Research, Development and Technical Issues

The 1956 Wright Brothers Lecture by Sir Arnold Hall—Part 2

LAST week we published the first part of the Wright Brothers Lecture delivered by Sir Arnold Hall, F.R.S., M.A., F.R.Ae.S., before the Institute of the Aeronautical Sciences in Washington. Here, virtually in full, we continue this notable paper; a third instalment will follow. The illustrations have been re-drawn from those accompanying the lecture. Formerly Director of the Royal Aircraft Establishment, Sir Arnold is now technical director of the Hawker Siddeley Group.

IN this part of the paper [said Sir Arnold] some matters that affect the development of aviation for civil purposes are discussed, and serve to some extent to illustrate points made in the previous part. Though a discussion of advanced military aircraft might be thought to provide better illustration, the operational efficiency of such machines depends on factors which cannot be discussed in an open lecture. I will therefore say little on the future possibilities of such types, but where digression from the civil theme is reasonable, the discussion is not confined to passenger machines.

Three technical matters from the many that affect civil aviation are of particular influence: the direct operating economy attainable; the integrity and useful life of the structure; and its noise nuisance. All three are inter-related, and all three place limits on what it is wise to attempt. The discussion is centred particularly on these three issues, but again without resisting digression.

The Range Equation. In Fig. 6 is plotted the relationship between weight, speed, engine performance, and range for aircraft which spend a large part of their flight cruising in the stratosphere at constant lift/drag ratio. (This data derives from the energy equation; the connection is outlined in Appendix I*.) The range needed (R), the speed proposed (V), and the specific fuel consumption (c) fix $\frac{Rc}{V}$ on the left-hand plot. This value is then related to the line marked with the lift/drag ratio expected; horizontal transfer to the right-hand plot then produces the relationship between the weight at the start of cruise (W_O), the basic weight (W_B), and the weight of the payload together with the items essential to its carriage (W_C). (The basic weight W_B is the sum of the weight of the structure, the powerplant and the systems; see Appendix I for details of this item and of W_C).

The main feature of this type of presentation is the rapidly varying slope of the curves on the right. This slope is an indication of the sensitivity of the design; where it is high, the aircraft is "easy" to achieve, since failure to produce the lift/drag ratio or the basic weight hoped for has relatively mild results on the payload. Where the slope is low the design is very sensitive to small changes in the aerodynamic or weight positions, and the aeroplane is difficult in the sense that the consequences of relatively small technical failures are great. The regions of "easy," "possible" and "hard" design are indicated on the plot; they are not, of course, hard and fast divisions.

The economics of the aeroplane can be derived roughly from the weight ratios emerging from Fig. 6; an approximate equation for this relationship is mentioned in Appendix I. As the aeroplane enters the "difficult" category, so its economics move adversely, since the fractional payload is becoming small. The next sections contain a discussion of values to be expected for the parameters on the range equation which govern the position of the aeroplane on the plot of Fig. 6, and therefore control the economics it can offer.

Trends in Parameters. *Lift/drag ratio:* At subsonic Mach numbers approaching 0.85 a lift/drag ratio of up to about 16 is achievable with conventional arrangements; thereafter there is a rapid fall with increasing Mach number, until in the "medium-supersonic" regime (Mach number 1.5-3), a ratio of 5.5 to 6 appears likely for a variety of practicable aeroplane configurations. This is illustrated in Fig. 7. (Higher subsonic values than 16 are, of course, obtainable with special arrangements, but this figure is typical of good practice in conventional civil aircraft.)

Anticipating for the moment the discussion on trends in specific fuel consumption, a typical consumption figure for jet engines at high subsonic Mach number is about 1.0 and at Mach number 2.5 is likely to be about 1.5. Using these figures for L/D and c, points for a high-subsonic aircraft of 5,000 miles range, and a Mach number 2.5 aircraft of 3,500 miles range are shown on Fig. 6. If, as is reasonable to assume, a basic weight of 45 per cent or better is achieved, both aircraft are at about the same position in the "not-too-difficult" class. The possibilities of medium-range operation at medium-supersonic speeds is clear. Unless, however, a substantial improvement can be made in the lift/drag ratio, or in the specific fuel consumption, very long ranges at medium-supersonic speeds will not be easily achieved using present-type chemical fuels; if the 3,500 miles cruise on which the supersonic point is based is changed to 5,000 miles for direct comparison with the subsonic point, it is evident that a design emerges which has a very low payload percentage and which is extremely sensitive to small changes in L/D and basic weight ratio. The situation would revert to the ease of the 3,500-mile range case if L/D were to rise to about 8.5 or if the specific consumption were to drop to 0.9—the latter very improbable without departure from present-type chemical fuels. (In considering these range figures with civil applications in mind, it should be remembered that a still-air range exceeding the stage length by about 60 per cent is needed to provide for weather and safety allowances.)

