

AEROPHYSICS

A knowledge of the upper atmosphere is very important now that vehicles are being launched into satellite orbits. For example, it is highly desirable to recover unmanned vehicles with their instrument records and it is essential to recover manned vehicles of the future. In such recovery, the drag of the atmosphere will probably be used to slow the vehicle to a safe landing speed, since it would be extremely uneconomical to accomplish this with rocket power. This means that air density must be known accurately in order to calculate the altitude where the vehicle will slow down and just where it will land on earth. As you know, air density decreases very rapidly as one goes up in altitude. The chart on your right indicates this fact by the decrease in the light scattered in the upper atmosphere. The red line on this chart shows the speed of a typical satellite vehicle at each altitude as it returns to earth. The yellow curve gives the speed of a typical returning space vehicle. As you will observe, the vehicles start to slow down at high altitudes, about 80 miles. Thus it is essential to know air density accurately to these levels.

The designer of a space vehicle must know many other properties of air besides its density, of course. Especially important are properties relating to energy or heat, for at these high speeds the instruments and human occupants must be protected from the large amounts of heat produced as the air drags the vehicle to slower speed. To see how this occurs, consider this chart showing the nose of a vehicle traveling through air at high speed. (Lower title chart.) The vehicle rams into the air and piles it up in this region ahead of the body. There is a sharp boundary between this higher density air and the air

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which has not yet been disturbed. This boundary is the well-known shock wave. The air is rammed so violently that it becomes white hot. Large amounts of heat are radiated to the vehicle and out into space. Still more heat is conducted to the vehicle as the hot air flows over the surface. In fact, if the vehicle is not designed properly to accommodate and minimize this heating, it can easily be vaporized to destruction, leaving only a luminous trail of vaporized material much like the meteors shown on the large chart.

The tremendous heat creates strange and interesting effects in the air. We would like to demonstrate for you one type of apparatus which we use to study these effects. This is the shock tube which you see on your left. This apparatus will produce, in the laboratory, air with temperatures of 25,000⁰ Fahrenheit or more, and with it we can duplicate some of the conditions experienced by these satellite and space vehicles entering the atmosphere. This particular shock tube is diagrammed schematically on this chart. (Lower chart 1.) A mixture of hydrogen and oxygen is exploded to heat and compress helium in the combustion chamber. Then, this diaphragm between the combustion chamber and the tube is ruptured. Here is a typical ruptured diaphragm. (Hold up diaphragm.) The hot helium flows into the shock tube at high speed and forms a shock wave. The air compressed by this shock is very hot. The hot air blows through this nozzle and past the model. The air blasting over the model has the same heat and energy as the air passing over a vehicle traveling through the atmosphere at high speed. The flow lasts a few thousandths of a second, long enough to measure the rate at which the model heats up. In a moment we will operate this

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shock tube. You won't see the air, but you will observe the deflection of these control flaps by the pressure of the air blast. (Speaker raise flaps.) The temperature at the nose of the model will be recorded on this oscilloscope. You will also hear a sharp report as the shock wave emerges from the nozzle. It will be about as loud as a pistol shot only, but please be prepared for it. The diaphragm will rupture when the pressure indicator reaches this red line.

Note the rapid temperature rise which has been recorded, and that the air blast has pushed the control flaps down. After the hot air flow is finished, the model cools off as indicated by the drop in the temperature record.

In the demonstration just given, unheated high-pressure helium has been used as the driving force rather than an exploding gas. The shock wave you just heard was much weaker, and the temperature rise of the model was considerably smaller than when the explosive gas is used to drive the shock wave down the tube. This shock tube, incidentally, is the pilot model for the larger shock tube in the background. The nozzle on the large shock tube opens up to a 1-square-foot test section which can accommodate models about 2 feet long.

In addition to its use for measuring the heating of models, the shock tube is a valuable tool for measuring basic properties of air at the high temperatures which occur around space vehicles. Let us see how some of these properties occur. As you know, air consists of small particles, called molecules, of oxygen and nitrogen. The molecules move about, bumping into one another. The quantity we call temperature is just a measure of the energy in this motion of the molecules. At

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higher gas temperatures, the molecules have more energy, that is, they move faster and collide with one another more violently. In this display (light on) you will see some model molecules flying about colliding with each other much like real molecules. The more violent the motion becomes, the higher the temperature which is simulated. It is interesting to observe the erratic, zig-zag path followed by an individual molecule, such as this bright orange model. (Hold up orange model.) (Run display 5 sec. on low pressure.) Now we increase the molecular speed to simulate higher temperature. (Run display 7 sec. on high pressure.)

