiates much of the incoming heat through high surface-temperature operation.

We will now demonstrate the severity of the entry environment by exposing a heat shield specimen to a simulated entry. The environmental simulation is produced by the electric arc-heated air jet in this enclosure. In this apparatus, air is heated to a temperature of approximately 7000° F by high-intensity electric arcs. After I raise this shield the jet will be started and the test specimen inserted for a short test.

ARC JET DEMONSTRATION

Tests such as this, in which we measure the temperature change of the structure behind the ablation material, provides a means for determining the thermal efficiency of heat shield materials.

CHART III

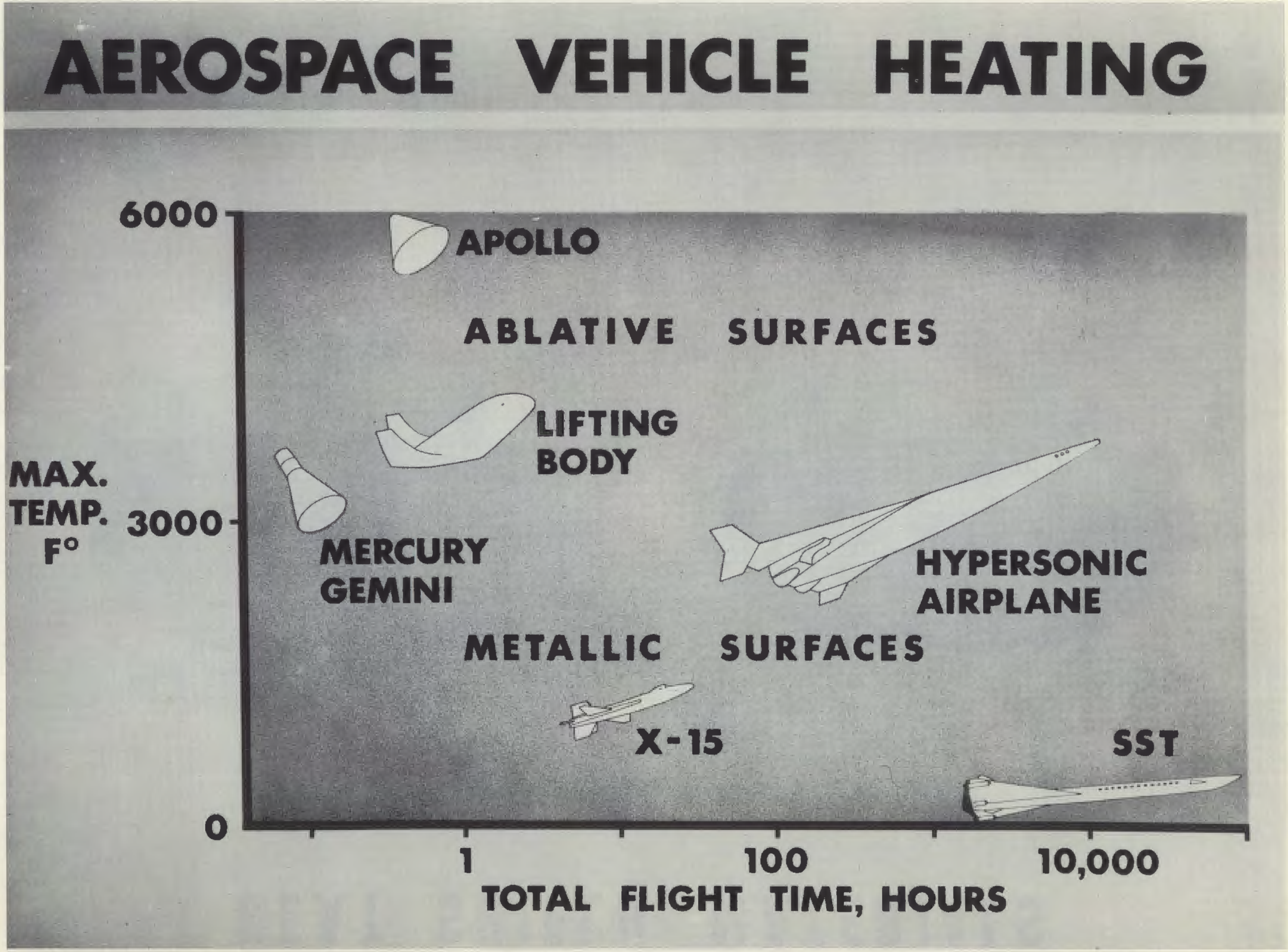
On this chart thermal efficiency in BTU per pound is plotted as a function of calendar years in the development of heat shield materials. It starts in 1959 with the heat shield for the Mercury capsule and shows an order of magnitude increase in efficiency in just 5 years. The material selected for Gemini is shown by the black dot in 1962. The elastomeric composites previously described are among the materials of highest efficiency. Many material combinations have been evaluated and only the best ones in a given year have been shown. The simulated entry environment in which these data were obtained is representative of a manned ballistic entry from an earth orbit, such as used by Mercury and Gemini; it is approximately that just demonstrated to you. The substantial increase in efficiency shown on this chart has been achieved by a combination of test and analysis of many mixtures of ingredients. Maximum efficiency is being approached unless our research reveals additional fundamental understanding of the processes involved.

