Fighters With a Future—Part II

Designing the Missile Platform

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In the first part of this article, which appeared in the June issue of CANADIAN AVIATION, Mr. Creasey stated the case for the manned interceptor as a missile platform. This month he describes the design requirements for such a vehicle.

As soon as we can rely on small airborne missiles to complete the interception of enemy aircraft under all conditions, then we can accept a complete change in philosophy as to the performance of the fighter. It will no longer be necessary for the fighter to have speed and altitude supremacy over all possible targets, but only sufficient over-all performance and manoeuvrability to get into position to use its airborne radar and then to launch its missiles.

In the meantime, the fighter must continue to have a large speed superiority until more sophisticated weapons have been brought into service. Even these will require the fighter to have an approach speed that is a high percentage of the bomber.

Since bomber speeds have generally increased to near the speed of sound, with the prospect of more at supersonic speeds, this means that future fighters must have substantial supersonic performance.

This needs very careful definition, and certainly requires economical solution of most of the problems associated with the sound "barrier." This means that aircraft like the Canberra are no longer of interest as fighters, even though they continue to be of value in other roles.

Area Rule Principle

The sound barrier has proved a true barrier to the operational use of many modern fighters and this can be explained by reference to the Area Rule principle. At transonic speeds, one merely needs to measure up the cross-sectional areas of an aircraft and plot these as illustrated for the Canberra in Figure 3. This simple form of area rule suggests that the wave drag of an aircraft near $M=1$ will be similar to that of a body of revolution having cross-sectional areas equal to the total shown.

Even a body of smooth shape will have an appreciable drag rise up to $M=1$, but the large bulges representing the unswept wings, engine nacelles, missiles and tail surfaces give the Canberra a prohibitive drag rise for efficient supersonic flight. It is of little value to try and boost such an aircraft with rockets. Not only is the fuel consumption prohibitive but the buffeting, wing dropping and other trim changes make an aircraft disobeying the area rule of little value at transonic speeds.

It is theoretically possible to reduce the transonic drag of the Canberra by the addition of fuselage bulges fore and aft of the wing, similar in principle to those tried on current fighters. This gives a small reduction of drag in practice, but it is doubtful whether the complication or weight penalty of the fairings is justified.

The direct method of reducing these problems is to cut down the cross-sectional areas: e.g. by using both less span and thickness on the wing and tail surfaces. Unless the full implications of the transonic area rule are realized (e.g. very large sweep back is used), the net result is only to eliminate most of the useful space in the aircraft and to give thrust and drag curves which at best resemble those of Figure

