

HYPERSONIC STRUCTURES RESEARCH FACILITIES

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HYPERSONIC AIRCRAFT STRUCTURES

At this stop we are going to discuss NASA research on structures for future hypersonic aircraft and the facilities required for research on such structures.

Models

These models represent two of the many possible hypersonic aircraft configurations. Each is designed to use liquid hydrogen for fuel. However, hydrocarbon fuel could be used for the air-breathing propulsion system of this first stage and liquid hydrogen for rocket propulsion of this second-stage vehicle. With air-breathing propulsion systems, large air inlets are required such as those located here under the wings.

At hypersonic speeds, very high temperatures occur on the structure. Advanced wind-tunnel facilities are needed to test the vehicle structures in high Mach number, high-temperature air streams. We are presently operating a small pilot facility that can achieve these conditions. In it the temperatures that will prevail on the surfaces of a hypersonic aircraft can be determined from tests of small quartz models like this one.

Film

This movie will illustrate how hot the surface of a hypersonic aircraft will get at Mach 7. The first scene is a view of the lower surfaces of the model as it will be tested. Now the model is under test conditions. You can tell the areas of highest temperature by the brightness of the glow. The hottest area is the lower lip of the air inlets. Also note that the leading edges of the wing and ventrals are hot, as well as the nose cap. These temperatures approach 2,500° F.

Chart 1

On this chart, test data have been summarized to show how hot the vehicle surfaces will be at a speed of seven times that of sound. Temperatures obtained are: 2,300° F on the nose cap, 2,500° F on the inlets, 1,600° F on the leading edge of the wing, and 1,700° F on the leading edge of the ventral fins. Somewhat lower temperatures occur over the remainder of the vehicle, but all surface temperatures on the structure are quite high.

Many structural problems are produced by these temperatures. A major problem is to keep the heat from vaporizing the fuel, particularly if it is liquid hydrogen. Since the outer surface of the vehicle is hot, some insulation or thermos-bottle effect must be provided between the structure and the tanks. The structure must carry the vehicle loads, sustain high external temperatures, contain the fuel, and at the same time provide the required

insulation. NASA research is providing new structural concepts to solve these structural problems.

Chart 2

This chart shows a structural concept called a hot monocoque structure. This is a schematic view of a hypersonic airplane fuselage. Between the hydrogen tank and the outer structure we have introduced carbon-dioxide gas. This gas prevents air from entering the unsealed structure. Should air get in around the tanks, it would liquefy and freeze and add excessive weight to the vehicle. Some of the carbon-dioxide gas condenses as a frost within the fibrous insulation on the tank. This lightweight CO₂ frost is a good insulator, and it cools the fuel tank as it sublimates during flight.

Structural details are shown here. The primary structure on the outside is made from a high-temperature superalloy in the form of a corrugation-stiffened panel structure. The CO₂ gas is between this structure and the tank. The tank is of aluminum waffle-plate construction. Panels of fibrous insulation are bonded to the outside surface of the tank. The CO₂ frost forms within the voids of this insulation adjacent to the tank wall.

CO₂ Display

This is a display model that shows the collection of CO₂ frost. A tank of liquid nitrogen is inside the model. Liquid nitrogen is used for this demonstration instead of liquid hydrogen for safety reasons. The temperature of the liquid nitrogen is -325° F, and CO₂ frost develops at -110° F. Carbon-dioxide gas is flowing into the space between the tank and the transparent outer surface of the model. The tan substance inside is fibrous insulation around the tank. CO₂ frost has been deposited within this insulation. I will lift a section of the insulation and you can see the white CO₂ frost. This frost sublimates during heating, absorbing heat that would otherwise be transferred to the fuel.

Specimen

This is a realistic section of the hot monocoque structure and the insulated, waffle-plate tank. A test model of the structural configuration has been designed for tests in the facilities to be described later.

Chart 3

A second structural concept for hypersonic aircraft is shown on this chart. We call it a multiwall structure because it is made of multiple layers of metal properly connected to produce an insulating effect. The multiwall structure is a sandwich of dimpled and flat sheets that are joined together by welds at the

crests of the dimples. The polished outer layers form reflective shields that resist the transmission of heat. The spaces between these layers are evacuated. The inner layers form the primary load-carrying structure, and also serve as the tank wall.

