HYPERVELOCITY AND ENTRY RESEARCH TECHNIQUES

presented by

10- by 14-Inch Supersonic Wind Tunnel Branch
and
Hypervelocity Ballistic Range Branch

Here we will explain two of the NACA's several devices for research on the descent of missiles and satellites through a planet's atmosphere. The type and magnitude of the problems encountered during atmosphere entry depend on the kind of trajectory used. For our discussion, two types of trajectory are shown on the first chart.

Here we show a portion of the earth's surface and surrounding atmosphere. The trajectory of a ballistic missile is shown by the upper curve. The rockets launch the missile into space far outside the earth's atmosphere. It then returns to earth under the influence of gravity at about 15,000 miles per hour.

On the lower curve we have a trajectory representative of the entry of a satellite. Satellites approach the atmosphere at about 18,000 miles per hour. The trajectory is nearly tangential as it approaches the earth and gradually steepens as the vehicle loses speed and altitude due to the combined effects of aerodynamic drag and gravity.

A major problem confronting engineers is the heating which a vehicle experiences as it travels through the denser air in this region (chart #1). We have all observed the burning of meteorites as they plunge toward the earth. Similarly, the heating associated with the atmosphere-entry of a ballistic missile or satellite is sufficient to destroy the vehicle unless skillful design is employed to prevent its destruction. We must all bear in mind, however, that the best designs are still subject to certain doubts. The final test, of course, is in full-scale flight, but these tests are both time-consuming and expensive. It is desirable to duplicate the entry conditions using a model of the missile with relatively simple apparatus on the ground. Thus, we have been led to the concept of the atmosphere-entry simulator now being used to simulate the entry of ballistic missiles.

We simulate the descent of missiles through the atmosphere by flying small-scale models of the missiles through a small-scale model of the atmosphere. These test flights duplicate the descent of actual missiles with respect to the total heat per unit weight and the thermal stresses as it travels through the lower atmosphere where heating is important. We have applied this technique to ballistic-type missiles, although we should point out that the same basic technique can be applied to returning satellites.

The ballistic-entry simulator is explained with the use of the next chart (chart #2). For proper simulation, the models must fly at the same initial speed as the full-scale missile. For this purpose the models are shot from a specially developed high-velocity gun as shown at the right of the chart. We must also duplicate the density variation through the portion of the atmosphere in which the major part of the heating occurs. For this purpose, the air from this high-pressure tank blows through this nozzle. The divergence of the nozzle walls causes the air to expand so its density decreases in the same way the density of the atmosphere decreases with altitude.

The sequence of a test is this: The tank is filled with high-pressure air. When all is ready, the air is released by rupturing the diaphragm. As soon as the flow is established, the gun is fired and the small-scale model flies upstream through the nozzle. By the time the model gets to the small end of the nozzle, the air has slowed it to a relatively low speed so that it can be recovered in the soft material contained in the catcher. During the model's flight, it is timed accurately by electronic apparatus and it is photographed at a number of stations along the test section.

A smaller simulator of this type was put into operation at this Laboratory about a year and a half ago. Its success encouraged us to build the larger and more useful simulator you see here. The high-pressure reservoir is at the end of the structure to your left and slightly behind you. The unique part of this facility is the long, gradually expanding nozzle which forms the small-scale atmosphere and extends forward from the reservoir. The large pipe at the end of the nozzle leads to a vacuum sphere outside the building. For safety, the special high-velocity gun that launches the models is mounted in another room beyond the nozzle exit, and is surrounded by a thick concrete wall. The instruments and controls are in that corner of the building adjacent to the gun room. Along the length of the nozzle you can see twelve test stations. The containers at each station contain the equipment for taking shadowgraph pictures in both the horizontal and vertical planes. The photoelectric detecting and timing units for each camera station are here.

In closing this part of the talk, we will show you some of the results from research in the original, smaller ballistic-entry simulator. The models were twenty-two-caliber cylinders, like this (hold up), with a piece of copper cemented to the forward flat face. The function of the copper is to absorb the heat associated with the simulated atmosphere entry. The following slide shows an enlarged view of the flat copper face of a model prior to its flight through the simulator. You can clearly see the small concentric machine marks as well as a few other scratches and irregularities. The surface was considerably altered by flight through the simulator as shown in the next slide. The irregularity at the bottom of the slide was caused by the model impacting in the catcher. The most striking feature, however, is the small craters in the surface. These craters vary in size up to about three times the diameter of a human hair. We believe they were caused by small particles of dust in the airstream. The full-scale missile may also experience comparable pitting. Notice also that you can see less evidence of the machine marks which were so clear before the test. It appears that a portion of the outer surface has been melted by the high heat encountered during flight. In our test, this model survived the same heating per unit weight and the same thermal stresses as a full-scale ballistic missile of similar shape. The gross implication is that such a full-scale missile, despite the severe surface pitting, can survive its descent through the earth's atmosphere.