CHART IV

Heat shield efficiency changes greatly with variation of the entry environment as shown on this next chart. In each of the four graphs, the change in thermal efficiency of two good heat shield materials is plotted as a function of changes in an important environmental parameter; for example, an increase in velocity from orbital to escape speed, such as going from the Mercury to Apollo mission. Also considered are the heating rate which changes with flight velocity and altitude, the severity of char oxidation environment, and an increase in the surface aerodynamic shear stress. Results are shown for two materials, the red line for the filled silicone elastomer previously discussed and blue for a low-density phenolic nylon similar to that used in our demonstration. The solid points represent data from the preceding chart. Each material responds in a different manner to the environmental changes, emphasizing the need to perform ground tests in a very accurate simulation of entry.

Unfortunately, present test facilities cannot duplicate the proper combination of all conditions encountered in the entry of advanced manned vehicles or sufficiently severe value of important parameters. Therefore, the design of heat shields for future vehicles is greatly dependent on the development of adequate engineering theories that extrapolate test data to predict the performance of a diversity of materials under a very wide variety of entry environments. NASA research is diligently seeking solutions to these important problems. In this effort, tests in ground facilities will be verified by selective flight tests of promising materials. On display here is a model of a rocket-launched entry vehicle for flight research on heat shields and various samples from our ground tests.

The next speaker will discuss structural and materials problems of manned space cabins.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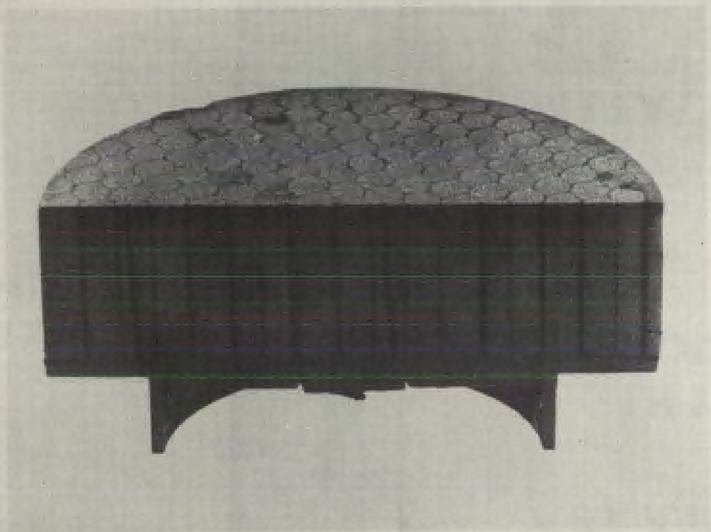
HEAT SHIELD MATERIALS



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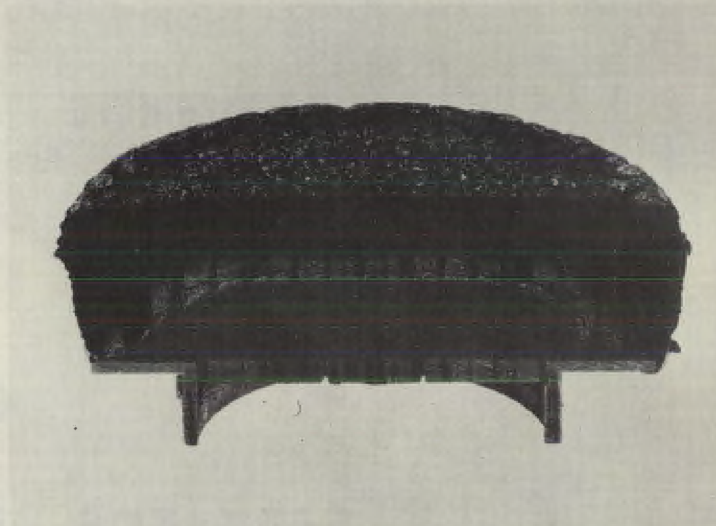

