STATIC STABILITY

presented by

6- by 6-Foot Supersonic Wind Tunnel Branch

1- by 3-Foot Supersonic Wind Tunnel Branch

During your tour of the Laboratory today you will notice that several of the discussions in the various facilities are concerned with problems of stability and control. This subject is highlighted at our inspection since it is in this field that many recent design difficulties have been encountered, and we felt that you would be interested in these problems and in the research that is being done on them.

Stability is a characteristic that you may not be aware of, particularly in an airplane, unless it is lacking. An analogy may be drawn with the automobile you drive. The fact that you can remove your hand from the wheel on a flat road bed and your automobile will continue on a straight path is evidence of its inherent stability. But we tend to take this stability for granted in our modern automobiles and we are not really aware of it until it is lost through some mechanical defect such as a misaligned front wheel. Then we find that, lacking stability, the automobile no longer tends to a straight course but must be constantly controlled by the driver. The situation is much the same for the airplane.

The subject of stability and control covers many inter-related fields of aerodynamics. You will hear discussions today on static stability, dynamic stability, controlability, and so on. In our presentation here we will be concerned only with static stability, which is fundamental to the design of any satisfactory airplane. It might be well to begin our discussion by differentiating between static and dynamic stability. This is most easily done with the aid of this spring-mounted demonstration model. If I displace the model (demonstration model mounted in recessed opening on stand) from its equilibrium position by applying a force on the tail, the spring exerts an opposite, or restoring, force which tends to return it to the equilibrium position. If this restoring force is present on the tail of an airplane in flight, then the airplane has static stability in yaw, which is sometimes called weathervane stability. An airplane with this type of stability will tend to return to its original flight direction if it is displaced in yaw. In a like manner, static stability in pitch provides an aerodynamic restoring force to the horizontal tail when the airplane is displaced in pitch. Dynamic stability, on the other hand, is a measure of how fast the airplane will return to its equilibrium position after being disturbed, and how violently the airplane oscillates as it seeks this position. Illustrating with the model again, I will give the airplane an initial displacement in yaw and release it. Notice that it oscillates about its equilibrium position with constantly decreasing amplitude and comes to rest relatively quickly.

This represents dynamic stability in yaw. If the airplane were dynamically unstable, (repeat demonstration with no damping) the slightest disturbance would cause the motion to build up in amplitude indefinitely. Actually, these two forms of stability are closely related. Static stability is a prerequisite for dynamic stability, and in the study of airplane motions, both types must be considered. For the remainder of our discussion we will be concerned solely with static stability, and some interesting phenomena which influence it.

In the preliminary design of an airplane, the designer can generally arrive at an arrangement of wing and tail surfaces, properly proportioned and located, which should provide the airplane with static stability. There is, however, another factor which must be considered which complicates the whole problem to a large degree. This is the mutual interference between wing, body and tail surfaces which makes it impossible to predict the stability of an airplane configuration by simply adding the effects of each of the components.

Two forms of interference are particularly troublesome. They are vortex interference and shock wave interference. The type associated with vortex flows may exist at all speeds, and hence is not a new problem. Shock wave interference, on the other hand, can exist only at transonic and supersonic speeds, and is, therefore, relatively new. We would like to discuss these two types of interference further. Mr. ______ will tell you more about the vortex and its influence on stability.

Some of the first forms of vortex interference encountered by airplane designers were the wing-tail interference problems which have received so much attention in recent years. In general, these problems are associated with the fact that the tail of the airplane or missile operates in the region of vortex flow generated by the lifting wing ahead of it. Since we wish to consider a related problem today, it will be helpful to review the fundamentals of this wing-tail interference, and to point out why it continues to be a problem.

The formation of vortexes behind a lifting wing is due primarily to the difference in pressure between the upper and lower surfaces of the wing. (Illustrate with hand model.) To develop the lift necessary to support the weight of the airplane, the wing must have a region of high pressure here on the lower surface, and a region of low pressure on the upper surface. The result is that at the tips of the wing the air flows rapidly from the high-pressure area, around the tip, to the low-pressure area with a swirling motion. As the airplane passes, this swirling air remains and forms the vortexes which trail back behind the wing tips, as illustrated here in this first chart. Now, the strength of these vortexes depends upon both the distance between them and the amount of lift produced. If two airplanes have the same weight, and, therefore, develop the same lift in level flight, the one with the shorter span will have the stronger vortexes. Consequently, for very large airplanes like the transport shown here these vortexes are much weaker than they would be for a small, heavily loaded fighter airplane of very short span.