In this exhibit, the models are about 200 million times larger than actual molecules. The air in this room, at sea level, is packed with about 400 billion billion molecules in each cubic inch. In contrast to this, the air at 80 miles altitude has only one molecule for every hundred million molecules at sea level - but there are still 4 thousand billion molecules per cubic inch, so we are interested in properties of air even at these altitudes and beyond.

The molecule models each consist of two balls connected together to illustrate the fact that each nitrogen or oxygen molecule consists of two atoms joined together. The molecules rotate at the same time they are moving from one collision to another. (rotate model), and part of the energy in real air is in this spinning motion of the molecules as well as in the linear motion. This rotation occurs even at low temperature such as experienced in low speed flight in this entire region of speed and altitude below 3000 miles per hour. (Hang first sign.) The two atoms are connected by electrical forces, and the connection behaves something like the spring in this model - the atoms

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can vibrate back and forth with respect to one another. However, the spring is so stiff that at normal temperatures the vibrations are negligible. At higher temperatures, the collisions between molecules are violent enough to stretch or compress the spring (compress spring), and the atoms vibrate at the same time the molecule is rotating and moving about. (Spin model while vibrating.) Like all molecular motions, these vibrational motions have energy too, and this energy contributes to the heat transfer from air to the high-speed vehicles. (Hang second sign.) As we show, in this next region of speed and altitude the vibrations become significant.

At about 6000 miles per hour, a vehicle will excite such violent collisions that some of the oxygen molecules will be ripped apart into two separate atoms. (Hand third sign.) Nitrogen atoms bind to one another more tightly than oxygen atoms, so that somewhat higher vehicle speeds are required to rip apart the nitrogen molecules. This occurs in this next region. (Hang fourth sign.) Large amounts of energy are needed to break the atoms apart, just as energy would be required to break the spring in our model. Unlike a broken spring, however, when the dissociated atoms later come close to one another they will snap together again. At the same time, the energy originally absorbed in breaking them apart is released. This released energy contributes to the heating of upper atmosphere vehicles, and of the models in the shock tube.

We have just considered some aerodynamic effects due to the structure of molecules. Now the atoms in the molecules also have structure - that is, they are not solid balls, but consist of a positively charged nucleus

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surrounded by a cloud of negatively charged electrons. This fact is indicated by this model inside the sphere representing one of the atoms. (Take apart model.) Above about 20,000 miles per hour the collisions are so energetic that even some of the tightly bound electrons are ripped away (take away electron), leaving positive atomic ions. Ionization is a dissociation of the atoms, and energy is absorbed when the electrons are knocked free and energy is released again when the free electrons come close enough to snap back into place. (Replace electron.) This energy exchange contributes to heating of high speed vehicles much like the dissociation of molecules. In addition, new phenomena known as magnetogasdynamic effects appear, because the charged ions and electrons are influenced by magnetic and electrical forces. These phenomena occur in this very high speed region. (Hang fifth sign.)

(Lower blank chart.) One magnetogasdynamic effect will be illustrated by this pump. We will demonstrate that a combination of magnetic and electrical fields can move an ionized fluid without the use of moving mechanical parts. Salt water is used in place of ionized air so the effect can be observed easily. The salt ions make the water an electrical conductor and take the place of the electrons and ionized atoms in hot air. The magnetic force lines cross the water channel between the poles of this large magnet. The electric force lines cross at the same place, but at right angles to the magnetic lines. An electric current flows across the channel through the fluid under the action of the electric force. When the magnetic field is also turned on, the fluid is pushed aside and is pumped through the channel, as you will see.

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(Pump Demonstration) The effect is much like the push on a wire which carries electric current through a magnetic field - the effect used to make electric motors go around. In a similar way, the fluid which carries electric current through the magnetic field is pushed aside. The same pumping action would occur if the salt water were a conducting gas, like the ionized air produced above 20,000 miles per hour. Although such magnetogasdynamics effects have not yet been put to practical use in flight, in principle they could be used to reduce heating or to produce a thrust engine for space flight.

We would like to show you one more apparatus used to measure properties of ions and also the effects which occur when these particles bombard surfaces of space vehicles. This is the ion-beam accelerator shown schematically on this chart. (Lower blank chart.) Nitrogen or oxygen ions are created by high-frequency electric waves at the top. These ions are accelerated to high velocity by the voltages imposed on this stack of electrodes. The accelerated ions are then focused by a magnet which also serves to separate one type of ion from all other kinds so a pure beam is obtained on the target. At present, we are studying the erosion which occurs when the ions strike metal surfaces at 15,000 miles per hour or faster. You will now see a short movie showing the ion accelerator in operation.

