Technical Comments

Comment on "Ideal Tail Load for Minimum Aircraft Drag"

Richard S. Shevell*
Stanford University, Palo Alto, Calif.

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 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.

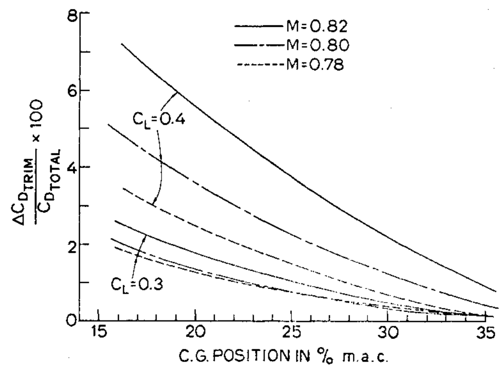

Fig. 1 Percentage change in total drag due to trim, DC-8-54 airplane.

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.

Received April 18, 1978.
Index categories: Performance; Configuration Design.

*Adjunct Professor, Dept. of Aeronautics and Astronautics. Associate Fellow AIAA.

Reply by Author to R. S. Shevell

E. V. Laitone*
University of California, Berkeley, Calif.

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.

Received June 7, 1978.
Index categories: Performance; Configuration Design.

*Professor, Dept. of Mechanical Engineering. Associate Fellow AIAA.

Shevell's second comment refers to his Fig. 1 which clearly shows both the increase in induced drag as the tail download increases when the c.g. is moved forward, and the increase in compressibility drag as the wing lift is increased because of this tail download. The author stated, following his Eq. (16), that a tail download of 5% *W* would increase the total drag coefficient by 2.4% over the minimum drag produced by a very small tail upload. The 5% fuel saving mentioned in the author's introduction would correspond to the DC-8 flying at $M=0.82$ with $C_{L_0}=0.4$ for the aircraft and $C_{L_1}=0.42$ for the wing (because of a 5% *W* download on the tail), in comparison with a design change that would move the wing forward approximately 15% m.a.c. (1.01 m or 3.31 ft.) so as to attain a zero tail load with $C_{L_0}=C_{L_1}=0.4$ and $C_{L_2}=0$. Then the decrease in both the induced drag and the compressibility drag increment, along with the reduced engine thrust requirement, would result in a total fuel saving of approximately 5%.

Shevell's third comment on the use of a larger tail area is irrelevant to the author's suggestion that a larger tail volume be introduced since a forward location of the wing would increase the tail volume without increasing the parasite drag. A zero tail load was, and still is, a desirable and attainable design goal as clearly stated in 1934 by A. Betz in Durand's *Aerodynamic Theory*, Vol. 4, p. 85. The common use of a tail download in modern transport aircraft has been erroneously justified by calculating the so-called "tail thrust" by using the total downwash of the wing on the tail, and then neglecting the effect of the tail upon the wing. The author's Eq. (8) verifies the fact that the complete circulation vortex system produced by a tail download induces a downwash on the wing that rotates the wing's lift vector rearward so as to increase the wing's induced drag. When the tail span is very small, relative to the wing span, then potential theory shows that the increase in the wing's induced drag is mainly produced by the trailing vortex system of the tail download. Conversely, a tail upload produces an upwash on the wing that rotates its lift vector forward, corresponding to a "wing thrust" increment. Consequently, the minimum induced drag always occurs with a slightly positive tail load if the tail is either above or below the wing. However, the author's Table 1 shows that a zero tail load gives practically the same total drag, so it provides a good design goal that can be attained by either the rearward c.g. position made possible by a greater spacing between the wing and the tail, or a reduction in the wing's moment due to camber. Sailplane designers are well acquainted with the advantages of a zero tail load and easily attain this by a very small and smooth upward sweep of the rear portion of the wing's profile so as to reduce the negative moment of positive camber.

One correction should be made to the author's original paper. In Table 2 on p. 191, $\sigma b_2/b_1$ should be replaced by $\sigma b_1/b_2$.

Errata

Integrated Scramjet Installation Effect on the Subsonic Performance of a Hypersonic Aircraft

P. J. Johnston,* J. L. Pittman,† and J. K. Huffman‡
NASA Langley Research Center, Hampton, Va.

[J. Aircraft **15**, 326-332 (1978)]

THE following paragraph was omitted from p. 332 of the article. It should immediately precede the "Concluding Remarks":

Performance Summary

Figures 16 and 17 show the effects of changing the engine location and nozzle angle on vehicle performance and also provide an overall perspective of the study results. Although many of the particular details have been covered, these summaries show that, despite the variety of engine geometry changes made, maximum lift-drag ratios fell in a rather narrow band, ranging from about 3.75 to 4.15. Although it was not tested below $M=0.4$, an extrapolation indicates the 16-deg nozzle configuration might have produced an L/D_{max} of 4.25 at low speeds; this advantage decreased with Mach number, however, so that, once choking occurred in the engine, all three nozzle angles produced identical values of L/D_{max}. The nozzle fences afforded small improvements in L/D_{max} across the speed range (Fig. 17) despite the fact that they were diverged a total of 6 deg and increased the vehicle wetted area by about 10%, both of which would normally be thought of as adversely affecting performance.

Received July 5, 1978.
Index categories: Aerodynamics; Transonic Flow; Airbreathing Propulsion.

*Aero-Space Technologist, Hypersonic Aerodynamics Branch, HSAD. Member AIAA.
†Aero-Space Technologist, Hypersonic Aerodynamics Branch, HSAD.
‡Aero-Space Technologist, Fluid Dynamics Branch, STAD.