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AERONAUTICAL PROGRESS IN THE UNITED KINGDOM*

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ABSTRACT

The progress in aeronautics in the United Kingdom from 1903 to the present-day has been traced. During the last 35 years there has been a great increase in the size. range and speed of aircraft. The advance in design could be traced partly to the steady improvement in techniques such as strength of materials, structural methods, aerodynamics and engine design, and partly to definite technical discontinuities such as the introduction of the unbraced monoplane and later of the jet turbine. The key to this progress has been the large investment made in science and technical research and the healthy integration between industrial enterprise and government planning.

New light alloys having strength to weight ratio better than the best aluminium alloys have found application. The ratio of cruising speed to stalling which is a fundamental aerodynamic factor was of the order of 3 to 1 during the bi-plane era. Now, this ratio is of the order of 5 to 1; but the existing runways are a limiting factor. Aircraft like Comet flying at 40 to 50 thousand feet have obtained improved flying efficiency without excessive demands on aerodrome facilities by exploiting the 5/1 change of aid density between cruising height and sea level. Advances in aircraft engine design during the last forty years is staggering.

Now-a-days, all military aircraft, both bombers and fighters are engined with jet and the piston engines may be retained only for general purpose aircraft. Aircrafts having turbo-jet engines are still in their infancy and significant improvements are expected in the future, particularly by developing conditions for achieving laminar flow. The struggle between fighter and bomber for speed superiority is still the dominant factor although one can foresee a time in the near future when the rocket driven guided weapon flying at perhaps a Mach number of 3 must have its effect over the whole field of air warfare.

Up to the present, military and civil aircraft development has kept in step. The demands for higher fighter speeds and for higher flying bombers has also met the requirements for increased all up weight in civil aircraft without exceeding the available aerodrome facilities. For some time in the future the advances in these two fields may be along different lines. If laminar flow becomes possible one may then expect bigger aspect ratios and thicker wings. Future military aircraft, on the other hand, may be expected to develop towards supersonic speeds involving straight thin wings with small aspect ratios. Eventually supersonic flight for civil use also may be possible. Although the advances during the last fifty years have been amazing enough, during the next fifty years they are likely to be fantastic by present standards.

Introduction

The defence organisation in the United Kingdom are not directly responsible for civil and industrial applications but many fields of research which are supported primarily by the defence ministries are of direct value to the civil economy. In the field of aeronautics in

* Based on a talk given by Dr. Cockburn during the C.A.C.D.S. Conference in March 1953.

particular the development of fighters and bombers of outstanding performance has been the major factor in restoring our position in civil aviation which we had temporarily to forgo while we were engaged in the pressing matter of military survival.

Communications have always been a vital factor in determining the level of development achieved in any particular era. The Roman civilisation was based on a network of roads many of which are still in use in Western Europe. The British Commonwealth grew up almost entirely on the basis of sea power which still remains the most economical method of bulk transport. It is often overlooked that this loosely knit Commonwealth is still the biggest user of the most efficient means of transport in the world. It is far cheaper to carry 10,000 tons of produce from, say, Melbourne to London by sea than from Los Angeles to New York by rail.

RAPID DEVELOPMENT OF AVIATION

We are now living in a period of cold war in which survival may well depend on the close understanding of other people's way of life and on the transport of ideas rather than materials. It is the rapid development of aviation and electronics which will make this possible and our present conference is one of the many direct consequences of the first true flight by the Wright brothers at Kittyhawk in 1903 and of Marconi's first wireless message from Poldhu in 1901. In less than fifty years aviation has revolutionised our travelling habits. The North Atlantic has been flown more than 100,000 times and in 1951 one third of all the people crossing the Atlantic went by air. Throughout the world there are some 200 scheduled airlines operating about one million miles of route with some 5,000 aircraft. In any one day the total distance flown by these aircraft is about two million miles.

The comparison of the Felixstowe Fury flying boat and the Handley Page 0/400 bomber of 1918 with the Saunders Roe Princess and the Bristol Brabazon show the tremendous strides that have taken place within half a lifetime. To the general public the most obvious advances have been the great increase in the size of aircraft and in their speed. These two factors are of course not independent, in fact the increase in AUW has only been possible because of the increase in speed.

Fig. 1.—*Felixstowe Fury.*

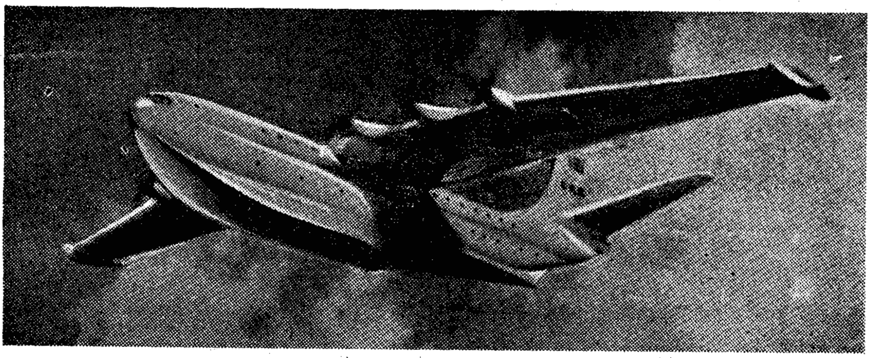

Fig. 2.—*Saunders-Roe Princess.*

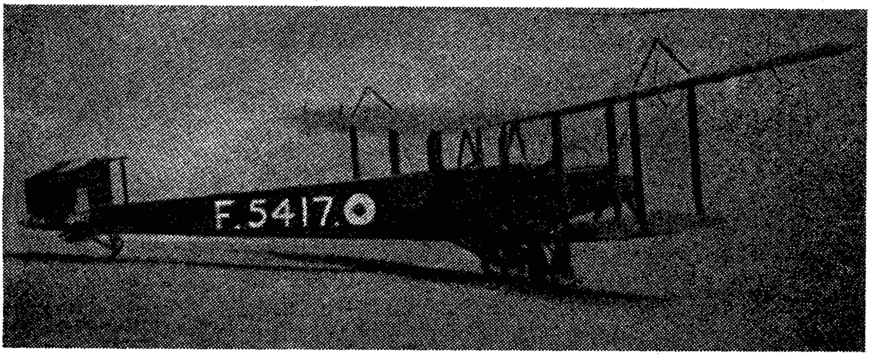

Fig. 3.—*Handley Page* 0/400.

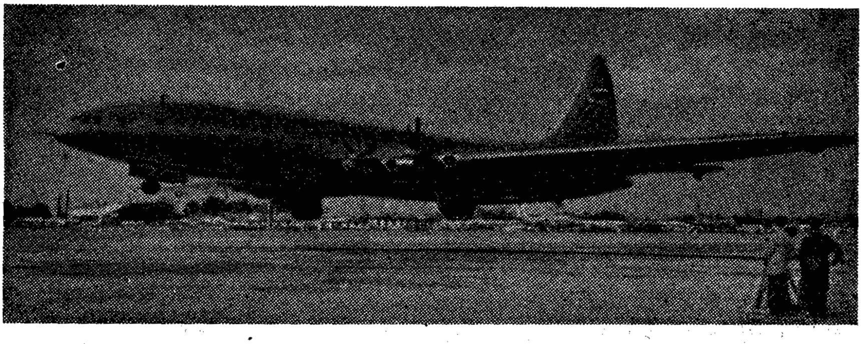

Fig. 4.—*Bristol Brabazon.*

Fig. 5 shows the increase in AUW of a range of flying boats. The trend to larger size is perhaps clearer than for land planes because the sea plane is not limited by landing and takeoff facilities. A similar curve but with a greater distribution could, however, be constructed for land planes.

