SUPERSONIC MISSILES

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Before we begin our talk, I would like to mention that the two tunnel operators seated at the control panel will start the 8- by 6-foot supersonic tunnel during the course of the first talk for the demonstration which is to follow. We hope this will not unduly distract your attention.

We have here two research models used in the 8- by 6-foot supersonic tunnel for studies of guided missile problems. The most of factors that must be considered in a missile design makes it unlikely that any two will be identical in detail. However, for research purposes it is possible to group general design characteristics into composite designs and that is what has been done in determining these configurations. The model on your right represents missiles with the engine submerged in the fuselage. In case you've been wondering, the engine is located in the rear of the fuselage, the nose is up forward. This model is currently being prepared for research in the tunnel. The model on your left embodies the general features of missiles with engines mounted on the wing in nacelles. In this installation the engines can be moved inboard and outboard on the wings, and the wings can be rotated to any position around the fuselage. Initial

investigations have already been completed on a version of this model. Both of these models can be used for actual burning engine tests.

Now at previous inspections we talked about some of the research problems involved in making the best possible isolated engine design. We have also discussed some of the additional problems that occur when the engine is considered as part of a complete missile such as on these models. Today we would like to extend our discussion into a third new phase, an evaluation of the effects of the missile flight maneuvers on the power plant performance.

Now even though a maneuver may involve nothing more than a change in the missile flight direction, it will require a higher engine thrust than in level flight. Therefore, any factor causing a reduction in engine thrust may prevent the missile from fulfilling its mission. The pressure at the engine combustor is a principal factor influencing the thrust of supersonic air-breathing engines. At supersonic speeds a high pressure is ideally available if the high velocity air can be brought to a low speed without loss, but in practice much of this pressure can be dissipated in the air intake system.

The effect of these pressure losses if they occur on the thrust of a ram-jet engine at 1500 mph is shown on this figure (fig. 1). We see, for example, that if 25 percent of the ideal pressure is dissipated as the air moves from the

atmosphere to the combustion chamber, this 25 percent pressure loss reduces the thrust 35 percent below the maximum value. The significance of these thrust reductions was illustrated by some of our recent research on a supersonic airplane. Through a reduction in the inlet pressure loss the top speed of this airplane was increased at least 250 miles per hour.

Pressure losses and therefore thrust losses are not wholly avoidable; it is never possible to attain 100 percent efficiency but research has enabled us to design inlets giving satisfactory engine thrusts in level flight. However, when the missile is maneuvering the engine will be inclined to the entering air flow and most inlets still cause a reduction in engine thrust under these conditions.

Here we show the thrust reduction suffered by a typical ram-jet engine as the inclination of the engine to the air flow or angle of attack is increased (fig. 2). At 20° angle of attack, which could be reached in a violent maneuver, the pressure losses have increased enough to reduce the engine thrust to 70 percent of the design value at zero degrees angle of attack. Now the angle of attack on these two research models is controlled by these bow planes at the fuselage nose which deflect as you see. A downward deflection noses the missile into a dive, the upward deflection puts it into a climb. When the bow plane is deflected, a vortex or spiral air flow disturbance originates at the tip and trails rearward. Here is a model of this air flow pattern. In appearance it

is similar to a whirlpool or tornado in that the rate of rotation increases toward the core.

We have recently conducted an experimental research program in which we measured some of the properties of this swirling flow in a plane perpendicular to the engine axis, that is, in this plane.

Here is the general picture of the swirl at the engine inlet for the beginning of a maneuver. (Fig. 3) The fuselage is alined with the flow but the bow planes are deflected 6°. As the arrows indicate the air is swirling counterclockwise. As the contour lines show the intensity of rotation increases toward the center of the vortex, reaching as high as a local 5° angle of attack. Now we have just seen that an angle of attack of the flow can have an adverse effect on engine performance, therefore, this region would be a poor location for a nacelle inlet.

Besides being a region of swirl, this area of the flow also represents a general region of reduced pressure. Here is the local pressure distribution for the condition just presented (fig. 4). The unshaded regions are areas where the air flow has not suffered any pressure loss. The deepening of the color indicates a progressive increase in pressure loss. We see that low pressures occur in the center of the vortex. Since these pressure losses occur ahead of the inlet, locating an otherwise satisfactory engine in this region would

penalize its thrust. We now recognise a problem, where can be put the engine?

A recognition of this problem is one thing, a suitable correction is yet another. If this condition were a steady operating condition we could obviously recommend not locating the nacelle in this region, on the center line of the fuselage, but up here, for example, by so doing, we could avoid the engine thrust loss to a large measure. But this is not a steady operating condition. As is mentioned earlier, it might correspond to the start of a maneuver when the fuselage is alined with the flow. An instant later it would respond to the control forces exerted by the deflected bow plane and would begin to rise. When the fuselage has risen 3° the pressure field has changed to this picture (fig. 5). The fuselage center line has started to drop under the center of the vortex, which tends to remain alined with the flow and move directly downstream of the bow plane trailing edge. The region above the fuselage center line, which was at a high pressure at the start of the maneuver is now in the low pressure lobe. This is also the region of greatest swirl and, consequently is no longer a good place for a nacelle inlet. Again we have the problem, where shall be put the engine?

There is no easy solution to this sort of power plant problem because there is no isolated problem to be solved. Instead, it is the sort of complex problem that requires a

complete evaluation through the whole range of anticipated flight conditions. A compromise power-plant location may then result, with the success of the compromise being measured by the ability of the missile to perform its intended mission.

The problem arising from the core of the vortex might, of course, be avoided in a missile that has an engine in the fuselage such as this one. As is commonly the case, however, we merely exchange one power-plant problem for another. In this (RJM-2) design there are possible thrust losses associated with the low pressure film of air that forms when the high velocity air rubs along the surfaces ahead of the inlet. We call this low pressure film the boundary layer. Recent research by the NACA has shown the importance of adequately removing this boundary layer in order to prevent large engine thrust losses. Now the problems that will confront us when we attempt to remove the boundary layer can best be illustrated by some of our completed research on an isolated body of revolution. Such an isolated body would be representative of the forward part of the model fuselage without the disturbing influence of the bow planes (fig. 6). When the body is alined with the blow the boundary layer is uniform. When the body is inclined, however, the boundary layer tends to thicken into lobes on the top quadrants, and to thin on the lower surface. Now the thin uniform layer on the bottom suggests a natural location for a scoop type inlet since the design of an adequate boundary layer removal system is straight forward.

However, the boundary layer is thin along the bottom in this case because the body or fuselage is inclined upward. During the course of maneuvers the fuselage may nose downward or in fact incline itself in many successive directions in order to arrive at its target. The low pressure lobes then will shift and the boundary layer thickness at any given point will be continuously changing.

