AIRFOIL-BODY COMBINATIONS
by
6- by 6-Foot Supersonic Tunnel

Research on Interference Problems

I would like to talk to you today about the research being done in the various NACA laboratories on the aerodynamic effects of mutual interference between wings and bodies. In the past we have been concerned, primarily, with airplanes which were composed of a wing of rather high aspect ratio on a relatively small body and with a relatively small tail plane on the after portion of the body to provide the required stability. Such an airplane is illustrated here on this first chart. It is evident, I believe, from examination of this airplane, that the interference problems here are (1) the interference of the wing on the body and (2) the interference of the wing on the tail. Since the body diameter is small relative to the wing span the interference of the body on the wing is almost negligible. In general, since for such an airplane the body or the fuselage contributes only a small portion of the total lift and pitching moment, even the interference of the wing on the body is not a major item, so that, with proper design, the interference problem here is reduced, essentially, to one of the effect of the wing on the tail.

With the development of faster aircraft, however, other interference problems have become much more significant. In order to fly with reasonable efficiency at high subsonic or supersonic speeds we must utilize wings which are very thin. This means that in order to carry the same lift we must reduce the span of the wing so that the bending stresses near the wing root section are not excessive. In such a case, as illustrated by the airplane shown here, it is evident that the diameter of the body is much larger relative to the wing span than for an airplane designed for lower speeds. It should be noted also that the reduction of the wing span, or the reduction in wing aspect ratio, results in more serious interference between the wing and tail of the airplane since in this case the downwash of the wing becomes highly distorted.

The interference problem becomes even more accentuated when we consider the design of high-speed missiles. For supersonic missiles there is even a further restriction on the aspect ratio of the wing, since the wings must be very thin and since the missile must develop very high accelerations so that it can turn in a tight circle when pursuing its target. For a typical missile the wing span may be only twice the body diameter, the body size necessarily being large in order to house the electrical guidance system and the rocket propelling motor and war-head. It is evident from the foregoing that the higher the speed the greater these interference problems become, until at Mach numbers of the order of 2 the wing-body and the wing-tail interference are primary factors in determining the aerodynamic characteristics of the aircraft. It is our purpose here today to discuss with you both the theoretical and experimental research that is being conducted on these interference problems.

Wing-Body Interference

Let's discuss first the mutual interference of the wing and body. On this chart are shown results of an experimental investigation performed in the Langley 8-foot High-Speed Wind Tunnel. Here, we show the load distribution over the isolated body and over the isolated wing, and in this figure is shown the load distribution over the combined wing and body. These dashed lines show the load distribution calculated as the sum of the separate load distributions, neglecting interference. The solid lines show the experimental distribution over the wing-body combination. You'll note that the load over the wing near the body and the load on the body near the wing are affected by interference, the interference being shown by the difference between the dashed and solid lines. These results show that the wing-body interference results in a loss in lift for the wing-body combination, which loss we call the interference lift. The wing-body interference effects here are significant in that: first, for a given lift, the bending moment in the wing is increased by the interference effects and: secondly, the airplane must go to a higher angle of attack to obtain the same lift which means that the airplane drag will be greater.

The next chart is the result of a theoretical investigation of a wing-body interference problem especially applicable to missile designs. In this chart we have plotted the spanwise distribution of the lift for the wing-body combination as calculated by simple superposition of the wing and body lift pressures shown by the dashed lines and also from a more adequate theory which considers the interference between the wing and body. It will be noted that in the vicinity of the body the lift is greatly reduced. In this case, since the span of the wing in terms of the body diameter is much smaller than for the airplane we discussed in connection with the previous chart, the interference effects are much larger.