Multiwall Display

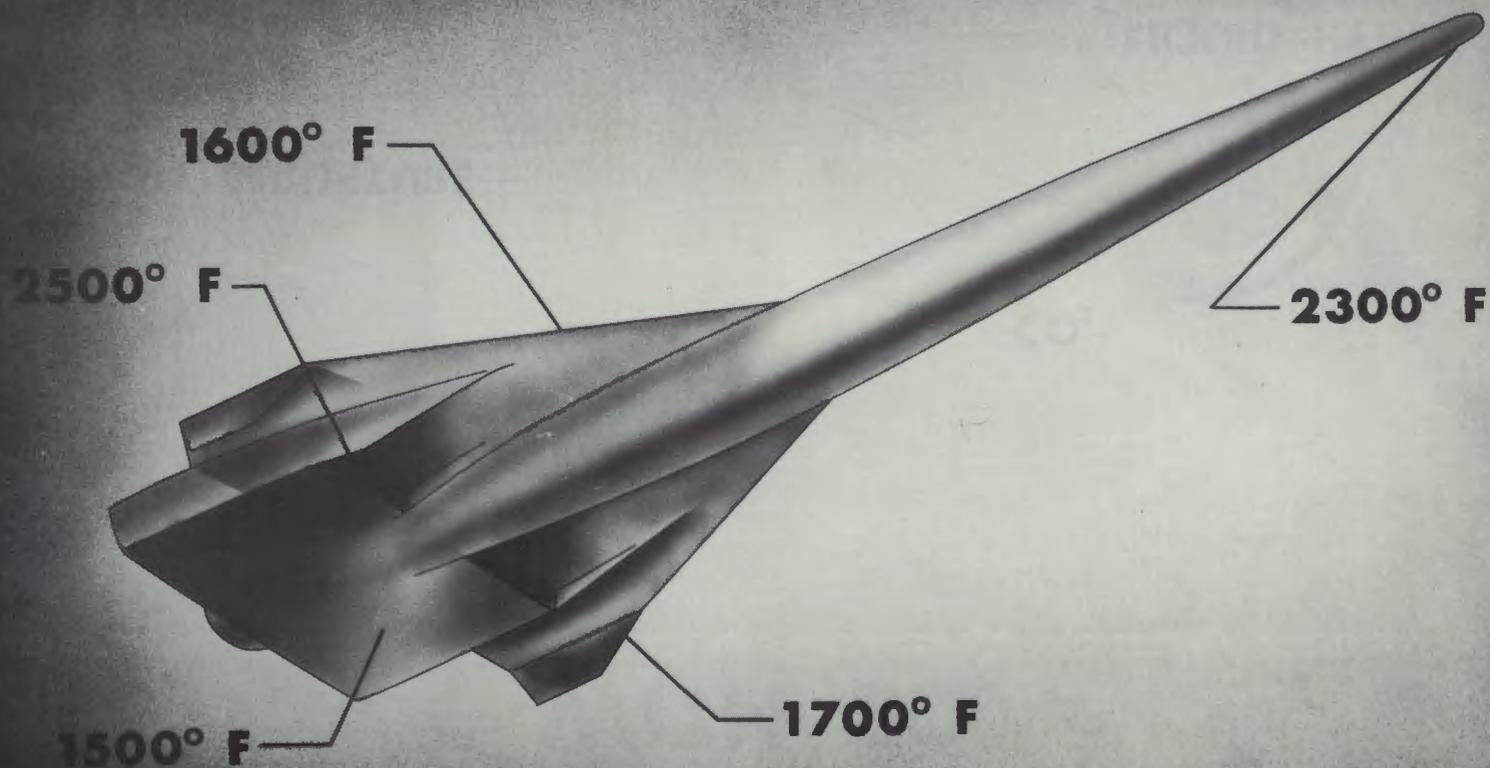
A specimen of multiwall sandwich is attached to this arm. The specimen (MW specimen) on this table is similar to the one on the arm. Note the multiple layers of metals. Behind the test specimen is a bank of radiant heaters. Thermocouples are attached to the two surfaces of the specimen so you can see the temperature of the hot face of the specimen rise on this lower instrument when I turn on the heaters. The temperature of the cold face is recorded on the upper instrument. Note the rapid rise in temperature of the hot face of the specimen. In spite of the fact that we have an all-metal structure, the temperature on its cold face is lagging far below the temperature of the hot face. I will heat the hot face of the specimen to 1,700^o F; you see, the temperature of the cold face remains virtually unchanged. As I swing the specimen away from the heaters, observe the hot glow of the heated surface and the wrinkles caused by thermal expansion.

