12-FOOT PRESSURE WIND TUNNEL

INTRODUCTION

Arthur Amuedo or Robert Reynolds

With the spectacular advances in airplane design during the past ten years, there has been an ever increasing demand for additonal wind-tunnel testing to obtain those data which are essential to a successful design.

A great new field for aeronautical research resulted when contemplated flight speeds exceeded the speed of sound. The range of flight conditions to be investigated was greatly increased, but more than this, it was indicated that the conventional airplane would require some major changes in design to enable it to fly at supersonic speeds. For example, there has been considerable departure from those airfoil sections and wing plan forms for which a great mass of data was accumulated over many years of research. Not only must data be obtained on these new configurations at supersonic speeds, but to permit intelligent design and better understanding of the flow phenomena involved, tests must be made over the complete range of flight conditions, from landing and take-off to high subsonic and supersonic speed. The 12-foot pressure tunnel is actively engaged in obtaining aerodynamic data applicable to the design of these new airplanes. We would like to discuss results of some of this work today.

Before proceeding with the main subject of this discussion, which is concerned with low-aspect-ratio wings for supersonic airplanes, I would like to describe briefly some features of this tunnel:

From the schematic drawing shown here (fig. 6(b)) you will note that the 12-foot pressure tunnel is similar to the conventional wind tunnel in both appearance and basic principle of operation.

It consists of a steel duct of circular cross-section which varies in diameter from 60 feet at the spherical section to 12 feet at the test section where the model is placed. The duct forms a continuous closed circuit through which air is circulated by two large fans driven by electric motors totaling 12000 horsepower. A very low-turbulence level, or smooth uniform flow, in the test section is achieved in this tunnel by placing 8 fine mesh screens across the duct at the spherical section. These screens remove eddies and cross flow introduced in the air stream by the propellers and turning vanes.

The 12-foot pressure tunnel differs from the conventional wind tunnel in that the internal air pressure can be controlled. The air which is circulated in a conventional wind tunnel is essentially at atmospheric pressure. The pressure of the air in this tunnel can be varied from 6 atmospheres to 1/6 of an atmosphere. This variable air-density-characteristic is an extremely important feature, because the effective scale of a test may be changed simply by changing the air density. Thus, if a 1/6-scale model is tested at an internal pressure of 6 atmospheres, full-scale flow conditions will be duplicated. The model test data will then be directly applicable to a full-scale airplane. Such tests at full scale, because of tunnel power limitations, are restricted to speeds corresponding to the landing condition. Although we cannot attain full-scale flight conditions at the higher test velocities, we can maintain a constant scale throughout the speed range by varying the tunnel pressure. This is important, for it allows the effects of Mach number to be isolated from those due to scale.

The advantage of reducing air density below atmospheric is that very high test velocities are attained with a moderate expenditure of tunnel power. This tunnel is capable of testing complete airplane models at speeds up to 95 percent of the speed of sound by reducing the tunnel pressure to slightly less than 1/2 atmospheric pressure.

I would now like to introduce to you Mr. Crane (Mr. Kolbe) who will present a comparison of the relative merits at various speeds of two possible airplane configurations for flight at supersonic speeds.

LOW-ASPECT-RATIO WINGS

Robert M. Crane or C. D. Kolbe

Aerodynamic investigations have indicated several wing plan forms suitable for flight at supersonic speeds. Today we will consider and compare the characteristics of two such wing plan forms, a triangular wing of aspect ratio 2 and a thin wing without sweep of aspect ratio 4. The wings in both cases are about 5 percent thick and the wing profiles are sharp-edged supersonic sections.

A pictorial representation of three possible types of supersonic aircraft is shown in this chart (fig. 6(c)). The large swept-back wing airplane discussed in detail in one of today's talks in the 1- by 3-foot supersonic wind tunnel, is a type which is believed to be suitable for long range missions at moderate supersonic speeds. The two smaller airplanes, with which we will be concerned in the following discussion, are considered suitable for high-speed pursuit and interception.

Just as the P-80 cannot be expected to attain the range and the load-carrying capacity of the B-29, neither can these two airplanes with wings of low aspect ratio be expected to attain the range of the highly swept-back wing airplane. However, the low aspect ratio wing is usually superior to the swept wing in regards to structural strength and rigidity and consequently the two small airplanes are capable of engaging in maneuvers which are not feasible for the larger airplane.

The characteristics of the triangular and the straight-winged aircraft are compared on the following series of charts and through such comparisons we will endeavor to show the speed ranges in which one is superior to the other. The data at subsonic speeds on all of the charts were obtained from tests in the 12-foot wind tunnel. The data at supersonic speeds are theoretical values with adjustments to correlate with the available supersonic data from the 1- by 3-foot and 1- by 3-1/2-foot supersonic wind tunnels.