AFTER

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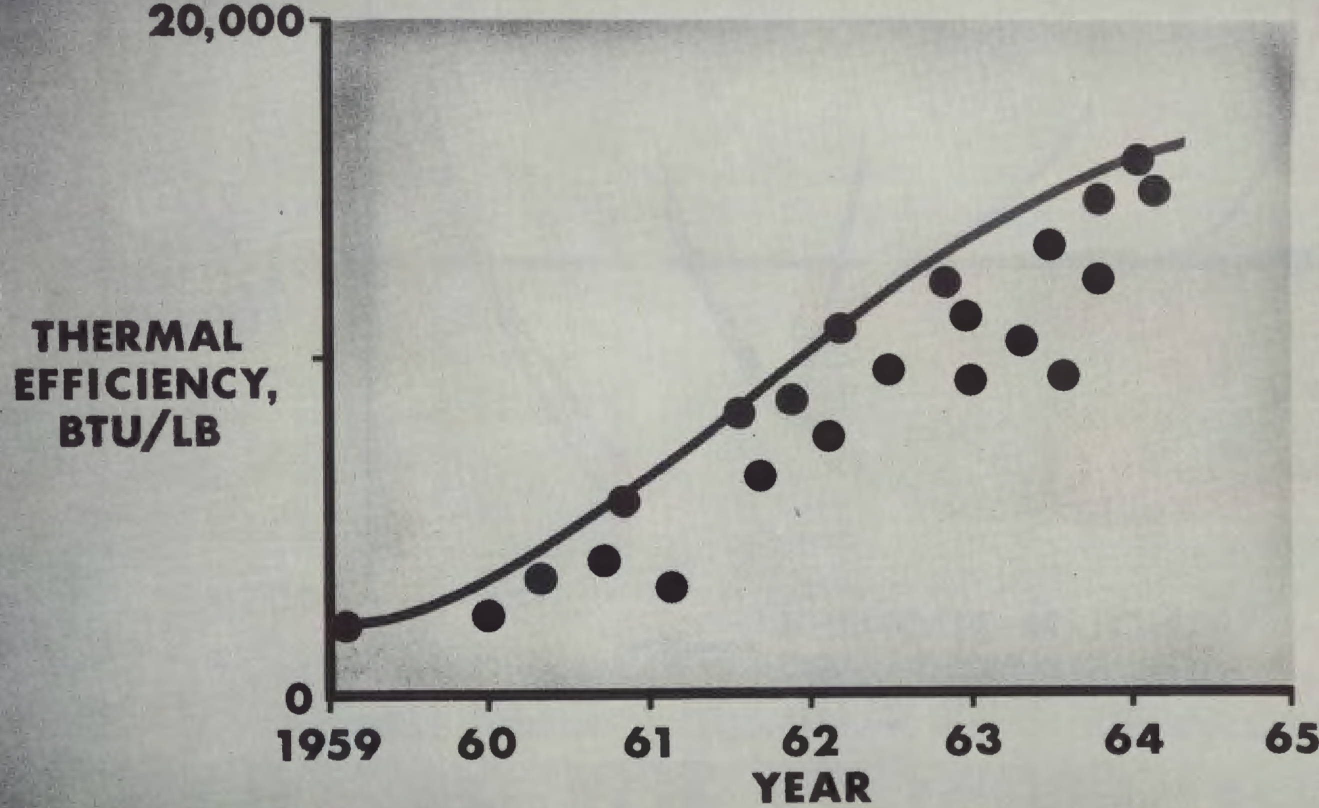