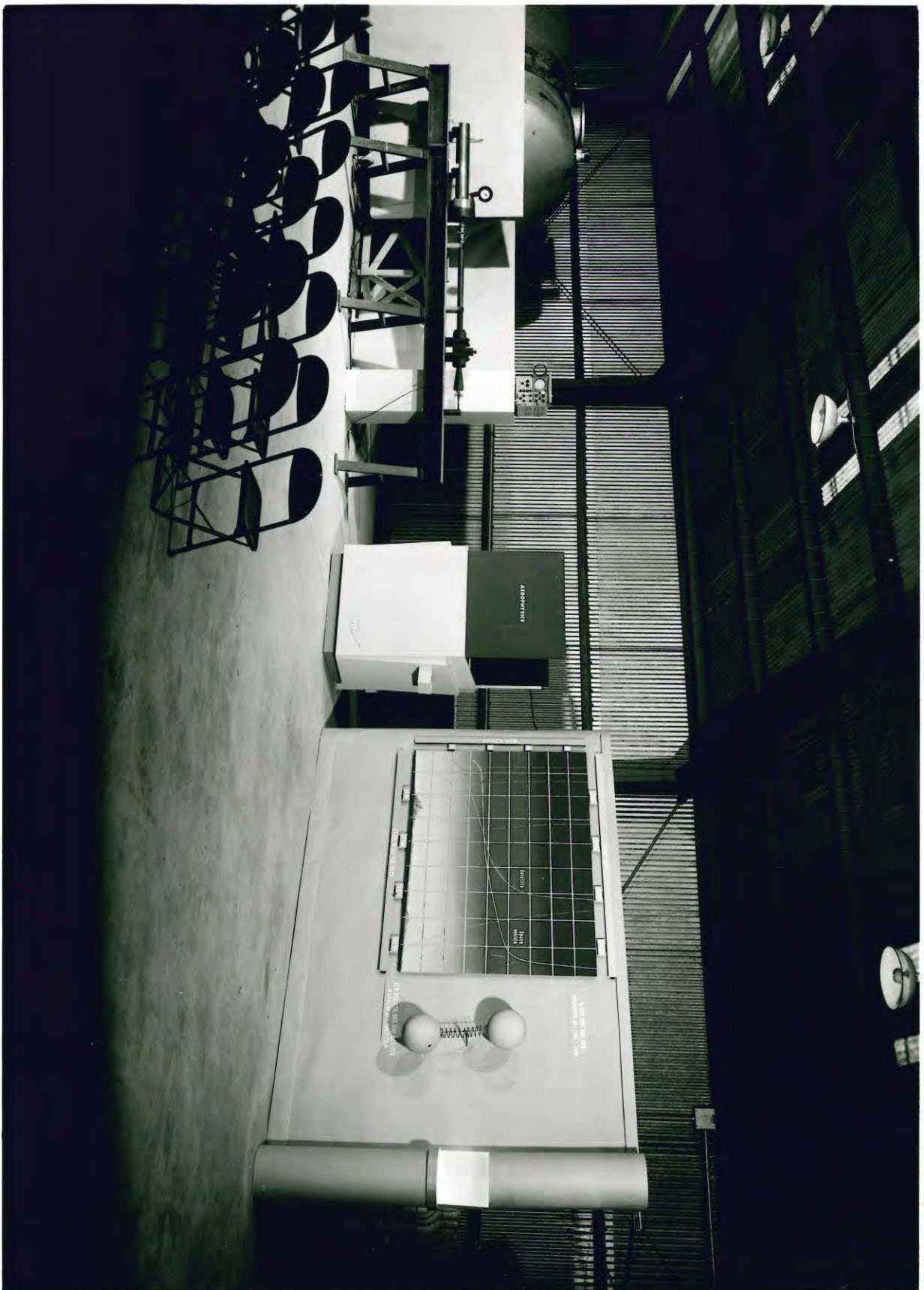
(Lights out - Movie) The glass jug which you see is the ion source. It is pumped out to a pressure one million times smaller than atmospheric pressure. Now the high-frequency voltage is being applied to the coil about the jug and you see the violet glow emitted by the nitrogen ions that are formed. The camera now moves down to the small windows along

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the stack of accelerating electrodes which also focus the beam to a small diameter. At this point the ions enter the strong magnetic field which turns them 90° into the target chamber. About one thousandth of an ampere, that is, 6 million billion ions each second, strikes the target. The target you see is an aluminum model which glows a bright blue on the impact of the beam. This is the target magnified 600 times normal size. As you can see, the ion bombardment has created numerous pits on the surface. We expect that some pitting similar to this will occur on the surfaces of space vehicles.