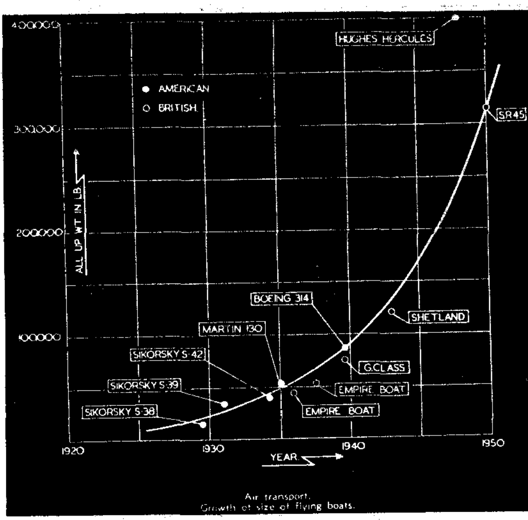

Fig. 5.—*Increase in A.U.W. of flying boats.*

Advances in Aircraft Design

Figures 6 & 7 show the increase in fighter and in bomber speeds over the last fifty years. They show a continuous trend to higher speeds and two major discontinuities due to the introduction of the monoplane in 1935 and of the jet turbine in 1945. The advances in design which the photographs indicate can be traced partly to the steady improvement in techniques such as strength of materials, structural methods, aerodynamics and engine design; and partly to definite technical discontinuities such as the introduction of the unbraced monoplane and later of the jet turbine. The gradual improvement in techniques and materials is part of the scientific capital on which all progress must be based. This capital resides not only in the very expensive facilities which are nowadays necessary such as large wind tunnels, engine test beds, electronic and metallurgical laboratories but also in technical schools and industrial firms, university graduates and craftsmen and such imponderables as learned societies, scientific and professional institutions and the numerous technical publications which encourage the free exchange and discussion of ideas. Scientific capital depends as much on the intellectual atmosphere as it does on laboratory facilities. One of the main factors contributing to the encouraging state of British aviation today is the healthy integration between industrial enterprise and Government planning.

The main trend in aircraft design has been the steady increase in wing loading and figure 8 shows this trend for fighter and bomber aircraft. One of the earliest generalisations in aeronautics was the so-called square cube law. The weight of similar structures increases as the cube of their linear dimensions while the load bearing capacity increases as the square, so that a structure becomes steadily weaker as the size increases. Indeed this is the law that has limited the size of land animals. The legs of a man are much thicker in proportion than those of an insect, and the legs of an elephant much thicker still.

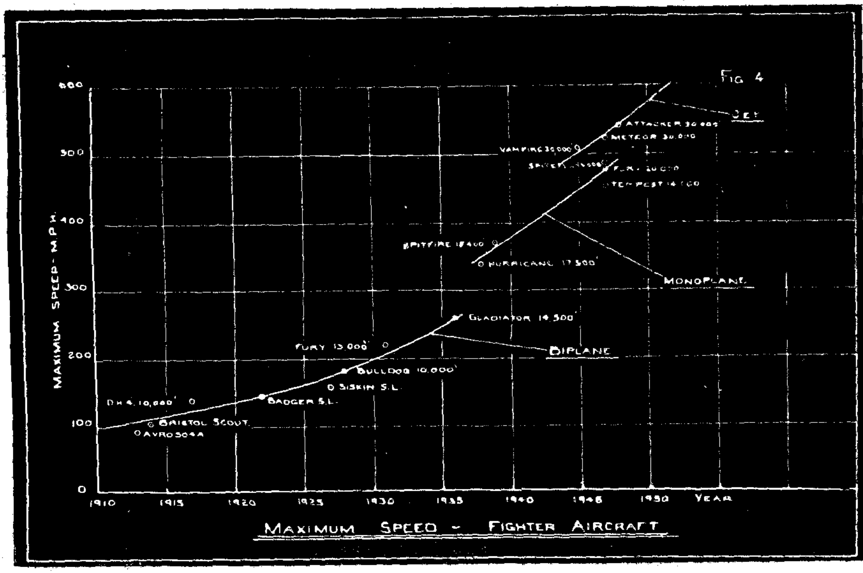

Fig. 6.—*Increase of maximum speeds of fighters.*

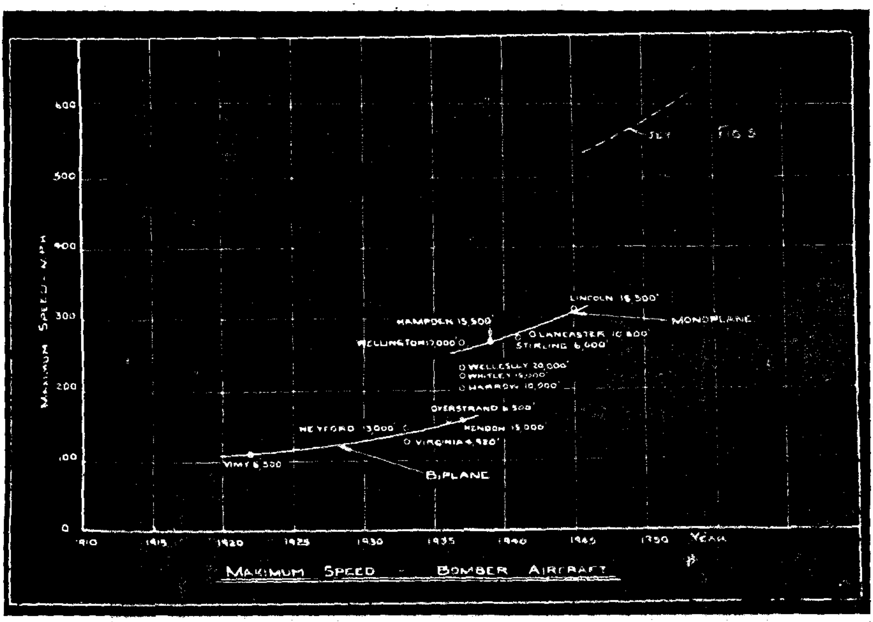

Fig. 7.—*Increase of maximum speeds of bombers.*

With the structural materials that nature has available the elephant represents about the limiting size for a land animal. Larger animals are compelled for structural reasons to become amphibious such as the prehistoric brontosaurus, or aquatic such as the whale. The early aircraft were only just built to lift their own weight with that of a pilot and petrol for a short flight and it is not surprising that designers were pessimistic about the possibility of much larger aircraft. Indeed in 1912 it was suggested that the limiting all-up weight of an aeroplane would be about 2,000 lb. and Lanchester in 1914 expressed the view that a span of about 100 feet was unlikely to be exceeded. That the square cube law was given such prominence at this time implied that no great change in wing loading was considered possible. This is not surprising since the early designs of engine were so heavy and of such low power that the aircraft could only just get themselves off the ground. By 1918, however, it was clear that big improvements were to be expected in engine design and that with the higher speeds that would then become possible the wing structure could become more compact and aerodynamically clean. It was then clear that increasing wing loading rendered the square cube law invalid and there was no reason to anticipate any serious limit to the all-up weight of aircraft for many years. As the size of aircraft has increased and the specific weight of engines decreased the disposable load available for either payload or fuel has steadily increased. It is interesting to note that throughout the whole period under review the proportion of the all-up weight of an aircraft consumed by the structure has remained in the neighbourhood of 30 per cent. This probably arises because the aircraft designer can exploit improvements in strength of structure either to increase directly the disposable load or to refine the aerodynamic shape and improve fuel consumption or range. It would appear that the second alternative has been the more important consideration.

