HIGH SPEED AND RANGE

presented by

Flight Engineering Section

10- by 14-Inch Supersonic Tunnel Section

We are going to discuss various factors that influence the maximum speed and the maximum range of airplanes and missiles. First, we'll indicate some of the more important factors and how they affect speed and range. Then we'll show typical results of NACA research which have added to our knowledge of these factors. The first part of the discussion will deal with aircraft for which the wing is large in relation to the fuselage.

Let's first consider how different aerodynamic factors, like lift and drag, affect the maximum speed and range. We should also include propulsion in the discussion, because it affects high speed and range as much as the aerodynamic factors. For simplicity, however, we'll keep the discussion of propulsion to a minimum.

Now, any aircraft flying at a steady speed has to develop enough lift to support its weight. The drag that's coupled with that lift determines the high speed and range of the aircraft. With the help of this first chart (chart A-1) we can show how drag is related to high speed and range. On this chart we have a curve showing the variation of drag with speed, expressed here in terms of Mach number, for a supersonic airplane as it changes its angle of attack to maintain flight at a constant altitude of 35,000 feet. This increase in drag at low Mach numbers is due to the larger angles of attack required. If we assume this aircraft to be jet propelled, then the thrust produced by the power plant would vary with Mach number somewhat as indicated by this curve. The maximum speed is, of course, the speed at which the power plant develops just enough thrust to offset the drag. This limit is at the intersection of these two curves.

To understand how the maximum range is determined, we have to introduce another factor in addition to the drag,--that is, the fuel load. The work done, hence the fuel burned during a flight, is the product of the drag and the range. With a given fuel load the range will be greatest when the drag is least. That is, for maximum range we should fly at this speed. Sometimes, the efficiencies of power plants vary in such a way that greater range results from operating at slightly higher speeds, but, in general, we can say that the drag in this part of the curve will define the maximum range.

Now let's consider how we would reshape these curves to increase the maximum speed or the range of this airplane. Basically, the solution for both problems is the same--the drag must be reduced. For example, to increase the maximum speed, the drag must be reduced as indicated by this curve; to increase the maximum range, the drag must be reduced as indicated by this curve; and, to increase the speed at which the maximum range is obtained, the drag must be modified as indicated by this curve.

A large number of factors influence the shape of the speed-drag curve. Aside from the size of the airplane, such factors as the wing plan form, or shape of the wing as viewed from above, the wing thickness, the shape of the engine air inlets, and even the requirements for stability of the airplane can affect the shape of the speed-drag curve. Sometimes these factors are conflicting, so that a change the designer would like to make to increase the maximum speed will reduce the range, or vice versa. This points up two facts: one, that the designer has to balance a lot of factors to arrive at his final design; and, two, an important role of the NACA is to give the designer quantitative information on the effects of these factors so that he can arrive at the best compromise.

Now let's see in more detail how changing some of the physical dimensions of an airplane affects the speed-drag curve. The next speaker will review test results that show the separate effects of wing plan form, wing thickness, and airplane stability on the speed-drag curve of an airplane. Mr. __________.

Considering first the effects of plan form on the speed-drag curve, we will use these six wing shapes for illustration. The speed-drag curve for each of these models was calculated from wind-tunnel data. To put the calculations on a comparable basis, the following factors were held constant for all six wing shapes: an airplane weight of 30,000 pounds, an altitude of 35,000 feet, and wings designed for a landing speed of 150 mph.

The speed-drag curves for the six plan forms fall within this overall shaded area. However, within this area there is a definite demarcation between what we might call the "low-speed" and the "high-speed" plan forms. Let's develop that point a little. This straight wing with high aspect ratio would be represented by this drag curve. Obviously, for flight at supersonic speeds, this wing would be completely out of the picture. We classify it as a low-speed wing. This wing would have this drag variation and would be much more satisfactory for high speed. Or, if the available thrust were reduced to this level, say, then this wing represented by this curve would have a greater maximum speed.