Inasmuch as there is little choice available in the inlet location our research on this maneuver-induced power-plant problem will primarily involve an evaluation of boundary layer removal systems that can adequately cope with the variable boundary layer thickness. On this model, provision has been made to adjust the effective height of the boundary layer removal scoop by varying the approach ramp angle. The scoop opening increases as the ramp surface submerges into the fuselage. (Demonstrate) From the data obtained for a range of scoop settings we will be able to evaluate whether an adjustable scoop with its complicated mechanism and added weight can offer enough performance gain to warrant practical application.

A secondary part of the boundary layer removal problem will also be studied on this model, the drag cost of removing the boundary layer from ahead of the inlet. After the boundary layer has been removed here, it passes through a series of short ducts and reenters the main air stream through these flaps. The opening of these flaps will be remotely controlled (demonstrate) to ascertain the minimum drag penalty associated

with the boundary layer removal system.

From this brief discussion you can appreciate the complexity of the power-plant problem for supersonic missiles. The recognition of the difficulties arising from the complete missile and its flight path is an essential part of our work because we may then return to our research on the basic engine as an isolated unit in an endeavor to discover alternate solutions or designs that will eliminate the necessity for a maneuver induced compromise in the engine performance.

At present we have an isolated ram-jet engine installed in the tunnel. Our next speaker will demonstrate the operation of this engine and will, incidentally, give two of you gentlemen an opportunity to sit at the throttle of a supersonic engine.

At the present time we are investigating problems associated with the operation of a full-scale ram-jet engine. The engine corresponds to the nacelle type shown on the model to your left. For the present tests it is mounted by a sweptback strut. The slide (fig. 7) shows the relative size of the engine in the tunnel test section. The inlet is located in the field of view of the tunnel observation

windows so that a picture of the air flow about the inlet can be seen. We have arranged to televise the schlieren picture and you will see it on the three television receivers.

While this discussion has been going on the tunnel has been started and is now operating at a speed of 1100 miles per hour. We would now like to demonstrate the starting of the ram-jet engine and some of the features accompanying the engine operation. We will illustrate the starting procedure by this engine diagram.

Air enters the inlet at about 1100 miles per hour and is decelerated to about 200 miles per hour at the combustor inlet. The main flame holder of the engine surrounds a pilot located in the rear of a center body. In the start, fuel is first injected into the pilot, then ignition is accomplished by a spark plug.

The main fuel is then injected through atomizing nozzles within the flame holder to permit mixing with the air. This fuel-air mixture is ignited by the pilot flame in the sheltered regions of the flame holder and combustion is completed in the combustion chamber.

We have dials showing the main fuel flow, the pressure in the combustion chamber, the thrust force exerted by the engine, and the pilot burner temperature. As the operator opens the throttle you will see the thrust and the internal pressure increase as the fuel rate is increased. The operator will now make the start. (Demonstrate)

The engine is now running at a low fuel flow and low power setting. With this electric throttle I can regulate the fuel flow. Let us see what happens as we increase fuel flow. Now you have observed several simultaneous responses. As the fuel flow increased, the internal pressure increased, the thrust increased, and the air flow pattern at the inlet finally changed. Let us repeat this fuel flow change and examine each of these qualities in more detail.

Let us pose a problem. Suppose that our missile is operating in a cruise condition. For this condition we would like to have maximum efficiency. The combustion chamber inlet pressure is a measure of the efficiency of the ram jet. Thus, if we increase the fuel flow to the condition of maximum pressure we will have attained our cruise condition. (Demonstrate)

Now let's suppose that we are approaching our target and desire to maneuver the missile. We would require maximum thrust regardless of efficiency. Also a strong shock will move ahead of the diffuser inlet and will be oscillating. This can, however, be a potentially dangerous operating condition leading to combustion blow out. (Demonstrate)

Most of you have not had the chance to stand at the throttle of a ram-jet engine. I would like to give two of you this opportunity today. Would this gentleman please step forward and take over this throttle? I will reduce the

fuel flow to its lowest value, and I want you to increase it to the cruise condition or maximum combustion chamber pressure. (Demonstrate)

Thank you, sir, you did a fine job of setting our cruise condition. Now would this gentleman please step forward and set our maneuvering condition or maximum thrust point. (Demonstrate) Thank you, sir.

It took about one-half minute for these gentlemen to make their required settings, which is very good. During this time, however, the missile traveled about 10 miles. Accurate control of the missile would require that an automatic fuel make this setting in a fraction of a second. You will attend a discussion and demonstration of automatic controls in the Altitude Wind Tunnel.

As you depart you will witness a graphic demonstration of the effectiveness of our new acoustical absorption installation which we were required to build to suppress the large volume of noise that is emitted when operating ram-jet engines. We have here a diagram of the 8- by 6-foot supersonic tunnel (fig. 8). You are now seated in the observation room. Your bus will pull up to about this point and you will witness the tunnel operating with the noise suppressed. An access door will then be opened into this area in order that you can hear for yourself the magnitude of the sound being absorbed inside. You will leave by the door at your left for this part of the demonstration. Thank you.

SUPERSONIC MISSILES
PRESSURE
THRUST
TEMPERATURE
C-28526
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Supersonic Models Displayed in Lobby
of 8 x 6 Foot Supersonic Wind Tunnel