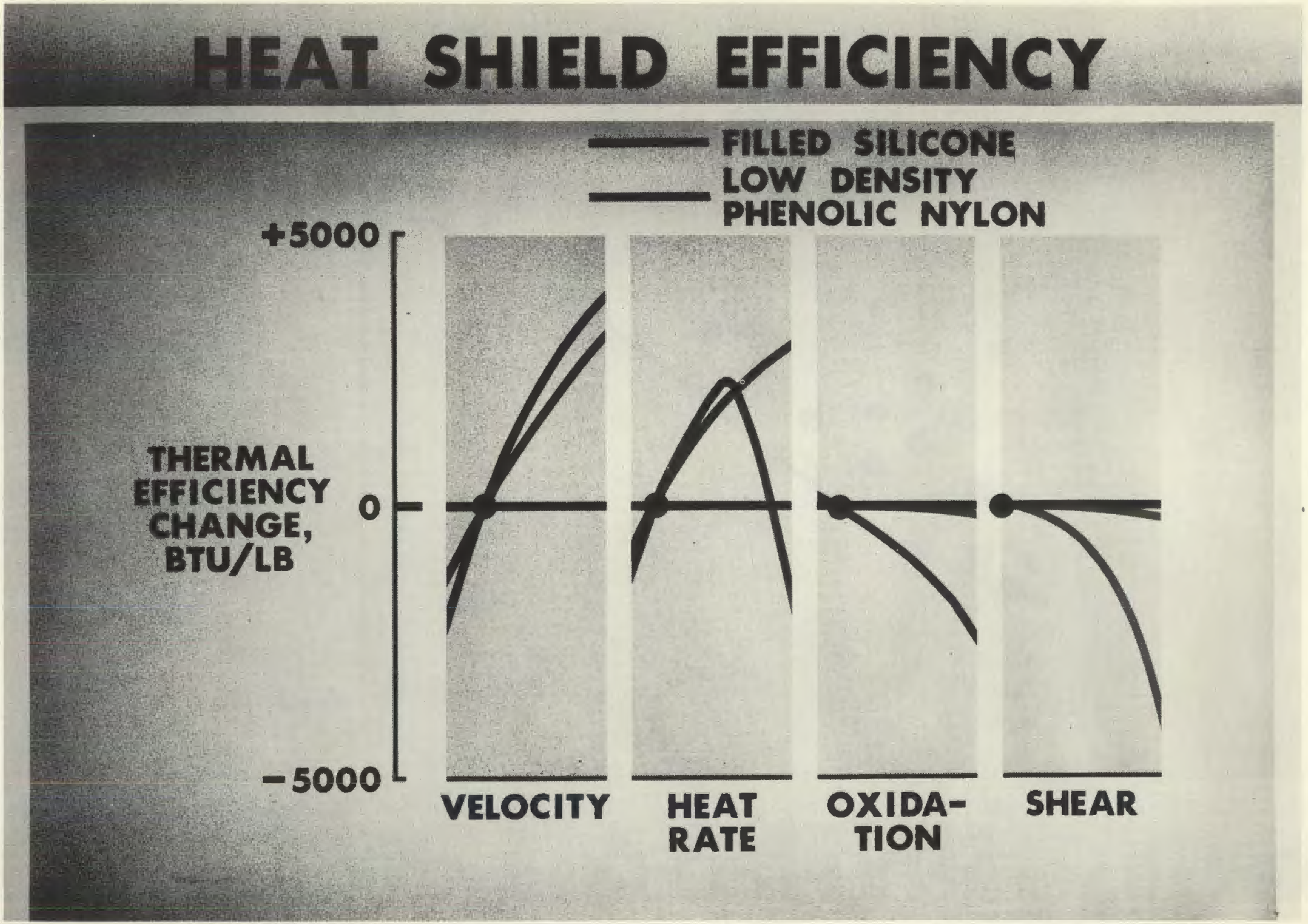
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VELOCITY
HEAT RATE
OXIDA-TION
SHEAR

MANNED SPACE CABINS

The space cabin wall forms a protective barrier between the astronaut and the hazards of the hostile space environment, as shown on the first chart.

CHART 1

The cabin walls reflect heat arriving directly from the sun and that reflected from the earth's surface. In addition it must radiate to space that excess heat generated by men and equipment inside. Consequently, the walls must insure a delicate thermal balance between these factors to maintain a comfortable temperature inside.

Another function is to minimize the probability of meteoroid penetration. The severity of the meteoroid hazard stems from the high velocity of these particles in space, estimated to range from 40,000 to as high as 200,000 ft/sec. At these speeds even a small particle can inflict substantial damage. Since even one penetration could result in an aborted mission, the wall design is such that even one penetration is highly unlikely.

Finally the wall must attenuate harmful ionizing radiation, charged subatomic particles with energies so great that no practical wall construction could stop all of them. The flux of these particles can be reduced, however, so that they are not a hazard to the men and equipment inside for a reasonable time in orbit.

Some of our research to determine how these diverse functions are incorporated into a space cabin wall will be discussed in this talk.

CHART II

Two orbits that might be considered for a manned space station are shown on the next chart. Both are circular orbits inclined at 30° to the equator. The high orbit is inside the ionizing radiation trapped by the earth's magnetic field, commonly called the Van Allen belt. The low orbit is between the lower fringe of this region and the upper atmosphere.

The meteoroid environment is essentially the same in both orbits. A variety of wall configurations have been investigated for the space station in each orbit.

CHART III

This chart gives the wall weight in lb/sq ft as a function of the number of days in orbit for three representative designs. Note the logarithmic scales.

The horizontal green curve is the wall weight needed to maintain the internal atmospheric pressure and is independent of time in orbit.

The dashed lines give the wall weight necessary to keep the radiation inside the station below the tolerable level. Note that this weight depends not only on the duration of the flight, but also on the orbit altitude as shown by the curves for high and low orbits.

This solid white line gives the weight of a single aluminum sheet that provides adequate protection from the meteoroid hazard. The weight is the same for both orbits but is a function of duration of flight. This weight, however, can be reduced by using a more sophisticated wall configuration.

NASA research has shown that a wall composed of several layers is considerably more effective pound for pound than a single sheet. The outer wall shatters the meteoroid, forming a cloud of smaller particles and spreading the projectile energy over a large area of the second sheet; consequently the total damage is reduced.

Taking advantage of this bumper phenomenon, a composite wall can be designed for meteoroid protection that is about 1/3 of the weight of an equivalent single sheet as shown by this solid orange curve.

From this chart we see that for short stays in space, the pressure requirement is the only critical design condition. For longer durations, the radiation environment or the meteoroid hazard is the critical design condition, depending on the orbit. If one man stays in the station for a very long time, even at the low orbit, radiation protection requirements again become critical.