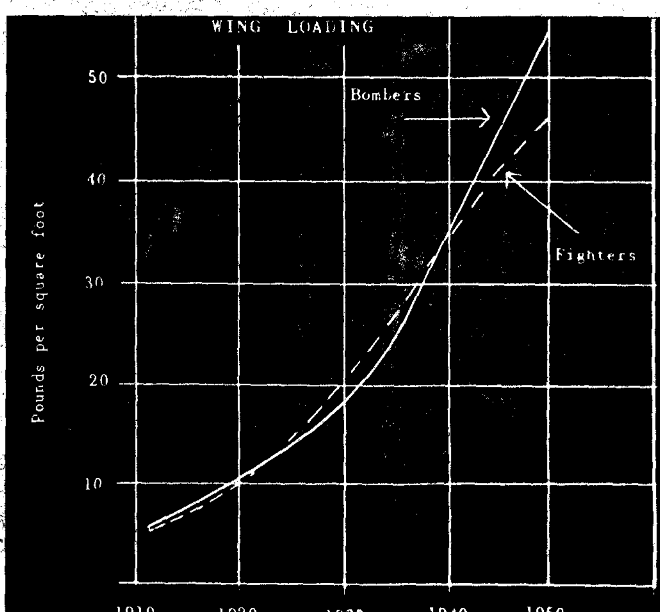

Fig. 8.—*Increase of wing loading.*

The Schneider Trophy seaplane contests provided tremendous impetus to the development of higher wing loading. The absence of aerodrome limitations made possible long landing and takeoff runs and allowed the aircraft designer to exploit to the limit the structural possibilities of high wing loading. In particular these contests demonstrate beyond question the advantages of the monoplane over the biplane. By 1935 it had become obvious that the biplane would be completely superseded by the monoplane for land-based military aircraft.

The change to monoplanes represented a great advance in structural and aerodynamic design, the possibilities of which had been explored by Melvill Jones in 1929. The aerodynamic cleanness of stressed-skin metal wings and fuselages focussed attention on the high drag of exposed undercarriages, bad nacelle fairings and wind screens and the elimination of unnecessary excrescences which had hitherto been tolerated had a far-reaching effect on the whole design. This is shown by the distinct gap in the curves of Figures 6 and 7.

The change from the fabric-covered biplane to the beautifully finished monoplane was only possible because of advances in the properties of light alloys and in structural methods. In 1903 aluminium was little more than a scientific curiosity, a weak metal of about 5 tons per square inch costing several pounds sterling a pound. Modern aluminium alloys have a tensile strength as high as 40 tons/square inch and cost only a few shillings a pound. It was the availability of light alloy sheet which made possible the stressed-skin monoplane in which efficient use of the structural material is obtained by bringing it as close as possible to the outside surface. The skin now provides nearly all the torsional stiffness of the wing and makes a significant contribution to the bending strength. Recently the new magnesium alloys especially those containing zinc and zirconium with a strength to weight ratio 20 per cent. better than the best aluminium alloys have found an application in light-weight casting and already account for one third of all light alloy castings supplied to the aircraft industry.

The strength of these alloys falls rapidly with rise of temperature and this is one of the limiting factors in improving engine efficiency without increasing specific weight. The possibilities ahead for titanium alloys giving twice the strength for 1½ times the weight of aluminium alloys justify intensive research. The cost of titanium is high at present, about £5 a pound, but can be expected to become very much less as new techniques of extraction are developed.

Aircraft Performance

The great advances in aircraft performance made possible by increasing speeds and wing loading were not obtained, however, only by re-optimising the design equation of the aircraft. They involved as well a corresponding increase in landing and takeoff runs. Between 1930 and 1940 the speeds of aircraft were doubled. The increase of 100 per cent. was made up of the following :—

50 per cent. through increase of stalling speed ;
25 per cent. through the effect of supercharging ;
15 per cent. from reduction in drag ;
10 per cent. from reductions in the specific weight of engines.

The ratio of cruising speed to stalling speed is a fundamental aerodynamic factor which enters into the design of all aerofoil aircraft.

During the biplane era this ratio was of the order of 3 to 1. Now-a-days with the increasing cleanness of design, the use of flaps and other high lift devices and the great increase in optimum cruising heights, ratios of the order of 5 to 1 or even higher are obtainable. Despite this great improvement, however, the limitation on take off and landing speeds imposed by existing runways is now a controlling factor on the future development of aircraft.

Aerodrome Facilities

During the 1930s the standard R.A.F. aerodrome was 800 yards square of grass. In 1939 there were only nine concrete runways in the whole of the United Kingdom and the longest was 1,000 yds. The adoption and development during the war of the high wing loading monoplane for fighters and bombers involved a heavy investment in 2,000 yd. runways and now-a-days we have to cope with even longer and heavier runways up to 3,000 yds. in length. In the field of civil aviation the construction and maintenance costs of modern airports are already a factor of overriding importance. London Airport, for instance, has concrete runways 3,000 yds. long and 12 inches thick and has already consumed enough concrete to make a double-track motor road 400 miles long from London to Edinburgh. The total cost of airport to date is about £10 M. and it may well have reached £20 M. before it is finally complete. The civil operating companies are very conscious of the difficulties of operating advanced aircraft. They regard 7,000 ft. as the maximum feasible length of runway on existing international routes, implying a stalling speed for civil aircraft of not greater than 90 knots. The present position is that of 120 major airports in the world only 20 have runways greater than 7,000 ft. and only 40 greater than 6,000 ft. About 90 per cent. of these major airports have runways of the order of 5,000 ft. or greater.

Apart from the expense, any large extension in runways is in many cases physically impossible and any further increase in performance of civil aircraft will be rather towards easier landing and take-off requirements to meet conditions of increasing traffic density to be expected in the future.

Aircraft like the Comet flying at 40—50,000 ft. represent one way of obtaining improved flying efficiency without excessive demands on aerodrome facilities by exploiting the 5/1 change of air density between cruising height and sea level.

AIRCRAFT ENGINE DESIGN

One of the difficulties in analysing the development of aeronautics is the close inter-relation that exists between structure, power plant and aerodynamic shape. Any marked improvement in any one of these has a direct effect on the other two. It is, therefore, perhaps unprofitable to single out any one factor as having the dominant effect. However, Dr. Cockburn's opinion was that the engine is the primary controlling factor, although this would be hotly contested by others. He thought it might be agreed that much of the progress in aeronautical engineering has had to await the development of improved propulsion. It takes even longer to prove a new engine than to prove a new aircraft and as soon as a new engine becomes available the aerodynamics and structural engineers are usually ready and waiting to exploit a new aircraft concept. In the military field at any given period the superiority of one air force over another both in fighters and bombers may well depend on which has developed the better engine.

The advances in aircraft engine design during the last forty years have been staggering. The horse-power of a single power unit has increased from the 20 h.p. of the Wright engine to 3,500 h.p. of modern piston engines such as the Rolls Royce Eagle or the Napier Sabre. The weight per horse-power has improved from 3 or 4 lb. per h.p. to less than 1 per h.p. now-a-days with greatly improved reliability and despite all the ancillary equipment such as superchargers, variable pitch propellers and drives to accessories of all kinds. During the same period the fuel efficiency has only improved by about 20 per cent. to its present figure of about ½ lb. per h.p. per hour, although it must be remembered that the requirement for low specific weight of engine is not compatible with obtaining the greatest fuel economy. Most of the improvement in power/weight ratio has been achieved firstly by increasing the power handling capacity per cylinder and secondly by increasing the number of cylinders per unit without proportionately increasing the engine scantlings and associated auxiliaries. In the last twenty years the number of cylinders per unit has increased, for instance, from 9 in the Bristol Mercury to 24 in the Napier Sabre.

Progress in engine design is perhaps revealed most strikingly by considering the improvement in h.p. per cubic inch of cylinder, shown in figure 9, of 11 to 1 in the last forty years. (The ratio was, however, of the order of 1 for the Schneider Trophy aircraft in 1931). This can be traced primarily to the introduction of high octane fuel for which the American petroleum industry must be given full credit. This alone by permitting much greater compression ratios has accounted for at least a four-fold increase in h.p. per cubic inch over the period we are considering. Supercharging is another factor which has had a major effect on aero engine design. In 1918 the G.E.C. of America fitted a blower to the Liberty engine and raised its h.p. from 230 to 365. Since then the supercharger has been continuously improved so as to give greater power at take-off and also to allow the engine to operate efficiently at much greater heights. The mechanically driven supercharger was brought to its highest state of development in the Rolls Royce engines, notably in the famous Merlin series, one of the most flexible engines of World War II. It was the Merlin which was used in the Spitfire and the Lancaster and also in American bombers and fighters.

Difficulties surmounted

The large increases in power per cylinder of course involve very much higher operating temperatures and advances were only possible because of the steady improvement in engineering techniques and in materials for operation at high temperature. The use of Cobalt-Chromium-Tungsten alloys for exhaust valves, of sintered aluminium oxide for sparking plug, and of copper-lead bearings are examples of the improved materials which became necessary.