In this portion of the chart we show the results of some experiments run in the Ames 1- by 3-foot wind tunnel for the purpose of determining the correspondence between the theory and the results of experiment. We have plotted here the lift interference; that is, the loss in lift occasioned by the mutual interference between the wing and body as a function of the ratio of the wing span to the body diameter. The physical significance of the horizontal axis of this curve is illustrated by the sketches of the wing-body combinations which were investigated. You will note that the theoretical results show that the interference becomes smaller as the wing span increases relative to the body diameter until with large wing spans the lift interference is negligible. The results of our experimental investigation are shown by the circled points. The experimental results indicate that in general the wing-body interference is somewhat less than predicted by the theory. The discrepancies can be attributed to certain simplifying assumptions in the theory made to permit the solution of the complex mathematical equations.

Because of the small wing span relative to the body diameter, the interference effects determine in a large part the aerodynamic characteristics of a missile. This interference problem is further accentuated by the fact that, on many missiles, cruciform wings are necessary since the missile must simultaneously develop high, normal and lateral accelerations. An airplane can, of course, develop large lateral and normal accelerations by a combination of banking and turning, but for a missile there is not sufficient time to perform the bank and turn maneuver. Some missiles, therefore, are required to accelerate laterally without banking, which means that vertical lifting surfaces as well as horizontal lifting surfaces must be provided. An example is shown in this sketch. For such a missile we have the further problem of the interference between the vertical and horizontal wings. In the interference problem here, we have considered the case of roll control for the missile where two halves of the horizontal wing are deflected differentially, this one up and this one down, and the vertical wing constitutes an interference plane. On this chart we have shown the load distribution over a cruciform wing-body combination obtained from a theoretical investigation in the Ames 6- by 6-foot Supersonic Wind Tunnel section. The load distribution shown here over the horizontal wings represents those loads which tend to oppose the rolling motion. It will be noted that the loads induced on the vertical wing give an opposite moment around the missile axis to that caused by the loads on the horizontal wing. In this case, the interference effects influence the rolling power of the control to a significant degree.

Wing-Tail Interference

One of the most serious interference problems is that which is concerned with the effects of the downwash of the wing on the tail of an aircraft. This problem becomes much more severe as the speed of the aircraft increases, since, as was noted previously, the aspect ratio of the wing must be reduced as the design speed increases. On this chart we have shown a graphical representation of the downwash field behind a wing of moderate aspect ratio designed to fly at high subsonic speeds and a wing of low aspect ratio such as would be used for a missile flying at a Mach number of 2 - - that is, at twice the speed of sound. It will be noted that for the moderate aspect ratio the vortex sheet behind the wing distorts very little by the time it reaches the tail plane, so that in this case, the interference between the wing and the tail is small and can be easily determined. For the low aspect ratio, however, the vortex sheet rolls up rapidly and is greatly distorted at the location of the missile tail. The distortion of the vortex sheet in this case causes a complex flow pattern in the region of the tail and results in interference that is of large magnitude and difficult to calculate. The problem has been solved theoretically, however, by recent work by the Ames Theoretical-Aerodynamics Group.

As was pointed out previously, many high-speed missiles are fitted with cruciform wings. This, of course, further increases the complexity of the downwash field in the vicinity of the missile tail since in this case the mutual interference of the wings and the interaction between the distorted vortex sheets from each wing causes such a complex flow that serious stability difficulties may be encountered by such missiles. An experimental investigation of the downwash behind cruciform wings has been recently made in the Ames 6- by 6-foot supersonic wind tunnel. Results of the investigation are shown on this chart. The flow fields shown here are for the missile at an angle of attack and with three different angles of bank. The results are shown in the form of vectors which represent the magnitude and direction of the transverse flow velocities in a plane perpendicular to the missile axis. The plane represented here is located at the probable position of the missile tail. Here, with zero angle of bank it will be seen that two vortices appear in the flow field just above the projected wing location. In between these two vortices there is a region of high downwash velocity and outside of these vortices the flow velocities are upward. The flow field here does not differ from that for a single horizontal wing since in this case the vertical wing carries no lift. When the missile is banked 22-1/2° as shown in the next chart, however, the lift is carried by both wings and in this case four vortices appear as shown here. The flow has no symmetry in this case. The complexity of this flow is illustrated by the circulation that takes place at each of the vortices, which combines in the general flow field to give a large downwash in this region and a large sidewash velocity in these regions From data such as these the characteristics of the tail may be calculated since these data permit the angle of attack of various sections of the tail plane to be determined, which in turn permits the loading on the tail to be calculated.

