SUPERSONIC AIRPLANES

presented by

The 8- by 7-Foot Supersonic Wind Tunnel Branch

Man is continually striving to move people and materials over long distances in the shortest possible time. This graph will remind you how well he has succeeded in moving ever faster. These speeds have been achieved by fighters and research airplanes which sacrifice range for speed. But man wants to move not only faster but over long distances as well.

During the next few minutes we would like to tell you about some of the aerodynamic problems encountered in designing transport and bomber airplanes to fly, say, 2000 miles per hour and the progress which has been made toward their solution. Such progress stems from research, much of it conducted with wind tunnels such as the one located over here. Wind speeds up to three and one-half times the speed of sound can be created in the test section with the compressor shown in this photograph which is driven by electric motors totaling 180,000 horsepower. This test section is just one of three that alternate using the same drive system. Here you see an aerial photograph of the whole arrangement.

Let us now preview the various factors which determine the ability of an airplane to cruise for long range. These factors are spelled out here: first, the aerodynamic efficiency of the airframe expressed as the ratio of lift to drag; second, the propulsive efficiency shown as the ratio of net thrust to rate of fuel consumption; and third, the structural efficiency given as the ratio of take-off weight to landing weight. These three basic factors must be made as large as possible if we are to achieve long range.

Through very skillful application of the fruits of past research, the aircraft industry is now manufacturing turbojet transport airplanes capable of cruising transcontinental and intercontinental distances at speeds between 500 and 600 miles per hour, just a little slower than the speed of sound. On this chart we see how the range of one of these airplanes varies with flight speed. As the speed of this airplane is increased up to the design speed, we see that the range increases rapidly due primarily to the increased efficiency of the turbojet engine which is included in this second term of the range relation. Beyond the design speed, however, the range decreases sharply. To obtain a better understanding of this curve let us examine this next chart which shows how these efficiencies influencing airplane range are affected by speed. For reference purposes, the curve from the preceding chart has been shown again but converted to this efficiency form.

We see first that the efficiency of the turbojet engine increases steadily with increase in speed. To complete this picture, however, we see that there are two additional factors involved in the range relation which show quite an opposite effect. The losses incurred by the inlet and exhaust systems at the higher speeds are represented by this upper curve. Added to these losses are the even larger losses resulting from the reduction in the lift-drag ratio shown by this lower curve. The final variation of range with speed of the airplane then hinges primarily on these two curves, this engine performance curve and this summation curve. Below the design cruising speed the engine performance increases steadily while the other two efficiencies show practically no change. This explains the rapid rise in range up to this design speed that was mentioned previously.

The situation above the design cruising speed, however, depends upon how rapidly this lower curve deteriorates compared to the rise in engine performance. It is obvious that the aerodynamic features of the transport airplane for which these curves apply are not suitable for flight at higher speeds.

In order to cruise efficiently over long distances at speeds greater than the design speed shown, it is clear we need an entirely different airplane, one in which improvements must be made in these two efficiencies. Most of our discussion here today, therefore, will be concerned with research progress in the fields of improving the lift-drag-ratio term, and the efficiency of engine inlet system.

Now I would like to introduce Mr. ____________, who will discuss the first factor, dealing with research leading to improvement in the aerodynamic efficiency of supersonic airplanes.

The first factor influencing airplane range is indicated here as the ratio of lift to drag. The lift must equal the weight of the airplane, so we seek to provide this required lift with a minimum of drag. To illustrate the work in this field we would like to concentrate on two current wind-tunnel research programs, both aimed at maximizing this lift-over-drag ratio. These two avenues of exploration are exemplified in the two models you see here. Despite the fact that in appearance they differ a great deal, both are designed to explore the possibilities of achieving a maximum lift-drag ratio at 2000 miles per hour.

In the case of this first model, what you see is essentially a flying wing with no prominent fuselage. The model obviously is greatly simplified by omission of stabilizing surfaces and engine nacelles. The fundamental concept in this design is to achieve as efficient a wing as possible by concentrating on a reduction of two components of the drag known as form drag and drag due to lift. Let us consider these two components, then, in that order.

Form drag arises when an aerodynamic body is not properly streamlined. The air flow separates from the surface, thereby reducing the air pressure over the rearward-facing surfaces. This suction tends to hold the airplane back. The importance of proper streamlining can be illustrated by this wing and this small wire. Being streamlined, this wing actually has no more drag than this much smaller wire at low subsonic speed.

At supersonic speeds the picture is somewhat different. Shock waves occur on the surface of the wing which in themselves promote flow separation in spite of streamlining. However, this trouble can be avoided to a large degree by sweeping the wing back so it lies completely behind the shock wave emanating from the wing-fuselage juncture. Then the flow at right angles to the leading edge is subsonic and the wing behaves more like the wing on a subsonic airplane. For this reason, on this first model the wings have been sweptback 80° in an attempt to preserve these favorable subsonic drag effects in the supersonic speed range. With this much sweep we can take advantage of a relatively thick wing with a rounded leading edge.

The second item of drag minimized in this design is that arising directly from the production of lift. The airplane, to get lift, must leave a trail of descending air. In effect, the airplane must fly uphill in a column of descending air just to maintain level flight. The force required to continuously ascend this figurative hill is called "drag due to lift."