Let's look at two representative space station wall configurations, one for each orbit for 1 year as represented by these points.

This is a small section of the wall for a station in a high orbit. It weighs 10 lb/ft^2 to provide sufficient radiation protection. This amount of material is enough to provide for all other wall functions with rather simple design. The thick aluminum exterior cover sheet protects these coolant tubes from meteoroid punctures. The tubes are part of the environmental control system that transfers the heat generated within the cabin to the outside wall where, through proper surface coatings, it is radiated into space. Good thermal conductance between the tubes and the exterior surface is needed.

The interior aluminum wall forms the gas tight pressure shell that contains the livable atmosphere. This interior wall must be fabricated as leak free as modern technology allows. Even a short hairline crack could result in the loss of 1000 pounds of valuable air in a year.

The material between the inner and outer sheet is polyethelene plastic that adds the remainder of the weight needed to attenuate the ionizing radiation. Polyethelene was chosen because it is very efficient in stopping radiation. It also provides thermal insulation for the cabin.

This wall for a space station in a low orbit is more complex but it weighs only 2 lb/sq ft, 1/5 of the weight of this one (the wall for the high orbit station).

As before, coolant tubes are protected from the meteoroid environment; but here a double-walled structure is used to save weight. The inside wall is identical to the inside wall of the heavier panel, but lightweight super-insulation, consisting of many layers of thin aluminized mylar, is used to thermally insulate the cabin interior from the exterior surface.

These two walls were designed by an analysis of the known characteristics of the space environment and its effect on structures and materials. Whether they will perform as desired must be determined by subjecting them to a simulated space environment. In the time that remains I will describe a device that we are using to approximate high-velocity meteoroids.

Most guns used to fire high-velocity particles fall far short of attaining meteoroid velocities. Only a few devices have been built to date that reach the estimated lower limit. NASA research is seeking ways to attain true meteoroid simulation in ground facilities. Two new meteoroid guns are currently under construction here, one of them, an electrostatic gun, will fire a stream of fine dust-like particles at meteoroid velocities. The other gun, of which a pilot model is in operation, is capable of firing a single particle heavy enough to penetrate structures. A schematic of this device, called an exploding foil gun, is shown on the next chart.

CHART IV

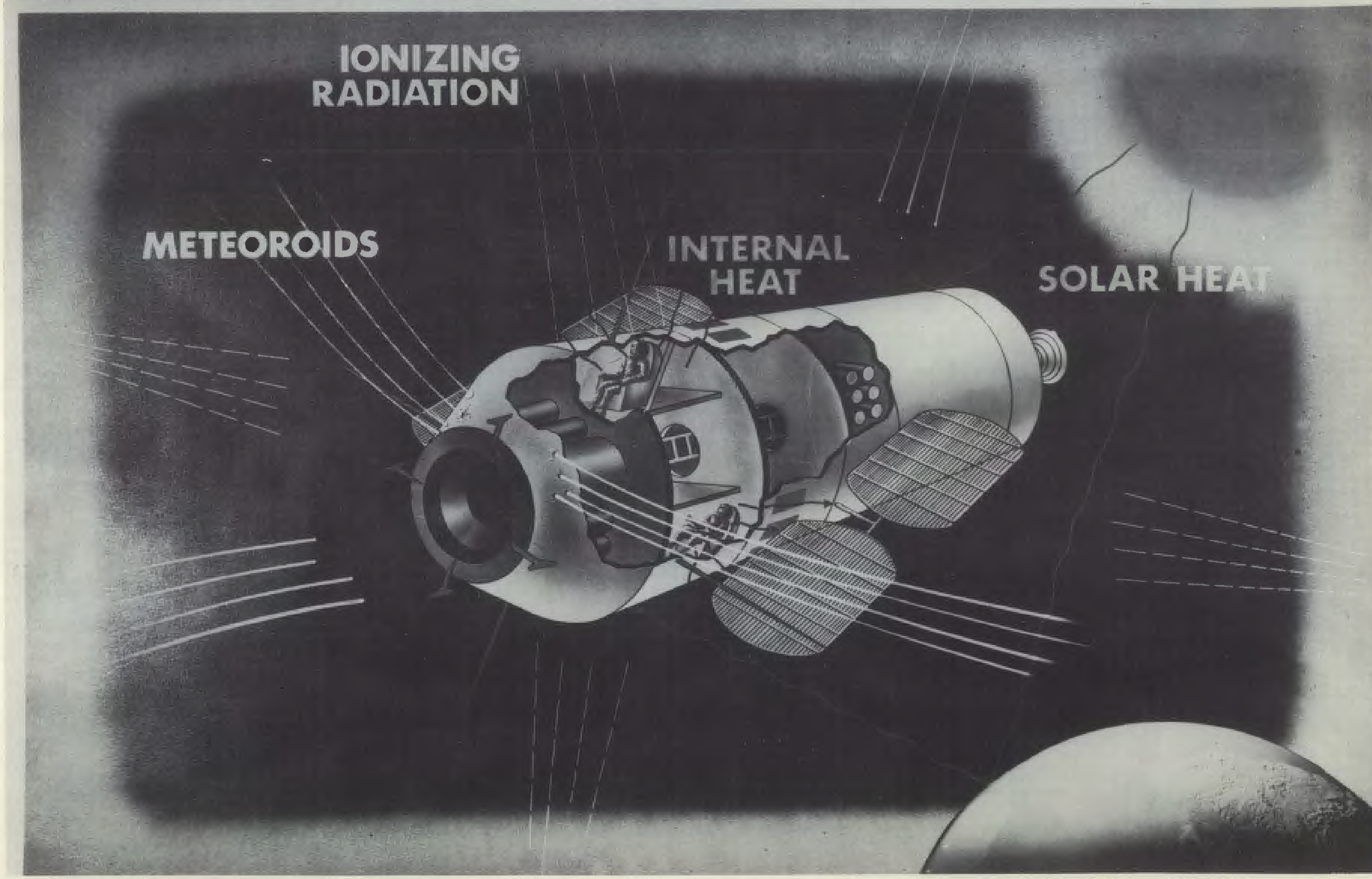
The explosive foil gun is powered by a bank of large capacitors charged by a high-voltage power supply. These capacitors are discharged through a switch into a thin strip of aluminum foil, momentarily producing a heavy current which explodes the foil. The breech of the gun contains the aluminum foil and a diaphragm of material used to simulate the meteoroid. A disk-shaped particle is punched from the diaphragm by the exploding foil. This projectile shoots down the gun barrel (a plastic tube) into a vacuum chamber and impacts on the target.