The atmosphere-entry simulator is but one of the important tools being used to study the effects of heating in high-speed flight. Mr. ___________ will now discuss another.

In this building a Hypervelocity Ballistic Range is now being completed. At this range we will be concerned with some of the many problems arising from the very high speeds of missiles, satellites, and space vehicles, with particular emphasis on the problem of aerodynamic heating.

In this facility and in the atmosphere-entry simulator tests are conducted in much the same manner; that is, we measure the aerodynamic characteristics of small models in free flight. The test conditions are different, however. In the Ballistic Range, the models are shot into a long chamber in which the air is at rest. Thus, the models fly through air of uniform pressure, density, and temperature in contrast to the varying pressure, density, and temperature in the Entry Simulator. Whereas the Atmosphere-Entry Simulator will be used to determine the total, overall effect of flight from above the atmosphere down to sea level, the Ballistic Range will be used to take a close look at the effects of flight at selected pressures or altitudes. Knowledge of these effects is essential to further our basic understanding of such problems as aerodynamic heating. This Range will provide the designer with information he needs to design such craft as glide vehicles that will fly at more nearly constant altitudes for extended periods.

The Ballistic Range is illustrated in schematic form on this chart (chart #5). It consists basically of a gun and a flight test chamber. The chamber is 8 feet in diameter by 500 feet long. Models are shot at high speeds from the gun into the flight test chamber where photographic and electronic apparatus measure and record the model's flight characteristics. The pressure in the chamber can be varied from test to test to duplicate atmospheric conditions at different altitudes. If desired, other gases can be substituted in place of air to study flight through the atmosphere of planets other than our own.

By testing scale models at the true flight speeds in air at appropriate pressures the aerodynamic heating and forces encountered by actual missiles and space vehicles will be duplicated. The curves on this chart (chart #6) represent the variation of flight speed with altitude of a satellite, a glide vehicle, and two types of long range ballistic missiles returning to the surface of the earth. At these points (indicate red shaded region) along the trajectories the heating encountered by these vehicles is a maximum. The test region of the Ballistic Range, indicated by the large light colored region, is bounded by a maximum simulated altitude of 45 miles and a top flight speed of about 16,000 miles per hour. The critical region along these trajectories where the heating rates are the highest are well within this test region.

The next chart illustrates that the air pressures and temperatures developed by these same vehicles entering the atmosphere can be duplicated in the Ballistic Range. Here are plotted the temperatures and pressures of the air behind the shock wave adjacent to the nose of the vehicle where heating is a maximum. Upon entering the atmosphere the temperature increases to extremely high values, even higher than the temperature at the surface of the sun. As the vehicle descends further into the atmosphere it slows down and the air temperature decreases. The increasing air density, however, causes the rate at which heat is transmitted to the vehicle to increase until it becomes a maximum at these points. The heating is then reduced because of the rapid decrease in speed. The large shaded area again represents the test region of the Ballistic Range and you can see from this and the preceeding chart that the critical conditions along the trajectory where the heating is a maximum are within our test capabilities.

To achieve these test conditions a special gun was developed. It is similar in principle to the gun used in the Atmosphere-Entry Simulator, in that helium, compressed to high pressures and temperatures, propels the model. Helium is used instead of powder gas, as in a conventional gun, simply because it is lighter and, as a result, less of the available energy is expended in accelerating the gas itself. The helium is compressed by a piston which is driven by the explosion of gun powder. The principle of operation can be illustrated with this schematic model. This smaller-diameter tube represents the launch tube. The model is initially at this point. This is the pump tube. A quick-acting valve isolates the model from the pump tube. The piston is initially here. The pump tube in front of the piston is filled with helium. Gun powder, ignited in this chamber, drives the piston down the pump tube to compress the helium. At the rear of the gun a sliding valve relieves the internal pressure at the end of the firing. (Start operation of demonstration model.) The cycle is initiated by igniting the powder. The exploding powder drives the piston down the pump tube (push button), compressing the helium to the required pressure; then the high-speed valve opens and the helium pushes the model out the launch tube. (Run through demonstration once again.)

The actual gun, which covers a total length of 200 feet, will fire a model approximately three quarters of an inch in diameter.