At subsonic speed, to achieve minimum drag due to lift requires, first, that the wing be stretched out in the spanwise direction as far as structural limitations allow, and second that the wing be shaped to give an elliptic distribution of the lift over this span as shown here on the chart. For the supersonic case, on the other hand, the theory of Mr. R. T. Jones of this Laboratory indicates that for minimum drag due to lift the wing must be stretched out not only in the spanwise direction but in the streamwise direction as well, and, furthermore, that the loading must be elliptic in every direction. Applied to the extreme, this theory suggests a yawed elliptically shaped wing such as this simple balsa-wood model. The sight of an airplane like this streaking across the sky might be a little unnerving, but, as you can see, the model actually flies. This little demonstration, of course, shows only one of many ideas on the subject and is intended to merely illustrate a point. Returning to wings arranged in a more familiar fashion, the ideal elliptic loading indicated by theory for minimum drag due to lift can be approximated by warping the wing. As shown here, elliptic loading is achieved along the center line by this means, as well as in most directions across either wing panel. This first model has the wing stretched out as much as feasible both in the spanwise and streamwise direction. The wing is also warped to approximate the desired elliptic loading to explore these theoretical concepts experimentally. However, if we carry these ideas too far it is obvious we will run into other serious problems such as how to land the airplane or how to prevent wing flutter. These and other problems, therefore, turn us to explore other approaches to drag reduction.

Another approach is illustrated by this second model. This wing and fuselage are designed to provide favorable pressure fields through mutual interference. Here, particular emphasis was placed on minimizing the supersonic wave drag due to thickness of the wing as well as the wave drag due to lift. First, before we discuss these two drag components, what do we mean by using interference pressure fields? Let us consider a circular fuselage mounted symmetrically on a thin wing at zero angle of attack. A front view of this arrangement, along with the disturbance pressures caused by the body, is shown at the top of this chart. Quite obviously, the downward pressure forces on the top of the body and wing just cancel the upward pressure forces on the bottom. However, we see that by eliminating the upper half of the body we obtain an unbalanced pressure force. This phenomenon occurs only at supersonic speeds. If we carry this one step further we see that by bending down the tips of the wing it is theoretically possible to deflect downward some of the outward flow caused by the body so as to gain even more lift. These basic concepts were used to design this second supersonic model. The design was also planned so the lift from this fuselage-created pressure field would have a favorable distribution to help minimize the drag due to lift. Moreover, where the necessary lift is generated at a relatively low angle of attack, the wing can be thinner and have a sharper leading edge without incurring a drag penalty from flow separation. And with thinner sections the drag due to wing thickness is greatly reduced. Therein lie the principal differences in design philosophy between these two research models. The first model employs, in a broad sense, some of the well-established subsonic design principles. It derives lift from angle-of-attack changes. This entails close attention to wing loading and airfoil sections in order to control the drag due to lift and still avoid separation of the air flow. For the second model, on the other hand, the drag due to lift is reduced by generating part of the necessary lift by interference at a relatively low angle of attack, thus permitting emphasis on minimizing the drag due to wing thickness. For obvious reasons, however, neither of these research models in its present form could meet all the other design requirements. Instead they offer only a starting point for research on one small phase of the overall problem.

Your next speaker, Mr. ___________, will discuss the second quantity of the range equation, that dealing with the propulsion system. Mr. ___________.

Mr. ___________ has just told you of recent advances in the science of how to minimize the force required to push airplanes through the air at high speed. Now, obviously, it is equally important that the propulsive system furnish this push as efficiently as possible. This second term represents this factor. It simply means that we want the required thrust from the least amount of fuel in order to fly the greatest possible distance. To see how this might be accomplished let us first consider how an air-breathing engine operates and then review some typical advancements that are being made through research.

Fundamentally, an air-breathing jet engine produces thrust by capturing a portion of the air stream here in the inlet and ejecting it rearward from the exhaust nozzle at a greatly increased velocity. The increased velocity is imparted to the air by heating it in a combustion chamber indicated here only schematically. Actually in the turbojet engine a compressor and turbine would be housed either side of this burning region. The incoming air cannot be allowed to enter the combustion chamber at supersonic speed since we have not yet determined how to operate the engine efficiently under these conditions. Consequently, aircraft flying at supersonic speeds must incorporate some means for reducing the internal flow to subsonic speed before it reaches the combustion region. This speed reduction is accomplished by proper design of the inlet and the internal duct following the inlet, known as the diffuser. The aim of inlet and diffuser design is to reduce the engine airspeed in an efficient manner. The process of slowing the air increases its pressure in the combustion chamber and hence increases the thrust output from the engine.

Let us next consider the efficiency with which four types of inlet-diffuser combinations slow the engine air. We see here that the efficiency of the simplest system used for many years on subsonic airplanes and consisting of just an opening in the nose of the engine nacelle deteriorates rapidly with increasing speed. The explanation for this is simple. The incoming air is slowed too abruptly to subsonic speed through a strong shock wave you see here. This very sudden slowing in a single shock is accompanied by a large loss in pressure. This loss can be reduced considerably by slowing the air gradually in a step-wise fashion before the main shock wave is reached so that the final jump from supersonic speed to subsonic speed is small. This is the reasoning that led to the "all-external-compression" type of inlet illustrated here. This inlet derives its name from the fact that the engine air is slowed and compressed by passing through a series of small shock waves in front of the inlet. Because the air has been slowed gradually, the shock losses are much less, and, hence, the over-all efficiency is greatly improved as can be seen from this curve. This type inlet is in current use on several supersonic airplanes.