If you will rise and follow the guide at the back of the room, he will lead you to inspect the ion accelerator while it is in operation. Thank you.

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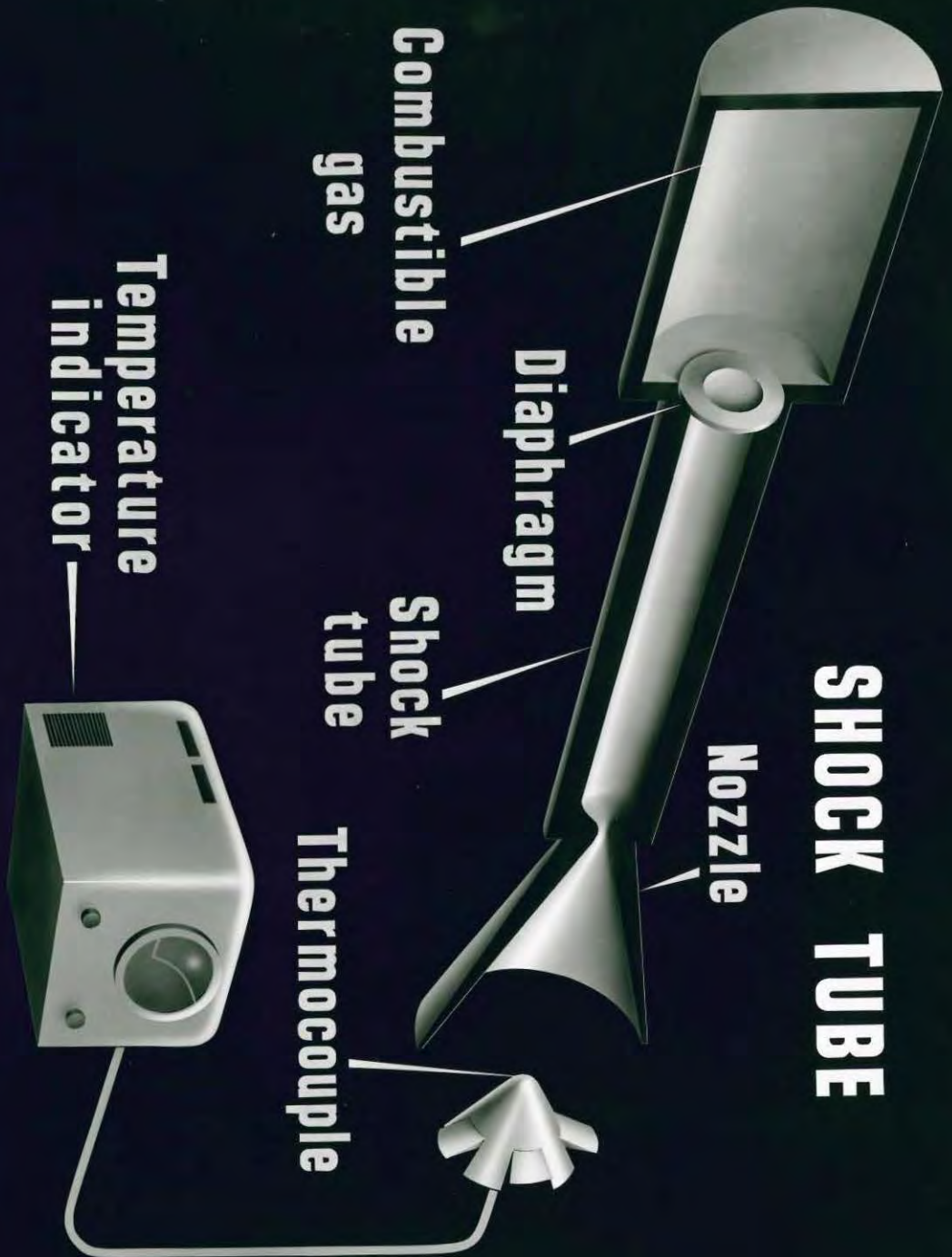
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