The first chart (fig. 6(d)) compares the minimum drag of the two wings at various Mach numbers from 0.2 to 2.4. At Mach numbers less than 0.8 there is little choice between the two wings insofar as minimum drag is concerned. At Mach numbers between 0.8 and 1.7 the drag of the triangular wing is considerably less than the drag of the unswept wing. The rapid rise of drag on the straight wing is due to the formation of shock waves on the wing as the speed of sound is approached. This drag due to shock waves persists throughout the supersonic speed range. On the triangular wing, however, shock losses are delayed until a Mach number of about 1.7. This delay is due to the sweepback of the triangular wing which reduces the component of velocity perpendicular to the line of maximum wing thickness to subsonic values until a Mach number of 1.8 is attained. At Mach numbers above 1.7, the drag of the triangular wing is greater than the drag of the straight wing as a result of the large shock losses on the triangular wing at these supersonic speeds. The first peak on this drag curve of the triangular wing occurs at the forward Mach number at which the component of velocity perpendicular to the line of maximum wing thickness first reaches the speed of sound, while the second peak is associated with sonic velocities normal to the leading edge of the wing. Thus the sweepback of the triangular wing does not eliminate the large drag due to shock losses usually associated with flight at supersonic speeds but merely delays the drag rise to some forward Mach number greater than unity. By further decreasing the aspect ratio of the triangular wing, in other words by increasing the leading-edge sweepback, these shock losses can be delayed to an even higher supersonic Mach number. Practical considerations for a maneuverable airplane, however, limit the leading-edge sweep which can be tolerated and it is felt that for sustained flight at Mach numbers above 2 or 2-1/2 an airplane equipped with straight wings will have a lower minimum drag than a triangular wing.

Two parameters which influence the longitudinal stability and control of an airplane are compared in this next chart (fig. 6(e)). Consider first the longitudinal location of the center of lift which is shown in the upper half of the chart as a function of the Mach number.

The center of lift must always be behind the center of gravity of an airplane to insure static longitudinal stability. The maneuverability of an airplane is, however, inversely proportional to the distance between the center of lift and the center of gravity. To obtain maximum maneuverability throughout the speed range, it is then desirable that the center of lift be invariant with Mach number. Inspection of this chart reveals that the triangular wing more closely approaches this desirable condition than does the unswept wing.

The center of lift is at approximately the center of area for both of the wings at Mach numbers greater than 1.5. At high subsonic speeds the center of lift of the straight wing approaches the leading edge of the wing while the center of lift of the triangular wing remains fairly close to the wing centroid. This means that for a given static stability at low speeds, an applied pitching moment on the triangular wing will produce a larger normal acceleration at supersonic speeds than the same applied pitching moment on the straight wing.

The lower half of the chart compares the angles of attack necessary to produce a lift coefficient of 0.3 for the two wing plan forms at various Mach numbers. As was the case with center of lift, it is desirable that this angle of attack show little variation with Mach number. Rapid variations in angle of attack for a constant lift are indicative of the necessity for rapid movements of the airplane's longitudinal control in order to maintain level flight. Comparison of the curves for the two wings indicate that the angle of attack of the triangular wing shows less variation with Mach number than the straight wing, but that both wings show a rather rapid decrease in angle of attack for 0.3 lift coefficient near a Mach number of unity. It may also be noted that the angle of attack necessary for a lift coefficient of 0.3 is considerably larger for the triangular wing throughout most of the speed range. This is due primarily to the fact that the aspect ratio of the triangular wing is only half as great as the aspect ratio of the straight wing.

This next chart (fig. 6(f)) compares the maximum lift-drag ratios for the two wing plan forms at various Mach numbers. The lift-drag ratio is a measure of airplane efficiency and is indicative of the range or endurance of the airplane. At subsonic speeds the straight wing is superior to the triangular wing as indicated by the higher value of lift drag ratio. At Mach numbers between 1 and 1.8 the triangular wing is superior to the straight wing. It is expected that by using a conventional section on the triangular wing instead of a sharp-edged section an increase in lift-drag ratio will be realized in this speed range. At Mach numbers greater than 1.8, the straight wing exhibits a higher lift-drag ratio than the triangular wing. As was the case with the previous chart on minimum drag, this Mach number is the forward Mach number associated with large shock losses over the triangular wing. Once again it appears that for flight at Mach numbers greater than about two, the unswept wing will be superior to the triangular wing.