Extending this concept of slowing the engine air as much as possible before reaching the main shock, we arrive at inlet designs illustrated in these two upper figures. The final shock, you can see, follows a larger number of the preferred weak waves; consequently, it is weaker and the efficiency of the inlet is increased. At the present time these two inlets show equal promise. Some variations of these types will probably appear on future supersonic airplanes.

There are, of course, many important side problems connected with designing an efficient inlet; for example, that of adjusting the size opening to match a given flight speed. As the speed of flight increases, the amount of air required by the engine also increases. This is illustrated by these two models where one inlet is scaled to accommodate the air needed by the engine at a subsonic speed of 500 miles an hour and the other for a supersonic speed of 2000 miles per hour. Obviously, the designer is faced with a monumental design problem here to devise a mechanism that will provide the necessary flexibility in the shape and size of such a supersonic inlet. Furthermore, the relative size of the inlet in proportion to the rest of the airplane is causing the inlet to assume an importance comparable to that of the wing.

We have reviewed briefly some of the problems involved in designing an efficient air ducting system so as to gain the maximum possible net thrust for this second term of the range relation. The fuel-consumption rate in the lower half of the ratio is being improved through research on fuels and combustion by both the NACA Lewis Laboratory and the industry.

The third item, dealing with structural aspects of the airplane, is studied by the NACA primarily at the Langley Laboratory and will not be given detailed consideration today. It is interesting to note, however, that research conducted by the NACA and the aircraft industry has evolved materials and structural configurations that insure light stiff aircraft structures for use even at elevated temperatures. These achievements over the last 20 years have contributed to a twofold increase in the ratio of airplane take-off weight to landing weight, thereby permitting an important increase in fuel load relative to gross weight.

The factors we have discussed here are the major ones controlling airplane range. With these recent developments in research, it now appears that transport and bomber airplanes can be made efficient enough to give attractive economy and range at supersonic speeds. This curve shows the range at various speeds of a hypothetical airplane designed to cruise about 2000 miles per hour. Of course the combinations of range and high speed indicated here have not been accomplished yet; the curve is only estimated at present on the basis of recent wind-tunnel data and predicted engine performance. We see that near the speed of sound the aerodynamic and inlet efficiencies are still so poor that they cannot be overcome by the increased engine efficiency. At the higher supersonic speeds, however, the aerodynamic and inlet efficiencies have not become much lower while that of the engine has steadily improved. The result is a range of considerable interest at speeds above 1500 miles per hour. Note that the predicted range then at the design speed is almost as great as that of the subsonic turbojet transport at its design speed. To simplify our discussion, the curve has been terminated at speeds where aerodynamic heating would require the use of more heat-resistant materials than are presently in use in the airframe and engine. It would appear from these considerations that cruising speeds in the vicinity of 2000 miles per hour can be reached with attractive range and with structures and engines not too different from familiar types.

In closing let's contemplate the significance of cruising at 2000 miles per hour. This means traveling three times the speed of sound, or as fast as a bullet shot from a high-powered rifle. Air travel at these speeds will take you from New York to San Francisco in 90 minutes. You will leave New York at 6:00 p.m. and be in San Francisco at 4:30 p.m. the same afternoon. We hope you will enjoy your trip. Thank you.