A research specimen of this multiwall construction has been designed here and is being fabricated for us by an aerospace firm. Large structural specimens of the concepts described, structural elements, and materials are being investigated in the NASA advanced research program to provide the structures technology needed for the future construction of hypersonic aircraft.

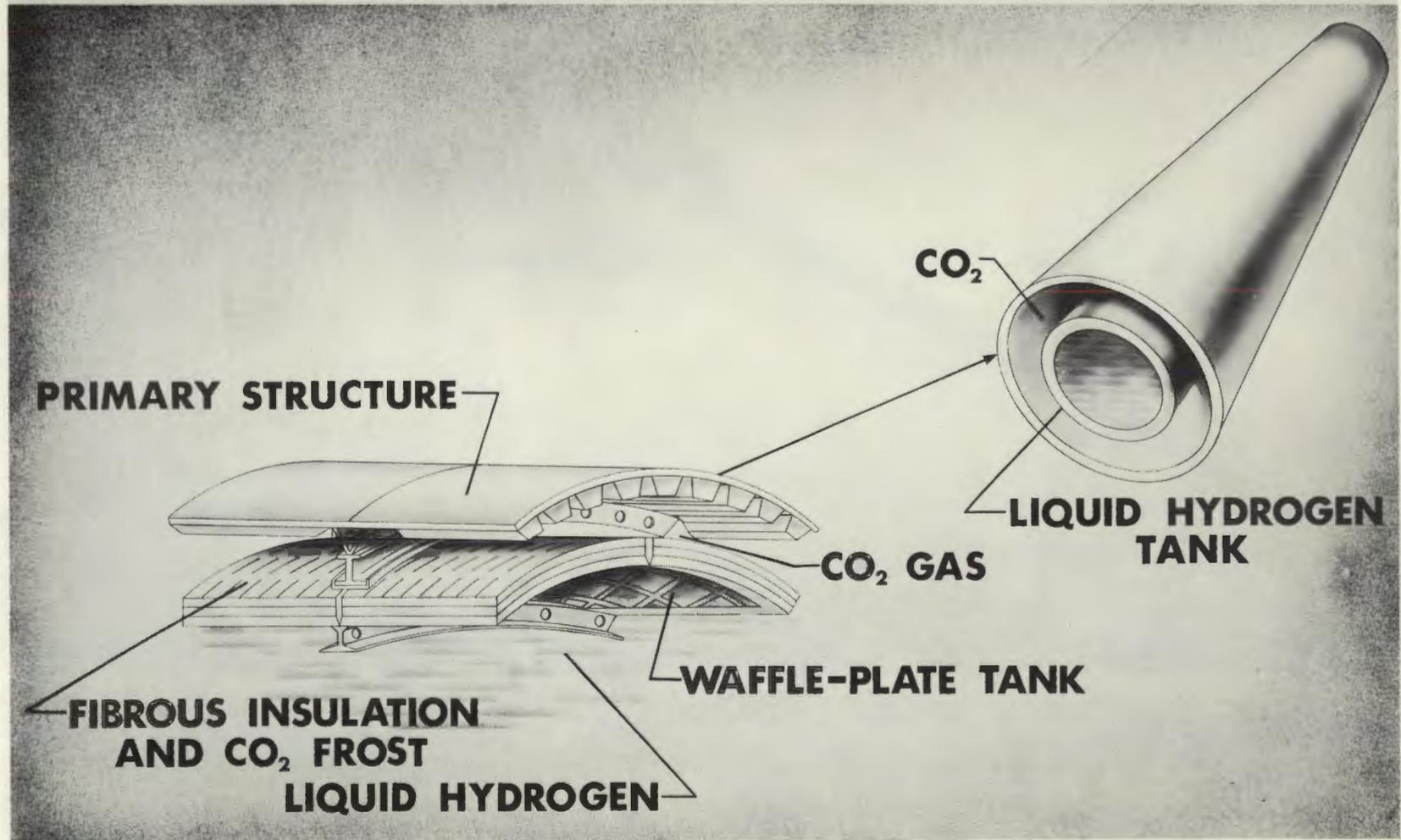
The next speaker will describe some large facilities that are essential if we are to make meaningful tests of hypersonic aircraft structures in our ground laboratories.

