THE SUPersonic TURBOjet

Kerosine is injected upstream of the turbine and vaporized without combustion during its passage through the blading. The latter is consequently cooled by extraction of the latent heat of vaporization from the flow. The vapour finally burns at a flameholder assembly in the tailpipe, in the usual manner.

Afterburning has been widely employed in some countries, but British affection for it has been lukewarm (we have not a single afterburning engine in full service). In subsonic aircraft, afterburners can be frowned upon as heavy, greedy and bulky, but at higher Mach numbers one gets a much greater return for the increase in jet velocity. For example, an afterburner capable of increasing the thrust of the engine by 35 per cent would result in a boost of 69 per cent at Mach 1, 105 per cent at Mach 2 and no less than 219 per cent at Mach 3.

At Mach numbers of the latter order the characteristics of the whole powerplant must change. No longer can the engine be considered merely as a piece of ironmongery capable of being made by the thousand and bolted into any kind of aircraft. The entire airframe and powerplant system must be designed together as one entity, the entire length of ducting in front of and behind the engine being as important as the engine itself. Moreover, any shortcomings in the installation will result in penalties far worse than at present.

Stemming from this argument is the far-reaching fact that, in the words of the chief engineer of the D.H. Engine Company, "We have come to the end of the all-can-do engine." For example, turbine-stage counts for engines of similar static thrust; furthermore, the fighter engine may have more complicated accoutrements and control systems.

Future Operational Requirements

Before discussing the supersonic turbojet it is advisable to outline some of the conditions experienced at supersonic speed at the tropopause. The normal ambient temperature and pressure can be taken as being —68 deg F and just under 3 lb/sq in.

In contrast, air taken in through the intake of an engine moving at Mach 2 would be found at 90 deg to the air flow) in which all the flow-changes from supersonic (i.e. complete absence of losses in the intake system), reach a steady pressure of no less than 100 lb/sq in and a temperature of around 516 deg K. While this is a very considerable advantage, in that it relieves the compressor of most of the work which it would otherwise be called upon to do, it also imposes demands on the engine which can be met only by powerplants of very different design from those we have been accustomed to.

It is of fundamental importance to appreciate the fact that, with a high intake total-head temperature added to a high temperature across the compressor, the margin left for burning fuel is very small before metal-temperature limits are met in the turbine. Again, although the optimum pressure ratio of supersonic engines tends to fall off as the flight speed is increased, the temperature at which the work is done now does not vary in anything like the same extent. For this reason more stages are needed for a given pressure ratio than would be required at low flight speeds; furthermore, only a slight increase in the required pressure ratio demands a great deal of extra weight in the compressor when the intake temperature is high.

As already noted, it is possible to develop supersonic turbojets as self-contained engines; and while these are ready for service when they can be bought by any customer, who has then merely to install them in his aeroplanes in order to obtain satisfactory results. The supersonic era demands much more specialization. Designers generally report that they will not be able merely to look ahead and produce a "good supersonic engine"; the whole propulsion system for any given vehicle will have to be carefully tailored to the requirements of the airframe and of the specific mission for which it is designed.

Curve A (below) traces a sortie by an interceptor of the classic "short dashes" type. Such an aircraft could be satisfactorily powered by a rocket motor, for the resulting very high thrust at all altitudes would confer outstanding acceleration and power of maneuvre, whereas the resulting limited endurance might be no great disadvantage provided the pilot could be both probably also be equipped with a relatively small turbojet to provide accessory power and to take over the propulsion of the aircraft during "stooge" periods, including the final circuit and landing. This type of propulsion for a military aircraft is, of course, a present-day, since it is of relatively minor importance to the maximum performance. One may assume that the forth- coming Saunders-Roe S.R.53 will fall into this category.

Curve B postulates a mission which may need to be flown by future bombers or large all-weather fighters. The requirements in this case are that the engine should provide good endurance at subsonic speed (a long-range cruise for the bombers and a long-duration "loiter" for the all-weather fighter) while having the ability to propel the aircraft at something over Mach 2 for short periods (during combat for the fighter, or in over-target "dashes" for the bomber).

This clearly demands a compromise-type of powerplant. The task could certainly be done by a combination of the high-compression turbojet and the At a flat Mach number of 0.5 the design is specified, in a closely integrated form, for the experimental Republic XF-103. Alternatively, the requirement can be met by a variable-geometry turbojet, the characteristics of which can be altered to suit the conditions obtaining at the different Mach numbers. For the subsonic case, a compressor with a high pressure ratio is a pre-requisite to low cruising specific fuel consumption. For maximum performance an afterburner is necessary, and this portion of the powerplant becomes dominant at the top end of the Mach scale. The author believes that such a powerplant should be exceptionally useful and versatile. It may be the optimum for the all-round requirements of mission B, in spite of the fact that the engine is not the optimum for either the subsonic or the supersonic regimes taken separately.

Mission C specifies a flight plan carried out entirely at supersonic speed, such as might be useful for certain types of bomber or (looking further ahead) transport aircraft. Pending the availability of nuclear propulsion, which is the obvious type of power to use, such a mission could be fulfilled by a fixed-geometry turbojet, the design of which is so arranged that the engine and the propulsion system reach peak efficiency under the supersonic cruising conditions. This type of engine is discussed towards the end of this treatise.

Part Subsonic, Part Supersonic

Returning to mission B, one of our artists has prepared an impression (pp. 562-3) of a hypothetical variable-geometry, afterburning engine (henceforth termed the VG). This illustration, which is believed to be unique, emphasizes the fact that this sort of machinery is not generally propulsion alone, but comprises, in fact, a coherent unit from upstream of the intake to downstream of the propelling nozzle. Possibly the best way to discuss the installation is to examine it, component by component, from front to rear.

Bearing in mind that engines might have to develop thrusts of from 30,000 to 50,000 lb, the first thing that the observer will notice will be the size of the engine. The VG could well have a length in excess of 40ft, although, as we have seen, this total need not more than one-third is occupied by the main rotating assembly of the engine itself. Upstream of the latter is a very large diffusing intake containing a central body with a pointed nose. The reasons for such an arrangement are well known but bear repetition.

In the past there has been a natural tendency for designers to fight shy of shock-waves and go to great lengths to avoid localized regions of sonic speed. At a flight Mach number of 1.5 the ideal pitot intake would probably be suited to this type of contour, provided it is of such a design that the effect of shock-waves in all directions. The existence of a shock-wave implies sonic velocity upstream of it, and as the flow travels through it the shock it encounters a sudden increase in pressure and temperature at the expense of velocity. As a proportion of the total energy of the flow is invariably degraded to the point of zero, there is no amount of the process is known.

Simple pitot intakes (plain holes) produce a normal shock (i.e. at 90 deg to the air flow) in which all the flow-changes from supersonic speed have to be completed. At Mach 1.5 the ideal pitot intake is still more than 90 deg to the flow, and at Mach 2 the number rises further the losses become unacceptable. If, however, a streamlined body is placed in the centre of the intake, the upstream point of this body will give rise to an inclined shock,