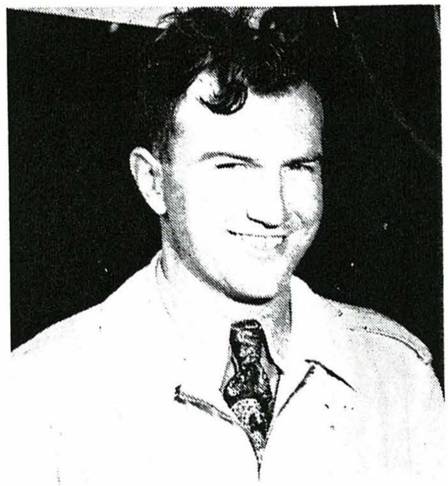
ALTITUDE PERFORMANCE OF JET FIGHTERS

By F/L BRUCE WARREN, D.F.C.



A TRIBUTE: The accompanying article is presented as a tribute to its author, the late Flight Lieut. Bruce Warren, D.F.C., who was killed when the CF-100 jet fighter he was test flying crashed near London, Ont. on April 5. F/L Warren, an outstanding fighter ace who continued his notable contributions to aviation after the war, was typical of the modern test pilot, careful, precise, scientific. If his article does something to stimulate the interest of newer pilots in the problems of high speed flight it will be a suitable memorial to its gallant author.

THE LIMITATIONS of the subsonic airframe and the power characteristics of the gas turbine combine to greatly reduce the ASI range and manoeuvrability of a jet-propelled aircraft at altitude. The immediate operational effect of this is to accentuate the difficulties of intercepting a high-flying jet bomber.

To deal first with the airframe. The stalling ASI of the aircraft remains practically constant to about 30,000 ft. altitude. Above that altitude the TAS of the aircraft is high, even at stalling ASI and the airflow appears reluctant to follow the contour of the wing and tends to break away, usually giving rise to a buffet before the actual stall at a higher ASI than at sea level. This is more apparent if the aircraft is under conditions of G with the angle of attack increased to maintain altitude. The over-all effect is that the stalling ASI tends to increase as altitude is gained, particularly above 30,000 ft. See Fig. 1.

All high-speed aircraft encounter what are known as Mach Number or compressibility effects. The cause of these have been fully explained in other articles but a simple review is proposed here. When an aircraft passes through the air, the air is compelled to flow around the wing. The air separates and flows over the wing and in doing so is compelled to travel further than it normally would have and therefore is speeded up. See Fig. 2.

Eventually the aircraft reaches a speed where the air speeded up is travelling at the speed of sound and a shock wave develops. FIG. 3. This shock wave greatly disturbs the air flow behind it and usually causes control difficulties which compel the pilot to reduce speed.

This speed is taken relative to the speed of sound and is known as the Mach Number. The critical Mach Number is usually taken as the Mach Number at which the first effects are felt i.e. buffetting, changes of trim, control snatching, etc., and the limiting Mach Number as the speed beyond which it is unsafe to go.

Since at constant ASI, the TAS of the aircraft increases as altitude increases, and in addition the speed of sound is reduced as altitude increases, the ASI at which the aircraft reaches its critical Mach Number is constantly reduced as altitude is gained. FIG. 4. The critical Mach Number is used rather than the limiting Mach Number since the pilot could not fight with his aircraft above this speed. In any case these two speeds are very close together. At low altitude there is usually a straight ASI limitation on the aircraft due to the excessive air loads imposed at high ASI on the airframe. See lower part of Fig. 4.

The value of the critical Mach Number is decreased with increasing angle of attack as the airflow has even further to travel around the wing. FIG. 5. This means that when the angle of attack is increased in manoeuvring to take care of the increased G imposed, the critical Mach Number is lowered still further. FIG. 6.

Combining the limitations at the low and high ends of the speed range we have FIG. 7.