EQUILIBRIUM TEMPERATURES

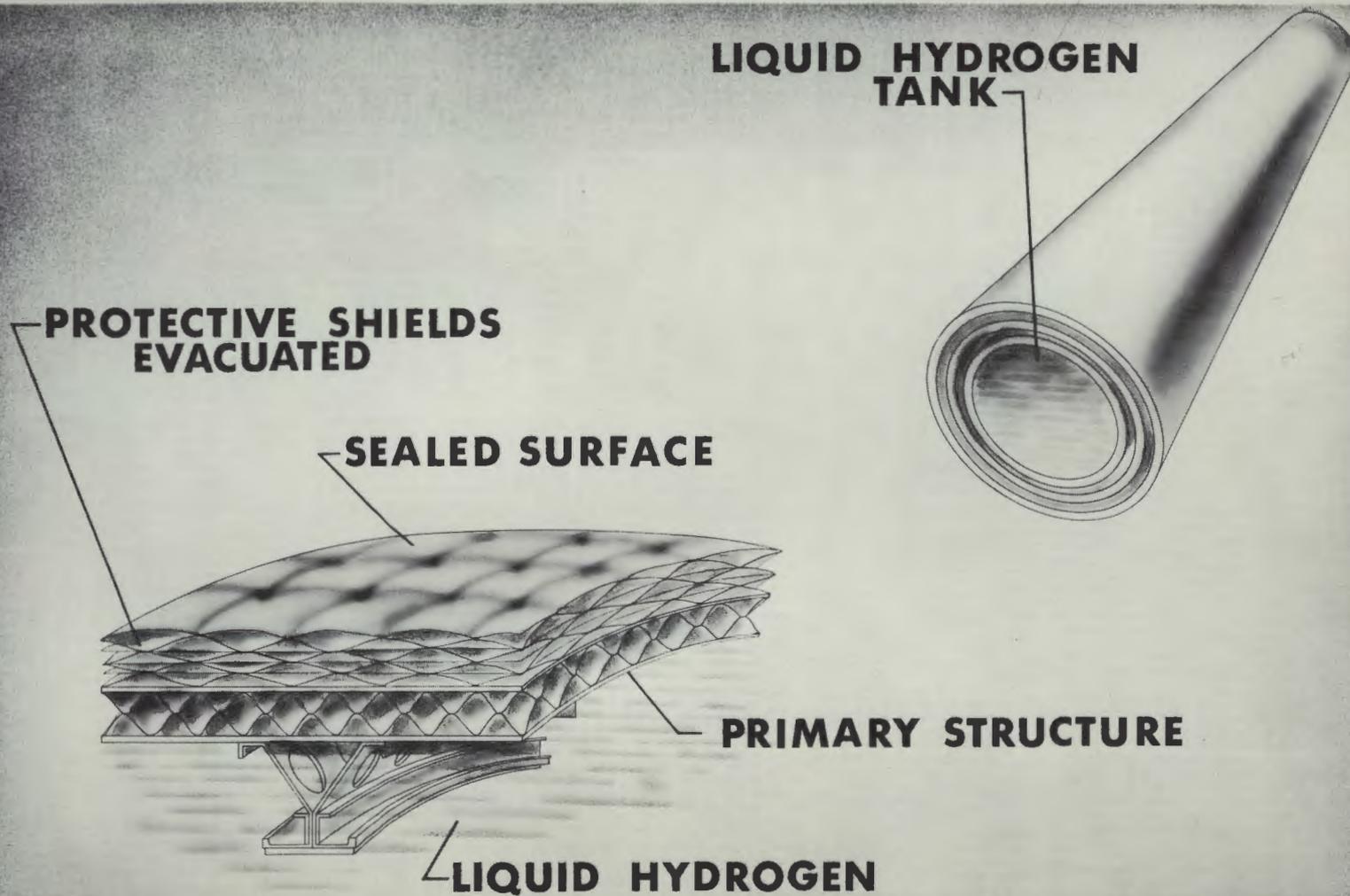
MACH 5 TO 100,000 FEET ALTITUDE



HOT MONOCOQUE STRUCTURE WITH CO₂



MULTIWALL STRUCTURE



HIGH-TEMPERATURE STRUCTURES TUNNELS

The structural concepts described by the previous speaker must be tested and qualified prior to trusting men's lives to vehicles that use them. For such tests, we need ground facilities capable of imposing realistic flight environments on structural specimens or vehicle components. Obviously, to test large specimens, the facilities themselves must be large.

A host of engineering problems must be solved to achieve and contain the gas temperatures needed for flight simulation. Consequently, considerable effort is expended by NASA in the design, construction, and continued improvement of these very necessary facilities.

At present NASA has two wind-tunnel-type facilities for structures testing. One of these duplicates the flight environment at three times the speed of sound; it has been in operation since 1958. The other, in final stages of construction, will simulate flight at seven times the speed of sound.

The Mach 3.0 facility is called the 9- by 6-foot thermal structures tunnel. This is a model of that facility. As the name implies, the cross section of the test region is 6 feet high by 9 feet wide. Air is stored in these large bottles at pressures up to 600 psi and then is discharged (or blown down) through large control valves into the nozzle, which develops the desired velocity, and then through a diffuser to the atmosphere. Hence, we call it a blowdown-type wind tunnel. To achieve the desired air temperature, a storage-type heater, composed of 300 tons of stainless steel, housed in this chamber, is used. This mass of steel is heated to temperatures up to 660° F by circulating hot air through it before each test run. During a test, the air is heated to the temperature of the steel as it passes through this section. Recently, propane burners have been added to heat the central core of the test gas to 1800° F.

