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Representation of the Drag Polar of a Fighter Aircraft

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Introduction

THE possibility of an analytical approximation of the drag polar of a fighter aircraft which would be applicable to the large values of angles of attack encountered in maneuvers is considered. Evidently, a simple representation can be conveniently used for making rather accurate estimates of turn performance in aircraft design and evaluation, and in the optimization of flight paths.

The classical representation, which approximates the drag coefficient, C_D, by $C_{D0}+kC_L^2$, is compared in Fig. 1 with the drag polars of YF-16.[1] In order to ensure the accuracy of the classical representation near zero C_L, the drag coefficient at zero C_L, C_{D0}, and the induced drag coefficient k are chosen so that the classical curve is tangent to the curve of the square of the lift coefficient, C_L, vs C_D. The need for an improved representation is evident. It is also clear that strakes and automatically controlled flaps do not change the qualitative nature of the curve. Available data on other fighter configurations further suggests that the nonlinearity indicated in Fig. 1 is quite typical.

The slope of the C_L^2 vs C_D curve changes gradually rather than abruptly, which is probably due to the gradual spanwise spread of the separated regions on the wing with increasing angle of attack. It is therefore inappropriate to approximate the curve by two straight lines. What is called for is an additive correction $f(C_L)$ to the classical representation that is insignificant at small values of C_L^2. This Note investigates simple functional forms of f that are capable of describing the available drag polars.

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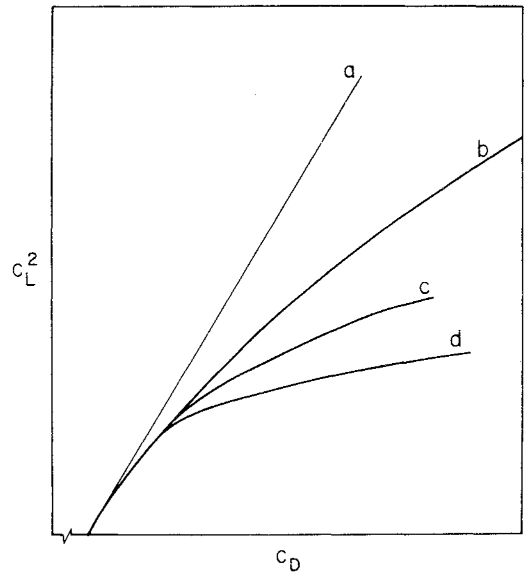

Fig. 1 The classical approximation (a) and the drag polars of YF-16 configurations.[1] (b) with variable LE flap and strake; (c) with flap only; (d) without flap or strake.

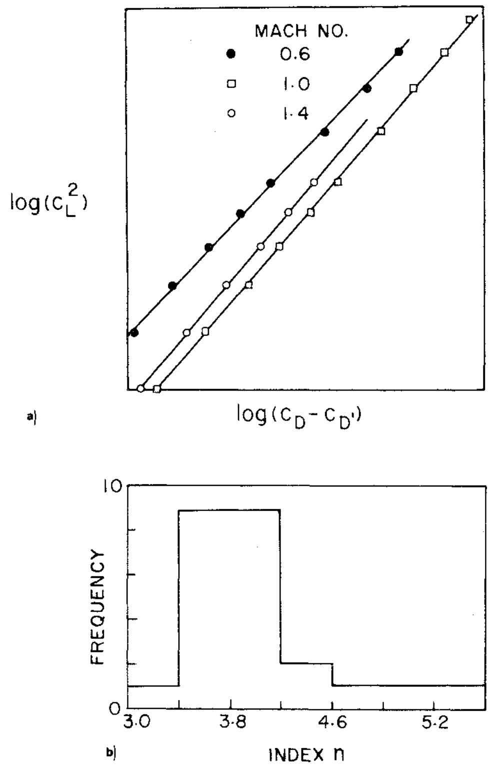

Fig. 2 The nature of the additive correction: a) $C-C_D' \sim aC_L^n$; b) the histogram of n for a sample of 24 drag polars.

Method and Results

A first step in examining the forms of the correction was to determine the appropriate classical approximation for the given drag polar. Since much of the data was available in the graphical form, a graphical method was chosen. A tangent was drawn to the smoothed C_L^2 vs C_D curve at the minimum C_D point, where the value of C_L was usually negligible. Let C_D and C_D' refer to the values on the given drag polar and on the tangent at a given value of C_L. (C_D-C_D') then gives the required correction. It was plotted against C_L^2 on a log-log plot. Figure 2 gives typical cases and shows that a straight line