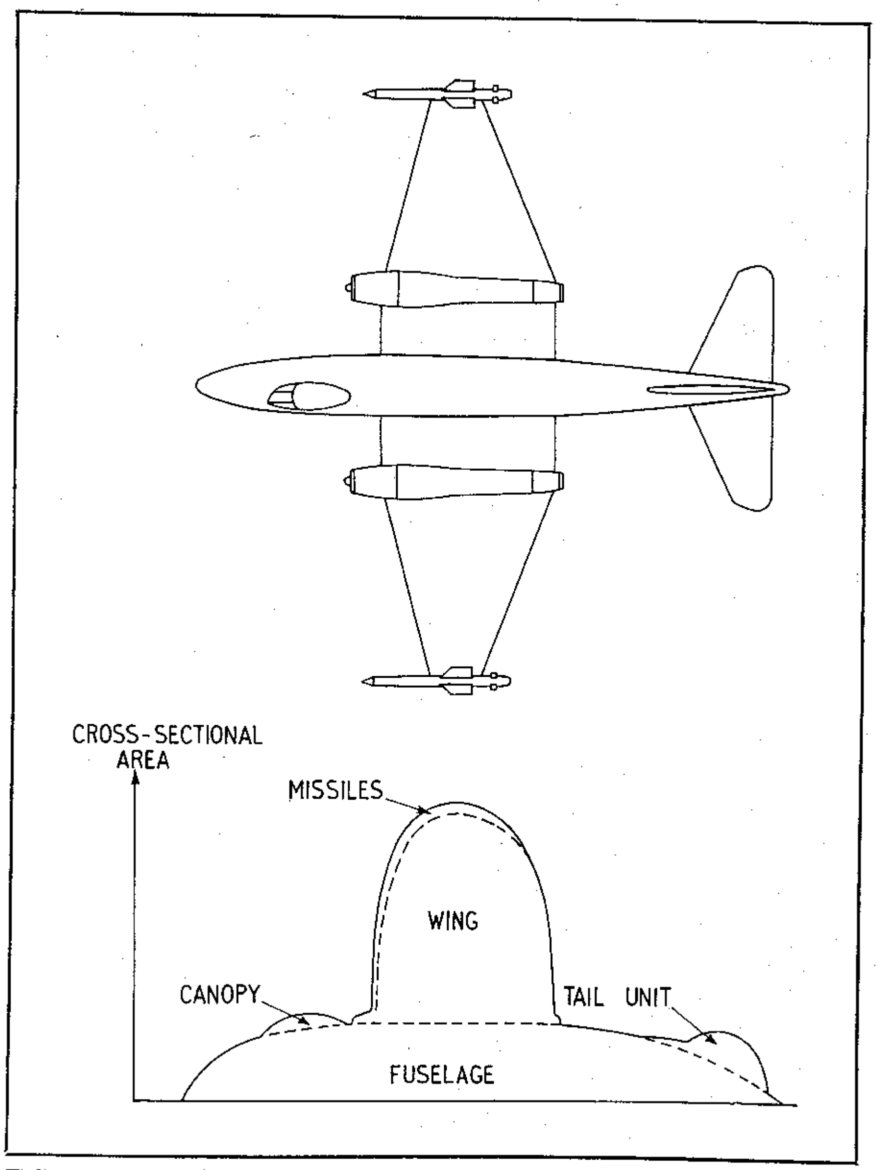

FIGURE 3. Cross-sectional area of the Canberra all-weather fighter plotted to show its unsuitability for passing through the sound barrier. Compare with Fig. 5.

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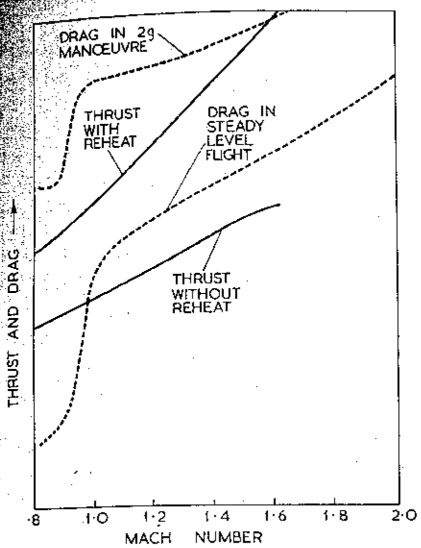

FIGURE 4. Thrust and drag graph for a fighter with insufficiently swept wings.

4. Even though these result in appreciable supersonic performance, there may be insufficient margin for practical interceptions.

Supersonic performance margins are now essential for a fighter. It is of little use reducing supersonic drag to the point where it is only slightly less than the total thrust. Although this can give Mach numbers as high as 2 or more on paper, these can be demonstrated only by flights in unrepresentative conditions.

Reheat behaves very much like a ramjet at these speeds and can give most impressive performances and altitudes. But the aircraft is of little practical use as a supersonic fighter if it cannot reach these speeds and altitudes quickly in interception manoeuvres, carrying all the operational loads required on the inside and outside of the aircraft.

Economical cruising is best carried out at high subsonic speeds and moderate altitude until a target is identified. A fighter with poor acceleration and climb away from this condition is in danger of failing to reach combat speed and altitude in time to make an interception.

The large increase in drag due to any necessary manoeuvres in this period (Figure 4) will delay the build up of interception speed and altitude for a considerable time. This not only gives the bomber time to launch its bomb, but the fuel consumption of an engine with considerable reheat will eat into the fuel reserves required for a safe return to base under adverse conditions.

Figure 4 shows that such a fighter relies completely on reheat for its supersonic performance. If the reheat system should misbehave due to lack of oxygen or other reasons, it will never complete the interception at all. Moreover, if this fighter cruises at supersonic speeds to try and make the

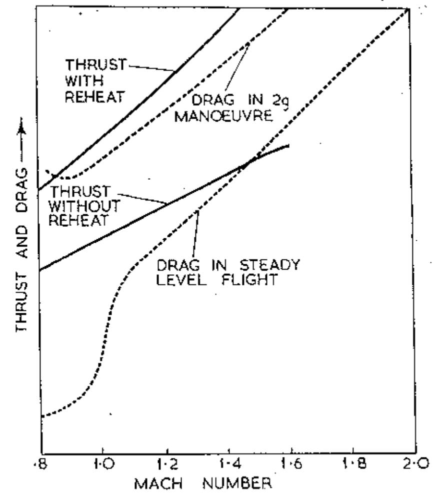

FIGURE 6. Thrust and drag graph for plane designed to conform with area rule.

interception more practical, the large amount of reheat required to maintain level flight will greatly increase the fuel consumption, which is already much higher than in economical low drag conditions at subsonic speeds.