This next chart (fig. 6(g)) compares the landing characteristics of two airplanes, the first equipped with a triangular wing and the second with an unswept wing. The chart presents power-off gliding speed or airplane velocity against sinking speed or vertical velocity for an airplane with a wing-loading of 60 pounds per square foot. A single curve is presented for the triangular wing airplane and two curves are presented for the straight-wing airplane, one with flaps up and one with wing leading-edge flaps and trailing-edge flaps deflected. The maximum forward landing speed and sinking speed which could be tolerated in a piloted airplane are difficult to ascertain. Successful landings have been accomplished by highly skilled pilots at sinking speeds as large as 30 feet per second and at forward speeds of as much as 150 mph. Of the three configurations shown, it would appear that the only airplane with which it might be possible to perform a safe landing with power-off, is the straight-winged airplane with the flaps down. This could be accomplished with a landing speed of 140 miles per hour and a power-off sinking speed of 35 feet per second. The minimum power-off sinking speed of the straight wing airplane with the flaps up is 42 feet per second at a forward speed of 250 miles per hour. The corresponding figures for the triangular wing airplane are 52 feet per second at a forward speed of 210 miles per hour. The application of a moderate amount of power would reduce all of the sinking speeds shown on this chart to more reasonable values. At speeds less than 180 miles per hour, the sinking speed of the triangular wing airplane is less than that for the straight wing airplane with flaps up. This chart emphasizes the benefits which can be derived from proper application of flaps to the straight wing and indicates the improvement that may be achieved by design and development of similar flaps for the triangular wing.

In summary, we have compared the minimum wing drag, location of center of lift, angle of attack for a lift coefficient of 0.3, maximum lift-drag ratio, and sinking speed of two airplanes having wings of low aspect ratio. This comparison indicates that for flight at Mach numbers below 0.8 the straight wing is slightly superior to the triangular wing. At Mach numbers between 0.8 and 1.7 the triangular wing airplane is superior in several respects to the straight wing airplane but for Mach numbers above 1.7 the straight wing demonstrates the better performance. There are many other wing plan forms which are superior in certain speed ranges to either of wing plan forms considered here.

We have, of course, generalized considerably in this comparison and have neglected such considerations as lateral and directional stability and control, control forces, landing attitude and other factors that might affect the choice of wing plan form. It is obvious that there are still many problems associated with the design of airplanes of this type and much basic research and developmental testing remains to be done before accurate predictions can be made of the characteristics of airplanes designed to be flown at supersonic speeds.

I would now like to introduce ____________________ who will discuss one of our methods of acquiring data of the type which has just been presented.

THE STRAIN-GAGE BALANCE

Lloyd Jones or William Otey

A portion of the data just presented was obtained from tests of this model (fig. 6(h)), mounted on the sting type support shown in this photograph. This type of support eliminates the conventional support struts and their fairings, allowing reliable test data to be obtained at very high speeds. The forces acting upon the model are measured within the model itself by means of a compact strain gage balance. This method of measurement eliminates all the tares due to direct air forces on the model support equipment.

Details of the balance may be seen in these photographs (fig. 6(i)). The balance is mounted on a sting extending upstream from the main support strut. The model is in turn supported by the balance through small structural members upon which are mounted wire resistance strain gages. Lift acting on the model is taken through these two members, drag through this beam, pitching moment here and rolling moment through a member located within the sting.

The balance unit is 4 inches in diameter, 12 inches long and has a capacity of 5000 pounds.

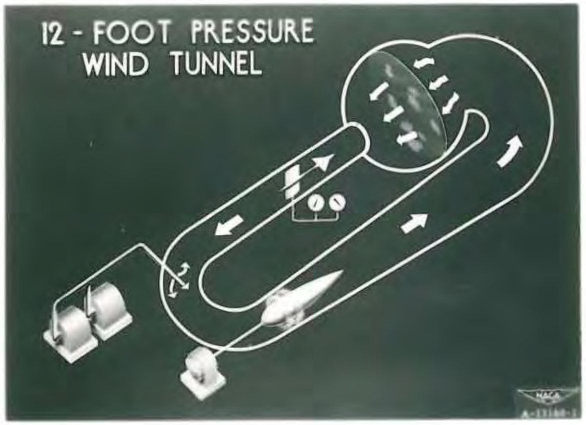
The apparatus on display here is the electronic follow-up mechanism employed to transmit strain gage readings to the printing unit. It consists of a light beam galvanometer, sensitive to change in resistance of the strain gage circuit and a photo-cell-prism arrangement for automatically tracking the deflection of the galvanometer. A light beam, reflected from the galvanometer mirror, is focused on this unit which contains a splitting prism and two photo-cells. This unit is driven by an electric motor which is energized by the photo-cells.

When the prism box is exactly in line with the light beam, both photocells receive the same amount of light and the circuit is balanced. I will deflect the galvanometer mirror and you can observe the motion of the follow-up in locating the light beam. Location of the unit is then transmitted by a selsyn motor to the control panel which is the panel on your right. Here a permanent record is obtained on printed tapes. This model of the triangular wing is mounted on the support sting. The strain gage balance is located within the model in this region, and is connected through a similar follow-up unit to the control panel. Application of a lift load upon the model is indicated on the dial A of the control panel. This mechanical recording equipment has greatly improved the efficiency of obtaining force and moment data on models using a strain gage balance.