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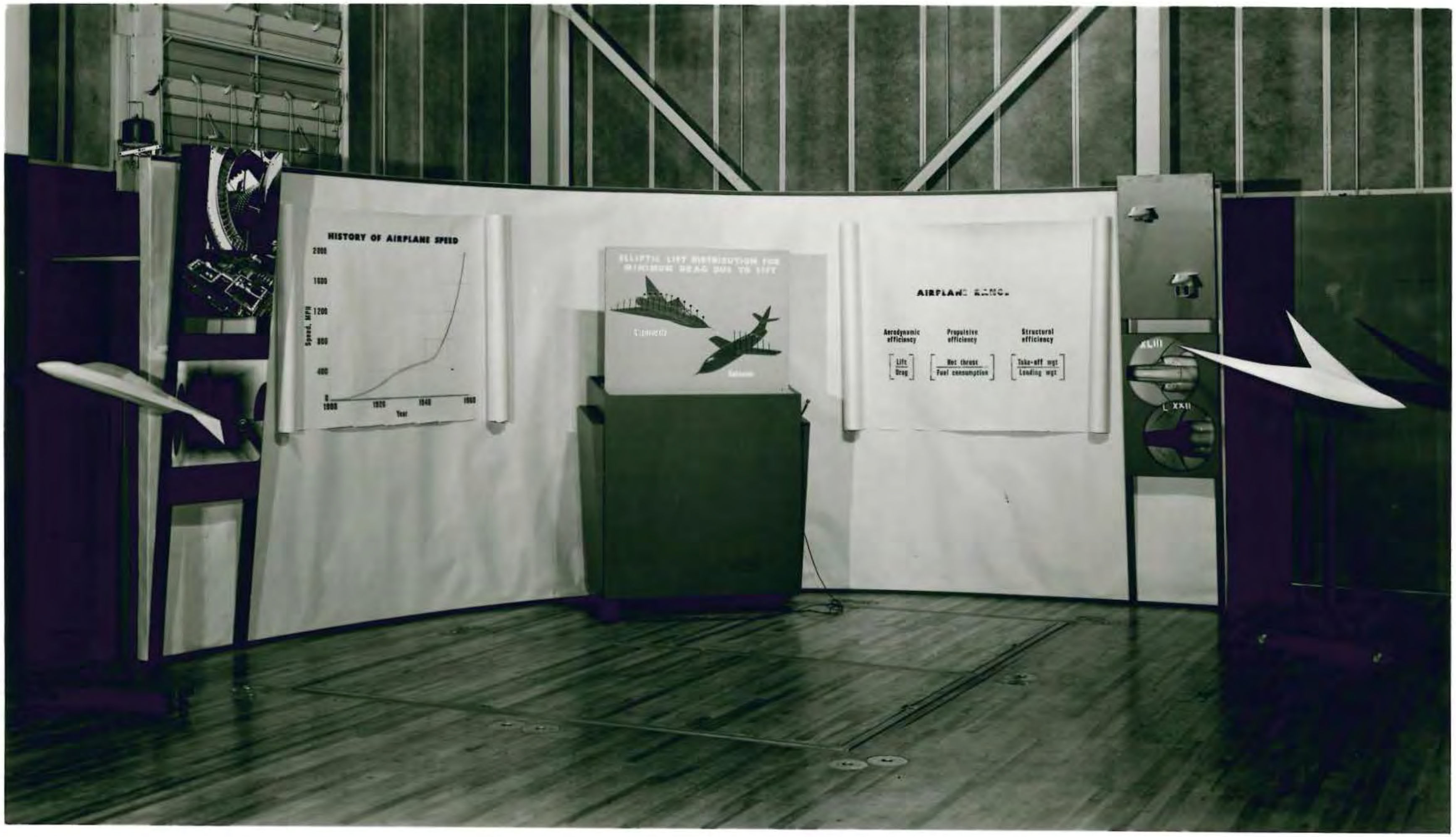

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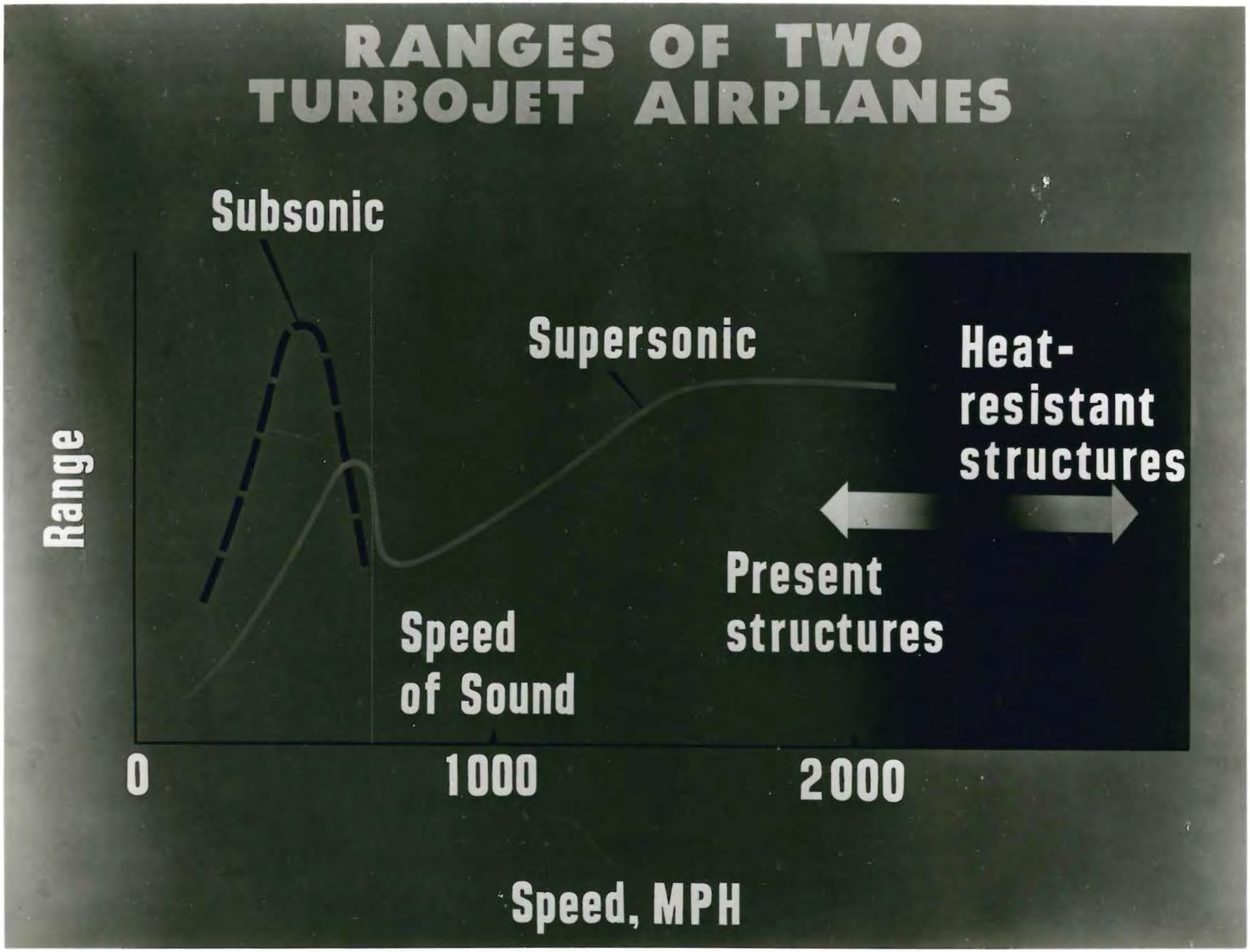