On this next chart, we have shown two fighter airplanes, one which represents designs of about ten years ago, and one of the newer designs. As design flight speeds have increased, it has been necessary to make the airplane more slender and its wings much thinner in order to reduce its drag. For this reason, and from structural considerations, the wing span has been reduced by a large amount. At the same time, the weight of the airplane has generally remained the same, or even increased. This means that, not only will the wing vortexes be considerably stronger, but they will pass much closer to the tail. It is for these two reasons, both stemming directly from the design trends associated with the requirement for higher flight speeds, that wing-tail interference problems continue to be of primary concern to the airplane designer.

Another problem, also resulting directly from the new trends in airplane geometry, is now confronting the designer. This is the relatively large influence on the vertical tail of the vortex flows generated by the fuselage of the new high-speed airplane. We have pointed out that a lifting wing produces vortexes. This is also true for any body that develops lift, such as an airplane fuselage. While the airplane fuselage of a decade ago developed only a small amount of lift, the fuselage of the new supersonic airplane is beginning to develop considerably more lift simply because it is becoming larger and larger compared to the wing.

On this chart (chart #3) we show a picture taken in the Ames 1- by 3-foot wind tunnel of the vortex pattern at the tail of an airplane model. The picture was obtained by the vapor-screen technique in which the vortexes are made visible in a plane of light by the introduction of a small amount of water vapor into the airstream. In this view the plane of light is cast across the tail end of the model, and these dark regions represent cross-sectional views of the vortexes in this plane. The camera was mounted behind the model and the picture represents a view from about this angle. The tail has been removed for these tests so that the vortex pattern could be photographed. Here we have represented the same airplane in flight to aid in visualizing the paths of the vortexes. Notice that the airplane is flying at a combined angle of attack and sideslip. Hence, the relative wind approaches from below and to one side of the airplane. Because of the angle of sideslip, this vortex, which originates on the right side of the fuselage near the nose, is deflected up over the wing and passes directly through the position of the vertical tail. The vortex from the left side of the nose trails back in the wind direction, passing under the left wing, and appearing here at the tail. This vortex, and the wing vortexes which trail back from the wing tips in the wind direction are relatively far removed from the vertical tail. As might be expected, however, this fuselage vortex, passing so near to the vertical tail, plays a very important part in determining the forces acting on the tail. This is illustrated in the next chart (chart #4). Here we show the same airplane, first with the vertical tail removed, and without the fuselage vortexes. On the right, we have plotted the yawing moment against angle of sideslip for a constant angle of attack. For this wing-fuselage combination, the dominant force acting on the airplane is a force on the nose of the fuselage. (Demonstrate with hand model.) This force results in a destabilizing yawing moment, since, if the airplane is flying at some angle of sideslip to the relative wind, the force on the nose tends to increase the angle. The unstable fuselage yawing moment is plotted here. Now if we add the vertical tail to the airplane, but still do not consider the fuselage vortexes (apply first overlay), we would predict that the tail would develop a large side force in this direction, producing a stable yawing moment tending to decrease the angle of sideslip. (Demonstrate with model.) Then, considering the complete airplane, but neglecting the fuselage vortex, the corresponding yawing moment curve would be stable and would look like this. This simply illustrates that the primary purpose of the vertical tail on an airplane is to provide stability in yaw. However, our wind tunnel tests have shown that when fuselage vortexes such as these (apply second overlay) exist, the airplane's stability is greatly reduced, and may be something like this. These tests have further shown that this effect is due primarily to the influence of this vortex on the vertical tail. Spinning in this direction the vortex exerts a force on the vertical tail opposing the normal stabilizing force. The result is a reduction in stability - in some cases sufficiently great to make the airplane unstable in yaw.

Without corrective measures, an airplane with these yawing-moment characteristics would be extremely difficult to fly and the pilot might even lose control. This laboratory, and the other laboratories of the NACA, are devoting a considerable amount of research to these interference problems, of both the wing-tail and fuselage-tail types. Solutions to many individual problems have been found in the proper designing of wing and fuselage shapes, and in the positioning of the horizontal and vertical tail surfaces. At the same time, general studies are under way to develop methods for predicting these interference effects so that the designer will be better equipped to contend with them in his preliminary designs.

Before leaving the subject of vortex interference, it should be mentioned that, because of the limited time available to us today, we have discussed this form of interference only as it pertains to the airplane. However, these problems are of equal, if not greater, importance for missiles. We have prepared a series of photographs showing the wing vortex pattern in the vicinity of the tail of a missile. These photographs were made in this wind tunnel using the vapor-screen technique, and illustrate the extremely complex flow field in which the tail of a missile may be located as the missile maneuvers. You will see this display as you leave the 6- by 6-foot wind tunnel today. I now present Mr. ______ who will discuss another source of interference, the shock wave.