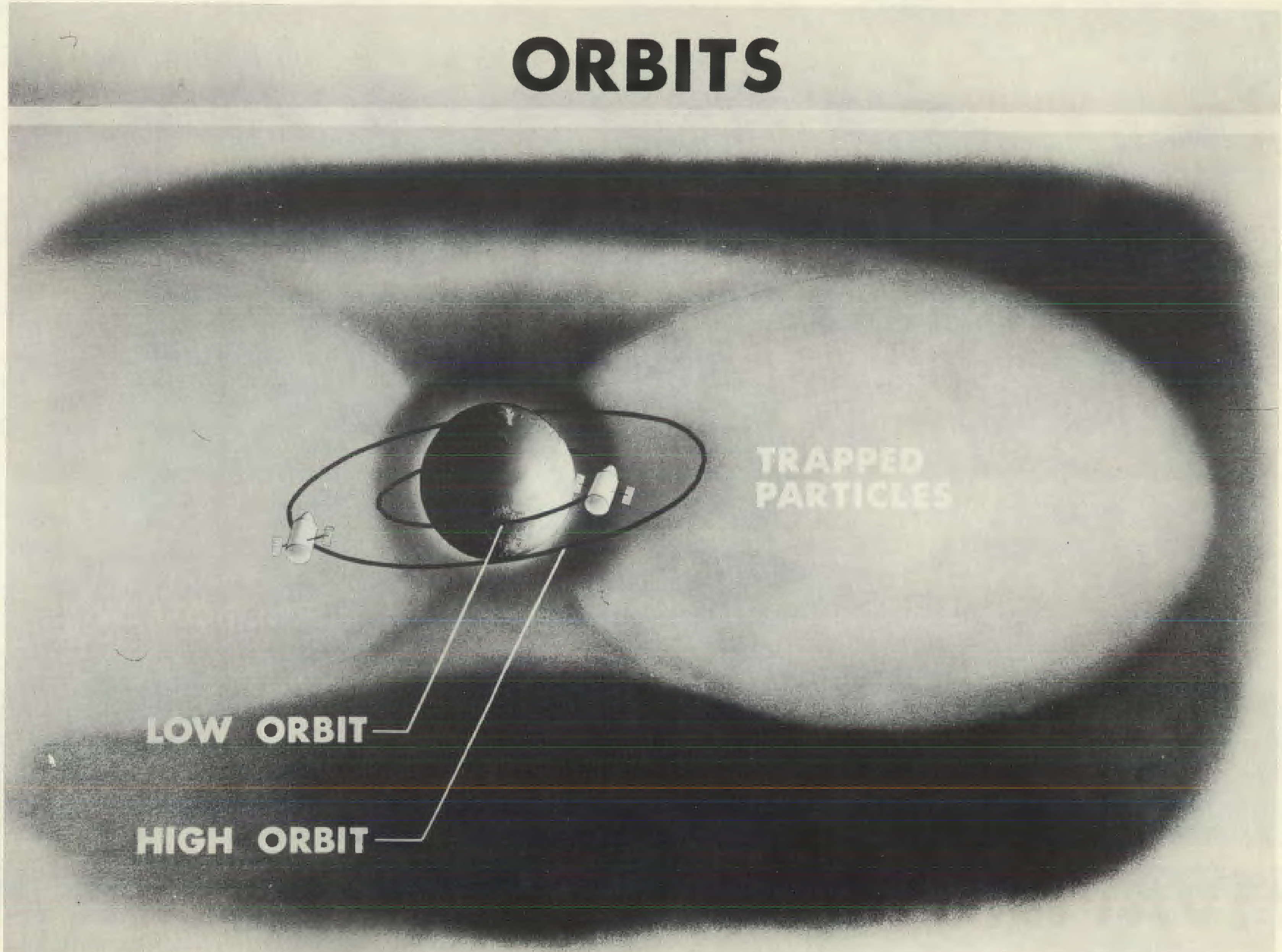
The pilot model of our exploding foil gun is installed in this room. The two large gray cylinders are the capacitors. Many such capacitors will be hooked together in the prototype device. The switch is located between the capacitors just back of the gun and target. The gun is the smallest part of the device as shown by this display model.