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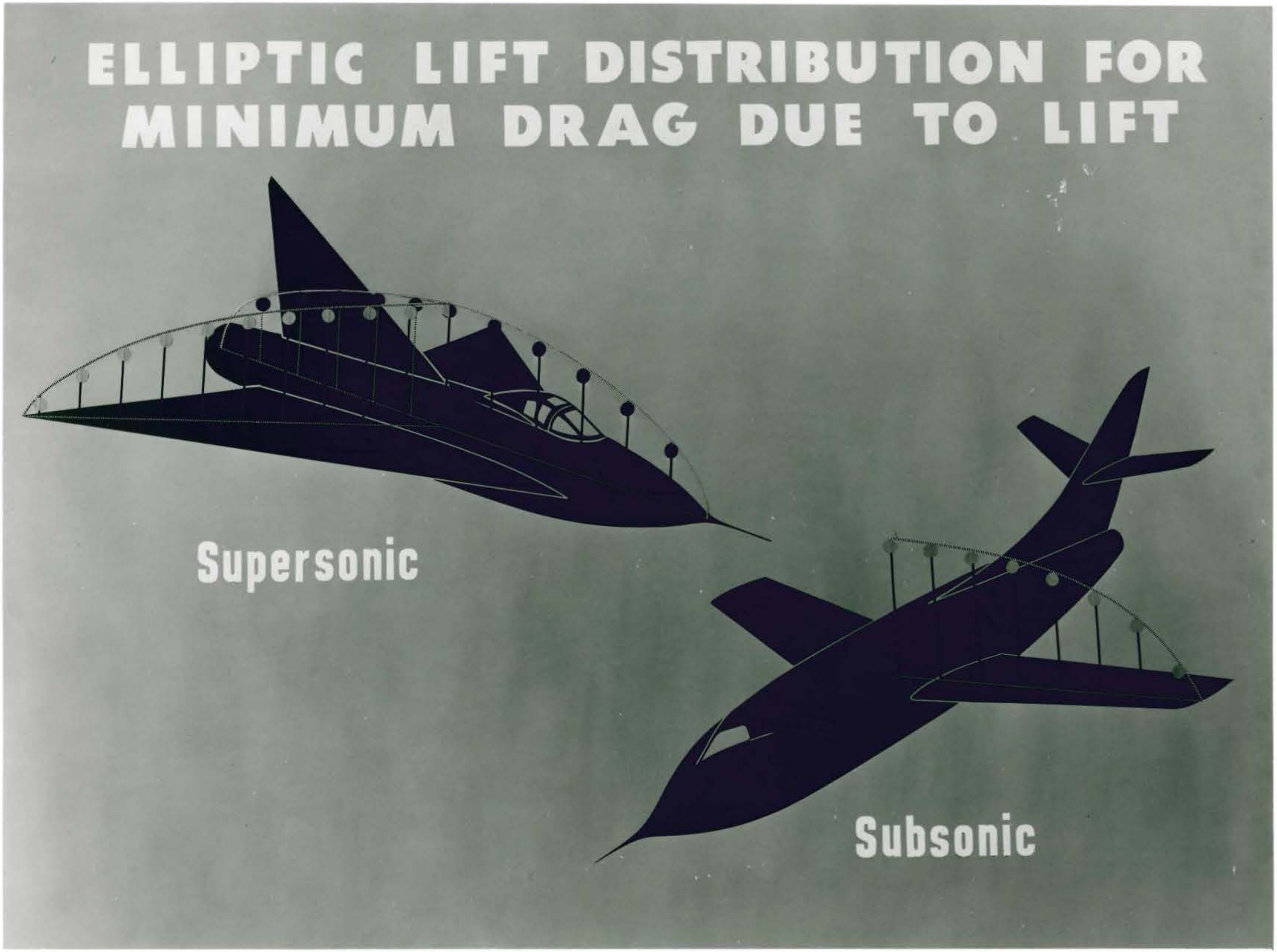