In addition to the stability problems contributed by vortex flows, which the previous speaker has discussed, the designer of supersonic airplanes must also contend with the effects of shock waves. Any object moving through the air generates pressure disturbances in the form of spherical pressure waves. These waves grow, or move outwards at the speed of sound. On this next chart (chart #5), we have represented the pressure disturbances eminating from the nose of two airplanes, this one flying at a subsonic speed, and this one at a supersonic speed. In this case, since the airplane's speed is slower than the speed of sound, the pressure waves move ahead of it. Consequently, the pressure disturbance is felt at points ahead of the airplane, and its intensity builds up gradually as the nose is approached. Here, however, the airplane is moving forward faster than the pressure waves, and these waves pile up to form a conical boundary of concentrated pressure disturbances. Ahead of this boundary the air is completely undisturbed. There is no gradual build up of pressure as in the subsonic case. Instead, when the boundary is crossed, there is an abrupt increase in pressure. This invisible conical surface in space is called a shock wave, and is associated with any object traveling at supersonic speed. Although, for simplicity, we have shown only the shock wave from the nose, every point on the airplane at which there is a sudden change in contour generates a wave, and these waves are swept back at an angle proportional to the Mach number, that is, the ratio of the speed of the airplane to the speed of sound.

One of the first experiences the general public has had with shock waves has been the phenomenon known as the sonic boom. An observer on the ground experiencing this phenomenon is simply <u>hearing</u> the shock wave from an airplane flying at supersonic speed. Those of you who have had this experience were undoubtedly impressed with the intensity of the sound as the shock wave reached you, and yet, you were probably several miles away from the airplane itself. Imagine now how severe the disturbance must be in the immediate vicinity of the supersonic airplane. It seems likely, for instance, that if a shock wave generated by one portion of the airplane were to strike another portion of the same airplane, or even of some nearby airplane, the effects might be quite severe. It has been found that in some cases this is true, and this form of interference has caused some difficult stability problems in recent designs. To give you some idea of the nature of this shock-wave interference, we will consider a representative problem in some detail.

On this next chart (chart #6), we have shown two hypothetical airplanes. They are identical except that the one on the right has engine nacelles mounted at the wing tips. We assume that both airplanes are flying at the same supersonic speed and at an angle of sideslip as shown. The nacelles on the airplane at the right will, of course, generate shock waves. Since these are the waves we wish to discuss, we have arbitrarily left all the other waves out of the picture. Looking first at the airplane without nacelles, we see that there exists a stabilizing force on the vertical tail. In this case, if the vertical tail is properly designed with regard to size and location, the airplane is statically stable in yaw. If the airplane sideslips, it will tend to return to zero sideslip as did the spring-mounted demonstration model. However, for the airplane with nacelles, we find that at this Mach number and sideslip angle the shock wave from the left nacelle strikes the left side of the vertical tail. Since there is a pressure increase associated with the shock wave, a force is exerted on the tail opposing the normal stabilizing force. As a result the stabilizing effectiveness of the vertical tail, tending to return the airplane to zero sideslip, is reduced. If this force due to the shock wave becomes too large, the airplane will be unstable in yaw.

We have arranged a short demonstration for you in our wind tunnel which will illustrate a similar shock-wave interference problem. The wind tunnel drive motors have been turned on and during the few minutes it takes us to bring the tunnel up to speed, I will explain what you are about to see. The model you can see through the window here to your right is mounted on a pivot so that if a yawing moment acts on it, it is free to yaw within fixed limits. It is also provided with a remotely operated lock so that it can be locked in a zero yaw position. The engine nacelles are hollow to allow air to flow through them simulating jet engines in operation. However, the right, or upper, nacelle has been fitted with a butterfly valve which can be opened or closed from outside the wind tunnel. (Pull out screen.)

