MILES ON SUPERSONIC FLIGHT

body, thereby enabling it to flow round the section in a smooth manner. The reason for this is that the body "warns" the oncoming air that it is approaching, this "warning" itself travelling at the speed of sound, and the air is therefore gradually deflected before meeting the obstacle.

On the other hand, when the body attains speeds greater than that of sound, the flow pattern cannot extend great distances in front of the body because by the time any disturbance has spread to a great distance from the body, it must necessarily have become a small one, and will therefore be propagated at the speed of sound, so that the body itself will tend to overtake any disturbance produced by it. The body, therefore, comes up suddenly against a wall of air through which it has to force its way. This forcing of the body through this "unwarned" air causes very large drags and very serious aerodynamic problems.

The disturbance due to the body must extend to a finite distance in front of it (although this distance may be extremely small) and must be propagated into still air with a speed greater than that of sound. This disturbance is called a shock wave, and its shadow may be seen in front of any body moving faster than the local speed of sound.

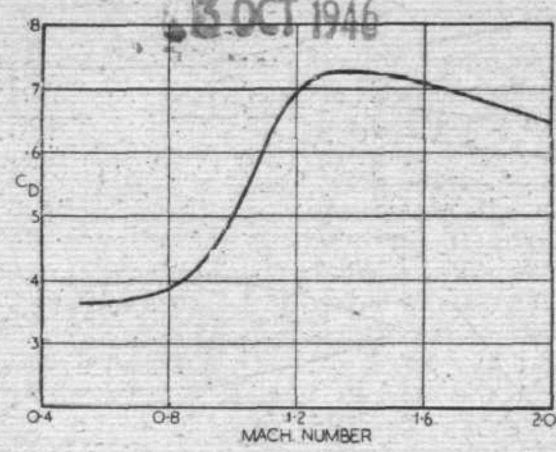

Fig. 1. A curve, obtained from ballistic data, showing drag increase through the sonic range.

A shock wave is a line of small but finite thickness, the velocity of the air which is downstream always being less than the velocity which is upstream of the wave front. The density, therefore, always increases on passing through the discontinuous sheet. Inside this narrow region, which normally is less than 1/10,000th of an inch, the density and pressure undergo abrupt changes, and part of the kinetic energy of the air is dissipated and converted into heat. Along with this development of shock wave, an aerofoil experiences a rapid rise in drag coefficient, and at the same, or somewhat higher, speeds, there is also a fall in lift coefficient and change in pitching moment.

Shock Waves

Shock waves, of course, may be formed on bodies travelling at less than the speed of sound, provided the local speed on some part of the body exceeds that of sound.

It will therefore be seen that, as the speed of a body increases and the critical Mach number is reached, a shock wave will begin to form on the body at points where the speed of sound is achieved. As the speed is increased, this wave will become greater, and for normal bodies will move forward until, at the speed of sound, a shock wave may be formed some way in front of the nose. As the speed is further increased, this shock wave will come closer to the body until a certain Mach number is reached, depending on the body shape, at which the wave may attach itself to the nose.

It will, of course, be realized that while these shock waves are rapidly moving about a body, the drag, pitching moment, etc., will be widely fluctuating. To give some idea of the drag increase in passing through the sonic range, Fig. 1 shows the type of drag increase realized. This curve was obtained from ballistic information.

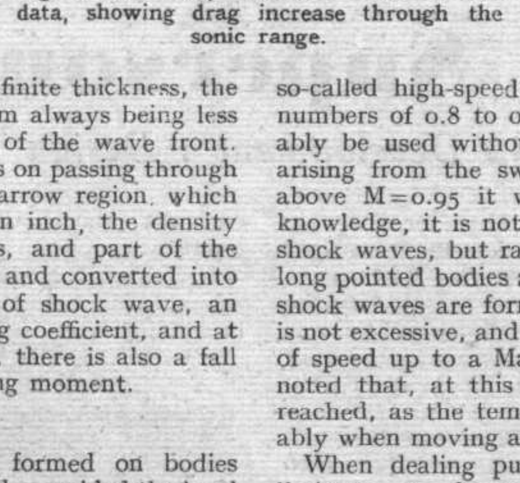

Fig. 2. Difference in drag between the M.52 and a Spitfire at speeds up to 1,000 m.p.h.

The drag of orthodox wings increases very rapidly at high Mach numbers, but the actual Mach number at which this increase can be expected depends very greatly on the thickness/chord ratio of the aerofoil and the profile chosen. The so-called high-speed sections were considered suitable for high-speed flight inasmuch as they delayed the critical Mach number for certain wing thickness by having a profile shape to give as small an increase in velocity for a given C_L as possible. However, it has recently been discovered that, although these sections delay the critical Mach number, having once exceeded this speed, they then become inferior to the more orthodox sections. Fig. 2 indicates the difference in drag between a Spitfire and the M.52 up to speeds of 1,000 m.p.h.

Information from Germany has indicated that very great advances in critical Mach number are possible for wings having large degrees of sweepback. [*The theory was stated by Mr. E. F. Relf in his Wright Memorial Lecture, Recent Aerodynamic Developments.*—ED.] However, while theoretically it has been easy to write down that the critical Mach number is increased approximately as Cos^2 of the angle of sweepback, in actual fact allowances must be made for end effects, etc. Moreover, it is not easy to design a practical aircraft having angles of sweepback of the order of 65 deg or 70 deg, as the low-speed problems become extremely difficult.

It will therefore be seen that, for aircraft normally operating up to a Mach number of, say, 0.7, the orthodox wing sections are satisfactory. For aircraft normally operating between $M=0.7$ and 0.8, the so-called high-speed sections may be used. For Mach numbers of 0.8 to 0.95, swept-back wings can most probably be used without unduly serious low-speed problems arising from the sweep-back necessary. But for speeds above $M=0.95$ it would appear that, with our present knowledge, it is not practical to try to delay the onset of shock waves, but rather to minimise their effect by using long pointed bodies and very thin pointed wings. Although shock waves are formed on these bodies, the drag-increase is not excessive, and there is no limit to the further increase of speed up to a Mach number of 1.5 or 2. It should be noted that, at this high Mach number, a new barrier is reached, as the temperature of a body increases considerably when moving at this speed.

When dealing purely with the supersonic range, preliminary aerodynamic calculations become much more straightforward, as most problems are soluble mathematically and, for preliminary analysis, very simple theories may be used; for example, Ackeret's wing theory has been borne out in practice.

Another important effect of supersonic flow is that the normal induced drag associated with aspect ratio does not apply under these conditions. When travelling supersonically, the aspect ratio of the wing has practically no effect on the drag. This means that if one were designing a machine for supersonic flight, a wing of very small aspect ratio would be desirable, but when considering a practical aircraft which has to take-off in the normal manner and climb to a reasonable height, the low-speed problems dictate the minimum acceptable aspect ratio.

The only portion of a wing travelling supersonically that could possibly have any "induced drag" is that included by the shock waves from the tip making the Mach angle to the wind. If, therefore, this is cut off the wing tips, no supersonic induced drag could be produced (Fig. 3).

As it was very desirable from the