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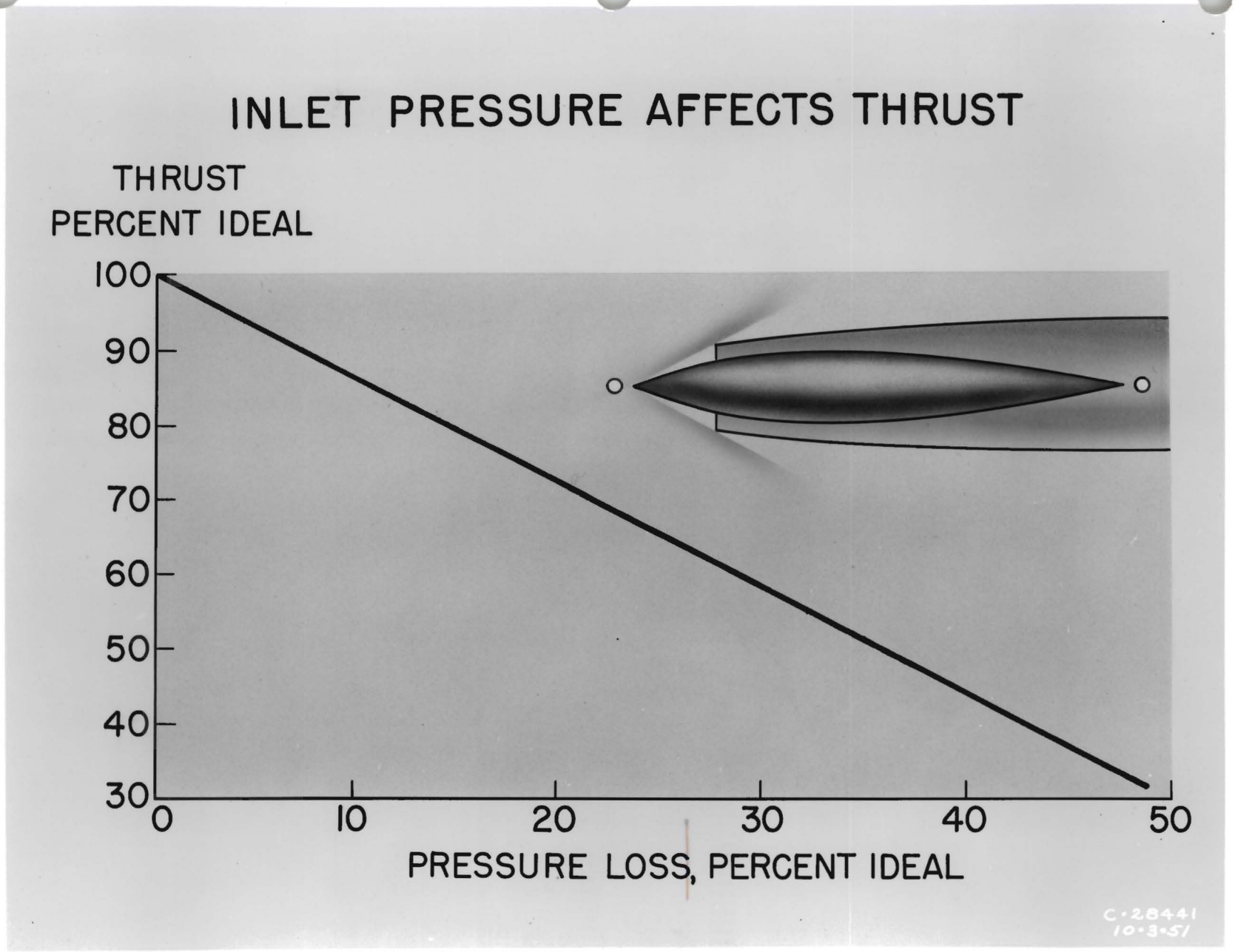
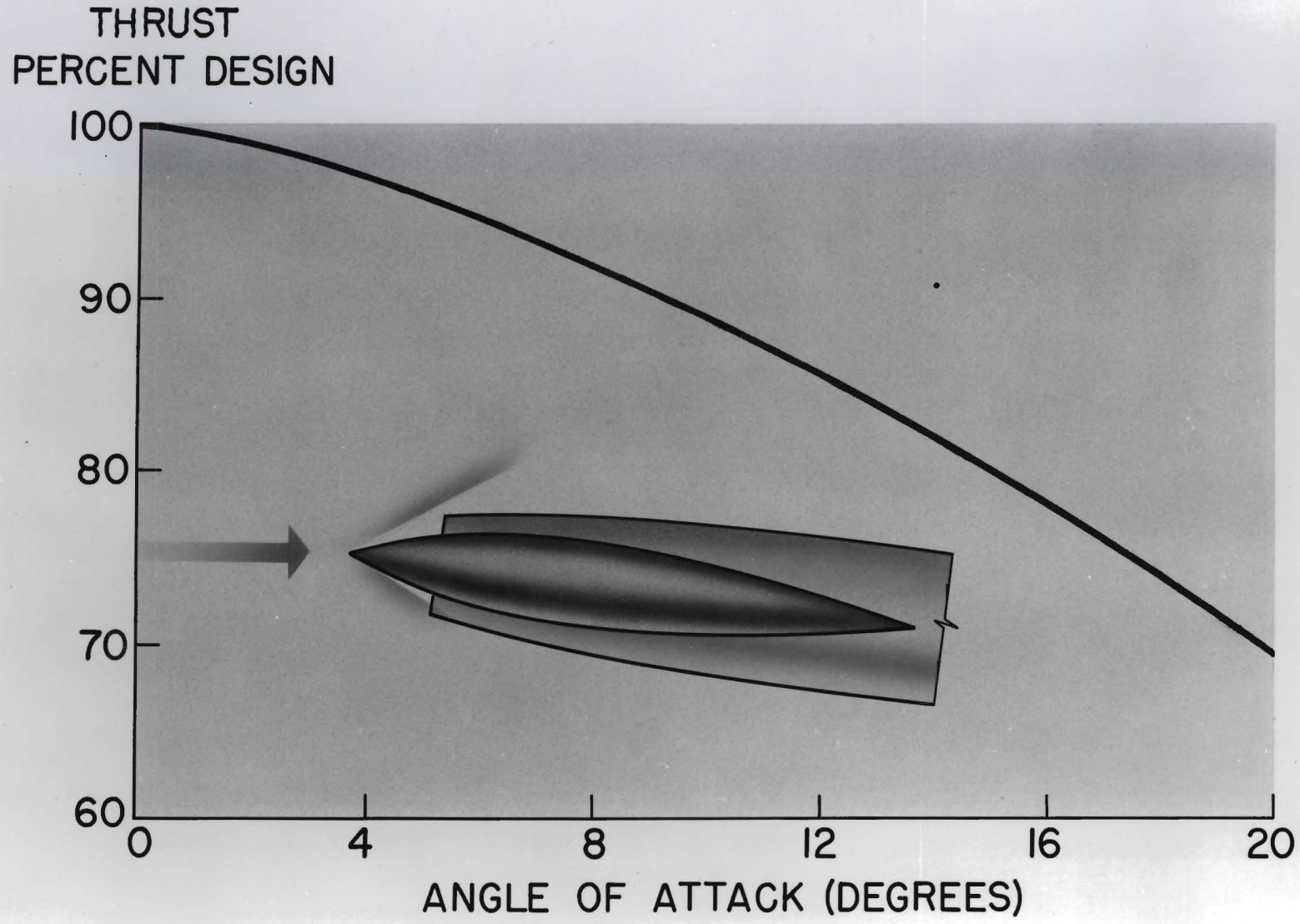