So we see that for maximum speed some wing shapes are completely unsatisfactory, and also that any one wing shape is not necessarily the best at all speeds. Incidentally, you will note that for all these high-speed wings there isn't much margin of thrust for a wide range of Mach numbers. This means that the airplane can accelerate to the maximum speed only very slowly, and in doing that would burn considerable fuel. If, for a particular case, this fuel expenditure became excessive, then it could represent an effective limitation of the maximum speed attainable.

Plan form also has an effect on maximum range. The best plan form from the standpoint of range is the one having this curve, but we have just seen that this shape is unsuitable for supersonic flight because of this extreme drag rise. The curves for these five high-speed plan forms lie within this heavily shaded area, and hence all have higher minimum drag than the low-speed wing. Thus, at the present time, plan forms suitable for flight at these higher Mach numbers will have less efficiency of flight than the low-speed wing. The development of wing shapes that will have the best possible cruising efficiencies at supersonic speeds is a problem on which the NACA is expending considerable research effort.

So much, for the effects of wing plan form. Another important factor is wing thickness, as shown by this next chart. This model shape was used in the computations for this chart. Here we see for this one plan form the effects on the speed-drag curves of increasing the wing thicknesses from 3 percent to 5 percent and to 8 percent. Again, this increase in drag at low Mach numbers is due to the larger angles of attack required to maintain constant altitude. The heavily shaded area from the preceding chart has been repeated on this chart to permit us to compare the effects of varying plan form with the effects of varying wing thickness. It is apparent that thickness changes can have as much effect on the speed-drag curve as plan form-changes. Incidentally, the best of these curves, from the standpoint of high speed, represents a thickness ratio (thickness to chord) about the same as some razor blades. It's obvious that, when you're working with thicknesses of that order, there are severe structural problems. The effects of thickness are not as pronounced at subsonic speeds as they are at supersonic speeds, but these seemingly small differences nevertheless represent sizable changes in maximum range. If the minimum values shown by these curves had occurred in the supersonic region, which might be the case for an airplane designed to meet different requirements, or if cruising at higher speeds is more efficient because of power-plant characteristics, the effect of thickness on maximum range would be even greater.

So far, we've discussed only the more obvious factors that affect the performance of the airplane. It isn't quite so obvious, but nevertheless true, that the need for stabilization and control of an airplane can have an important effect on its high-speed performance. This comes about from the fact that some sort of control must be provided to adjust the airplane attitude for cruising, climbing, maneuvering, or landing. This control may take the form of a tail on a conventional design, or a trailing-edge flap on a tailless airplane.

The stability of an airplane generally varies with Mach number. Therefore, the control deflection necessary for trim has to be varied as the Mach number changes. The control deflections required for trim produce increases in drag, which are illustrated in this next chart. Here, we see the speed-drag curves for an untrimmed wing and for the same wing with the tail required for stability and trim. You can see that for this thrust curve the maximum speed is greatly reduced because of the necessity for trimming the airplane.

In general, wings having different plan forms will have different variations of stability with Mach number and, as a result, the variations of control deflection will be different. The factors that determine these differences are discussed in more detail in the talk being given today at the 2- by 2-foot wind tunnel. In any case, as a result of the differences in stability of the various wings, different drag increases due to control deflection will occur. Thus, if a choice had to be made between two wings having otherwise similar drag curves, the different stability characteristics might determine which wing would be chosen.

A conventional tail was used in this example for simplicity of illustration. However, similar changes in maximum speed would probably have resulted had we chosen to consider the drag due to a trailing-edge control on a tailless design.

Mr. __________ will now tell us about problems concerning the maximum speed and range of aircraft for which the wing is either small in relation to the fuselage, or is non-existent. Mr. __________.