In addition to investigating the aerodynamics of flight such as aerodynamic heating which we've just discussed, the high speeds attainable with the light-gas gun enable us to study other problems of interest. For example, an investigation is now being made of the damage made by small bodies such as meteoroids impacting against a surface such as the skin of a satellite or space vehicle. As shown on the slide of the copper-faced model, presented by the last speaker, even small dust particles may cause damage at high speeds. We must supply the designer with knowledge of the impact of particles that are present in space, such as meteoroids, so he can provide reasonable protection on vehicles that are to remain in space for extended periods. Information has been available for some time on the penetration of bodies in targets at lower speeds. For example, the penetration of artillery shells into armor plate has been thoroughly explored. However, little is known about impact at very high speeds. Our tests have shown that the mechanism of impact at high speeds is quite different than at low speeds. The results of some of our research are shown on this chart (chart #8). The impact tests were made with small metal spheres striking metal targets. Up to a certain speed, the depth of penetration increases regularly as the speed increases. This photograph represents the type of cavity produced by a sphere of this size hitting the target at relatively low speeds. As it penetrates the target, the sphere remains intact. As the impact speed is increased, the forces become so great that the sphere breaks up into several pieces and the penetration decreases. As the speed is increased above this region, the forces on the sphere and the target become much greater than the strength of the materials involved. As a result, both the impacting body and the target behave like fluids. This photograph illustrates the type of crater formed. As you can see, the cavity is deeper and much wider. The light-gas gun will make it possible to extend these tests to much higher speeds.

You are now at this point in the building. (Chart #5 again.) As you leave, you will pass through this door, walk along beside the test chamber, and into the room where you will see the gun I have just described. The bus will be waiting just outside this exit. Attendants will be on hand to answer any questions you may have. Thank you.

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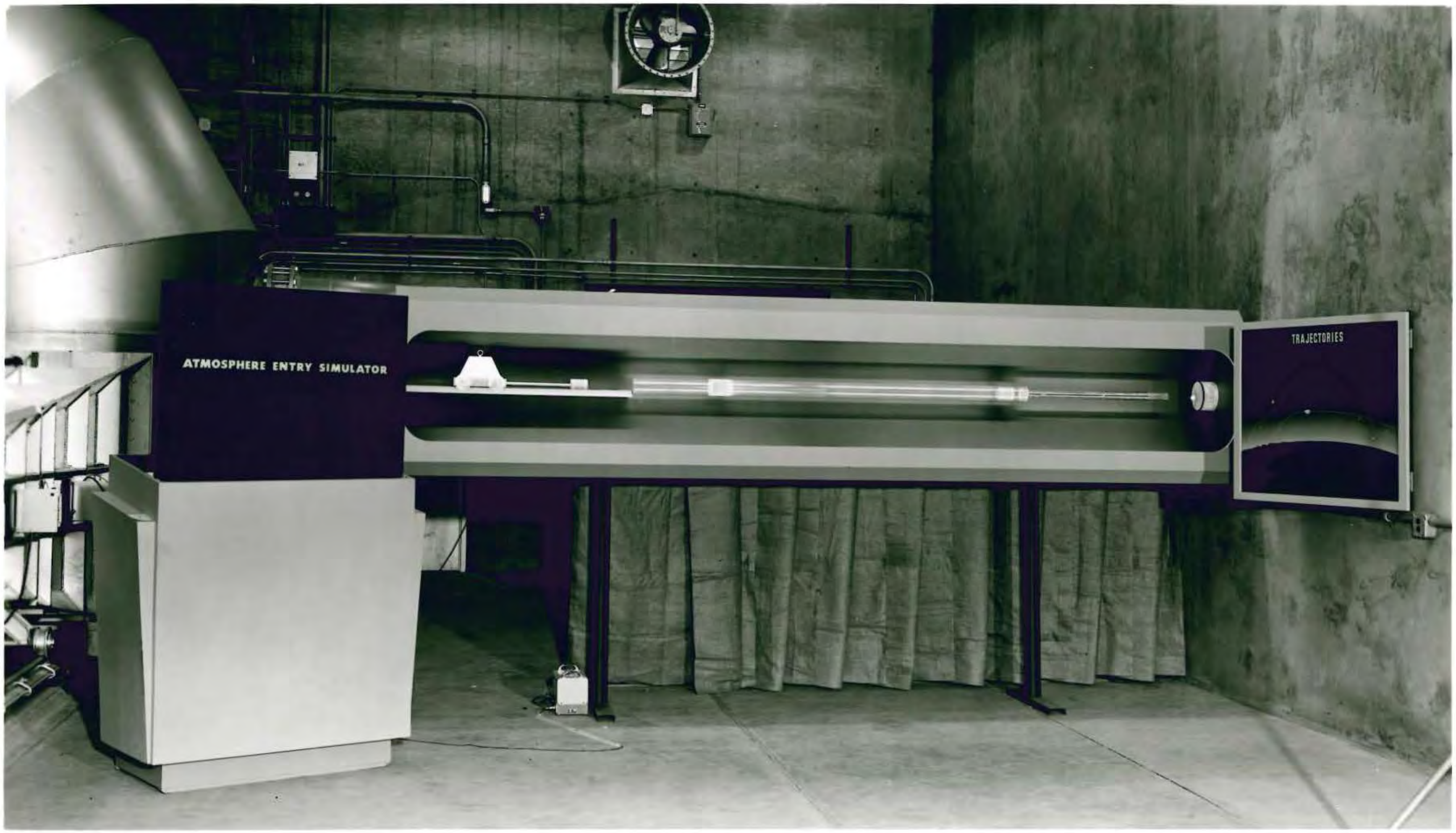