Swept Wing Gains

Area rule design is therefore important if we are to obtain sufficient margin of thrust over drag for practical interceptions. The highly swept wing of the P1, illustrated in Figure 5, is seen to spread its volume thinly and smoothly over the long length of centre fuselage, which is designed with approximately constant cross section. Any shaping of the fuselage is thereby confined fore and aft of the wing, in conformity with the area rule.

Local adjustments of this shaping are made at the front, to fit in the necessary vision for the missiles and pilot, and similarly toward the rear for the tail surfaces. It is possible to stagger two engines one partly behind the other in the long constant section of fuselage, thereby reducing the cross-sectional area and drag. This also increases the cross-sectional area of air entering the intake, which can be deducted from the total areas when considering the area rule (Figure 5).

It is then possible to arrive at a practical fighter which not only has a high thrust/drag at transonic speeds, but which maintains its superiority up to Mach numbers of nearly 2. This can be shown by application of the more complicated forms of area rule at higher Mach numbers.

The resulting improvements in thrust/drag relationship are illustrated on Figure 6. It will be noted that the drag in manoeuvring flight is even further reduced at subsonic and moderate transonic speeds. This is due to the development of an aerodynamic thrust on the leading edge of highly swept wings, provided the tip sections

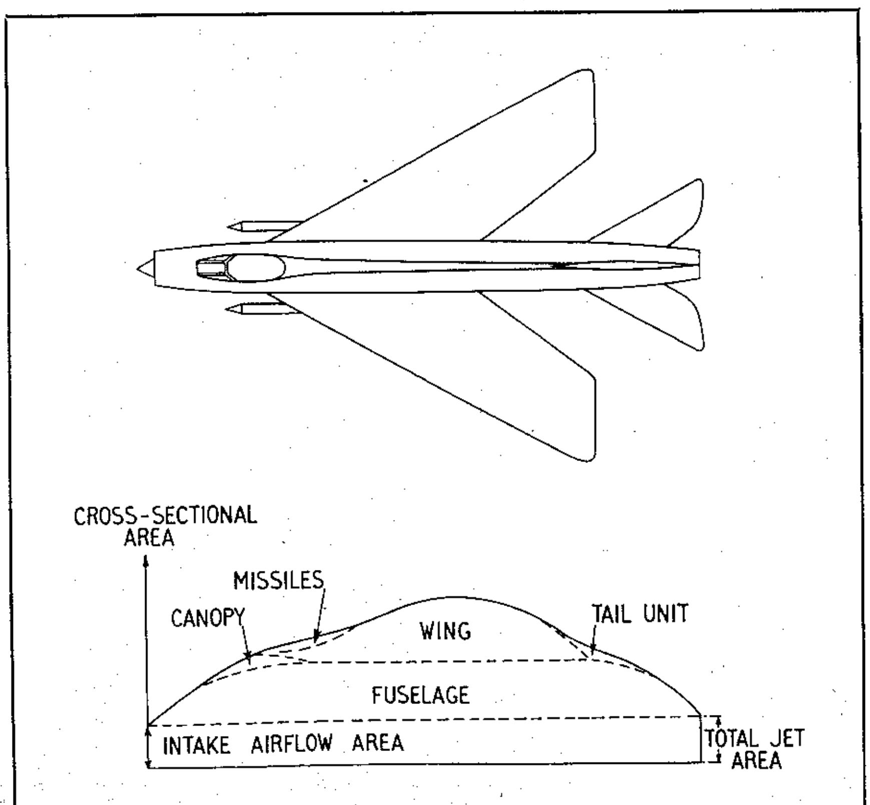

FIGURE 5. Smooth contour of this plot of the P1's cross-sectional area illustrates that the design of the machine conforms to the principle of Area Rule, as explained.

are properly rounded over the leading edge.

The net result is to help overcome all the interception problems discussed above. The aircraft is capable of cruising economically at moderately high supersonic speeds without using reheat. Use of reheat then gives a large increase in the rate of acceleration and climb from low supersonic speeds and allows speed and height to be maintained in significant manoeuvres.