In order to be able to see the shock waves on the model during the demonstration, we will use the schlieren optical system which projects the image of the model and the shock waves onto this screen. The rings of color you see here are caused by optical impurities in the window glass. No shock waves are visible since the air speed in the tunnel has not yet reached the speed of sound. When sonic speed is reached you will see shock waves forming at the nose, nacelles, and other parts of the model. As before we will be interested only in the shock waves from the nacelles. Since, in this case, we cannot arbitrarily eliminate the other waves, we will ask you to concentrate carefully on those from the nacelles. The small local shock waves now forming around the nacelles indicate regions where the air flows faster than the free stream and has already reached the speed of sound. Now the normal shock wave is moving down the tunnel and establishing supersonic flow everywhere on the model. As we continue to increase speed, the shock waves bend back. The amount they deviate from the vertical depends on the Mach number. Notice that the shock waves from the nacelles are crossing over the body of the model. As the speed increases, the point at which these waves cross the body moves back. Very soon we will reach a speed where these waves cross the body at the tail position and actually strike the vertical tail. We have stopped increasing the tunnel speed which is now approximately 1200 miles per hour or Mach number 1.6. The shock waves from both nacelles are hitting the vertical tail. The model is locked in the zero yaw position. Now, as we close the valve in the upper nacelle the shock wave from this nacelle detaches and becomes much stronger. Also, its position on the vertical tail moves forward. Since the shock wave from the other nacelle has not changed we would predict that there would now be a force on the vertical tail tending to push the tail down. To illustrate this, we will open the nacelle and unlock the model. The model is now free to yaw, restricted only by mechanical stops limiting the yaw angle to safe values. We will again close the nacelle simulating a jet engine failure.

The model has yawed up against the stops. Although the motion of the model is caused to some extent by the drag force on the closed nacelle, measurements of the force on the tail have shown that the force resulting from the shock wave is an important contributor to the motion.

These shock wave interference problems, and many others we have not considered, must be solved before flight at supersonic speeds becomes commonplace. The NACA is devoting a considerable amount of research in its supersonic testing facilities to the solution of these problems.

This concludes our demonstration in the 6- by 6-foot supersonic wind tunnel. Will you follow your group leader and leave by the door to your right. Thank you.

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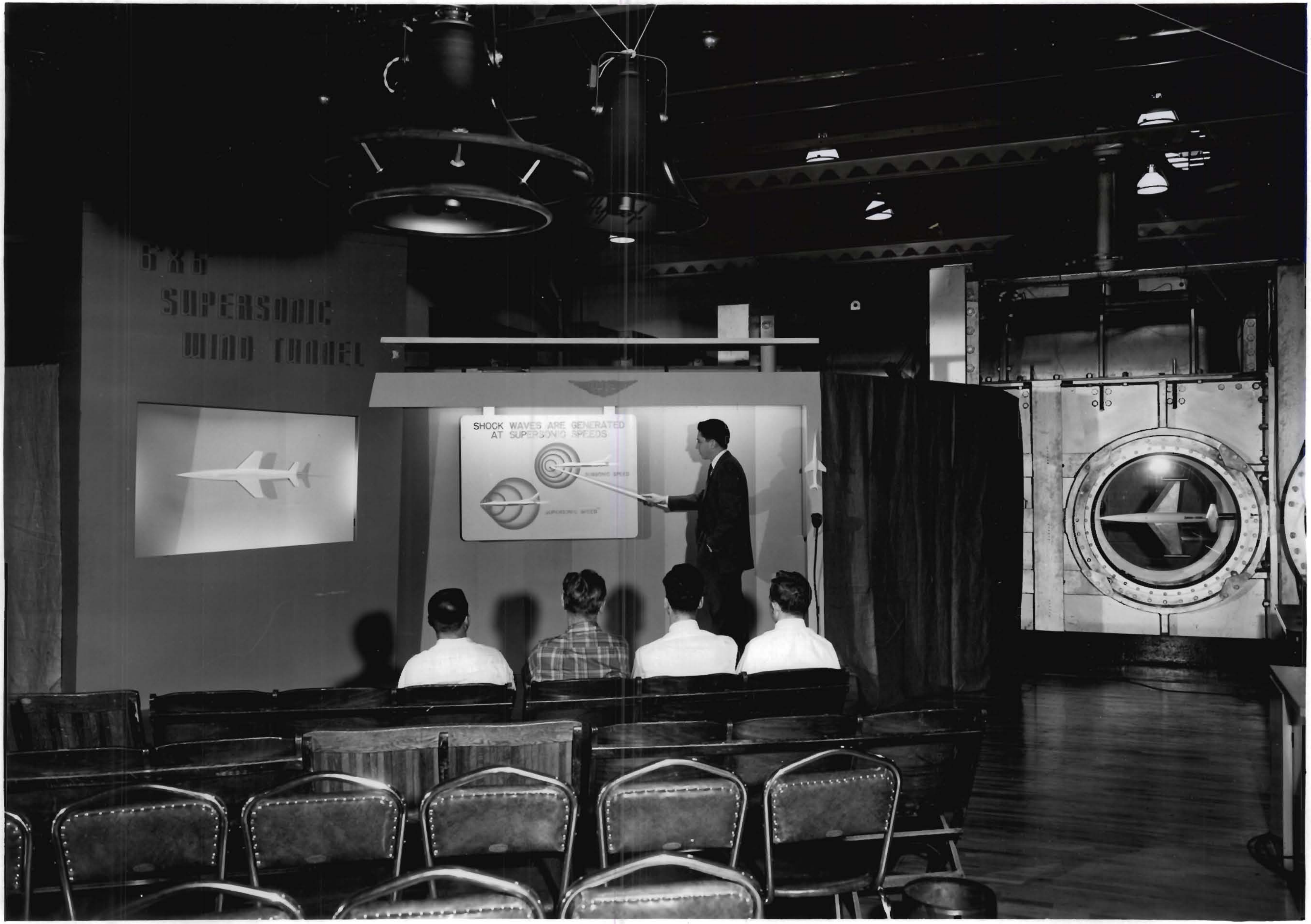