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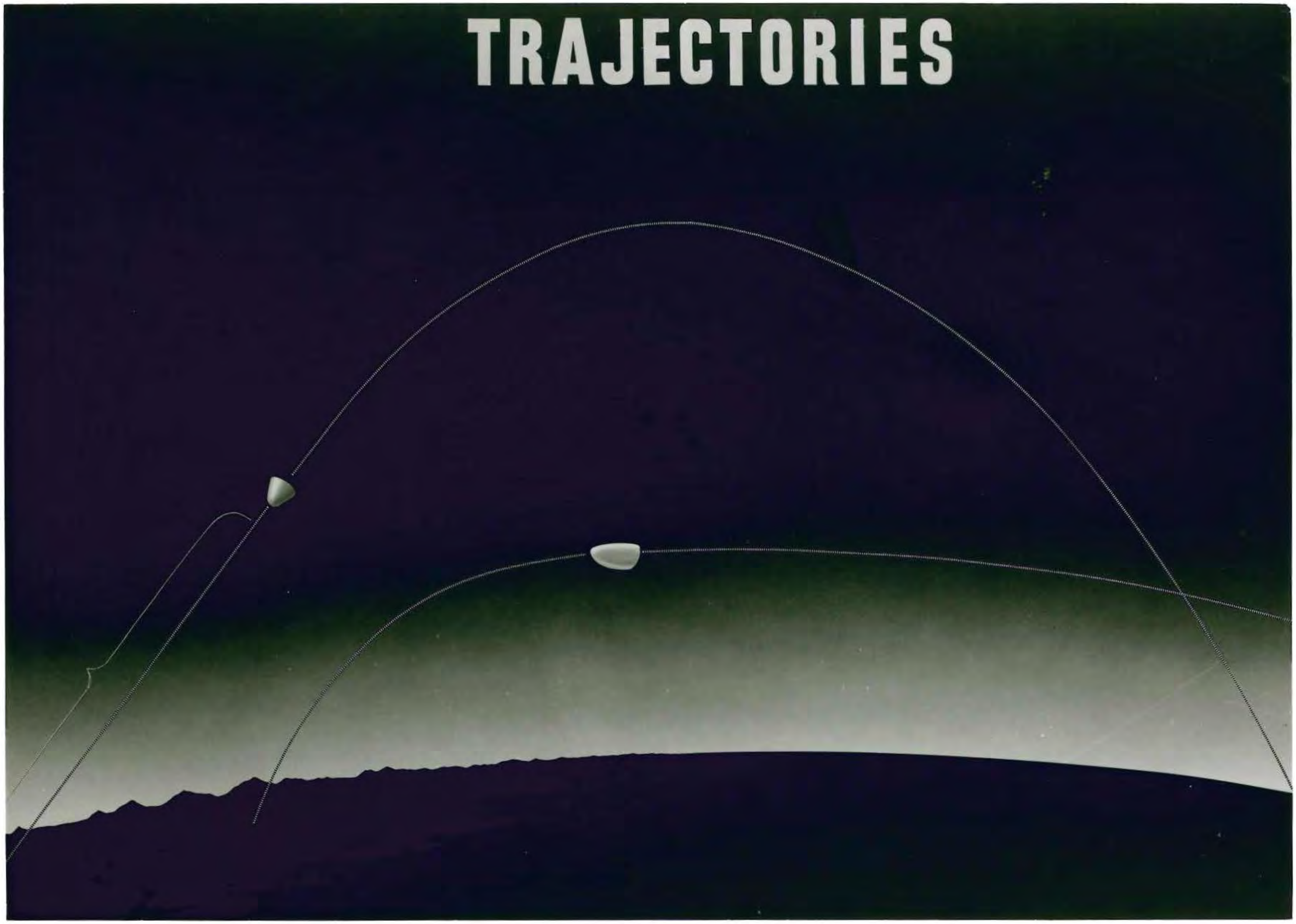