Supersonic Missiles -- Figure 1

ANGLE OF ATTACK AFFECTS THRUST



Supersonic Missiles -- Figure 2

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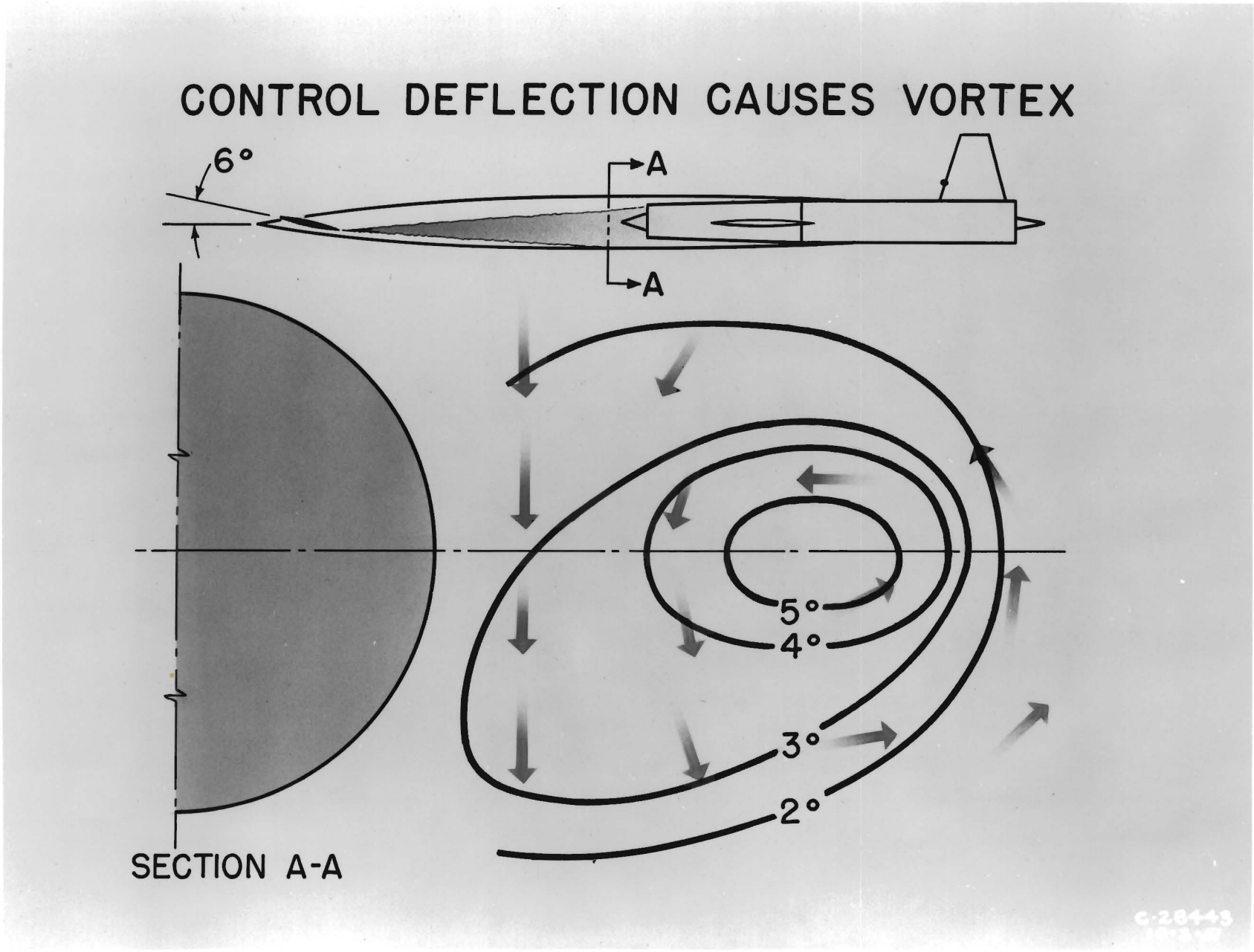

Supersonic Missiles -- Figure 3

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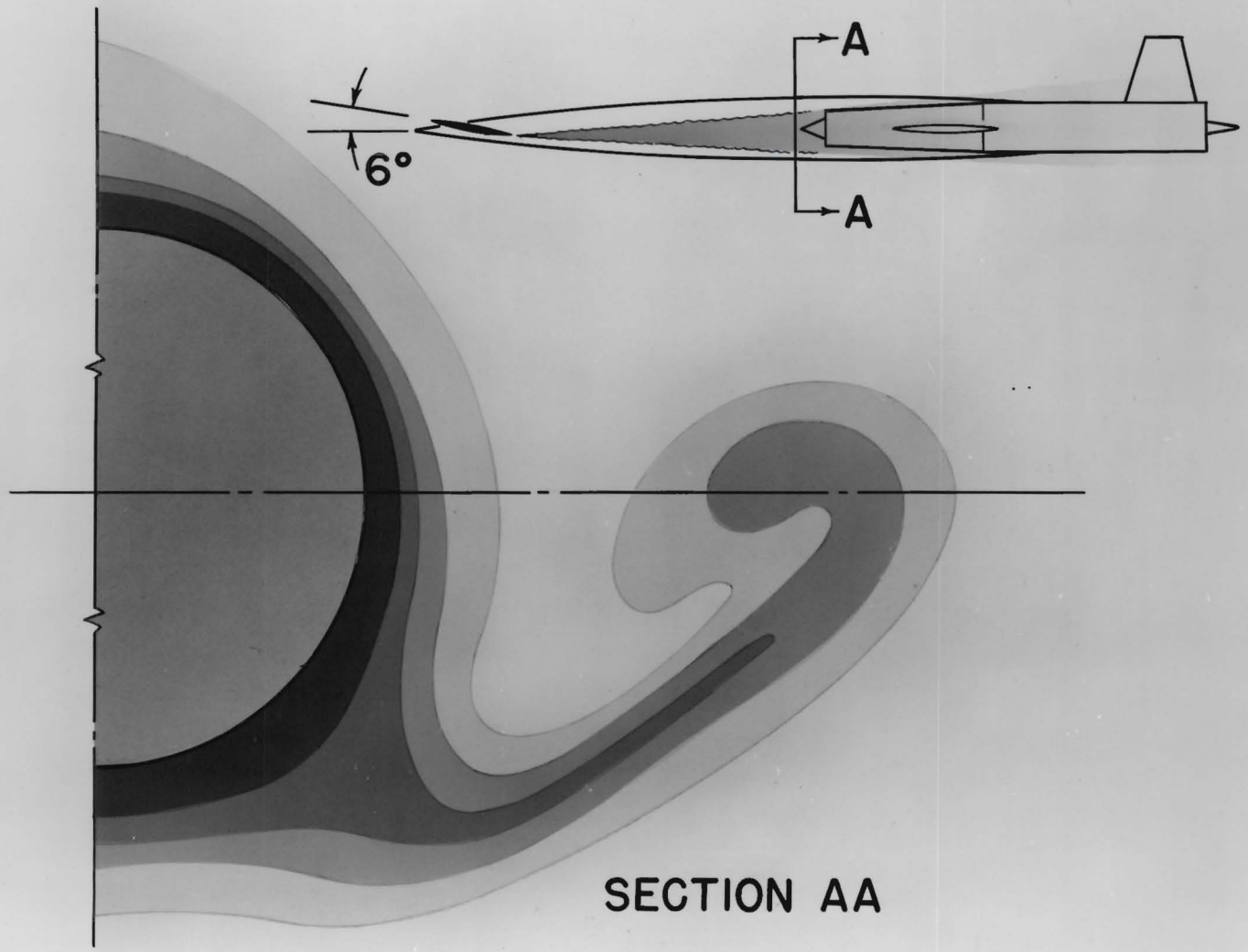
CONTROL DEFLECTION CAUSES PRESSURE LOSS