We will now fire this gun, shooting a 10 mg projectile at about 20,000 feet/second, considerably less than estimated meteoroid speeds. The projectile will be a disk of mylar plastic. You can see how light the projectile is as I drop several of them on the table. Such a disk will be fired at a thick piece of aluminum. Watch the specimen to see the results.

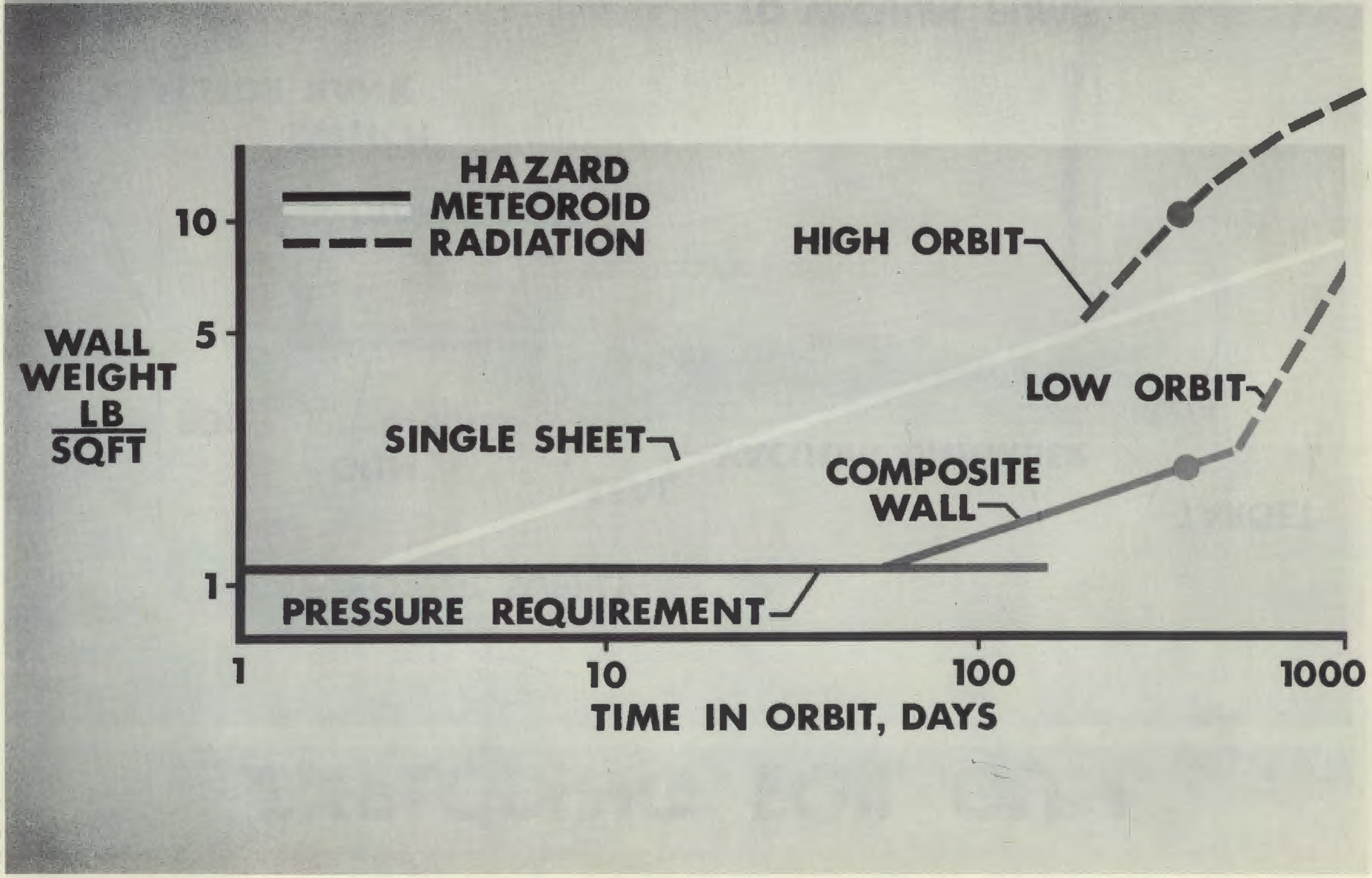
A large hole was punched all the way through the thick aluminum plate like this one. When such tiny particles, traveling at less than one-tenth the velocity of some meteoroids, create such havoc, you can understand why we are devoting substantial resources to develop facilities that will realistically simulate meteoroids in the laboratory. These devices will provide a valuable tool to prove the reliability of space station wall construction before our astronauts must risk their lives on prolonged journeys through space.