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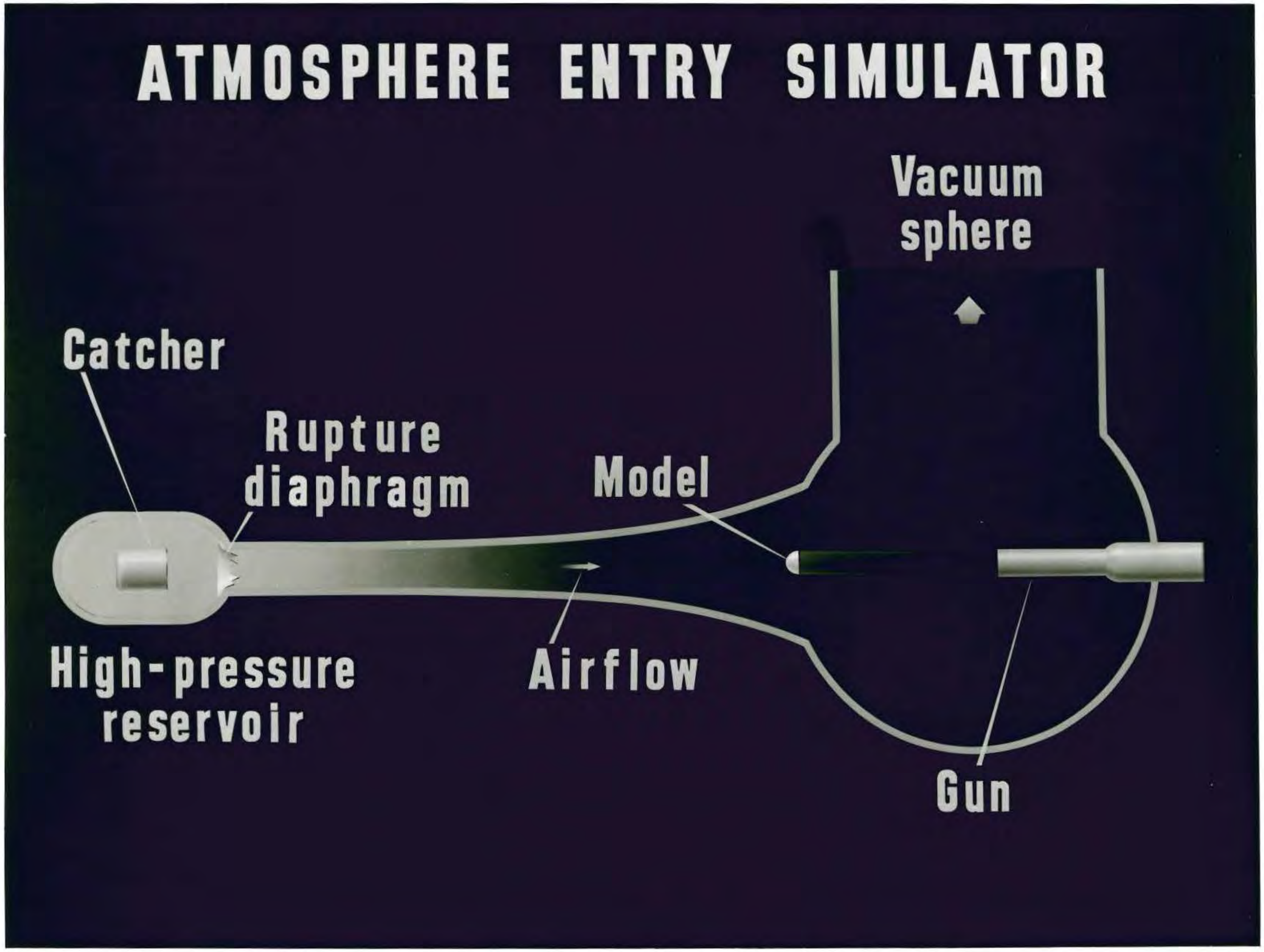