Here the missile is banked 45° and the flow again has symmetry. The mutual interaction of the vortices causes the two lower vortices to move apart and the two upper vortices to move together and downward. If we were to examine the flow at succeeding planes downstream we would find that the two upper vortices pass down between the two lower vortices, resulting in an even more complex flow field.

To illustrate further the downwash interference problem for cruciform wings we have prepared a motion picture of the flow behind such wings in the Ames 6- by 6-foot Supersonic Wind Tunnel. In order to visualize the flow behind cruciform wings, we have made use of a technique recently developed at this laboratory. In this visualization technique, a small amount of water vapor is introduced into the wind tunnel. Since the air, in passing through the test section of the wind tunnel expands to a low pressure and the temperature of the air becomes very low, the moisture which was introduced condenses and forms fog. By shining a plane of light across the test section throughout the condensed water vapor, the action of the vortices behind the cruciform wing can be observed.

The next chart shows a schematic drawing of the vapor-screen apparatus. Here we have a cutaway section of the wind tunnel showing the cruciform-wing model supported on a sting located between the two test-section windows. The light source was placed outside the far window and the light was passed through a slit so that in the tunnel a plane beam of light passes through the air stream, illuminating the condensed moisture particles in the air stream. The flow patterns in the downwash field behind the cruciform wing appear due to wake disturbances affecting the nature in which the light is scattered by the particles of water.

6- by 6-foot Supersonic Wind Tunnel Movie

Scene 1

This is a view of the Ames 6- by 6-foot Supersonic Wind Tunnel taken from where you are now seated, showing the test section of the tunnel and the flow visualization windows. As we move up closer to the wind tunnel you can see the cruciform wing model mounted on the support sting ready for tests.

Scene 2

Here is a view inside the tunnel showing the model and the supporting sting. In this tunnel the model angle of attack is changed in the horizontal plane through the differential movement of the two halves of the support system. For this reason the gun camera with which we take pictures of the vapor screen is mounted on the side of the supporting sting as shown here. The plane of light which illuminates the particles of fog which form the vapor screen is cast across the test section of the tunnel and intersects the model at about this position which is essentially the location of the stabilizing tail surfaces. The gun camera, therefore, is placed downstream of the vapor screen and the flow you will see in subsequent pictures is the view taken by this gun camera from this down-stream position.

Scene 3

We will now show you the flow studies taken at 0 bank angle. You will notice that as the angle of attack increases the vortices behind the lifting wings here appear first as two small dots. As the angle of attack increases up to about 5° these dots grow in size and the usual form of a vortex appears. You all have probably observed such vortices in water, in a stream for instance, which is flowing past various obstacles. This visual study of the rolling up and displacement of the trailing vortex sheet associated with a lifting wing is helpful in determining the downwash field to be used in estimating tail efficiencies. The angle of attack of the model has reached the maximum and is now decreasing. You can see that the strength of the vortices decreases as the angle of attack decreases. These motion pictures have been taken through an angle of attack range of 0 up through 15°, which is the usual range in which the missile flies during a turning maneuver.

Scene 4

In these pictures the model is banked 22-1/2° counter clockwise, which is equivalent to the missile accelerating in the lateral direction with about half the acceleration it is experiencing in the vertical plane. In this case, both wings are carrying lift and you can see that as the angle of attack increases the vortices appear behind each wing tip. The vortices behind the horizontal wings are more intense than those behind the vertical wings, since the strength of each vortex is proportional to the lift carried by each wing panel. You will note here that there is no plane of semmetry in the flow and that the flow field is extremely complex. In fact, the flow field here is so complex that no theoretical solution has been found which adequately describes the flow. The angle of attack has reached the maximum flow and has begun to decrease, resulting in a decrease in the vortex strength. I believe it is apparent that in this case the interference between the wing and the tail placed in such a flow field may be very complex and will result in unusual stability characteristics unless the tail is designed in such a manner as to minimize the effect of the complexity of the flow field.