It has been shown that the variation of drag with speed is of primary concern to the aircraft designer when he is considering the problems of maximum speed and range. In particular, it was pointed out that both speed and range may be increased if the drag of an aircraft is reduced. If we wish to fly faster even with a configuration having one of the better high-speed wings discussed previously, we find, however, that the drag rises rapidly with speed as shown on this chart. Much of this increase in drag occurs because the large wing the airplane requires to land at low speed is not used efficiently at high speed. If the landing condition is relaxed, as it frequently is for high-speed missiles, then the large wing will not be required. The drag curve for such a missile, one without a wing and having a carrying capacity and level flight path similar to the airplane, is also shown on the chart. We see that at high speeds, the trend is for the missile to have lower drag than the airplane and, although the missiles minimum drag is considerably higher than that of the airplane, it occurs at higher speed. The third configuration with a small wing has intermediate minimum drag occuring at intermediate speed. This change in the speed drag curves with wing size is one of the reasons why high-speed missile configurations are often predominately body with, at most, small wings. It should be emphasized that altitude has a pronounced effect on the speed drag curve of aircraft; for example, increasing the altitude tends to shift all the drag curves to the right.

This speed drag curve we have shown is typical of only one class of missiles, those that fly at constant altitude and are inclined so as to support their own weight aerodynamically. There are, of course, many other classes of missiles, including the ballistic missile which has a flight path like that of an artillery shell and which, in contrast to an airplane, does not support its weight aerodynamically. Though much of our discussion will apply to the speed and range problems for all types of missiles, we will only consider the first type; that is, missiles without wings such as the one shown on the chart. We will consider flight Mach numbers of approximately 3 to 7, or flight speeds of about 2000 to 5000 miles per hour. At these high speeds there are other considerations that often are equally as important as the aerodynamic characteristics of the particular missile, but let us consider only the aerodynamic properties.

There are, as in the case of airplanes, many factors which influence the drag characteristics of missiles. We will consider some of these factors that roughly correspond to those that were discussed for wings. Two requirements will be applied to all missiles considered: weight, 30,000 pounds; altitude, 35,000 feet. These conditions were chosen simply to be consistent with those used for the airplanes, and it should be understood that if we were to consider flight at high Mach numbers for any extended period of time, we would probably have chosen a higher altitude. Since the missile does not have to land at low speed, the body size will be fixed by assuming a reasonable volume.

We will consider first the effect of changing the profile shape of the missile nose. Profile shapes of bodies correspond roughly to the plan forms of wings that were discussed in the previous talk. The speed drag curves for missiles having three different nose shapes that have been investigated recently by the NACA are shown on this next chart. As we might expect, a missile having a nose with a relatively large blunt tip, such as this shape that might be used at low Mach numbers, has high drag at high Mach numbers. The pointed-nose missile that we compared with the airplane has much lower drag. Though bluntness increases the drag at the tip, it is interesting to note that tip bluntness will not always increase the total drag. In fact, using a small blunt tip, hardly visible on the chart, permits the remainder of the nose to be shaped to give a net reduction in drag. The drag of such a missile is represented by the green curve. It appears then that a small degree of tip bluntness may permit a reduction in the total drag of a missile, although an excessive amount may have decidedly the opposite effect.

The bodies considered so far have had a ratio of length to diameter, or fineness ratio, of 10. Now let us consider the effects of changing the fineness ratio while again keeping the body volume constant. As shown on this chart, fineness ratio affects the drag of missile bodies in much the same way that thickness ratio affects the drag of wings. We see that if the fineness ratio is such that the missile has the proportions of a low-speed bomb, the drag is very large. The reference missile of fineness ratio 10 has a much lower drag, particularly at high Mach numbers. Apparently, however, the drag cannot be reduced indefinitely by increasing the fineness ratio, for we see that the effect of further increasing the fineness ratio is not nearly so pronounced. This reduction of the effect of fineness ratio is caused by skin friction. Because they have more surface, the longer bodies have more skin-friction drag. Eventually the increase in skin friction overshadows the decrease in pressure drag brought about by making the body longer. The actual point at which this occurs is strongly dependent on the operating conditions and size of the missile. Skin-friction drag at high Mach numbers is an important problem and is being discussed today by other members of the Laboratory staff.