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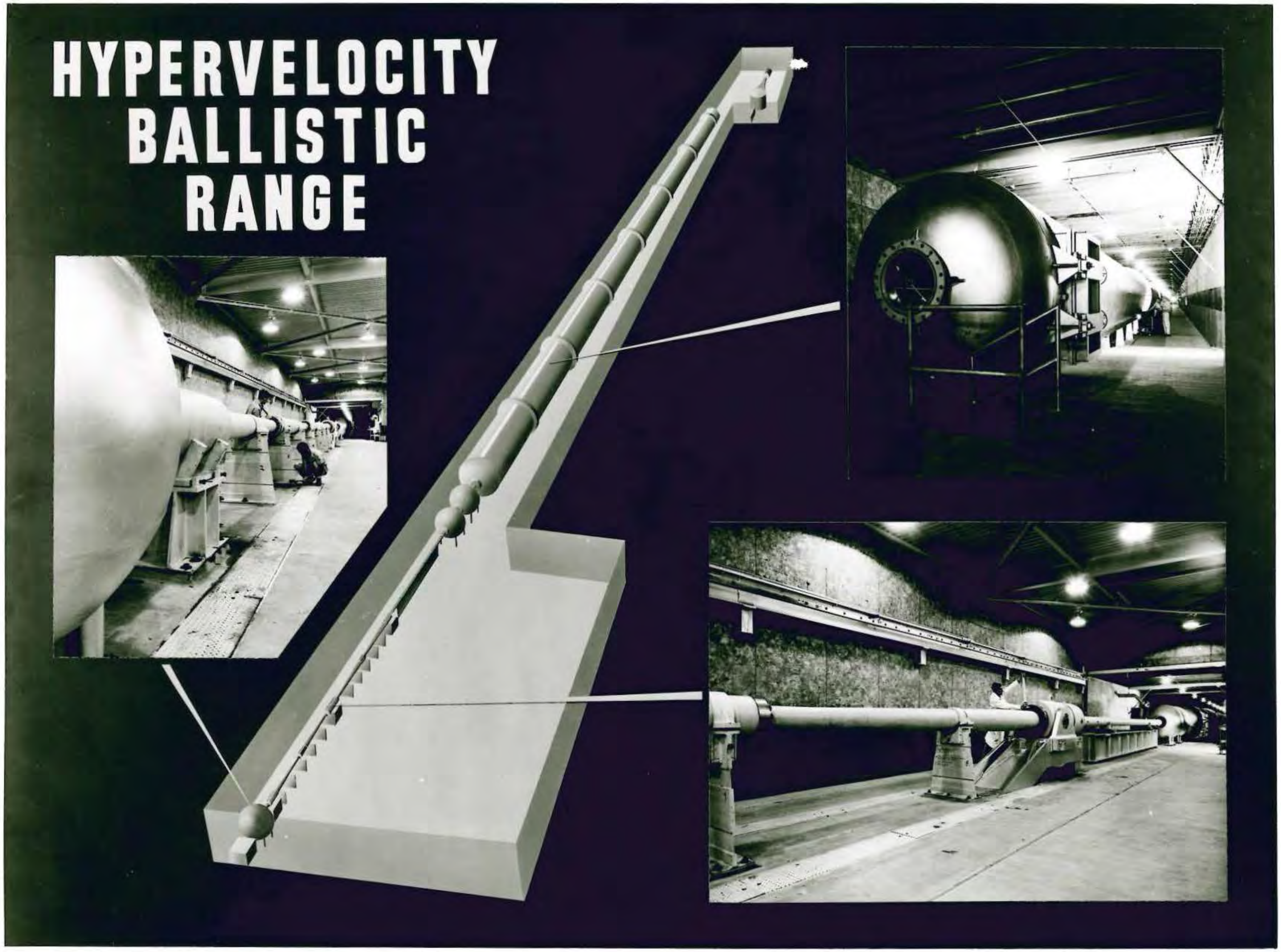

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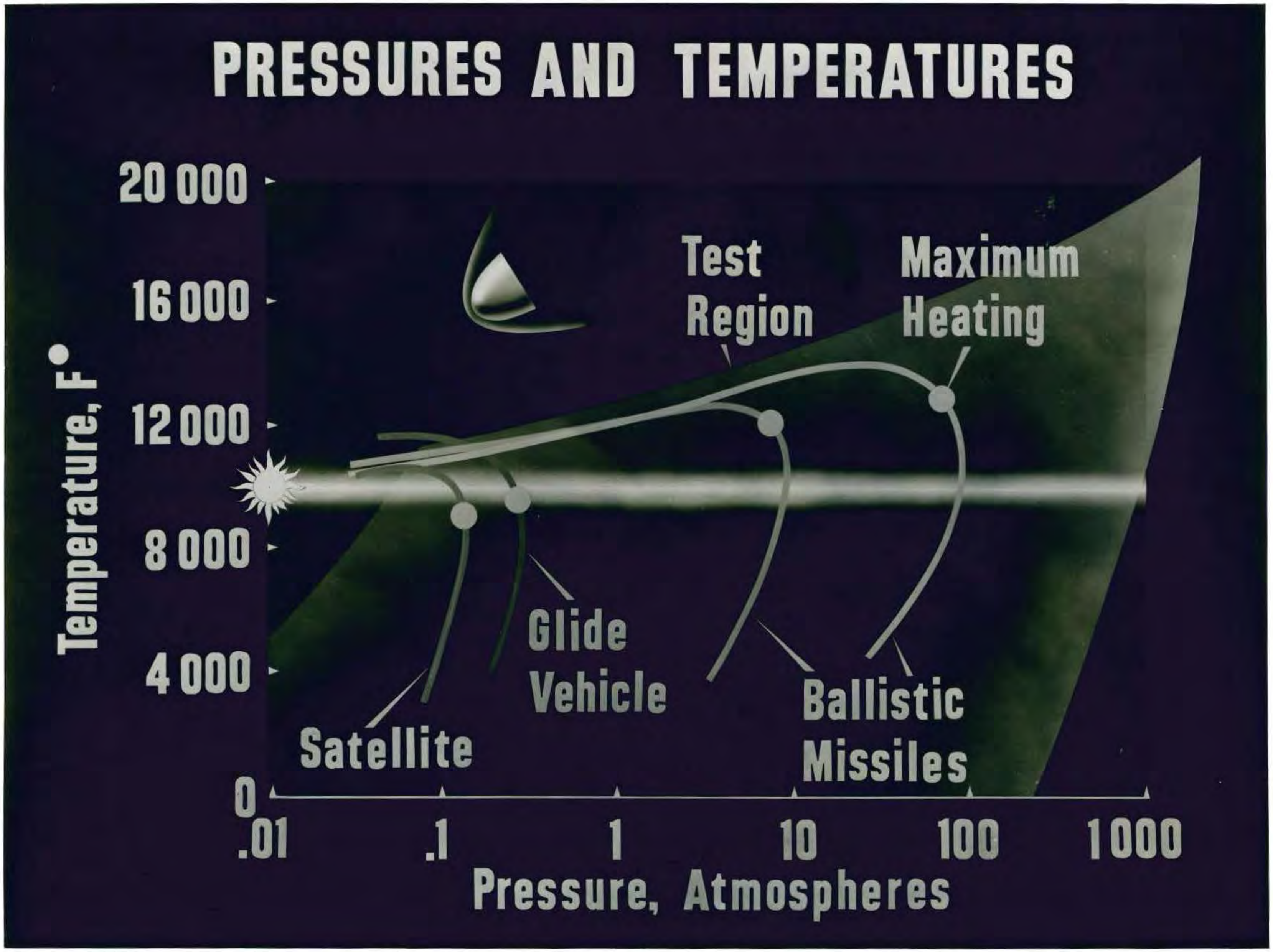