The removal of waste heat from the engine cylinder and its eventual dissipation into the atmosphere has, however, been a continual problem to the aero engineer. Indeed, in 1934 it was believed that this factor alone might place a limit on the maximum

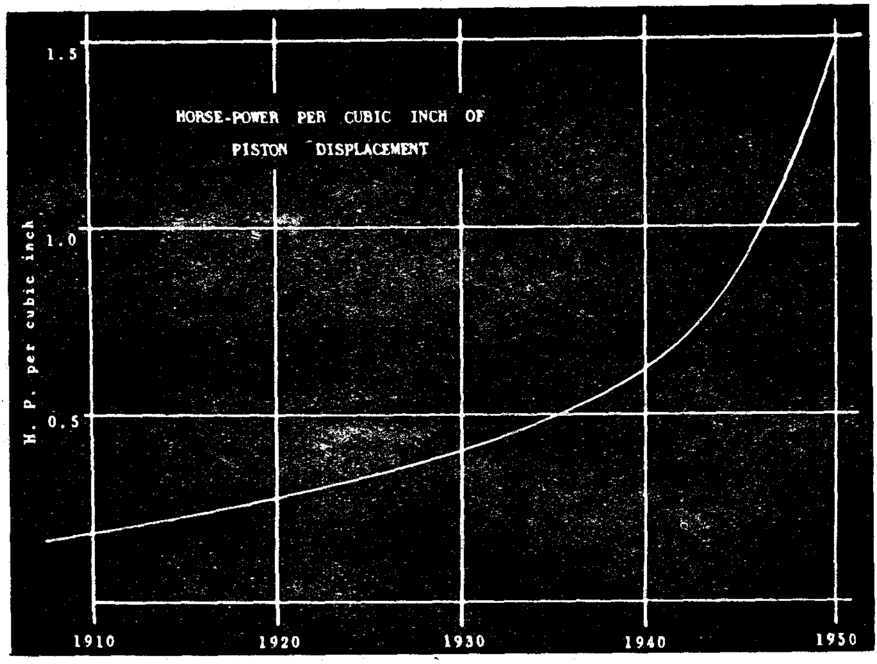

Fig. 9.—*Increase of h.p. per cubic inch of piston engines.*

speed of aircraft. However, improvement in heat exchange methods has led to a steady increase in power loading of aircraft. Perhaps the most significant advance was the development of the ducted radiator in 1935 which not only reduced radiator drag but even obtained a small thrust from the waste heat. In addition, however, the smooth flow conditions that were obtained by attention to aerodynamic design removed any fear of a limitation on speed since the ability of such a radiator to dissipate heat into the surrounding air will improve with speed. However, the full throttle climb still remains a critical limitation on piston engine aircraft.

The piston engine can only develop useful thrust by means of its propeller. At comparatively low speeds of the order of 350 knots this is quite an efficient means of propulsion, efficiency of about 85 per cent. being not uncommon. During the war demands for still greater speeds in fighter aircraft emphasised the severe reduction in propeller efficiency which occurs at speeds above 400 knots owing to the rapid build-up of compressibility effects and the resultant separation of the air stream over a considerable proportion of the blade. This is shown in figure 10. The inability of the propeller to meet the demands for higher speed foreshadowed the impending obsolescence of the piston engine just when it had reached a zenith of sophistication and refinement. Now-a-days nearly all military aircraft, both bombers and fighters are engined with jets and the success of the de Havilland Comet and the promise of propeller turbine aircraft such as the Bristol Britannia make it probable that in civil aviation too the piston engine will eventually be retained only for general purpose aircraft where its flexibility in operation can be fully exploited. The situation is

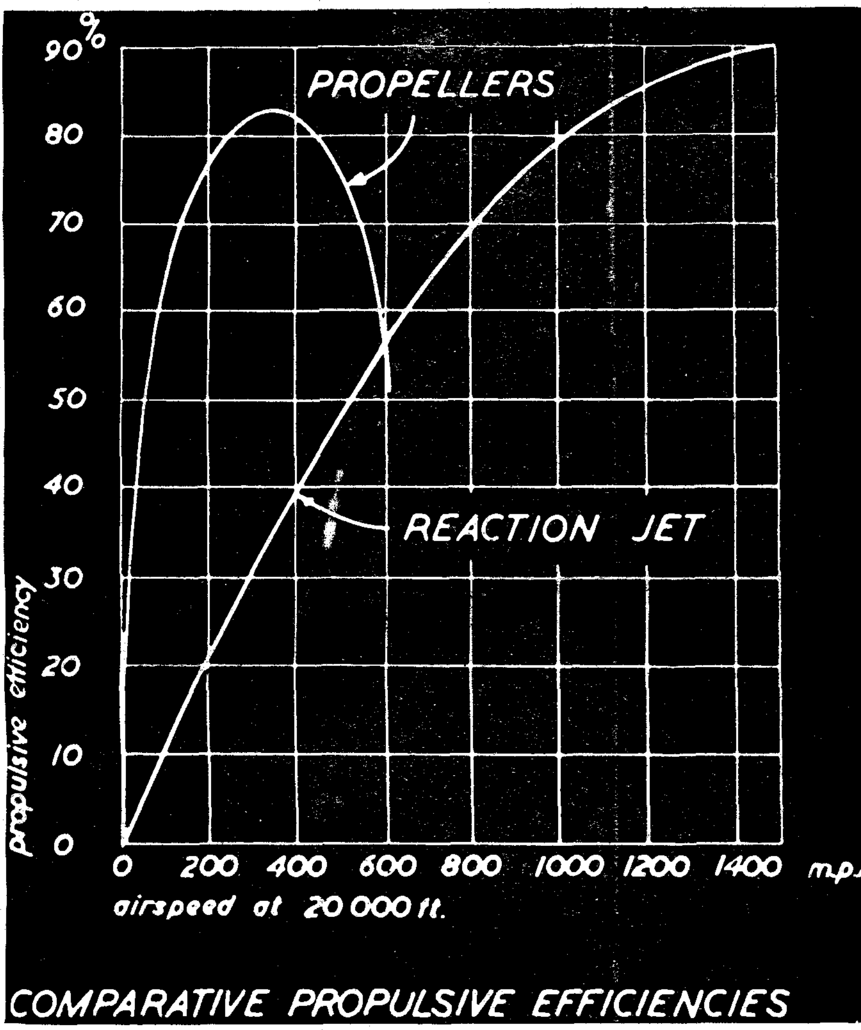

Fig. 10.—*Comparison of propulsive efficiencies of propeller and jet.*

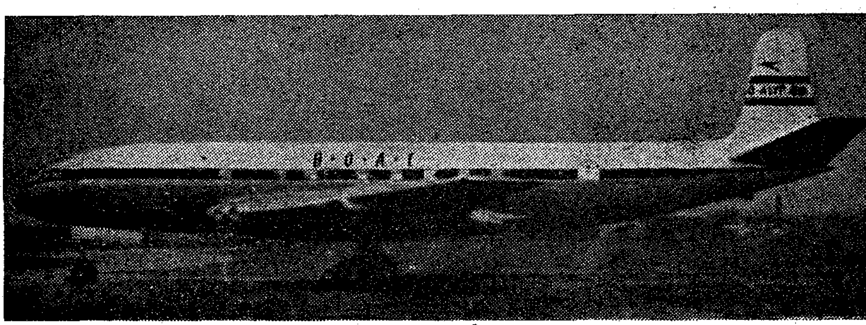

Fig. 11.—*Comet.*

somewhat reminiscent of the collapse of the sailing era when ships like the tea clippers "Cutty Sark" and "Thermopylae" were swept from the oceans by the coal-burning tramp steamer.