We have found in our brief discussion that fineness ratio and nose shape affect the drag of missile bodies at high Mach numbers. There are factors other than those that we have considered which also influence the drag. For example, it has been suggested that flat-bottom bodies, such as the model shown here, might be better than round bodies. The reasoning is that the high pressures on the bottom of the flat bodies will be acting in a direction to produce less drag for the same lift. At present, we are investigating the aerodynamic characteristics of flat-bottom bodies to see if the expected drag reductions can be realized.

In conclusion, we would like to emphasize that all the examples employed were chosen primarily to illustrate some of the factors which influence the drag and hence the speed and range of airplanes and missiles.

Only the aircraft designer who has all the pertinent information can select a suitable configuration. He will balance the drag characteristics with his other requirements, considering such things as the purpose of his aircraft, structure, ease of manufacture, distribution of load he wishes to carry, as well as many others. There are, of course, many possible combinations of the different shape variables we have considered. The NACA with its various investigations of these combinations attempts to place at the designer's disposal the basic data he needs in order to make his selection.

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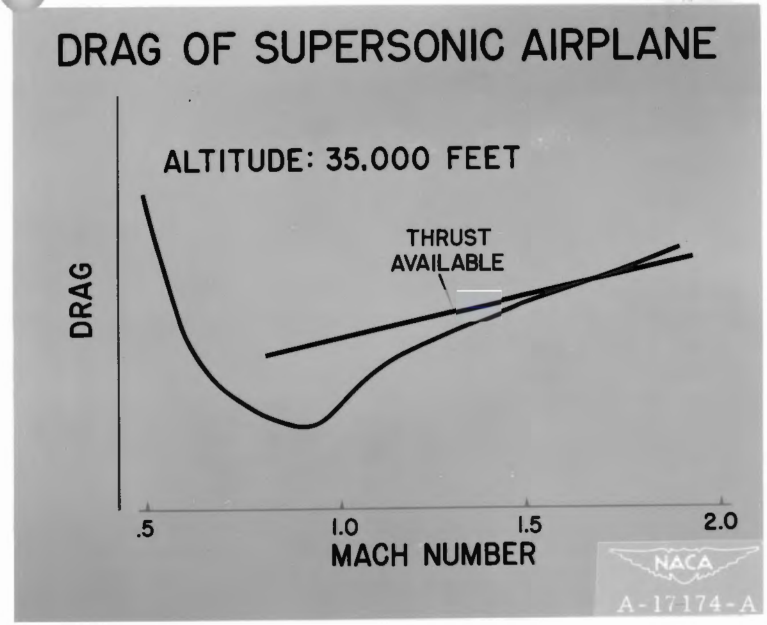