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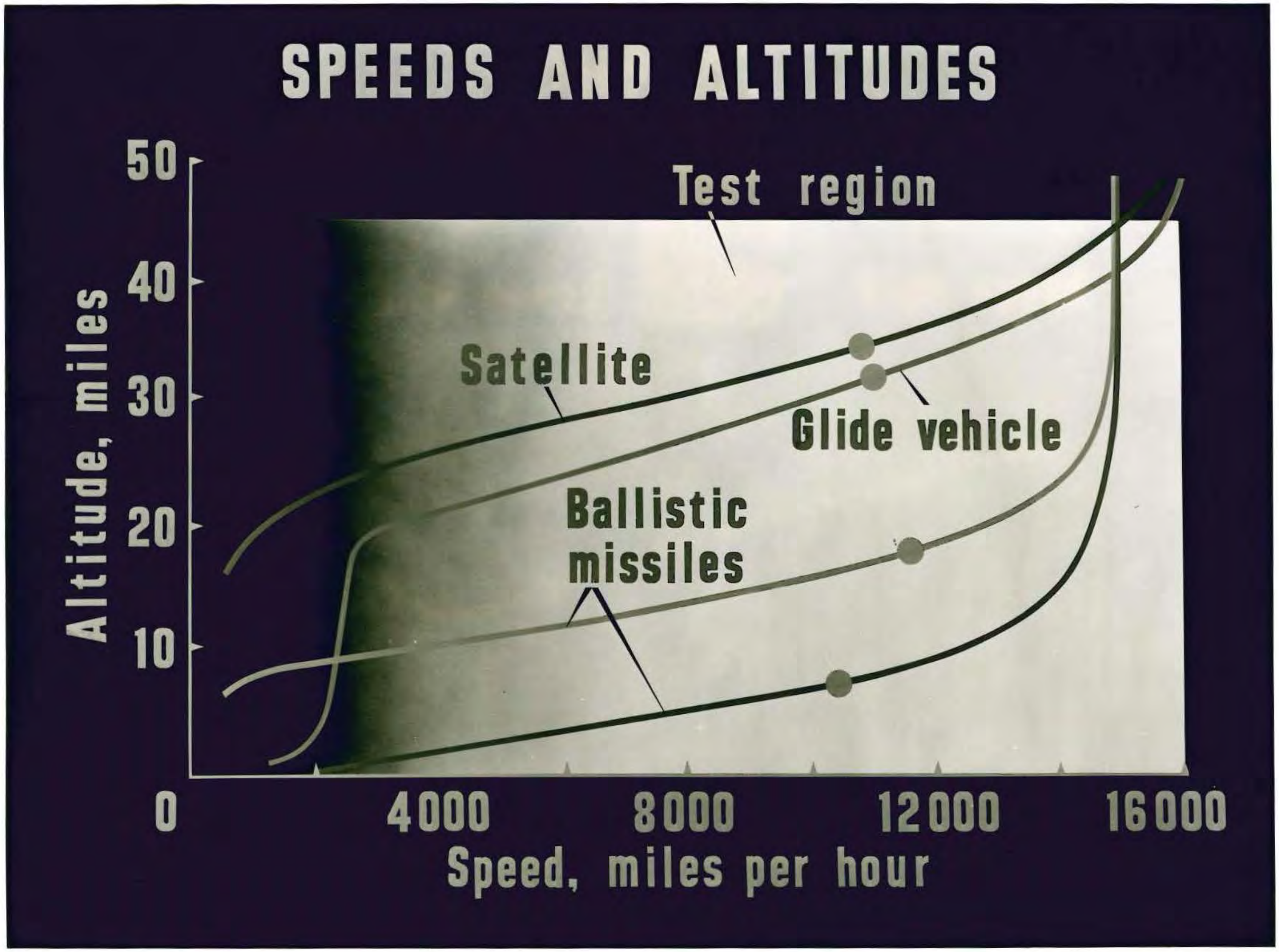
SPEEDS AND ALTITUDES
Test region
Satellite
Glide vehicle
Ballistic missiles
Altitude, miles
50
40
30
20
10
0
4000
8000
12000
16000
Speed, miles per hour