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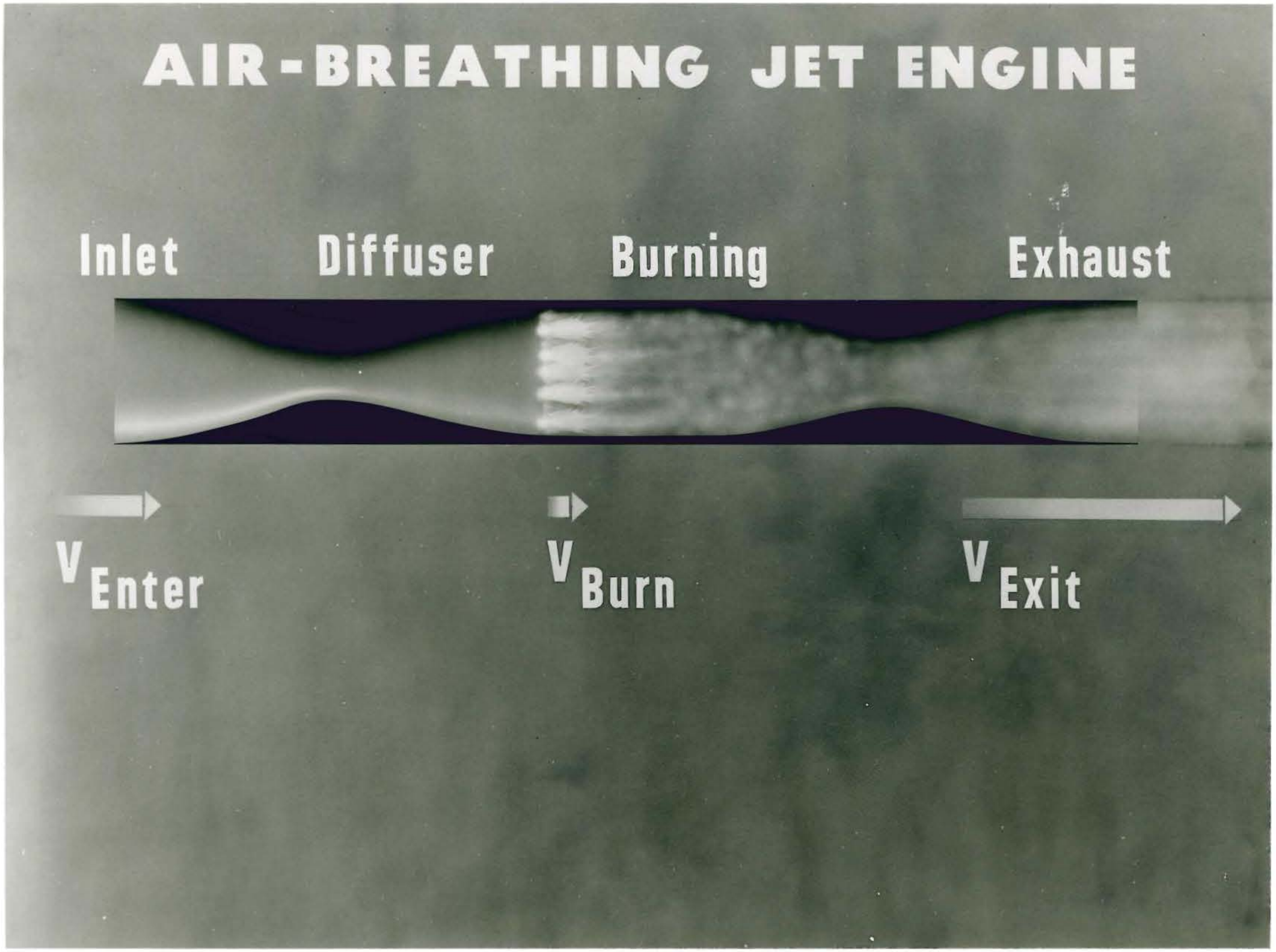