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LIFTING WING PRODUCES VORTEXES

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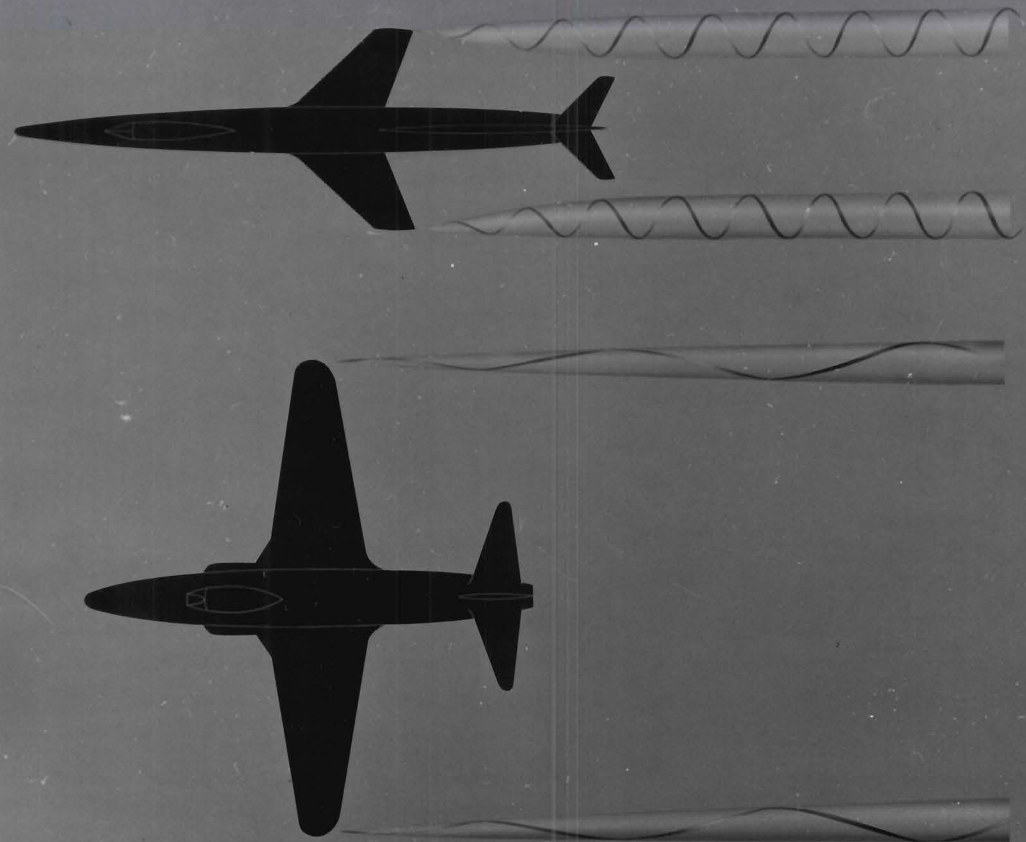
TREND IS TO SLENDER AIRPLANES WITH SHORT WINGS