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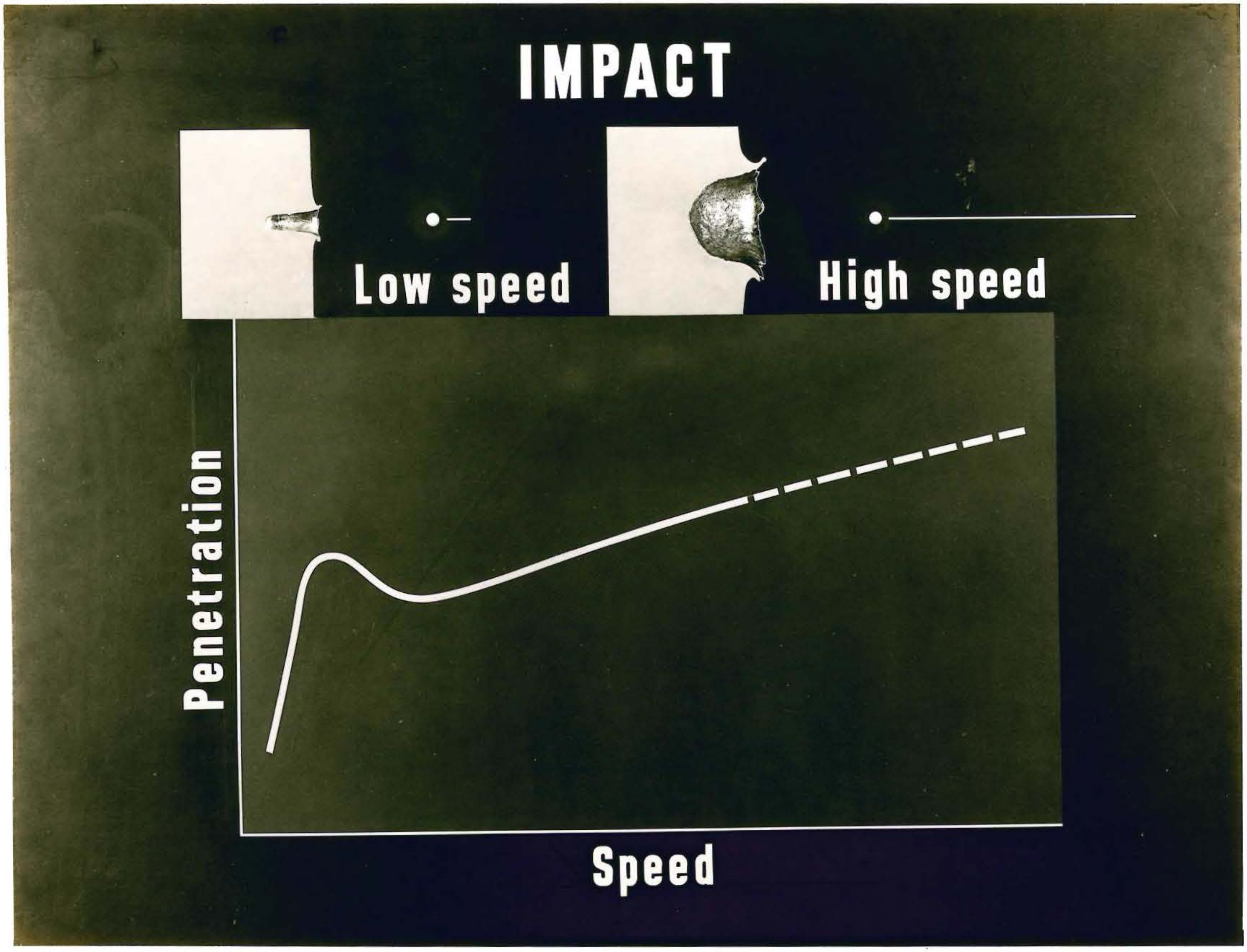

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