In some 6 years of operation, the 9- by 6-foot tunnel, a unique national facility, has been used for research on dynamic problems of aerodynamically heated structures and to define and solve a number of important structural problems for actual flight vehicles. Notable among these are the X-15 research airplane, the Project FIRE entry research vehicle, and several large launch vehicles.

The other facility, which will simulate flight at Mach 7.0 (or seven times the speed of sound) is known as the 8-foot high-temperature structures tunnel. This is a model of it here. You are presently seated in the combustor building, which is a part of the facility complex. The name 8-foot indicates the tunnel test region size. This facility is also a blowdown tunnel of the same test section size as the Mach 3 facility, but requires an order of magnitude increase in many factors. The air storage, for example, is at 6000 psi, ten times the pressure for the 9- by 6-foot thermal structures tunnel. This very high pressure is required to achieve the desired simulation of high-speed flight. A further requirement for this simulation is that gas temperatures must reach 4000° F as opposed to 660° F for the Mach 3.0 facility. Practical achievement of such gas temperatures at the large gas flow rates through the nozzle dictated use of a

combustion process. We actually burn a fuel in the air to generate the desired gas temperature, accelerate the resulting combustion gases to $M = 7.0$, and use them as the test medium. This is a model of the combustor unit used for this high-temperature gas generation process. The actual combustor, located here, is designed to deliver gas at 4000° F and 4000 psi and at a gas flow rate of approximately 1000 pounds per second. Fuel is injected into the air under pressure and burning takes place between the point of fuel injection and the entrance to the tunnel nozzle. To inject the fuel at this high pressure, it must be stored at 6000 psi in these horizontal vessels. As noted previously, you are in the combustor building. The large cylindrical vessel here is the high-pressure combustor unit, fed by two 4000-psi air lines on each side and the 6000-psi fuel line in the center.