The drop in lift/drag ratio in the supersonic regime is due to the onset of wave-drag. I would like to make a brief review of the advances made in recent times in controlling it. A few years ago wave-drag made its appearance at subsonic forward speeds, but considerable progress was made in delaying its onset by keeping the local effective flow over the lifting surfaces wholly subcritical (below the speed of sound) by the use of sweep-back and thinness. When this is done supersonic flow patterns, with consequent wave-drag, arise at the junction between the wing and the fuselage and at the wing tips. Dr. Kuchemann at the Royal Aircraft Establishment pointed out several years ago that if the body is suitably "waisted" it can be arranged that, in transonic flight, the pressure field due to the combination of wing and body approximates to that of the wing alone at points remote from the body. A subsonic flow pattern is thus retained at the junction and the onset of wave-drag does not occur earlier there than on the main part of the wing. Whitcomb's "transonic area rule," which originated concurrently in U.S.A., was a more general form of the same principle; this can be stated as "a reasonably smooth aeroplane flying at near sonic speed has the same drag as a body of revolution with the same cross-sectional area in planes normal to the flight direction." Linear supersonic aerodynamic theory was shown to be consistent with the transonic area rule as the Mach number approached unity, and this led to the investigation of whether linear theory could be used to develop an analogous rule applicable to wave-drag on supersonic aeroplanes. The "supersonic area rule" emerged, expressing the drag in terms of the cross-sectional areas in planes tangential to the characteristic Mach cone; this area rule, when applied to general shapes, gives

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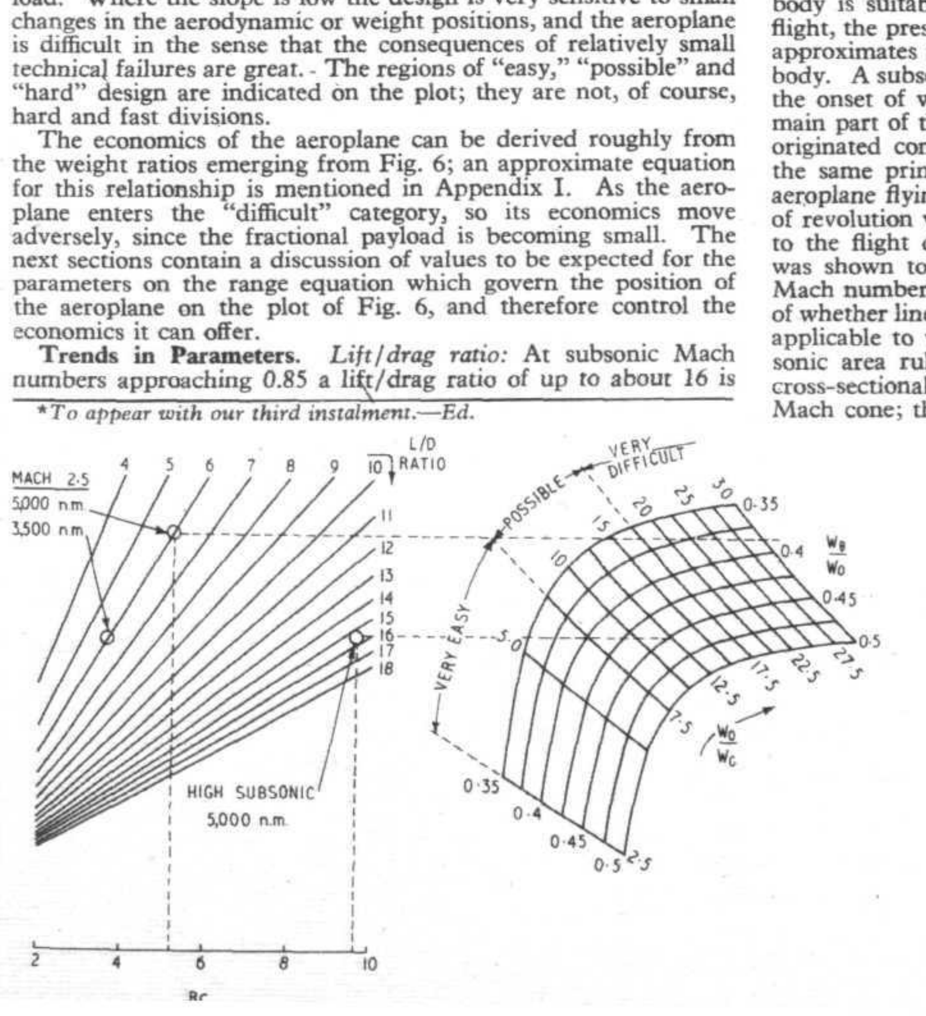

Fig. 6 (left). The range relation for cruise in the stratosphere: R, still-air range, no climb allowance (n.m.); C, s.f.c. (lb/hr/lb); V, t.a.s. (kt); W_O; total weight at start of cruise (lb); W_C, fixed equipment; W_B, basic weight (structure, powerplant and systems).

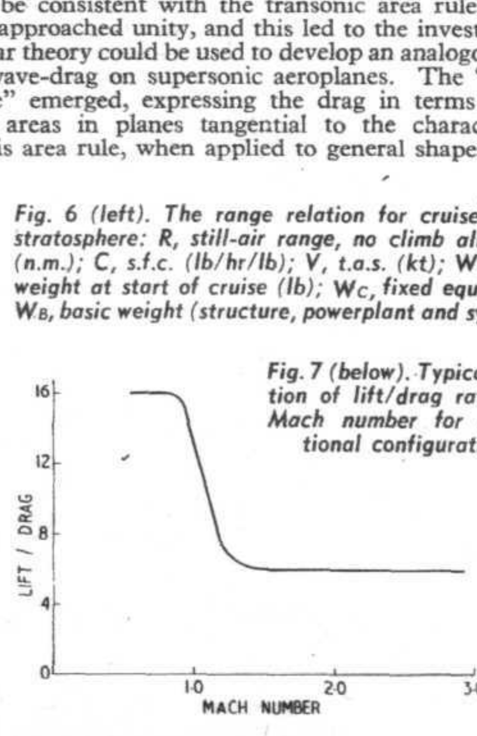

Fig. 7 (below). Typical variation of lift/drag ratio with Mach number for conventional configurations.