This concludes our presentation at the 12-foot pressure wind tunnel.

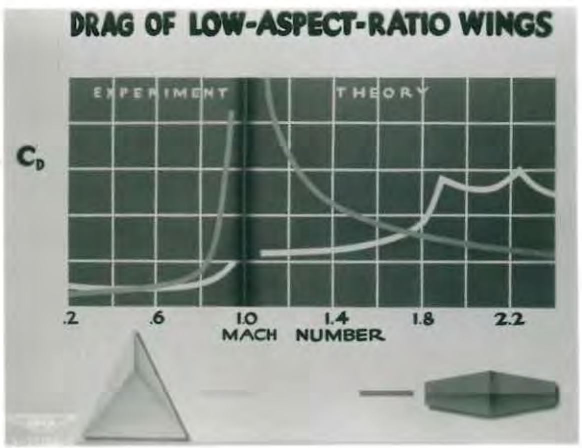
(a) General view.

Figure 6.- 12-foot pressure wind-tunnel exhibit.

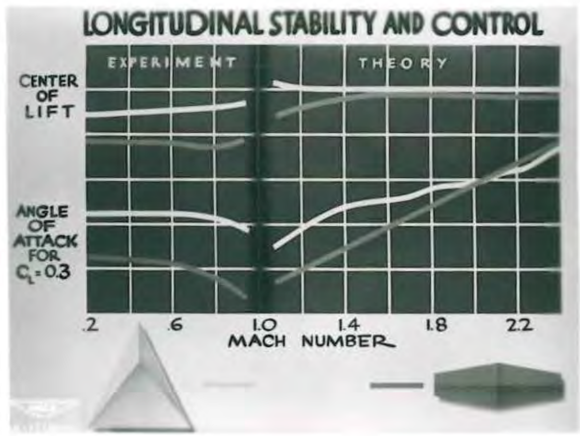


(b) First chart.

(c) Second chart.

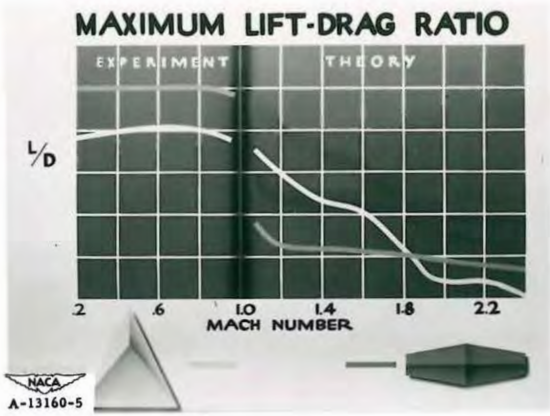


(d) Third chart.

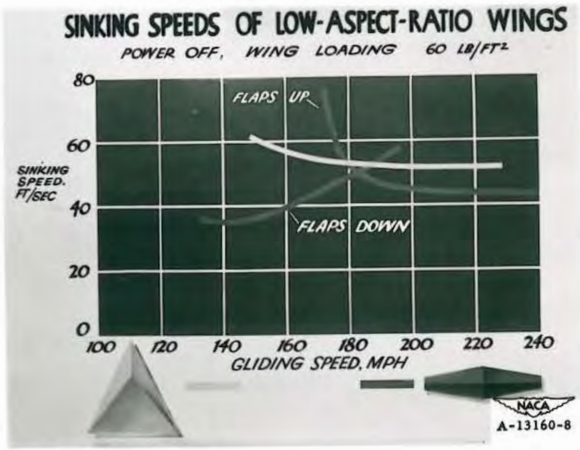


(e) Fourth chart.

Figure 6.– Continued.

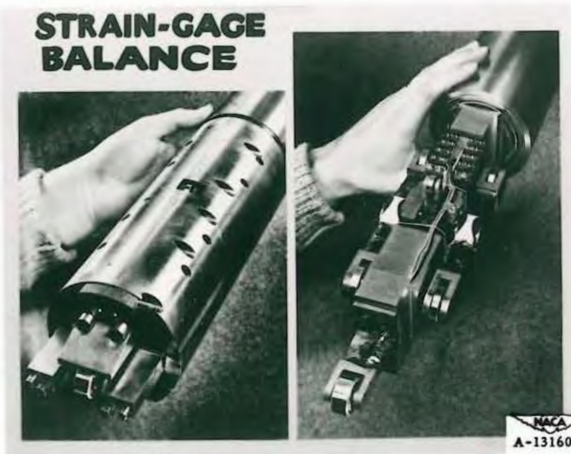


(f) Fifth chart.



(g) Sixth chart.

(h) Seventh chart.



(i) Eighth chart.

Figure 6.- Concluded.

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