We see that there is a point where

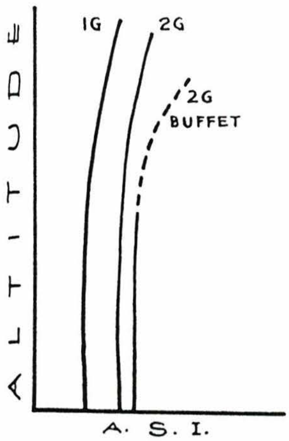


FIG. 1

FIG. 2

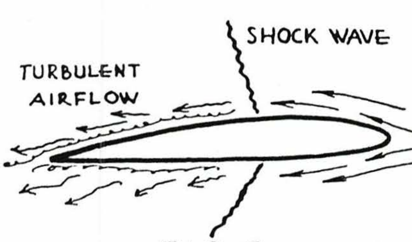


FIG. 3

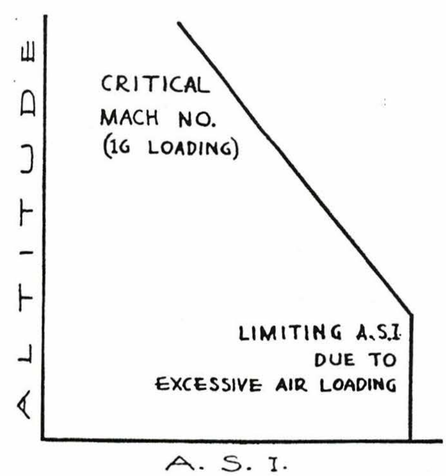


FIG. 4

the normal stall under 2G loading and the critical Mach Number under 2G loading intersect. Above this altitude the aircraft will not maintain height under a loading of 2G because of airframe limitations. The lines representing the maximum and minimum speed under a 3G loading would intersect below this point and the absolute ceiling would be indicated where the lines indicating normal stalling ASI and maximum level speed intersect.

Simultaneously with the airframe limitations the altitude performance of the aircraft is affected by the characteristics of the gas turbine power plant. The thrust output of the jet engine is reduced at altitude. This is readily seen if we recall the jet engine obtains its power from the reaction of consuming a certain amount of air, adding fuel, and expelling it at greatly increased speed. At 20,000 feet this certain volume of air weighs less than at sea level, therefore the thrust produced will be less. FIG. 8.

Because compressor efficiency increases with altitude, the reduction in thrust is not quite in the same ratio as the reduction in weight of the volume of air but for practical purposes it may be assumed to be so. Theoretically the jet engine produces no power when standing still since power equals force X speed. Therefore when speed is zero power is zero.

FIG. 9 illustrates the power required to fly level for a conventional airframe. This curve remains the same for any altitude since the angle of attack remains the same at all altitudes for a given ASI.

If on the "power required" curve we superimpose our power available at various altitudes we can readily see how the ASI range is reduced as we gain altitude due to engine characteristics. FIG. 10. This is the level-flight speed range only.

Further consideration will reveal another important fact. Although the aircraft is capable of a range of ASI at 40,000 feet, nowhere is there a marked excess of power available over power required to fly level. This has two marked effects. First, when the aircraft is turned and the angle of attack increased to provide increased lift to balance the effect of G in the turn, there is very little excess power available to balance the drag resulting from the increase in lift.

The aircraft in anything but a very gentle turn or pull-up will lose altitude or speed or both. Second there is very little power left to climb, since power to climb=power available minus power required to fly level. Note, however, that approximately the same amount of power to climb is available over a relatively large speed range, i.e., the pilot will get approximately the same rate of climbing at a low or high speed.

The lack of power at altitude obviously can be overcome by fitting larger engines initially. Another not-so-obvious solution is the fitting of a reheat device to the jet engine to increase the power when required. FIG. 11.

This extra power may be used for manoeuvring and also will increase the ceiling of the aircraft.

In summary, we will review the factors limiting the performance of subsonic jet aircraft at altitude and suggest the more simple solutions.

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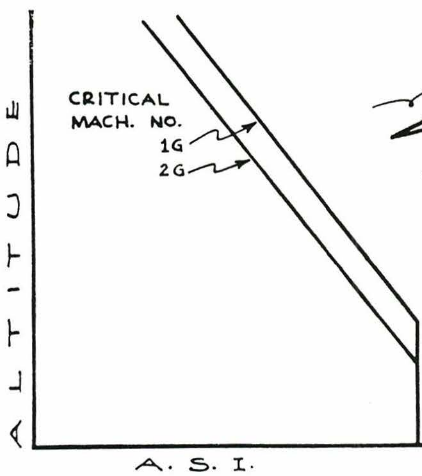