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Supersonic Missiles -- Figure 4

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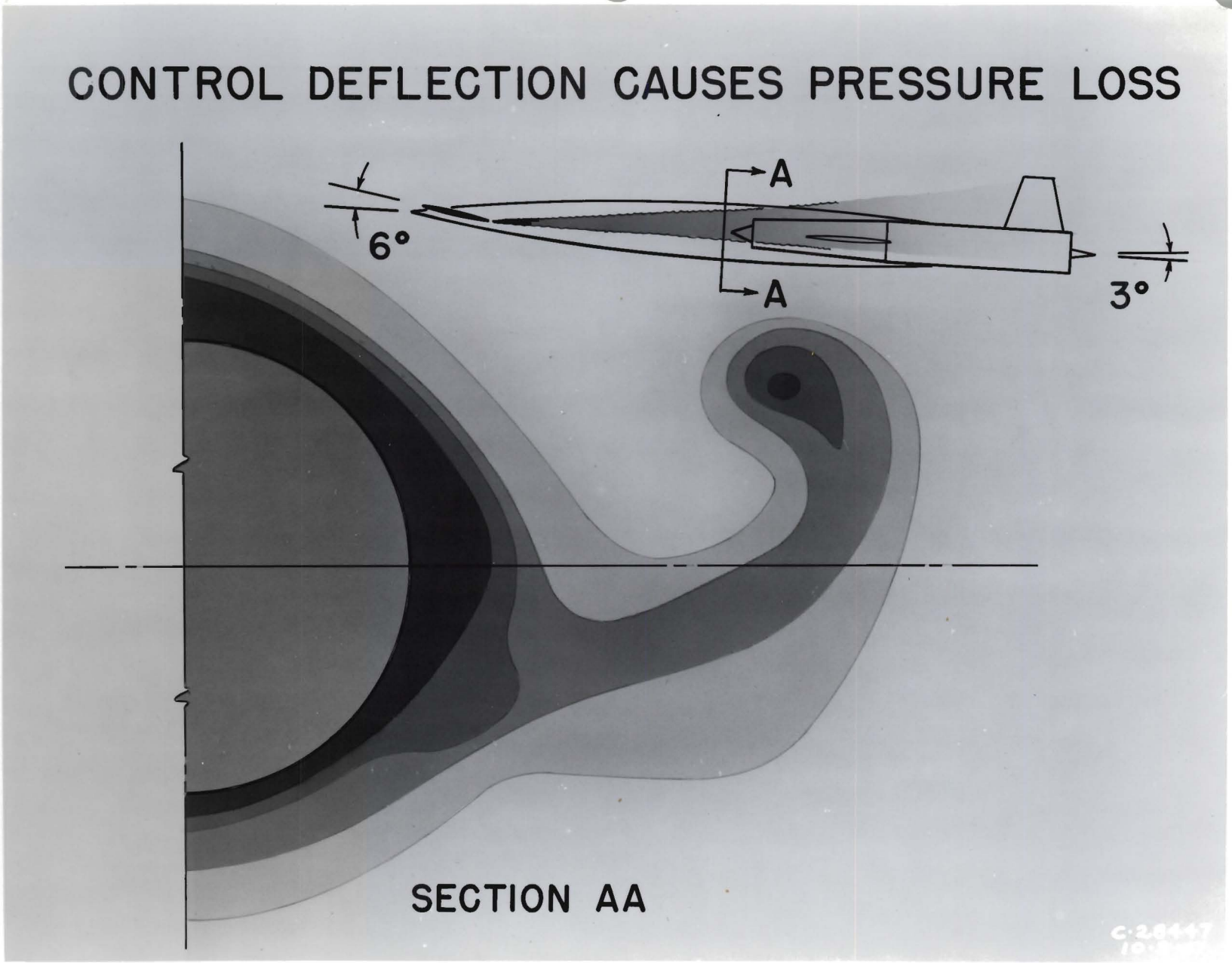
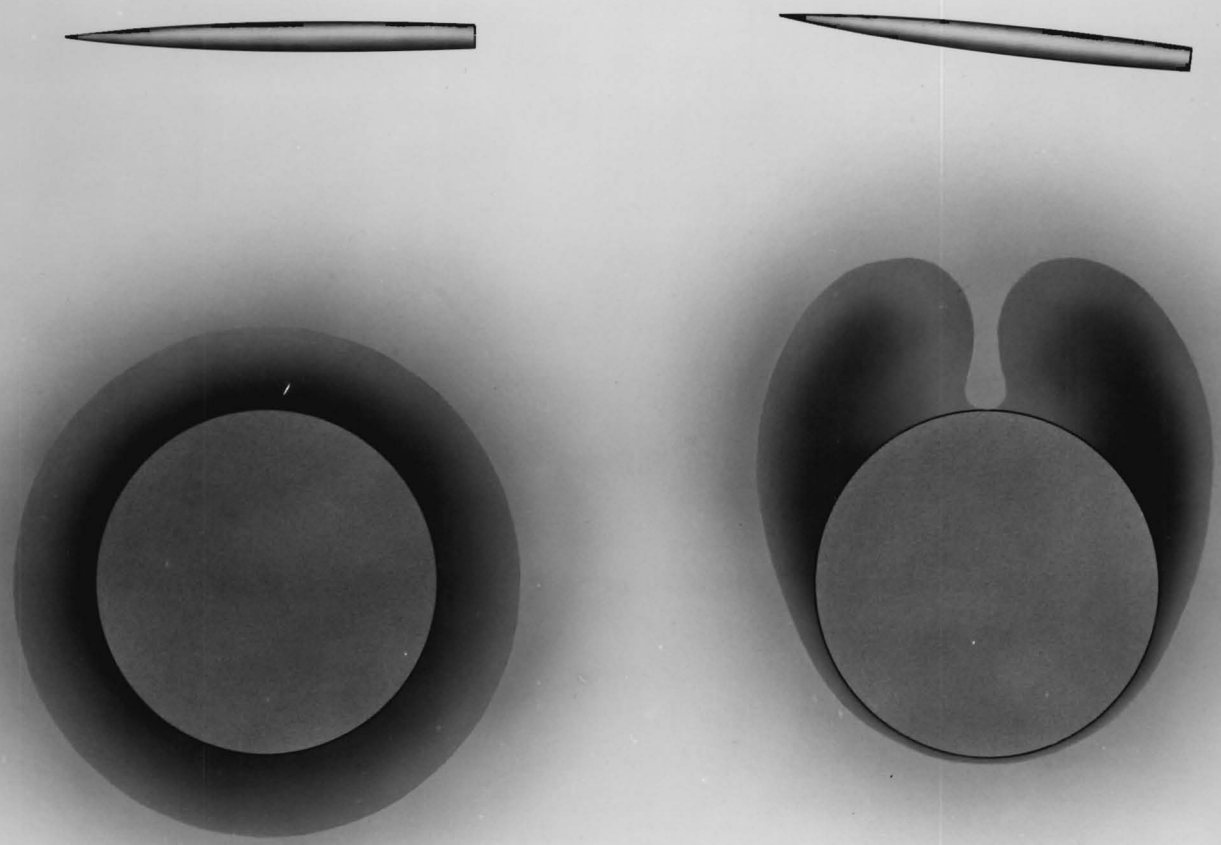
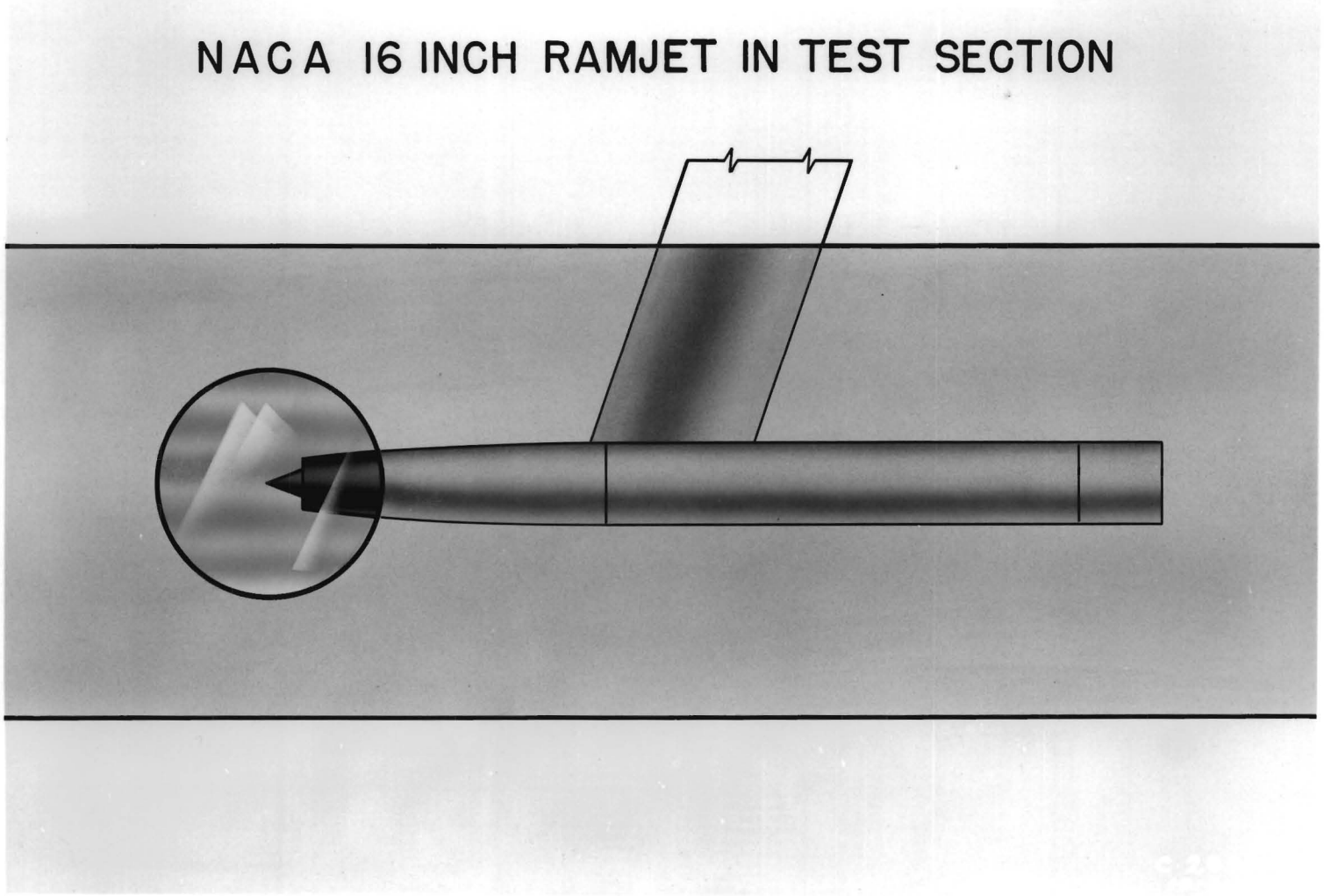


