Technical Comments

Comment on "Ideal Tail Load for Minimum Aircraft Drag"

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PROFESSOR E. V. Laitone's Engineering Note on "Ideal Tail Load for Minimum Aircraft Drag," [J. Aircraft **15**, 190-192 (1978)] is interesting in its use of the basic biplane equation and Munk's stagger theorem for estimating trim drag. However, there are errors in the conclusions and some of the basic assumptions of the note.

First, in modern high-speed transport aircraft the contribution of compressibility drag to the total trim drag problem is very significant. The download on the tail increases the total lift that the wing must carry and if the airplane is operating near the Mach number for drag divergence the required increase of wing angle of attack will cause an increase in compressibility drag. This compressibility contribution is of the order of half of the total trim drag. On the other hand, when compressibility drag is not present the interference term in the biplane equation introduces a negative drag term which compensates to a large degree for the obvious induced drag penalties on the tail due to its download and on the wing due to the greater wing lift.

Second, even with compressibility drag, trim drag is generally much less than the 5% mentioned by Professor Laitone. Figure 1 shows the variation of trim drag with center-of-gravity position for various lift coefficients and Mach numbers for a DC-8-54 aircraft. Typically, the DC-8 flies at a C_L of about .35. At the original design cruise Mach number of 0.82 and at an average center-of-gravity position of about 26% of the mean aerodynamic chord, the trim drag is 2.2% of the total drag. With some consideration of aft loading cargo the average center of gravity might be moved to about 29%. The trim drag will then be 1.6%. Since the dramatic rise in fuel prices, cruise Mach number has been reduced to 0.8 to reduce compressibility drag. The trim drag penalties are then 1.4% at 26% center-of-gravity position and 0.9% at 29% c.g. position. These representative numbers are well below 5%. Only at high C_L and Mach number and at far forward center-of-gravity positions can trim drag approach such high values.

Third, Professor Laitone concludes that large trim drag savings could occur if only transport aircraft were designed with larger tails. An aircraft design is a matter of complete integration and a savings in trim drag would have to be weighed against the weight and parasite drag penalty of the larger tail. If we accept the possibility of a 1% decrease in induced drag from the zero tail load case with tail upload this corresponds to something like a 0.4% reduction in total drag since induced drag is approximately 0.4 of the total drag in cruise. Then the total trim drag gain from current practice is of the order of 2.0% of total drag. To gain this 2.0% one would have to move the center of gravity well aft and to do that would require significant increases in the horizontal tail size. Since the horizontal tail contributes about 8% of the total parasite drag or about 4.8% of the total drag it can be seen that a significant increase in this tail size would quickly

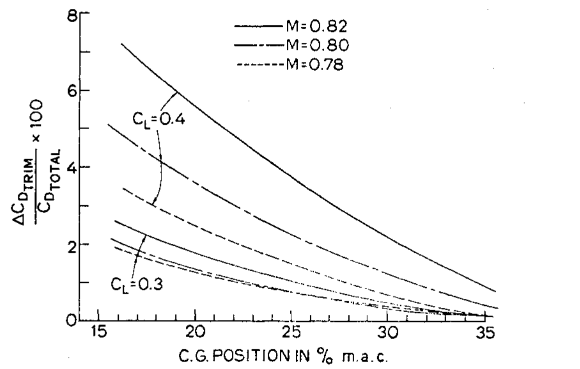

Fig. 1 Percentage change in total drag due to trim, DC-8-54 airplane.

begin to counteract the trim drag gained. Furthermore, the higher tail weight would be a negative factor. The one point that might be brought up is that a longer narrower fuselage with the same capacity as a shorter wider one will have a longer tail length and therefore require a smaller tail download for a given required trim moment. Thus short airplanes tend to have higher trim drag.

The last error in Professor Laitone's Note is the statement that prior to World War II most aircraft were designed to cruise with either zero or slightly positive tail loads. Almost all aircraft even in World War I had a positive wing camber. Such positive camber automatically gave a negative moment which had to be balanced by a tail download unless the c.g. was well behind the aerodynamic center. Airplanes were usually designed with the center of gravity close to the aerodynamic center but with a capability of maintaining stability with the c.g. some reasonable distance behind the aerodynamic center. Excessive tail size to permit excessively far aft center of gravity position was never a design criterion. Therefore, aircraft have always had tail downloads. The positive wing camber is required both for high maximum lift coefficients, and to achieve high drag divergence Mach numbers at the cruise lift coefficients. The maximum lift coefficient and cruise Mach number in turn affect wing area, sweep, and thickness. Obviously, the optimum airplane is not the airplane designed for minimum trim drag. In the future, when active controls become accepted and permit aerodynamically neutrally stable or even unstable airplanes, then minimum trim drag may be desirable since it could be approached without increasing tail size.

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THE author is in complete agreement with Shevell's first comment; namely, that a tail download increases the compressibility drag of the wing. It therefore follows that either a zero or a slightly positive tail upload will minimize both the compressibility drag increment and the induced drag.

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