FIG.6

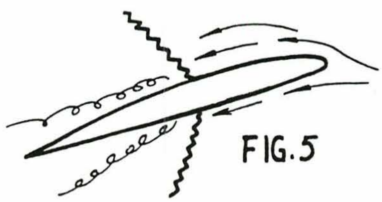

FIG.5

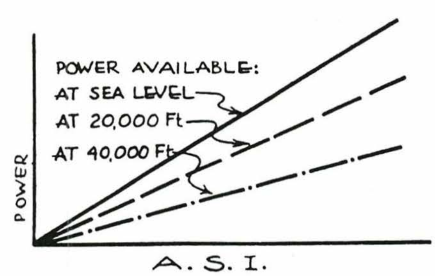

FIG.8

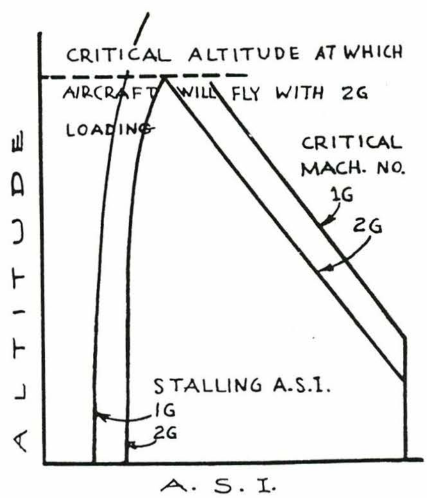

FIG. 7

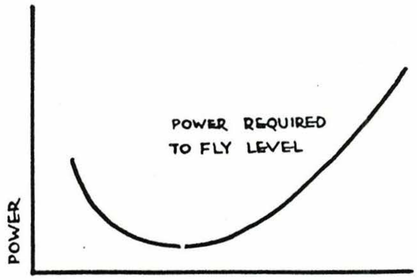

FIG. 9

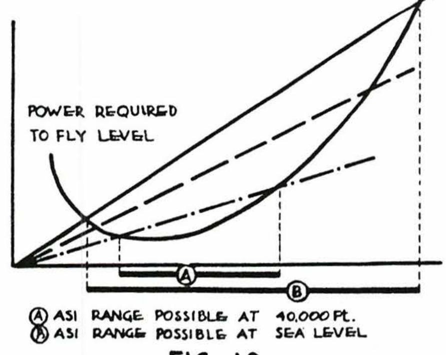

FIG. 10

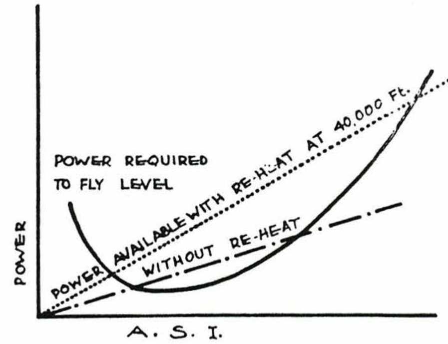

FIG. 11

ALTITUDE PERFORMANCE

(Continued from page 32)

Airframe Limitations—

1. Normal stall which limits low speed flight. **Suggested solutions—** a. high lift flaps; b. leading edge slots; c. lower wing loading;

2. Mach Number limitations on high speed flight. **Suggested solutions**—a. Swept wing and tailplane to increase critical Mach Number; b. Very thin wings and tail to increase critical Mach Number; c. Generally cleaner aircraft to reduce onset of buffet; d. Lower wing loading to avoid high angles of attack under G loading;

Engine Limitations—

3. Reduction in power available occuring with increasing altitude. **Suggested solutions**—a. Fitting larger engines; b. Reheat installation on present engines; c. Fitting booster rockets—same effect as reheat.

From the foregoing it is seen that the problems of designing and fighting a fighter aircraft to intercept a high-flying jet bomber are many. Although the bomber may start out with a lower speed than the fighter it will have the big advantage of being able to fly relatively straight and level under loadings of one G whereas the fighter will almost certainly be compelled to manoeuvre to intercept.

BIG AVRO PROGRAM

(Continued from page 20)

Co., of Chatham; Nicholson Tool & Die Co., of Windsor; Geo. W. Crothers Ltd., of Toronto; Viceroy Manufacturing Co. Ltd., of Toronto; Flash Fastener Co. Ltd., of Toronto.

Orders have been placed with the following firms for **machine shop work:** Aero Tool Works Ltd., of Toronto; Canadian Car & Foundry Co. Ltd., of Montreal; Coleman Lamp & Stove Co. Ltd., of Toronto; Corman Engineering Co. Ltd., of Toronto; Geo. W. Crothers Ltd., of Toronto; Dairy-Brewery Equip. & Engineering, of Toronto; Doherty Industries Ltd., of Toronto; Etched Name Plates Ltd., of Toronto; Heroux Machine Parts Ltd., of Montreal; International Aeronautical Corp. Ltd., of Toronto; Phoenix Engineered Products Ltd., of Toronto; John Inglis Co. Ltd., of