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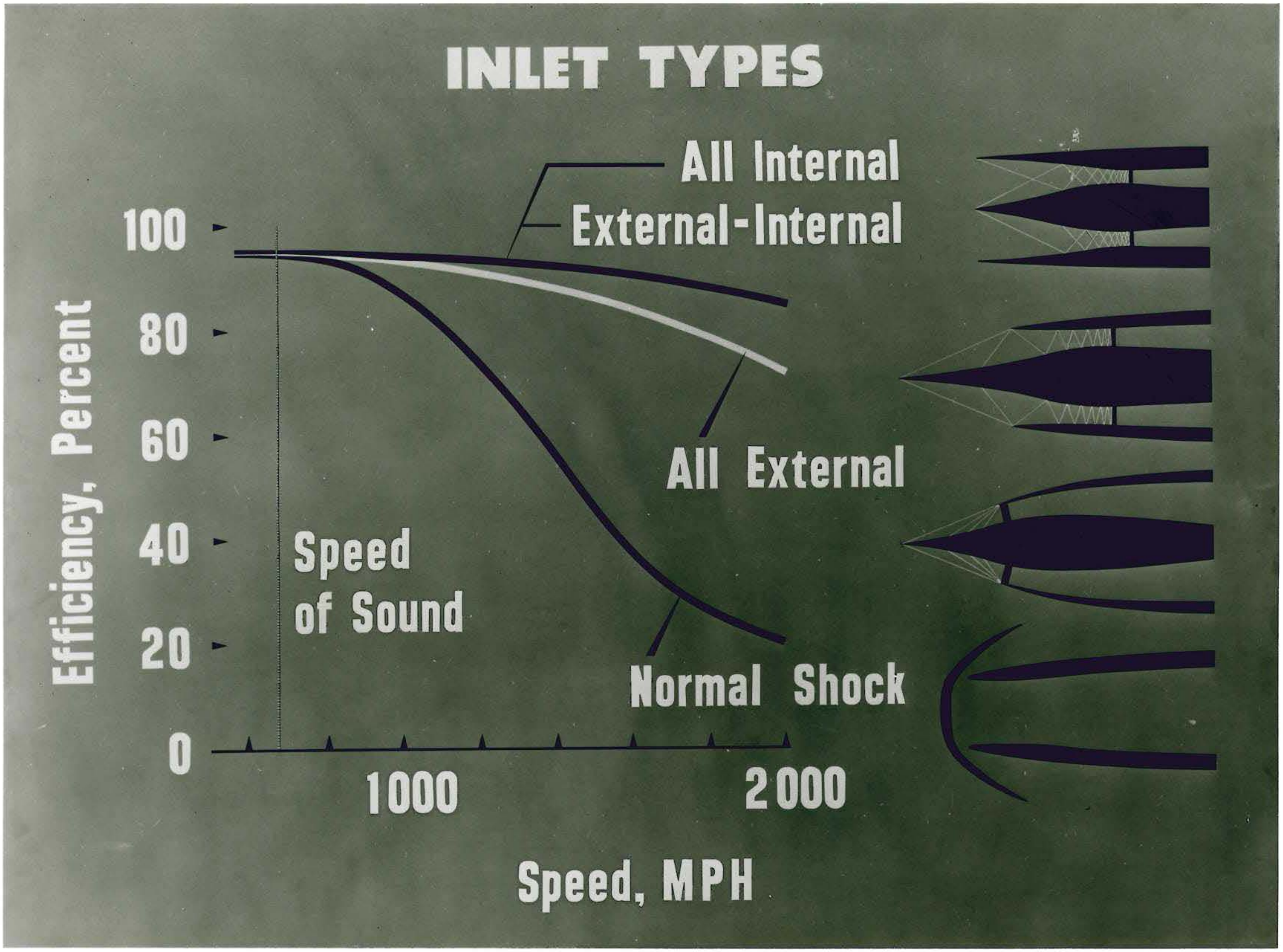
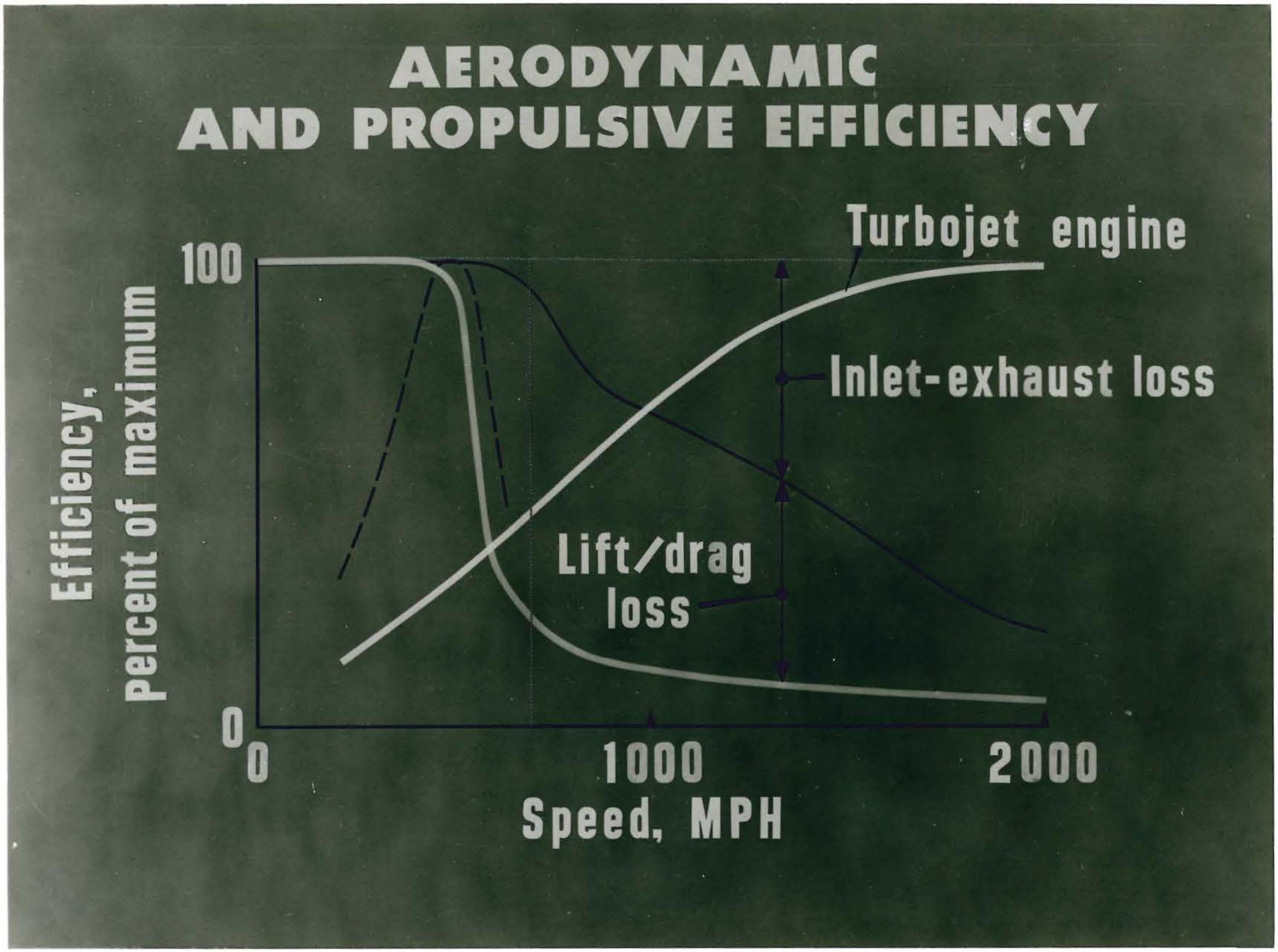