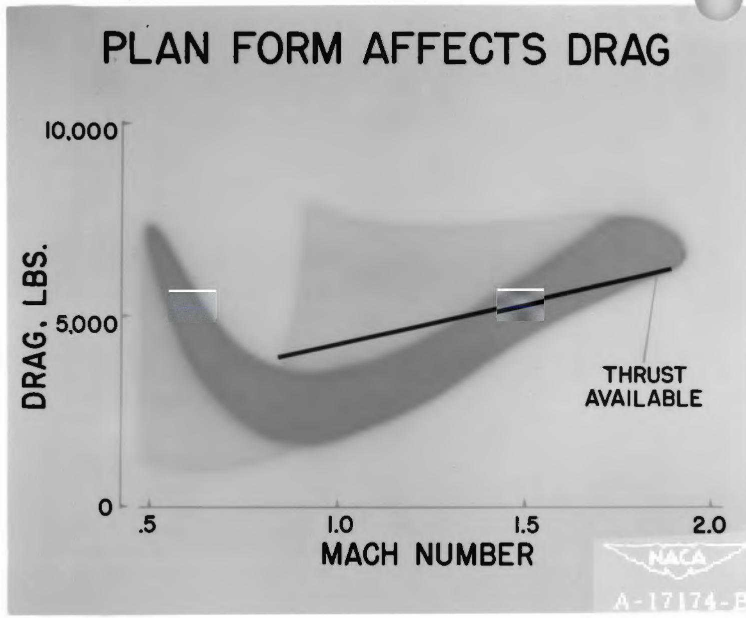

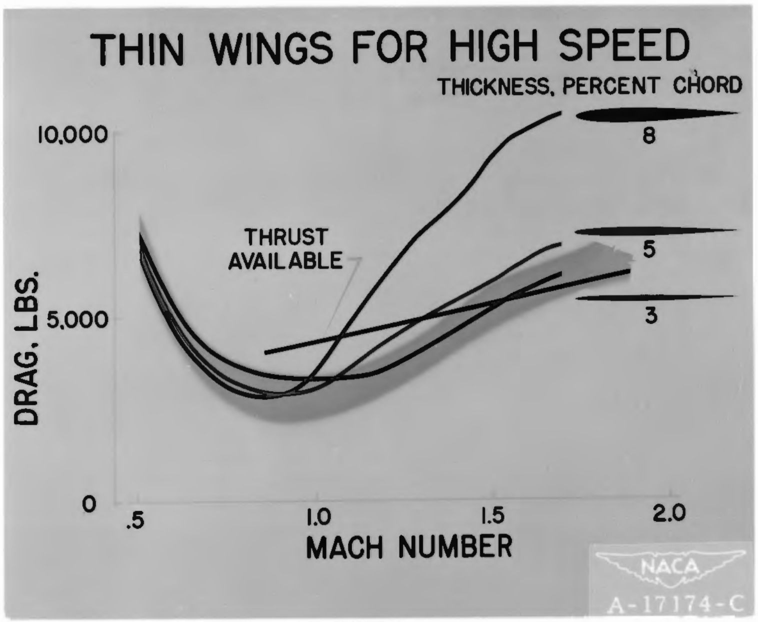

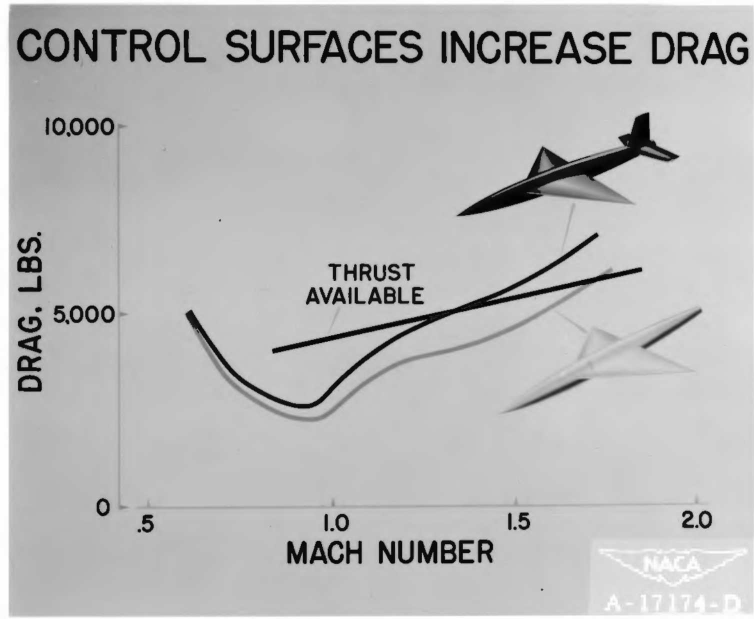

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