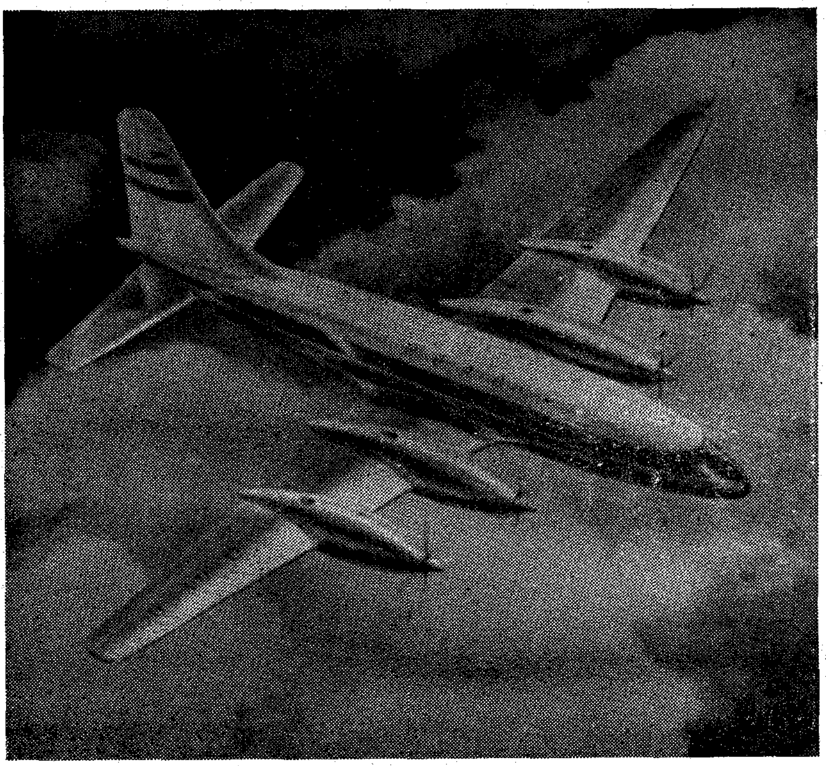

Fig. 12.—*Britannia.*

Turbo-jet Engines and Laminar Flow

The turbo-jet particularly with axial flow compressor can provide a greater thrust per unit area than any other type of air-consuming engine and it can be made to develop thrusts far in excess of anything hitherto obtainable. This makes the jet eminently suitable for propulsion at high speeds. It is also a very great saving in specific weight; for the same sea level thrust at 550 knots a piston-engine-propeller combination would weigh five times as much as a turbo-jet. The gas turbine is still in its infancy and its future development lies in obtaining higher working gas temperatures, higher compression ratios and improved efficiency of compression. A modern gas turbine can consume 5 tons of air a minute and we are now just as much concerned with the flow of air through an aircraft as over it. We can expect significant improvement in compression efficiency as our knowledge of aerodynamic flow at high speeds is applied to the design of compressor blades.

The very first experimental Whittle turbine had to use ceramic turbine blades before the working temperature could be raised sufficiently to provide any net thrust. Since that time great advances have been made in metallurgy with the development of new nickel-chrome and Nimonic alloys and the years of technical experience amassed during the development of the piston engine have proved of the utmost value in attacking the many problems arising in improving the efficiency of the turbo-jet. Figures 13, 14 and 15 show the general trend of improvement in specific thrust, specific weight and specific consumption and it will be seen that if this trend continues we may expect great advances in the future. The specific consumption remains high in the straight jet turbine, but the propeller turbine and the by-pass engine such as the Conway offer means of obtaining more economic operation while retaining most of the conditions of engine design and cleanness in aerodynamic shape which the small frontal area of the turbo-jet permits.

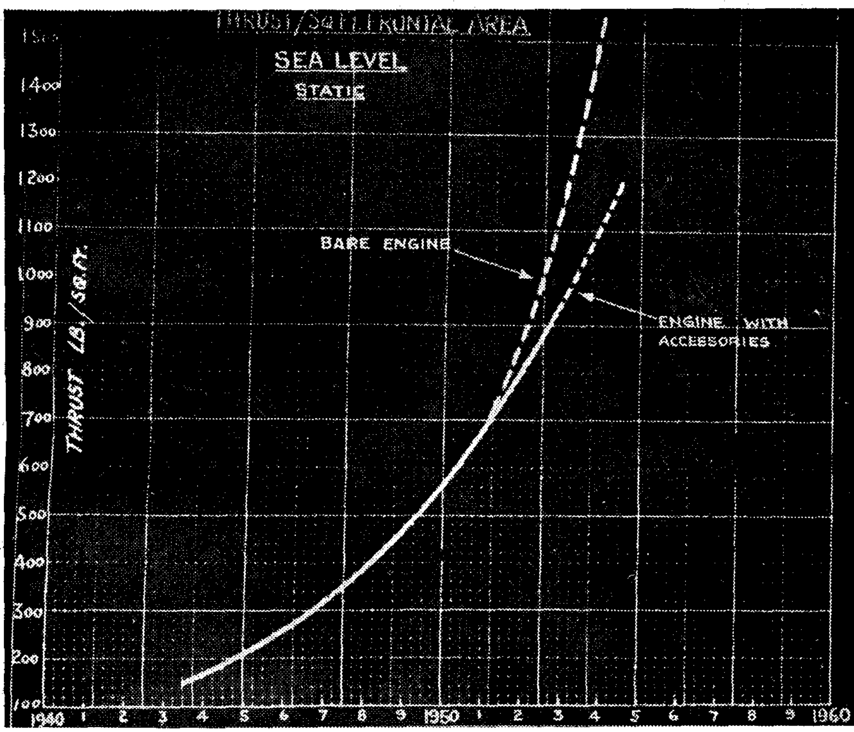

Fig. 13.—*Trend of specific thrust of turbo-jets.*

Even at sub-sonic speeds the introduction of the jet has already had a marked effect on aircraft design. The speeds of civil aircraft are likely to remain well below the speed of sound for many years yet and the main problem is improved economy at subsonic speeds. The small light jet engines are buried in the wing and the absence of engine nacelles and the elimination of the propeller remove one of the main sources of turbulence over the wing. The maintenance of laminar flow which the removal of the propeller makes feasible is therefore being actively considered. Figure 16 represents diagrammatically three typical conditions of air flow. The lower diagram corresponds to early aircraft designs in which excrescences of various sorts caused an actual break-away of the air stream. The middle

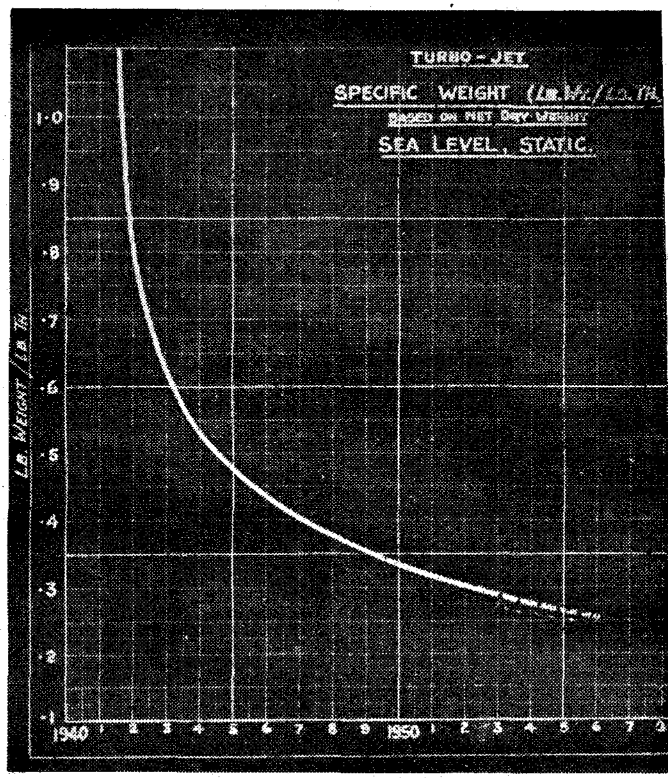

Fig. 14.—*Trend of specific weight of turbo-jets.*

diagram corresponds to existing clean aircraft in which break-away has been eliminated but where the flow is turbulent over most of the wing. The top diagram illustrates completely laminar flow. The much smaller velocity gradient of completely laminar flow compared with that through the thin laminar layer arising with the more usual turbulent flow offers a tremendous reduction in the transfer of mass momentum or energy. If this flow condition could be maintained over the entire aircraft, profile drag would be reduced by an order of magnitude.