INLET TYPES
All Internal
External-Internal
All External
Normal Shock
Efficiency, Percent
100
80
60
40
20
0
Speed
of Sound
1000
2000
Speed, MPH

A 4000-5F



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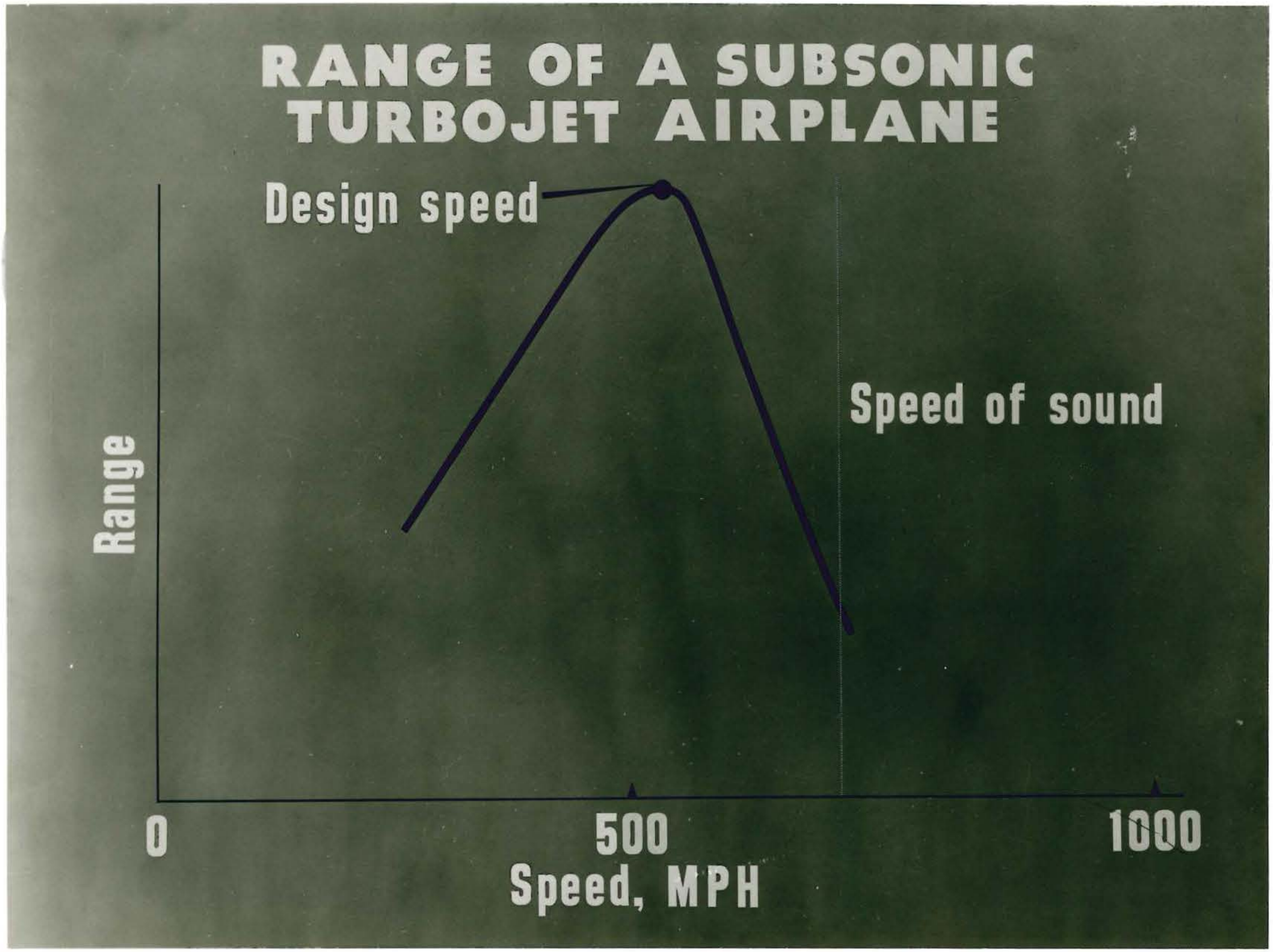

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