Scene 5

For these pictures the model is banked 45°, which is equivalent to the missile experiencing a lateral acceleration that is equal to the normal acceleration. In this case you can see that as the angle of attack increases the vortex flow behind each wing panel is of about the same strength as would be expected. The flow here has a plane of symmetry which makes it a little less difficult to treat. The reasons for the flow disturbances shown here are not understood at the present time. The vapor screen technique has only very recently been developed and the flow pictures have not been fully analyzed as yet. There is undoubtedly some interaction here between the shock waves given off by the wings and those given off by the body which may cause regions in which the fog is dispersed. The angle of attack has again reached the maximum value and is now decreasing. The results of these vapor screen studies have been correlated with the results of stream angle measurements behind the same model and it has been found that the vapor screen technique shows the location of the vortex cores with fidelity. What we need to do now is to determine some means of estimating the vortex strength from these pictures. If this is possible then the estimation of the downwash and sidewash characteristics of the flow in the plane of the tail can be done with greater ease with the visual stream technique than with the tedious method of measuring the flow angles point by point in an extensive wind tunnel investigation.

Concluding Remarks

The discussion given by the previous speaker and the results of the movie you have just seen give you a few examples of the work being done on important interference problems in the various laboratories of the NACA. It has been shown, I believe, that these interference problems have become of greater significance as the speed range of the aircraft increases, and they are of greatest importance in the estimation of the characteristics of guided missiles. Even more complex interference problems are being investigated at the present time including the effects of interference in determining the dynamic motions of a missile.

Display for presentation of "Airfoil-Body Combinations" by 6- by 6-foot supersonic tunnel.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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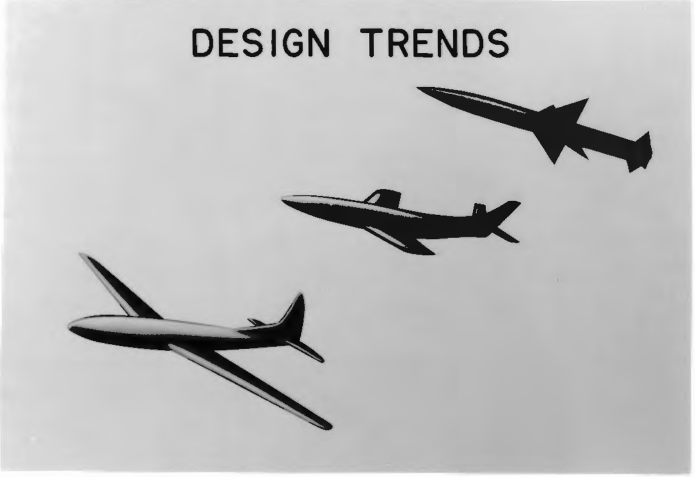

DESIGN TRENDS

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INTERFERENCE ALTERS LOAD DISTRIBUTION

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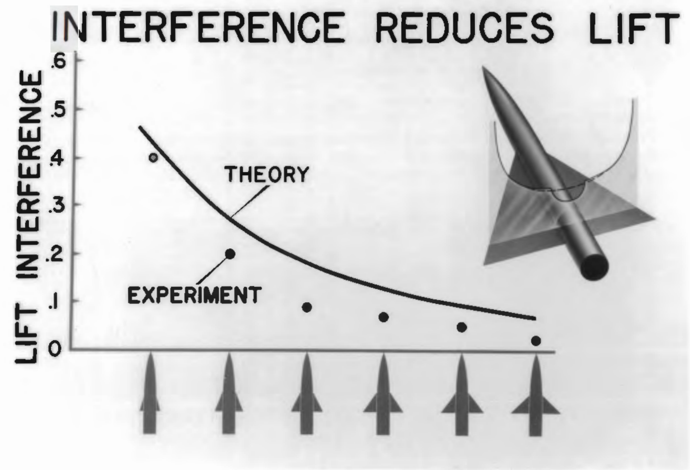