However, the conditions for achieving laminar flow are most exacting. The aircraft surfaces must be true and free of waviness to within a few thousandths of an inch and experiments have shown that flies or dust picked up on the leading edge will cause complete break-down of laminar flow. In the absence of such interference, however, laminar flow can be maintained as far back as 0.6 of the chord provided the pressure gradient across the wing is made to fall steadily by proper choice of section. By the use of suction laminar flow has been extended to as far back as 0.75 of the chord. If such an improvement could be guaranteed under normal operating conditions over both wings and fuselage the effect on future aircraft design would be very large. Apart from the improved economy of operation and the consequent increase of range for a given all-up weight it would be necessary also to reduce the induced drag by going to very high aspect

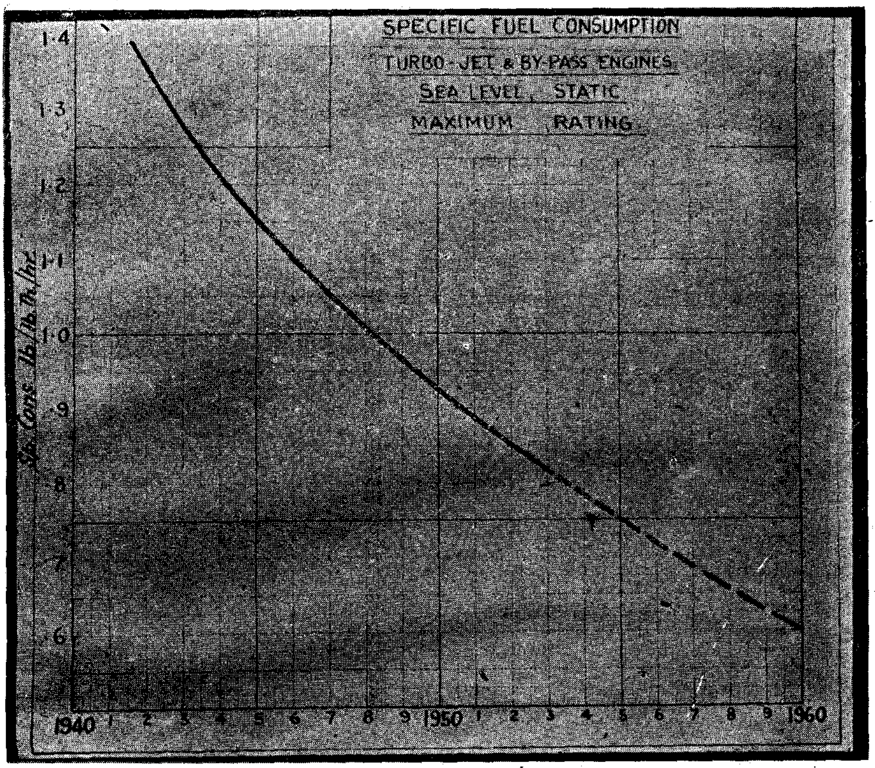

Fig. 15.—*Trend of specific consumption of turbo-jets.*

ratios and to low wing loading. It must be emphasised, however, that this is looking very far into the future and there are still many foreseeable difficulties which may not be solvable under practical conditions. Nevertheless the possibilities of laminar flow are intriguing.

In military applications the struggle between fighter and bomber for speed superiority is still the dominant factor although one can foresee a time in the not distant future when the rocket-driven guided weapon flying at perhaps a Mach number of 3 must have its effect over the whole field of air warfare. From figure 17, which shows the variation with speed of the propulsive efficiency of piston engine, turbo-jet, and ram-jet, it is clear that there are propulsive methods available at supersonic speeds; and the curves of figures 13, 14 and 15 indicate that progress in the development of turbo-jet 8 is rapidly translating these theoretical possibilities into practical reality. As more experimental data on the lift and drag at transonic speeds has become available the popular conception of an impenetrable sound barrier has disappeared and supersonic level flight by military aircraft is an achievement for the immediate future..