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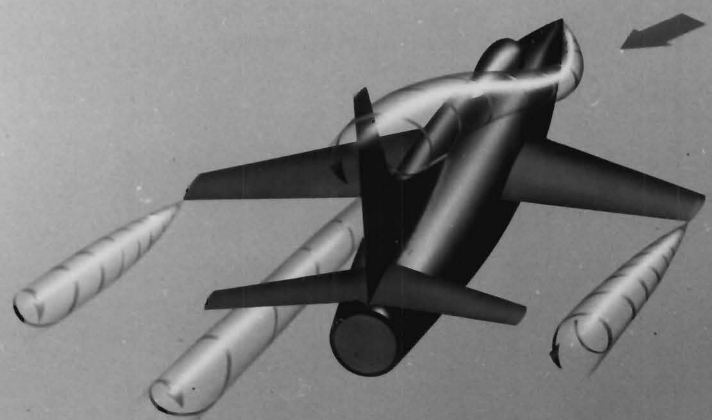
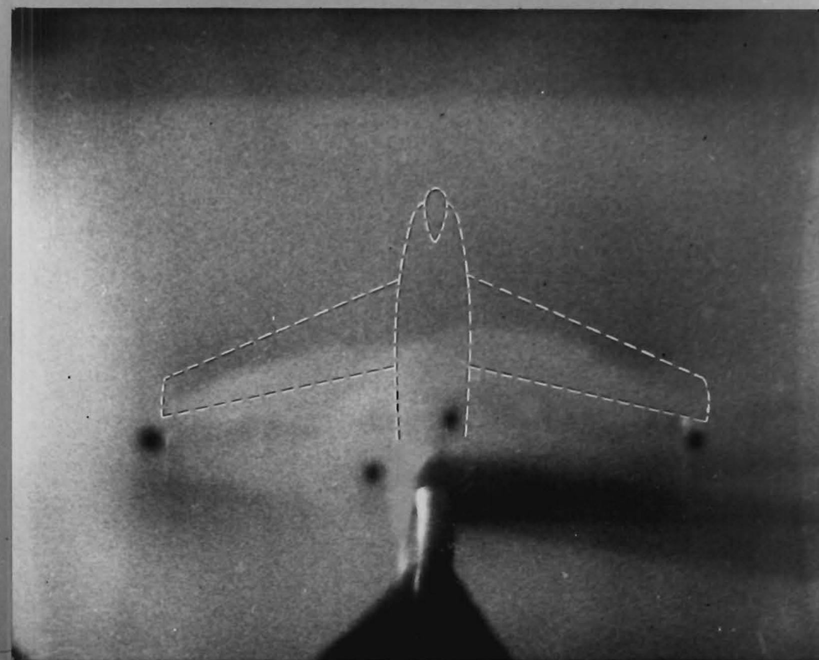
FUSELAGE ALSO PRODUCES VORTEXES





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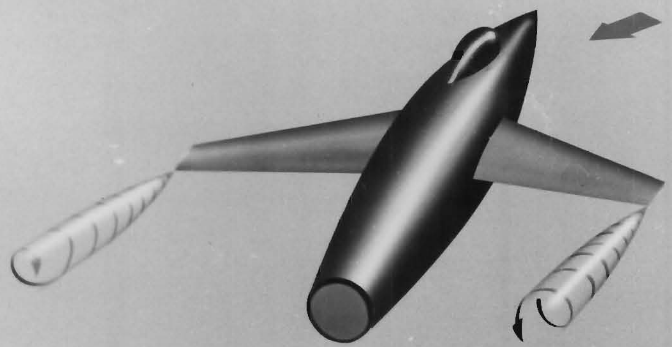
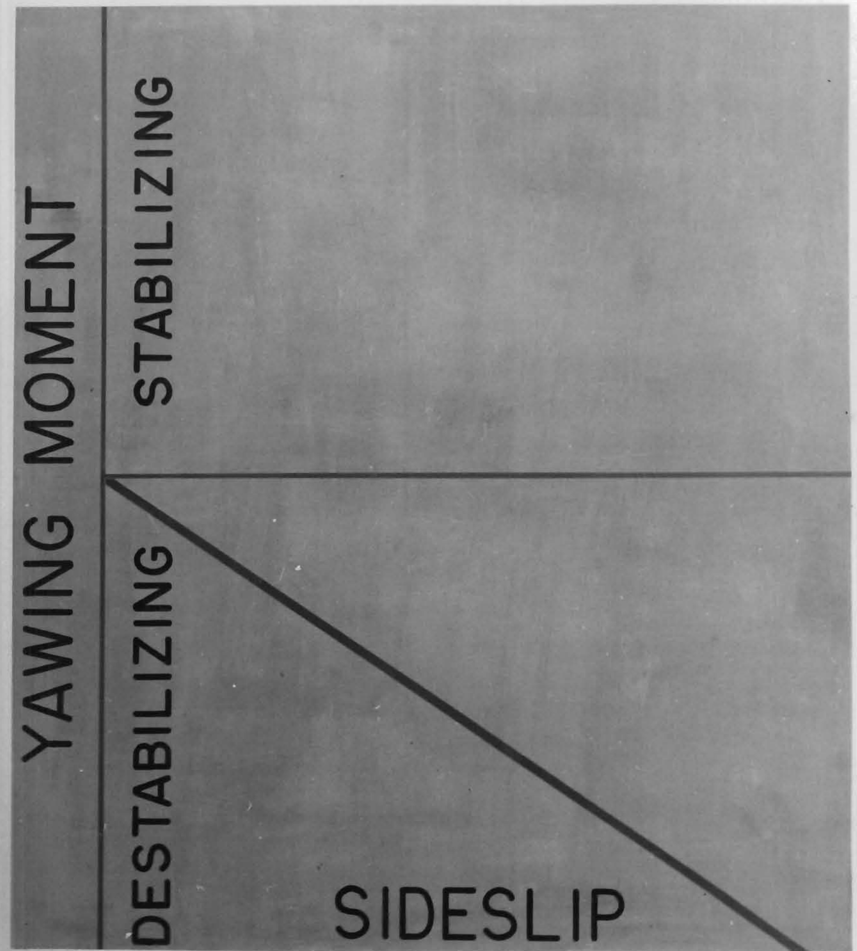
FUSELAGE VORTEX INFLUENCES STABILITY IN YAW