Supersonic Missiles -- Figure 5

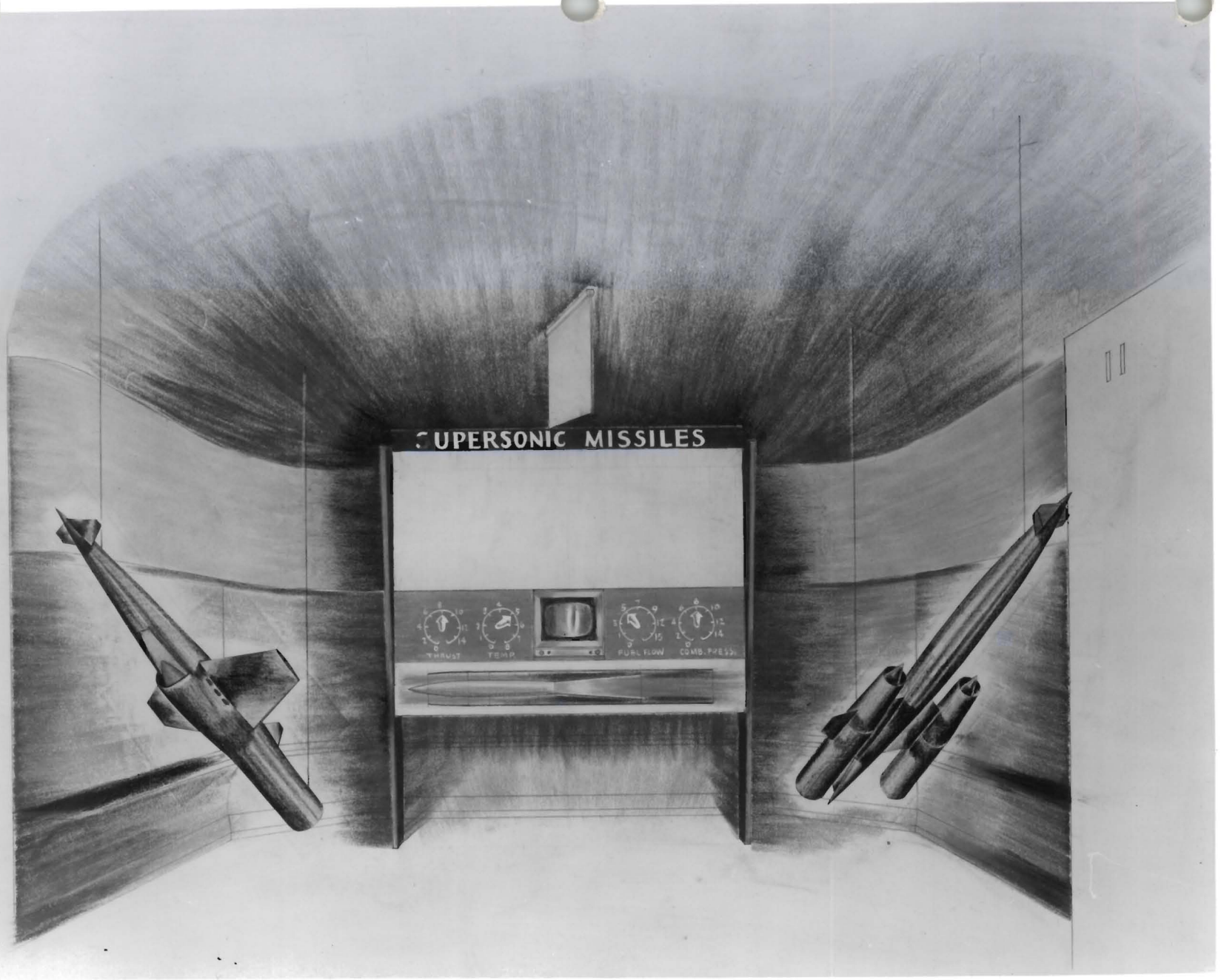
FUSELAGE AFFECTS AIRFLOW



Supersonic Missiles -- Figure 6



Supersonic Missiles -- Figure 7