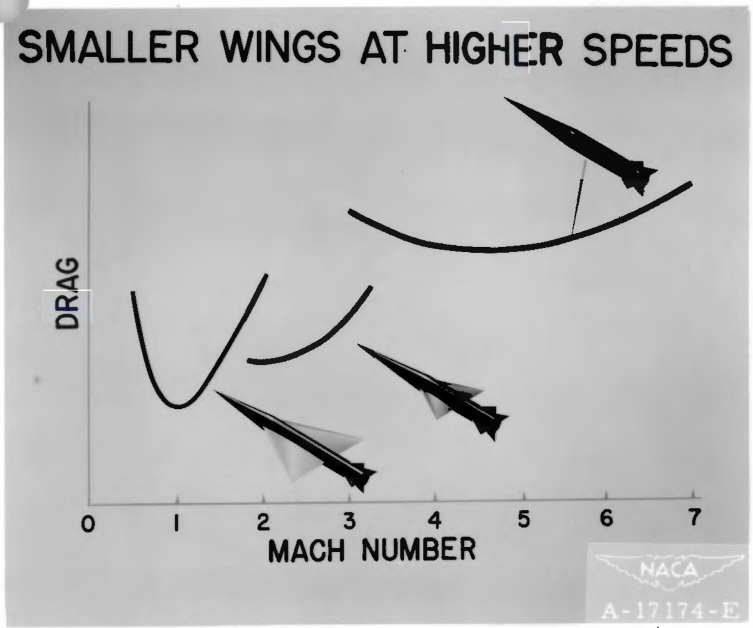

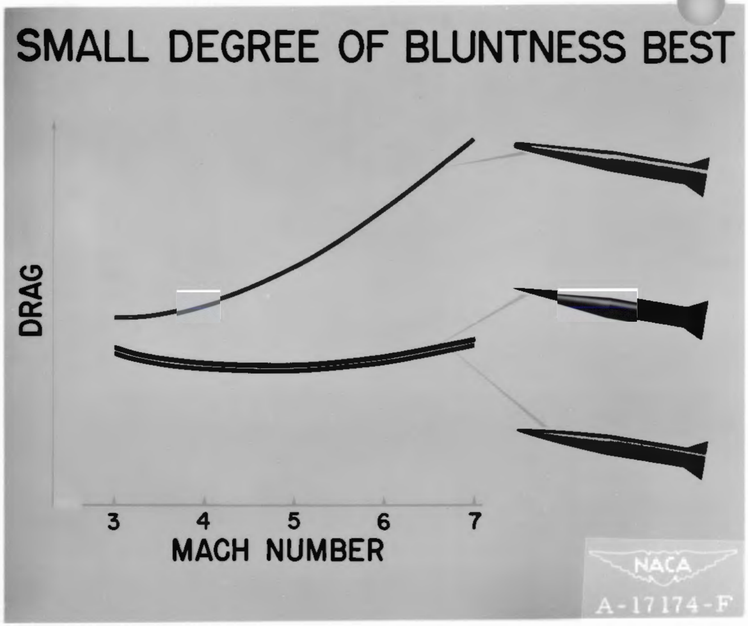

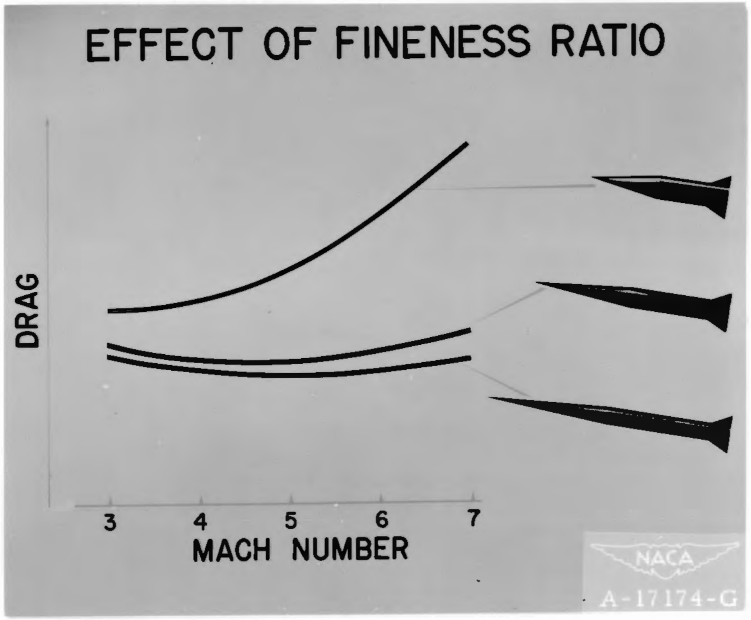

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