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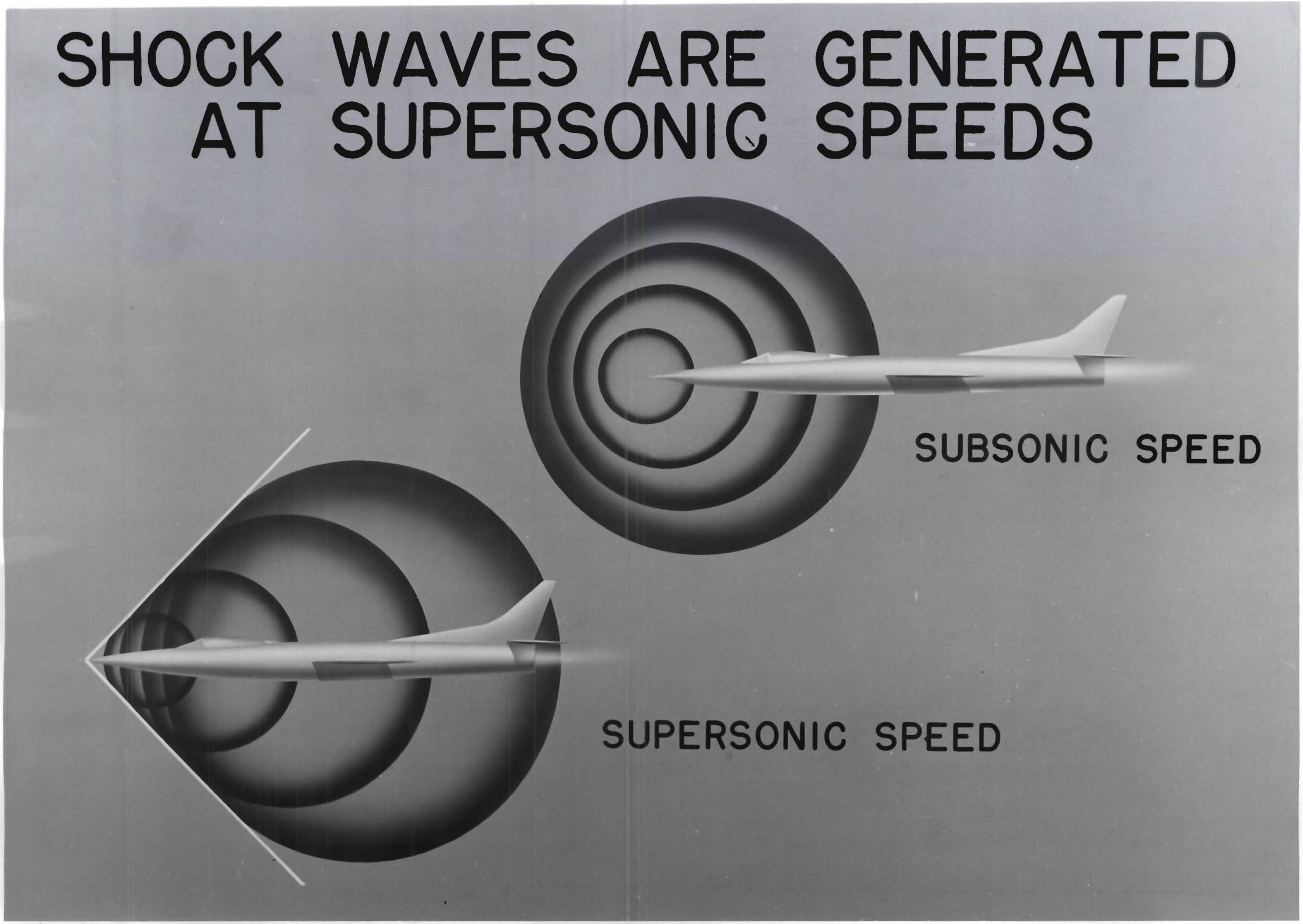