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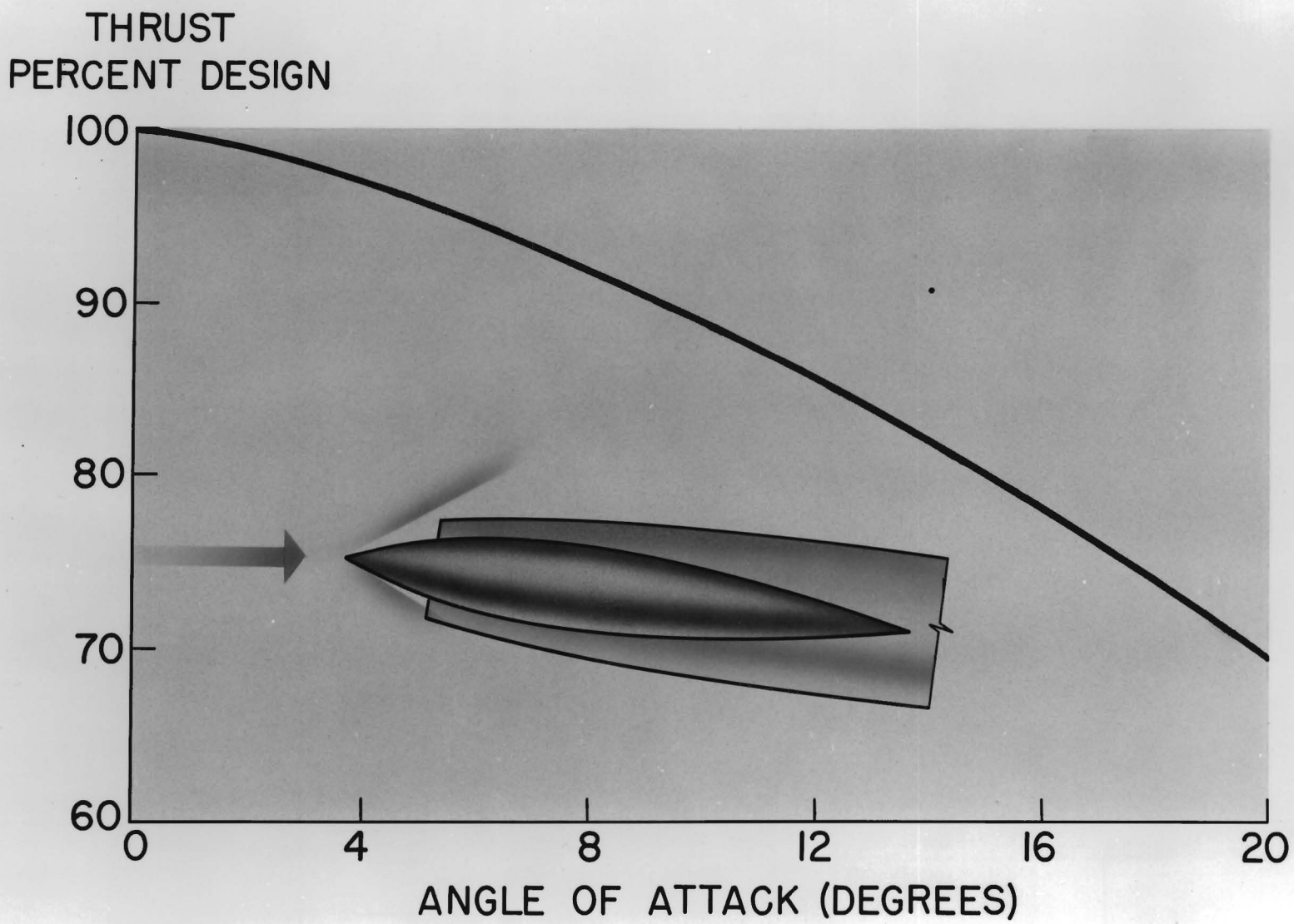
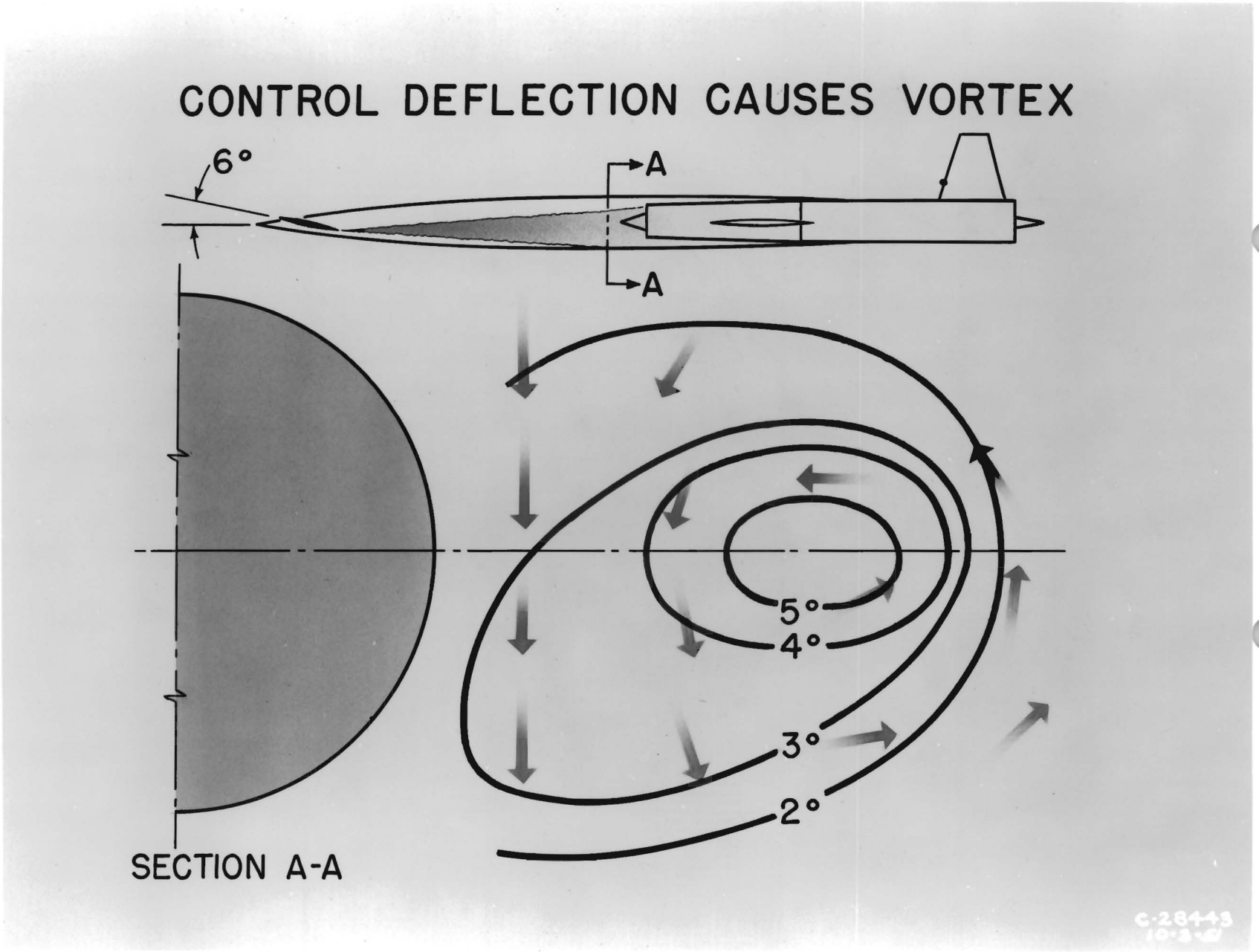
ANGLE OF ATTACK AFFECTS THRUST