Highly swept wings and tail surfaces give the best compromise for a modern fighter due to this emphasis on performance over a range of speeds, particularly moderate supersonic speeds. Experience has shown that such an aircraft, designed to the area rule from the start, can avoid buffet, wing drop and other trim changes, provided the necessary care is taken in the wind tunnel test program and in the details of the control system.

The thermal thicket or heat barrier is now of some significance, since the use of reheat makes it easy to reach Mach numbers of 2 or more. The pilot certainly needs refrigerated air, but much of the temperature-sensitive equipment and electronics can be situated either in the cabin itself or in compartments which receive the cooled air discharged from the cabin. Light alloy structures can be made sufficient for Mach numbers up to at least 2, provided a limited amount of titanium or steel is used around the engine and jet pipe sections.

Thermal Problems

It would seem pointless to penetrate further into the thermal thicket, where airframe and engine problems become much more severe, as it is doubtful whether a fighter has sufficient time or fuel to make much practical use of these speeds.

If bomber performance should penetrate the thermal thicket, it will be possible to obtain the increase in interception performance from small missiles, which require a much smaller amount of fuel to boost them quickly to the required performance. The thermal problems of the missile will, of course, have to be solved, but these are on a much smaller scale than on a complete fighter and are very much eased by the limited flight time of an air-launched missile.

Rocket boost can give a large increase in thrust at relatively light weight, but the total fuel consumption is many times that of a turbojet. The net result is compared in a general way on Figure 7, where it is seen that the rocket gives a lighter gross weight when a burst of thrust is required for a short period.

This period is too short for the rocket to be of practical value to the fighter at normal altitudes where it is already capable of extremely high performance with turbojets and reheat. This very high kinetic energy can be converted quickly into 30,000 feet or more additional altitude in a "zoom" climb.

Although we rely on turbojets as the primary fighter propulsion, a small proportion of exceptionally high targets may necessitate the addition of small rockets and fuel to maintain interception speeds at very high altitudes. The effectiveness of this combination up to above 70,000 feet was demonstrated recently by the record-breaking Canberra fitted with a Napier Double Scorpion rocket. This engine is designed for the P1B as an additional power plant, which can be quickly removed if operation at very high altitudes is not required.

The flight time of the air-launched missile is so short that it is best to use rocket propulsion, regardless of altitude. It is also much more economical to boost a small airborne missile to much higher speeds and altitudes than to boost a complete aircraft or ground-launched missile. This is why we aim to rely on the rocket missile to complete the interception, particularly at altitudes well above the fighter.

Emphasis On Safety

In this era of guided weapons and anticipated failure rates it is important to remember that there are still men in the main fighter components. The standards of safety must be as high as ever.

The importance of this is emphasized by the growth in cost of the complete weapon system, which means that we can afford fewer aircraft on a peacetime budget. Peacetime training wastage plus more rapid operational wastage must not eliminate the effective fighter force.

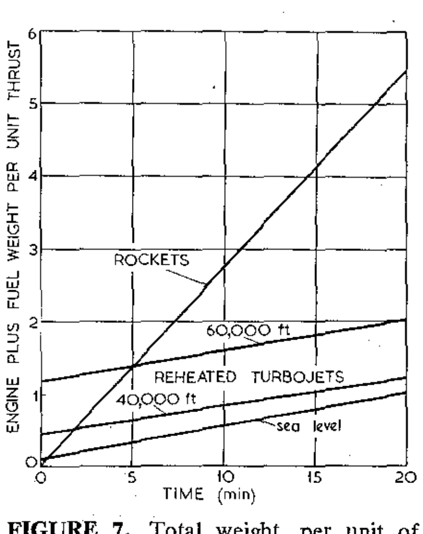

FIGURE 7. Total weight, per unit of thrust, for rockets and turbojets compared.

Controls are power operated in all practical supersonic fighters. This is forced upon us by the large erratic hinge moments which occur across the speed of sound making normal muscular efforts quite inadequate.

The mechanical reliability of these systems must be developed to a very high standard by exhaustive testing on the ground and the complete system must be duplicated in the aircraft. This must extend right through to the basic power supply. The only way of ensuring complete control up to touch-down is to have two or more engines.

Twin turbojet engines were chosen for the P1 as the most economical solution to this requirement for duplication. This not only allows a high thrust to drag ratio, with all the advantages previously discussed, but is a safeguard against the complete loss of propulsion. This is a serious emergency for the modern fighter pilot, as the resulting rate of descent of a supersonic aircraft is many times that catered for on the undercarriage.