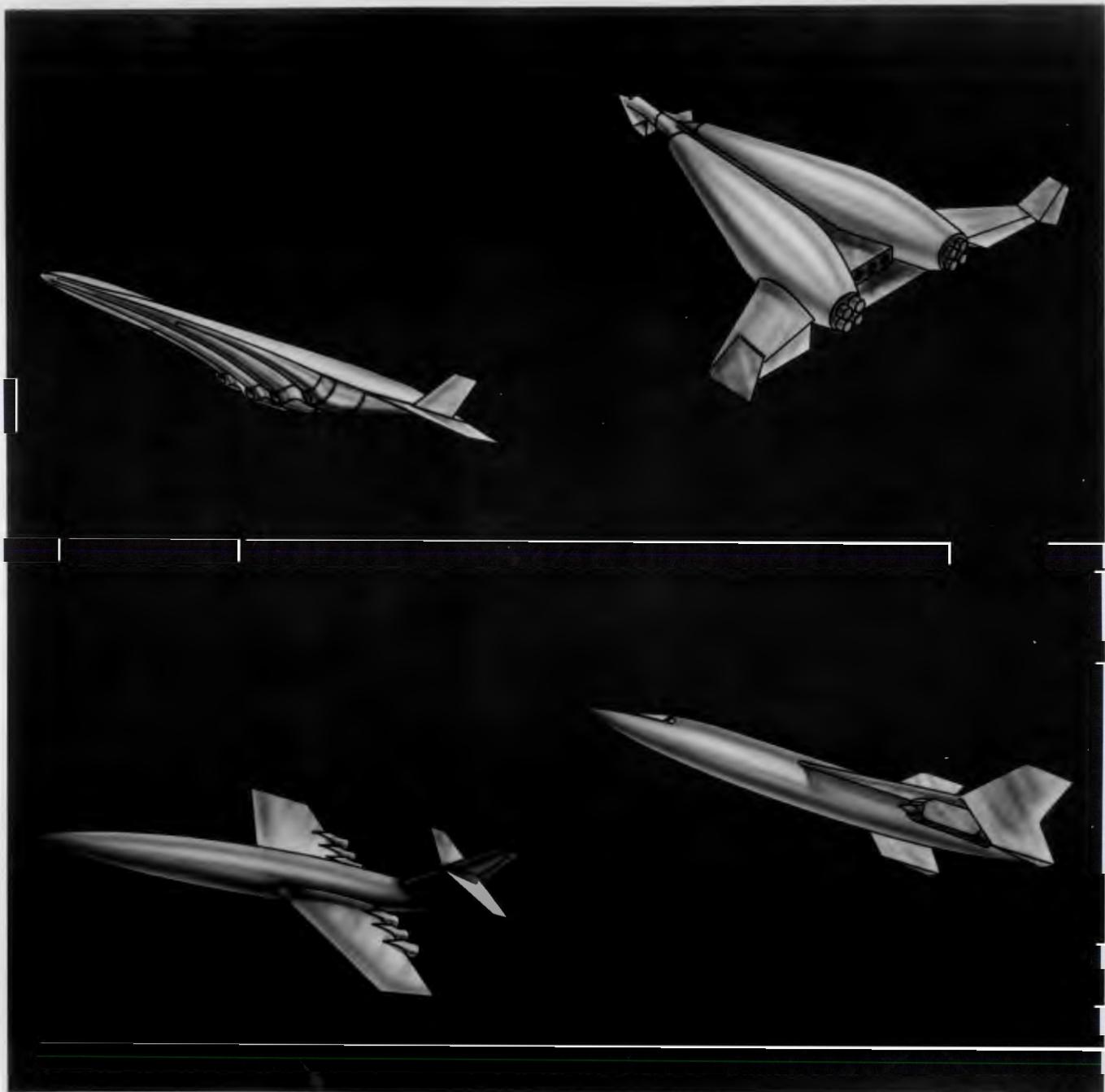
Another unusual feature of this facility is the model handling system. This system is demonstrated with this model of the tunnel test section. The models are held out of the test region while the tunnel is being started. Once test conditions are established, the model is raised into the stream. The time to raise the 15-ton elevator in the actual facility is 1 second, much faster than this demonstration. Once the model is in the test position, it can be pitched through a prescheduled attitude program. It is then returned to zero and retracted prior to tunnel shutdown. The scaled man here is 6 feet high, giving you an idea of the model and test region size.

This research facility, the 8-foot high-temperature structures tunnel, has been under development and construction since 1958. It will begin operating later this year. When it becomes operational, it will be the only facility of its kind in the United States, or in the entire world to our knowledge, and therefore will provide this country with a unique capability - that of being able to ground test structural concepts and components of hypersonic aircraft. Thereby we can prove the reliability of our structural design concepts before committing them to a flight vehicle.