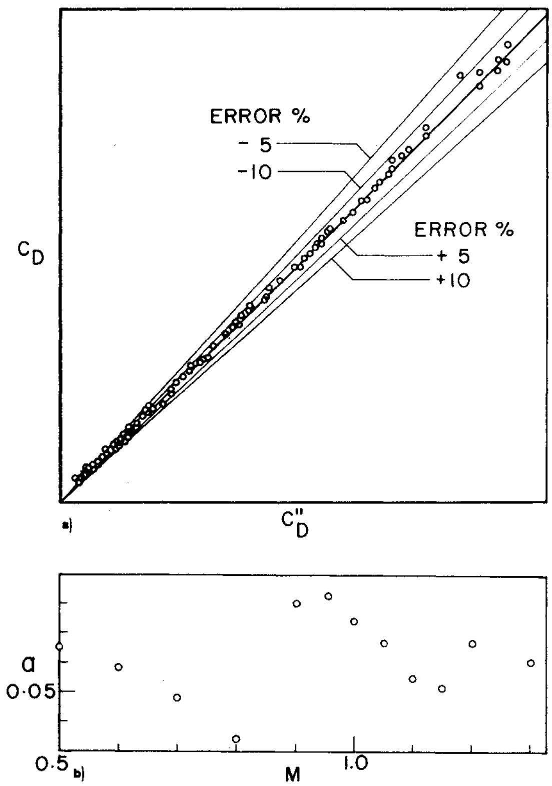

Fig. 3 a) Effectiveness of the representation given by Eq. (2); b) variation of a with Mach number, M.

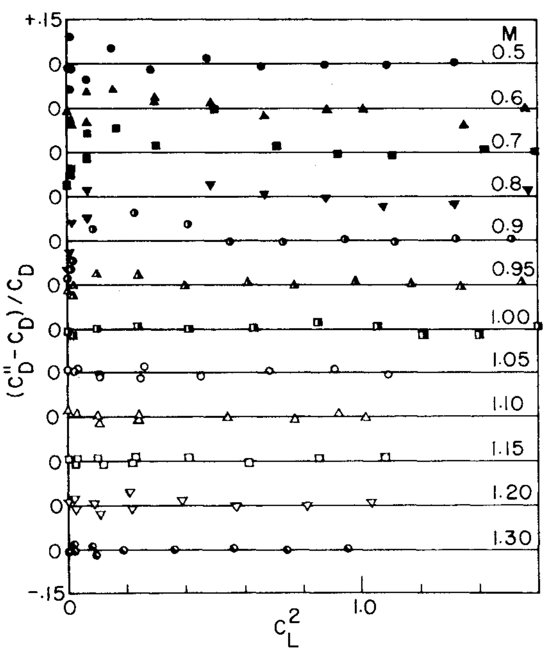

Fig. 4 The distribution of relative error $(C''_D - C_D)/C_D$ in subsonic, transonic and supersonic range.

can well approximate the curve. Hence it is reasonable to take the correction as

$$f=(C_D-C'_D)=aC_L^n \tag{1}$$

where the coefficients a and n have to be chosen for the given drag polar. The histogram of n (Fig. 2) shows that the three-fourth of the sample under study has n ranging from 3.4 to 4.2.

Further examination showed that the values of n were sensitive to the details of the method of determining C'_D. For instance, if a line with a slightly different slope was judged as a tangent, the value of f could significantly change for large C_L. A numerical method was selected to reduce the uncertainties. The classical representation was first fitted as a line of regression of C_D on C_L^2 to the four experimental data points having the smallest values of C_L^2. The index n was then found from the line of regression of log $(C_D - C'_D)$ on log (C_L^2). The values showed an increase in the transonic range. Also, differences between the numerically and the graphically obtained values of n were often significant.

Since n seemed to be rather sensitive to extraneous details, it was felt that a simpler representation, if sufficiently accurate, is to be preferred. With this view, we examined the simpler representation

$$C''_D = C_{D0} + kC_L^2 + aC_L^4 \tag{2}$$

The above expression can be considered as a quadratic curve of regression of C_D on C_L^2. The examination was restricted to two configurations for which we had detailed data.

The calculated values C''_D are compared with the experimental values of C_D in Fig. 3. There is no evidence of a systematic departure. Also, the index of correlation of Eq. (2), which is the ratio of standard deviations of C''_D and C_D, was typically in the range of 0.997 to 0.999. The closeness of this index to 1 is an indication of the effectiveness of the representation equation (2).

Figure 4 shows the relative error in the subsonic, the transonic, and the supersonic range. Evidently, the agreement of C''_D with the experimental values is better than 3% in the transonic and the supersonic range, perhaps due to the reduced relative error in measuring larger forces and the smaller range of C_L. While the relative errors are somewhat larger in the subsonic range, the agreement is still fairly satisfactory.

Conclusion

The present study suggests that the simple analytical approximation (2) can be advantageously used in the turn calculations of a fighter aircraft. The magnitude of a is of the order of k and hence aC_L^4 is comparable to kC_L^2 when C_L is of the order of unity. The variation of a with Mach number is shown in Fig. 3.

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Engine Life Cycle Cost: A Laboratory View

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LIFE cycle cost (LCC) is defined by Air Force Regulation 800-11 as "the total cost of an item or system over its full life." As applied to airbreathing engines, it includes the cost to develop and test the engine during the engineering development phase; the cost to produce the engine in quantity during

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