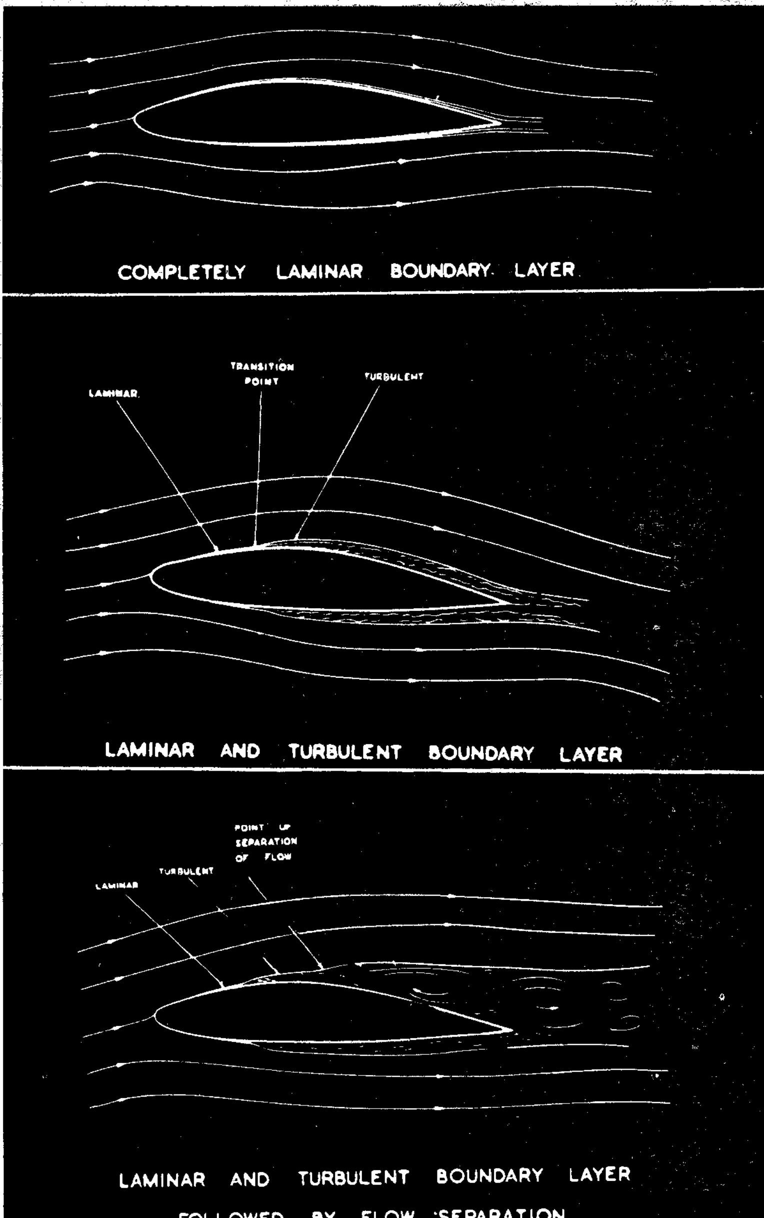

Fig. 16.—*Flow over aerofoil.*

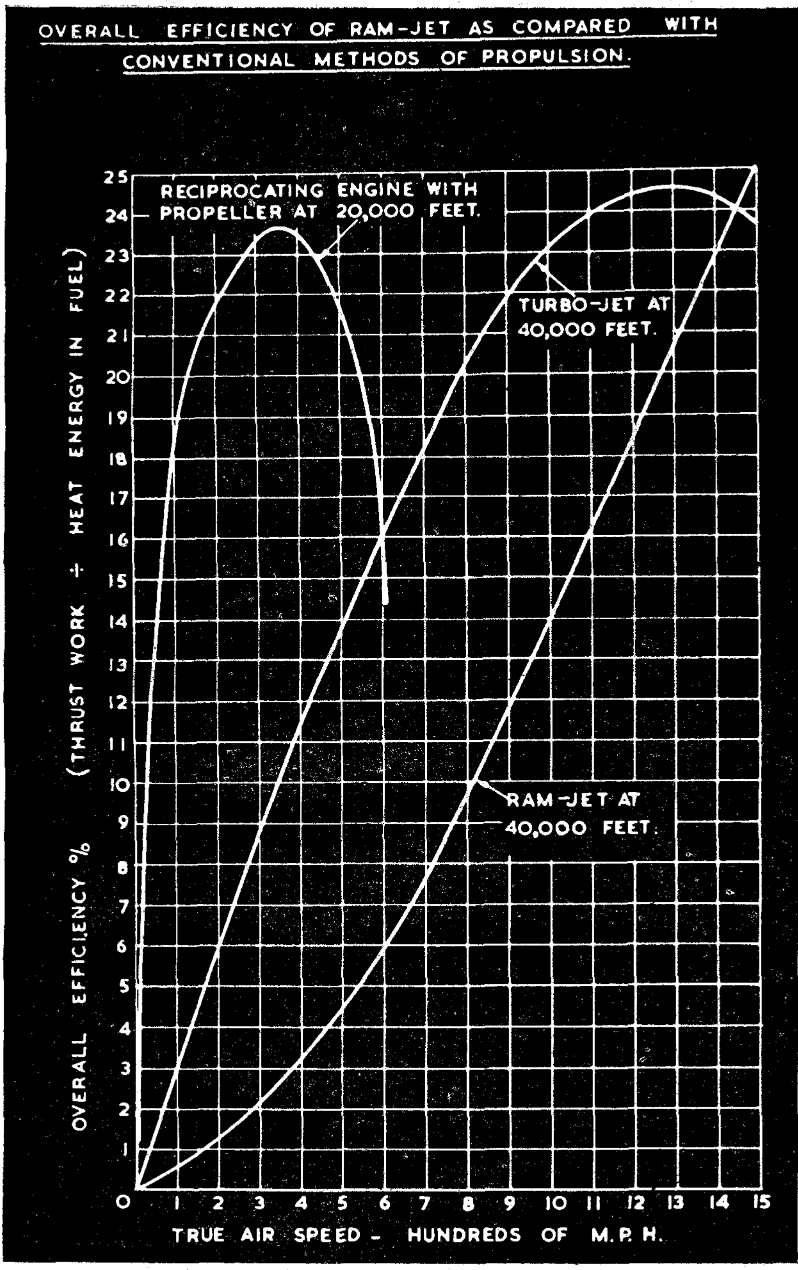

Fig. 17.—*Thrust efficiency of propeller, turbo-jet and ram-jet.*

Figure 18 shows the rapid rise in drag in the region of Mach 1 due to the creation of a semi infinite plane shock wave. The onset of these compressibility effects can be delayed by sweep back—or indeed sweep forward—so that only the resolved component of the total forward air speed traverses the chord of the swept wing. All modern fighters and bombers such as the Swift and Hunter and the Valiant have swept back wings. Sweep back, however, only delays the rise in drag to higher speeds. The promise of supersonic flight can be better appreciated by examining the curves of figure 19 which shows the variation of thrust and drag co-efficients instead of total drag as in the previous diagram. It will be seen that at higher Mach numbers the increase in drag with speed falls off and most rapidly with the unswept wing. The effect at these higher speeds is somewhat analogous to the small hole drilled through a pane of glass by a high velocity bullet as compared with the smashing which arises with a

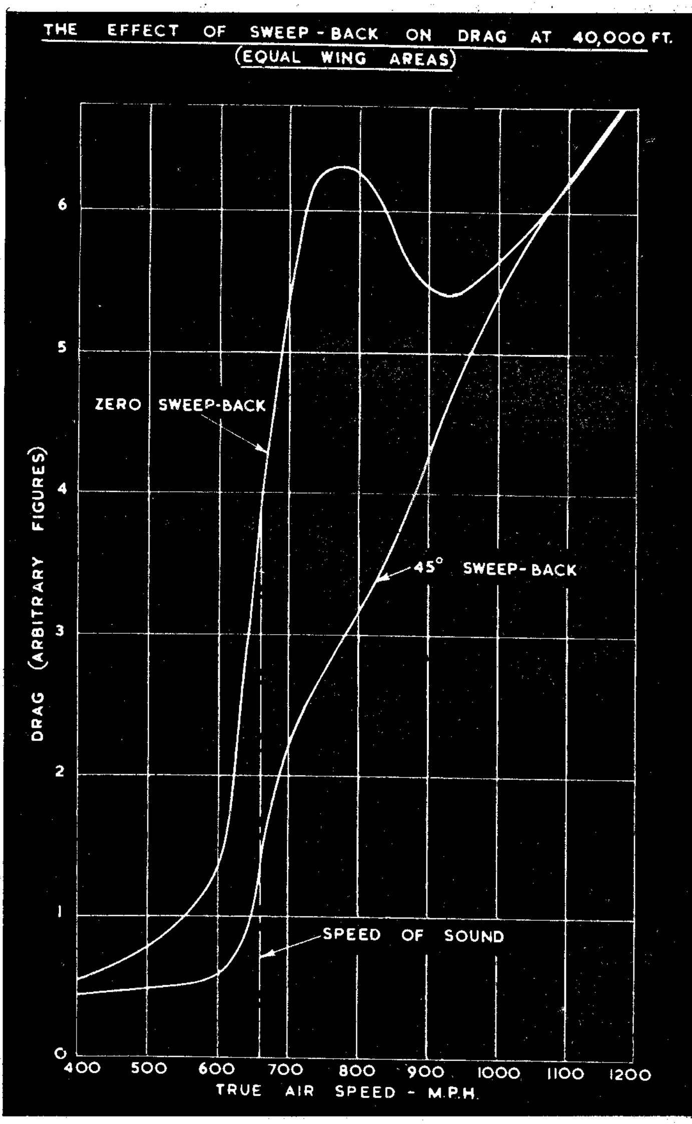

Fig. 18.—*Rise in drag at supersonic speed.*

slow-moving stone. Figure 23 also shows the variation of thrust co-efficient with speed : the lower curve corresponds to the present level of jet development and the upper curve assumes a 2 to 1 improvement in thrust.