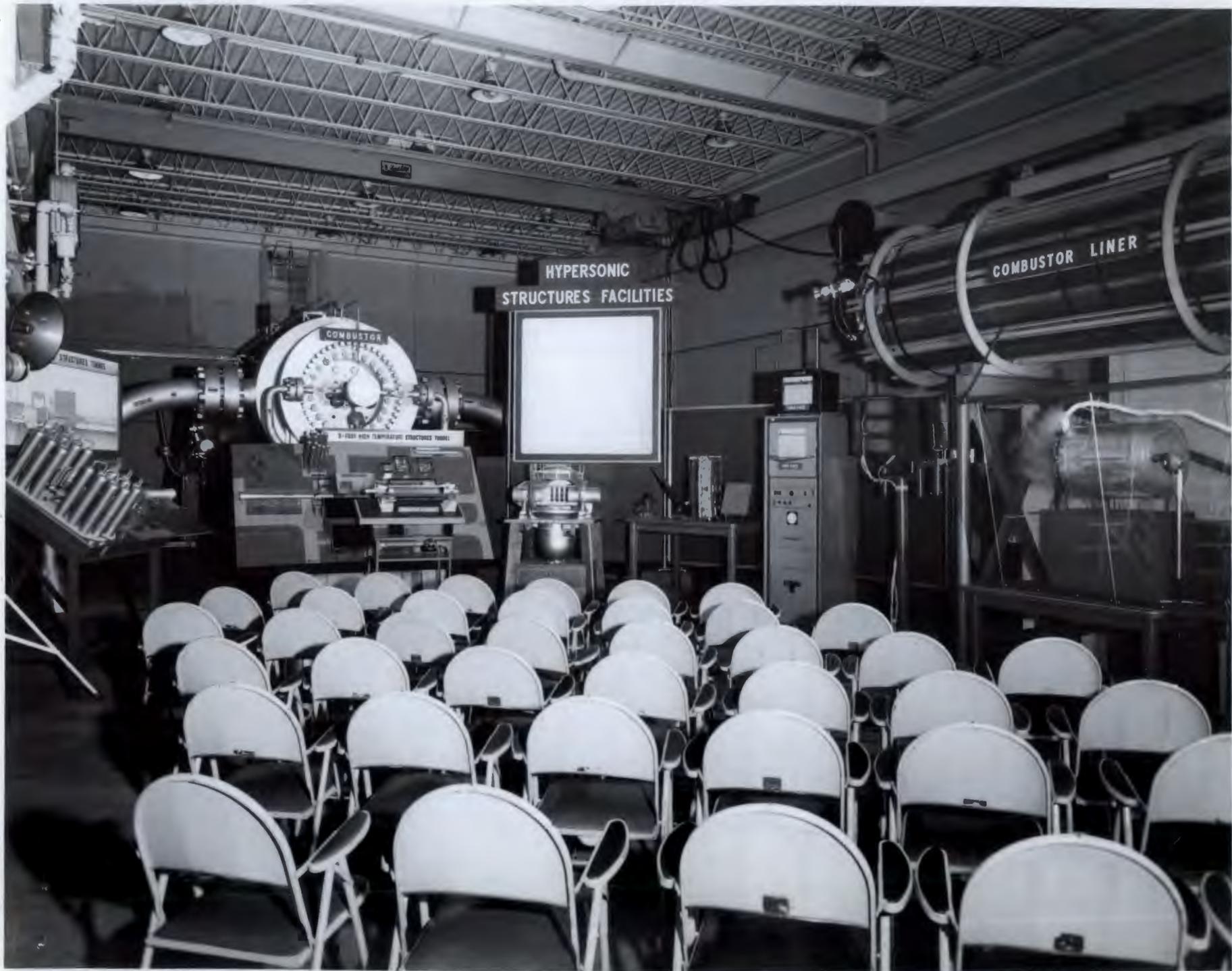
Now, if you will follow the guide, you will be taken on a short tour of the facility so that you can see the air storage field, the test region, and model handling carriage.