INTERFERENCE REDUCES LIFT

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INTERFERENCE REDUCES ROLLING MOMENT

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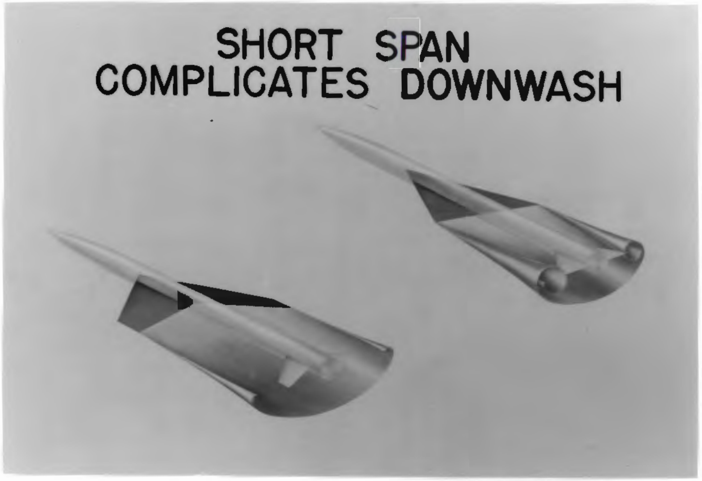

SHORT SPAN COMPLICATES DOWNWASH

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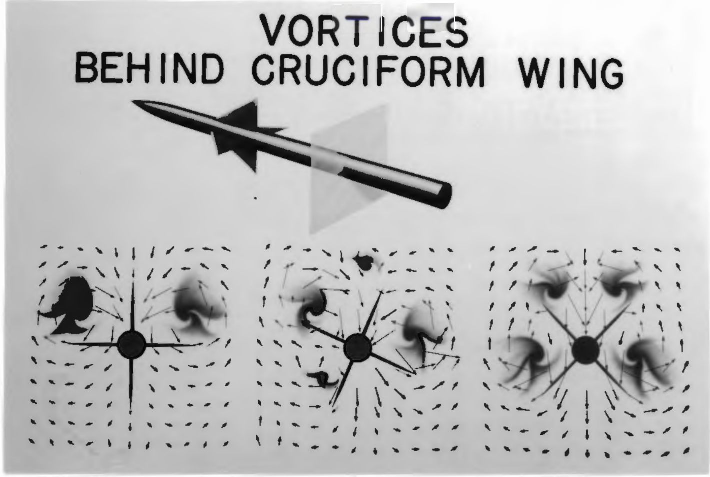

VORTICES BEHIND CRUCIFORM WING

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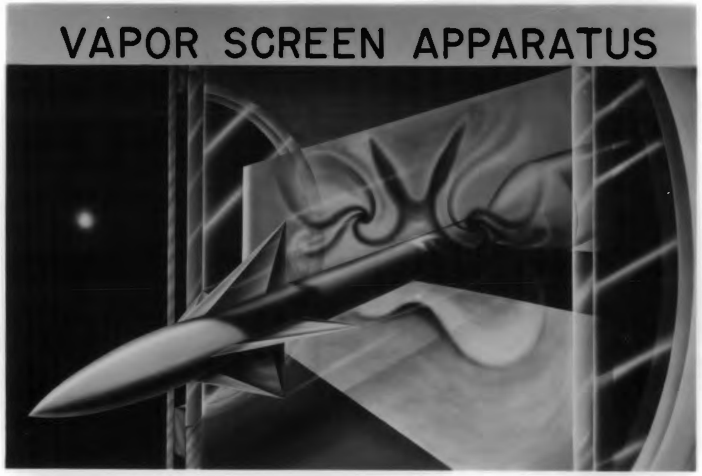

VAPOR SCREEN APPARATUS

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