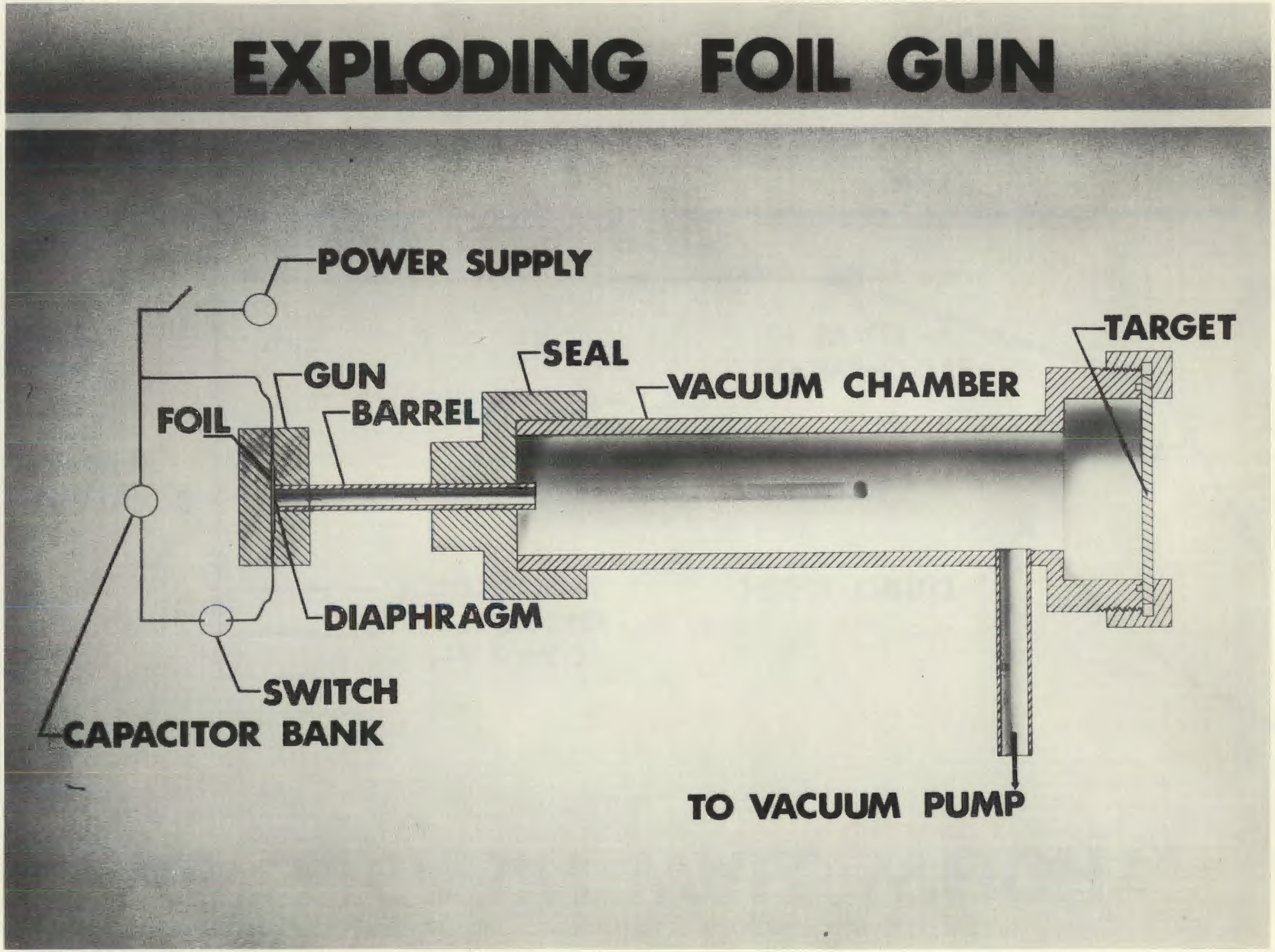
FUNCTIONS OF SPACE CABIN WALL




ORBITS
TRAPPED PARTICLES
LOW ORBIT
HIGH ORBIT

SPACE CABIN WALL WEIGHT





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