This is the elevator carriage for the model handling system. It is raised and lowered by a hydraulic cylinder. The stroke is 7 feet, the injection time is 1 second. The carriage and model weigh approximately 30,000 pounds. The circular-arc support you see on this carriage is for supporting three-dimensional models such as you saw on the test-section demonstration model. The elevator is, of course, enclosed in a well beneath the tunnel test section.

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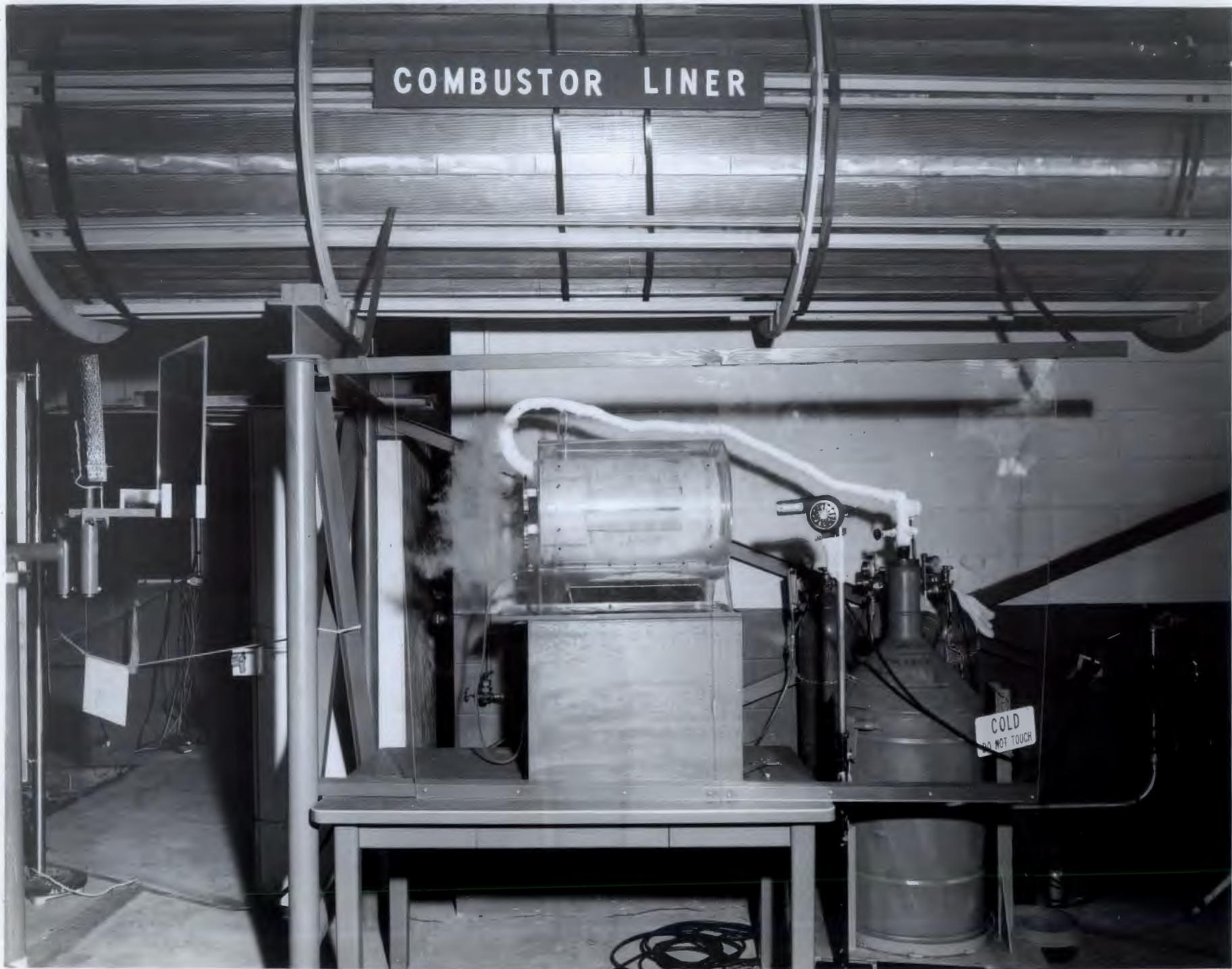


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COMBUSTOR LINER



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