CONTROL DEFLECTION CAUSES VORTEX
6°
A
A
5°
4°
3°
2°
SECTION A-A
C-28443
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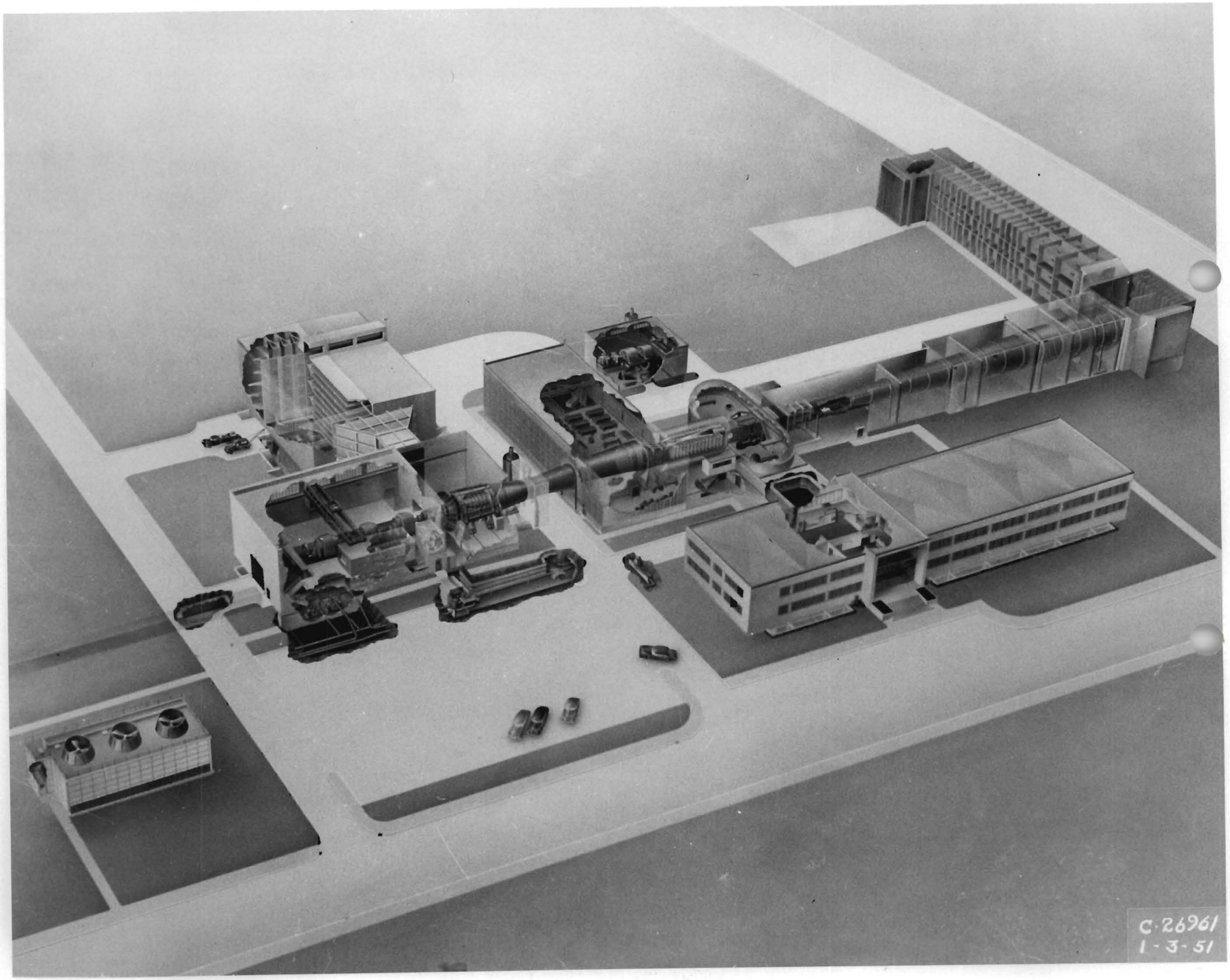

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