Tailplane control is required to give adequate manoeuvrability for supersonic interceptions. The use of elevons for foreplane will trim less than half the available lift from the wing under some conditions of flight. But an all-moving tailplane can trim all the lift available up to the buffet limit at low speeds and the directional stability or other limits at high speeds. It also allows trailing edge flaps to be trimmed out, with consequent improvement in airfield performance.

Delta Wing Value

A delta wing planform gives a good compromise between airfield and supersonic performance. If the fuselage is not long enough to give sufficient tail-arm the delta planform can be modified as on the P1.

Inherent stability is possible only if care is taken in the location of the tailplane. Low aspect ratio wings deflect the airflow down behind them by more than half the angle of incidence of the wing. Provided this downwash/incidence relation remains constant the effect on stability can be compensated by a more forward centre of gravity without loss in the manoeuvring power of the tail.

Beyond the incidence at which a complicated vortex wake system forms behind the wing, body and intakes, the downwash near the centre line (i.e. over the tailplane) can increase rapidly to as much as the incidence of the wing. If the aircraft is trimmed to these incidences the loads on the tail are such that all stability is lost abruptly and the aircraft "pitches" up to a

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Whirly-Bird Training

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at various pitch-power settings — all of which leads up to hovering solo. During this time (average three to six hours) an introduction is given to emergency procedures.

The next stage of two to four hours covers thoroughly all the emergency procedures with emphasis on engine-off landings. Having completed this stage, the pupil is ready for a solo flight comprising at least three complete circuits.

From this point, it is a matter of polishing up on flying techniques, getting to know the helicopter more intimately and learning to appreciate the potentialities of this versatile machine. Instruction covers precision flying, full-load flying, quick stops, autorotations, and other procedures such as water handling, required by the competent helicopter pilot.

By this time, the pupil will have become familiar with such terms as "over-pitching" and "autorotation."

"Over-pitching" results when the pilot overloads the main rotor by applying too much pitch for the engine to handle without losing rpm. If this is done whole hovering, the helicopter will sink to the ground. The corrective action is to increase power, if available, or to lighten the rotor load by decreasing pitch.

"Autorotation" is a highly desirable characteristic of the helicopter which enables it to make a safe landing in the event of engine failure. To achieve the state of autorotation, the collective pitch control is pushed down to its fullest extent, thereby reducing blade pitch to a minimum, which decreases drag and allows the blades to continue rotating at the desired rate.

While the rotor is autorotating it produces sufficient lift to permit a moderate sinking speed. A cushioning effect may be obtained at the touchdown through utilizing the inertia left in the rotor by raising the collective pitch control to momentarily increase lift. Full flying control can be maintained in autorotation as the tail rotor is driven by a shaft from the main rotor gear box.

Just in case all this makes it sound easy, here's a final note of caution. It must not be forgotten that the helicopter can bite back like any other aircraft. The helicopter is only safe when handled with intelligence and approached with respect. We all know the consequences of carelessness and over-confidence.

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higher incidence with serious effects on structural loads, or stalling the wing and intake.

It was found from wind tunnel tests that if the tailplane is situated substantially below the vortex wake system, the downwash decreases rather than increases. This gives a strongly stabilizing correction even if the aircraft should inadvertently be pitched to high incidence. The stabilizing effect can be so powerful as to seriously restrict the incidence that can be trimmed.

This can be prevented, as on the P1, by giving the wing just sufficient sweep back so that the unstable pitching moments caused on the wing by the vortex system just balance out the effects on the tail. The tailplane should, however, be kept below the plane of the wing if it is to be clear of wake disturbances under all conditions of flight.

Auto-stabilization might seem a satisfactory method of curing such unstable flight conditions, but these devices either limit the operational use compared with an inherently stable aircraft, or else become complicated and liable to failure. Having once accepted electrical signalling in the basic stability of the aircraft, arguments can soon be made in favor of electrical signalling to replace the mechanical linkage between the pilot's stick and the controls.

But present experience suggests that the electrical parts of the system will need to be at least triplicated to give the same standard of reliability as a properly designed duplicated hydraulic system or as an unduplicated mechanical system. This in turn leads to problems in the maintenance and inspection of practical Service aircraft.

Such complications have to be accepted in guided weapons, but these always give a degree of unreliability which cannot be accepted in the stability and control of a manned aircraft.

Future developments of manned military aircraft depend on the way in which automatics are used to allow man time to play the parts which electronics can never replace. His most important attribute is his relentless reliability in pressing home an attack on enemies of his land, adapting his tactics to any changes in the situation caused by enemy action or shortcomings of his own system. This proper combination of man with automatics appears to be irreplaceable.