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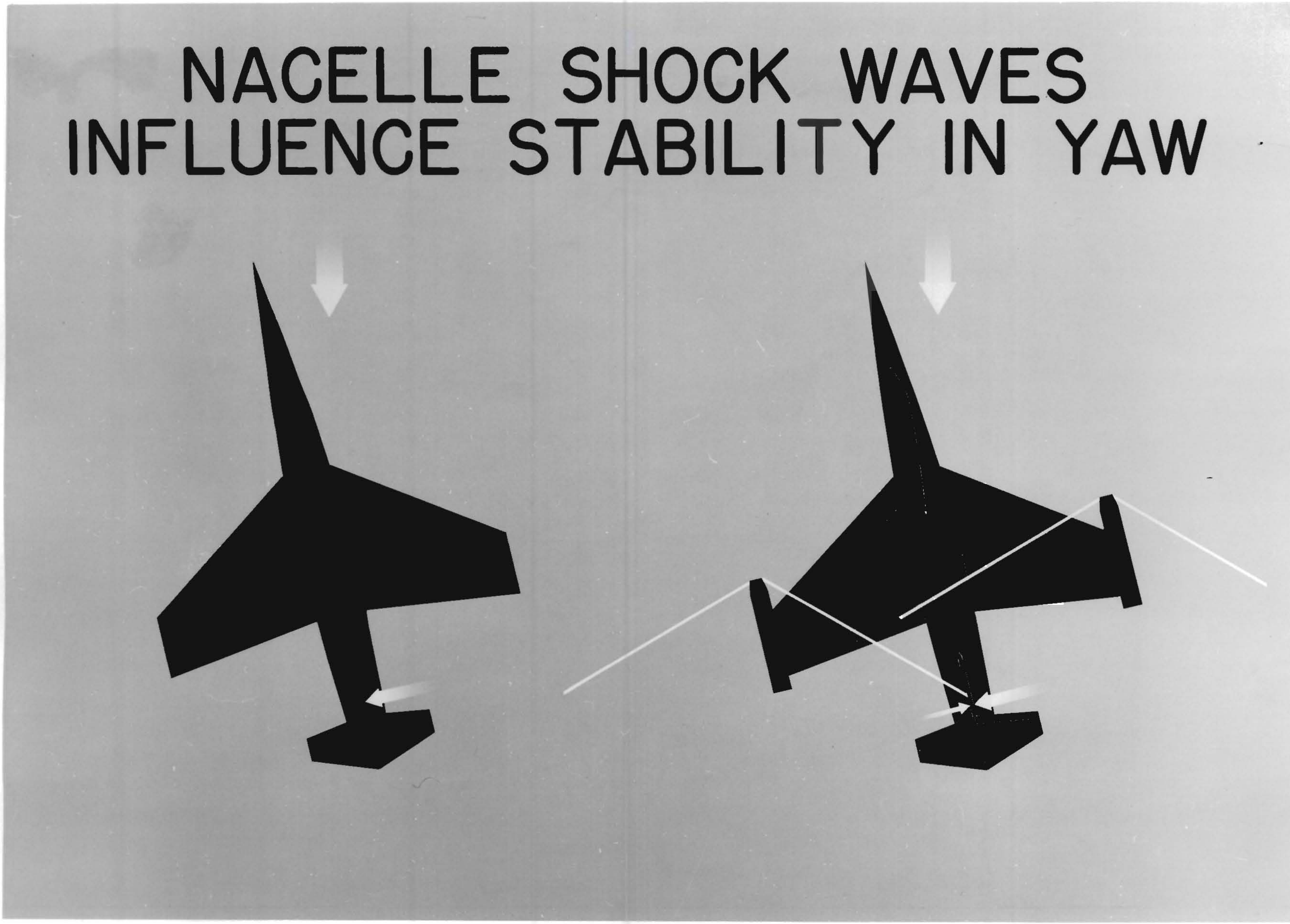
NACELLE SHOCK WAVES
INFLUENCE STABILITY IN YAW