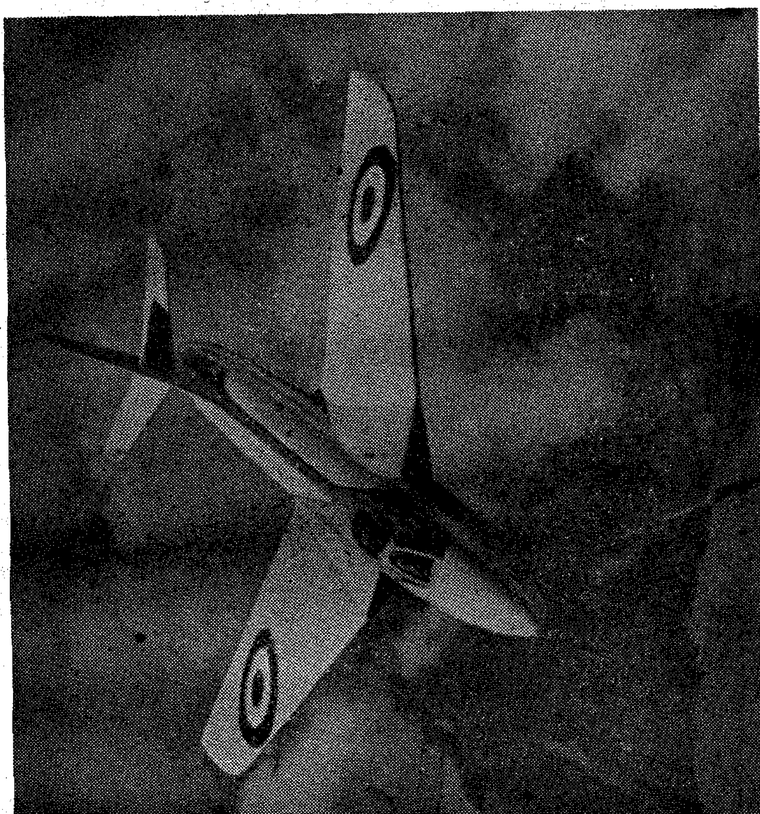

Fig. 19.—*Hunter.*

Although supersonic speeds in level flight are thus clearly possible, there are many problems to be faced. Most of the drag at supersonic speeds is due to wave drag which is proportional to the square of the wing thickness and the aircraft structure will, therefore, have to depart considerably from its present form. The rise of temperature of the air due to profile drag increases as the square of the speed and new problems of cooling will therefore arise. For instance at 1,000 m.p.h. the temperature rise is already about 100°C. and at still higher speeds the temperature rise may cause serious deterioration in strength on most of the existing structural materials. There are also difficult aerodynamic problems to be overcome before supersonic aircraft are fully controllable at all speeds in particular at landing and take-off. In military applications there are a number of expedients which could be adopted to accelerate the development of supersonic fighters and bombers. These might include, for take-off rocket assistance or air launching and for landing, arrester gear of various kinds. However, it may not be long before it is possible to

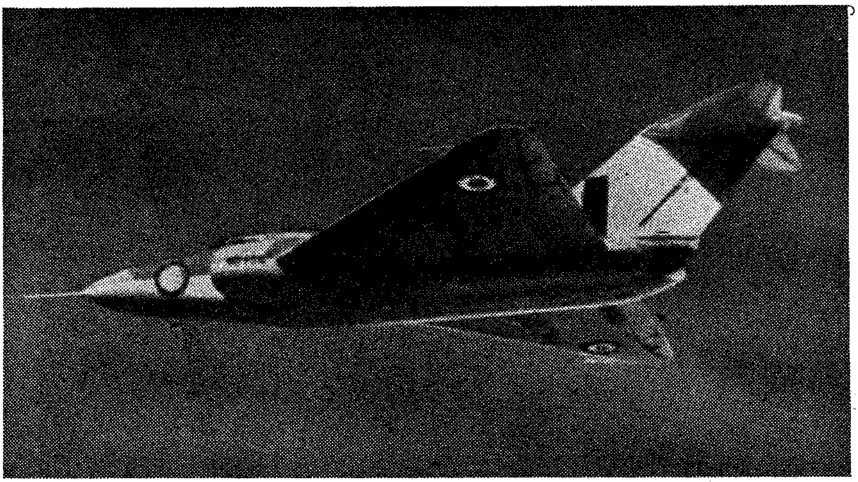

Fig. 20.—*Javelin.*

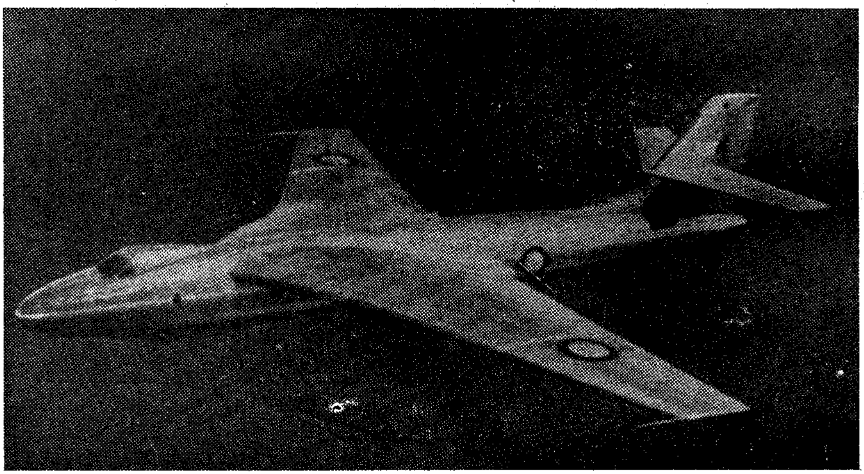

Fig. 21.—*Valiant.*

Fig 22.—*Vulcan.*

design aircraft whose take-off thrust exceeds the weight of the aircraft, opening up the possibility of vertical take-off and landing. This would have a far-reaching effect on the design of aircraft since it would remove one of the principal factors which, as we have seen, has limited the development of existing aircraft which must depend entirely on their aerofoils at take-off.

FUTURE MILITARY AND CIVIL AIRCRAFT

Up to the present, military and civil aircraft development has kept in step. The demand for higher fighter speeds and for higher flying bombers has also met the requirement for increased all-up weight in civil aircraft without exceeding the available aerodrome facilities. It seems clear, however, that for some time into the future advances in these two fields will proceed along different lines. Civil aircraft will be limited to about 500 knots with swept back wings to avoid wave drag and to 100 knots stalling speeds in order to accommodate themselves to existing airports. If laminar flow becomes practicable one may then expect much bigger aspect ratios and thicker wings. Future military aircraft, on the other hand, may be expected to develop towards supersonic speeds involving straight thin wings with small aspect ratios.

Eventually, no doubt, when the possibilities of safe supersonic flight have been demonstrated in military aircraft and the necessary materials and facilities developed in the interests of defence we may perhaps in our lifetime have civil aircraft spanning the Atlantic within an hour.

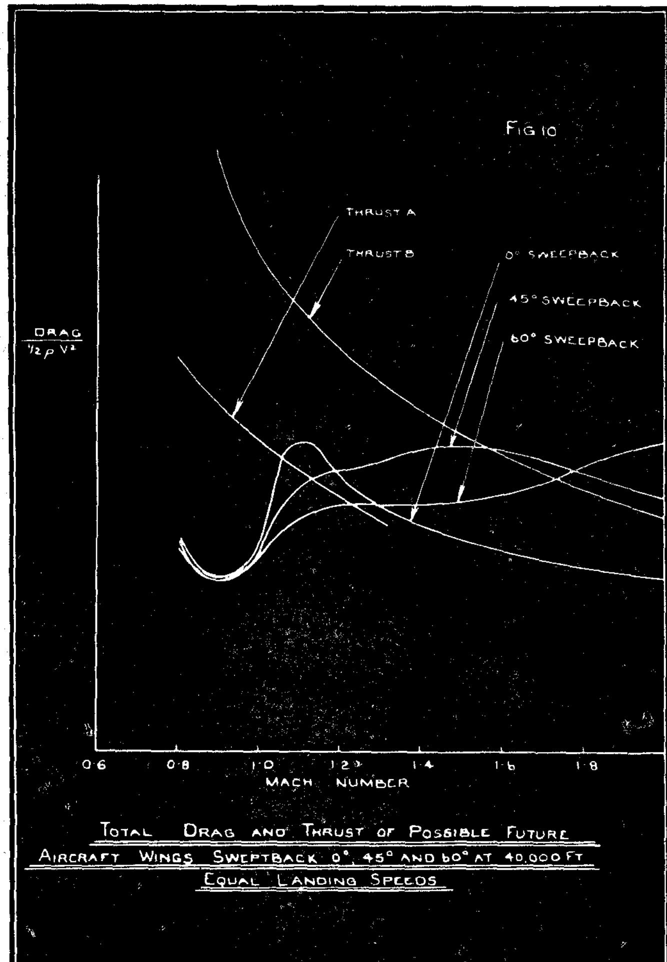

FIG. 23.—*Drag and thrust of future aircraft.*

Although the advances during the last fifty years have been amazing enough, during the next fifty years they are likely to be fantastic by present standards, but it must be emphasised that the promise of the next fifty years can only be realised by the continued development of new materials for structures and engines and by greatly extended aerodynamical knowledge. The effort involved is very large indeed and great foresight will be required to ensure that it is properly distributed. It may well be that as the field of aeronautics continues to expand no one nation will be able to provide the research effort which will be necessary if all possibilities are to be properly explored. Thus aeronautics may not only provide the improved communications which are essential to the integration of our complex society ; it may in addition provide yet another challenge to be met by a comity of nations.

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