N76 11019

7.1 Some Comments on Trim Drag

Jan Roskam
University of Kansas

Introduction

This paper presents a discussion of data of and methods for predicting trim drag. Specifically the following subjects are discussed:

- Economic impact of trim drag.
- The trim drag problem in propeller driven airplanes and the effect of propeller and nacelle location.
- Theoretical procedures for predicting trim drag.
- Research needs in the area of trim drag.

An Example of the Economic Importance of Trim Drag

Trim drag is here defined as the horizontal tail induced drag caused by the need to trim the airplane for $C_m = 0$. Tail profile drag is included in overall airplane zero lift drag.

Trim drag typically varies from .5 percent to five percent of total airplane drag in cruise, depending on airplane type and on center of gravity location.

For a typical business jet, Figure 1 shows the variation of $\Delta C_{D_{trim}}$ with center of gravity location. Using this example, assuming a cruise L/D = 10.8, a cruise thrust required of 1092 lbs. at M = .72 and 45,000 ft., Table 1 shows the fuel flow caused by this drag for three c.g. locations.

Table 2 summarizes what this means for an operation using one airplane 1000 hours per year. Table 2 also shows what the fuel expenditures due to trim drag are for a fleet of 500 airplanes in one year.

Although trim drag by itself seems so small as to be negligible, integrating it over time and fleets indicates that more careful attention should be paid to trim drag.

Preceding Page Blank

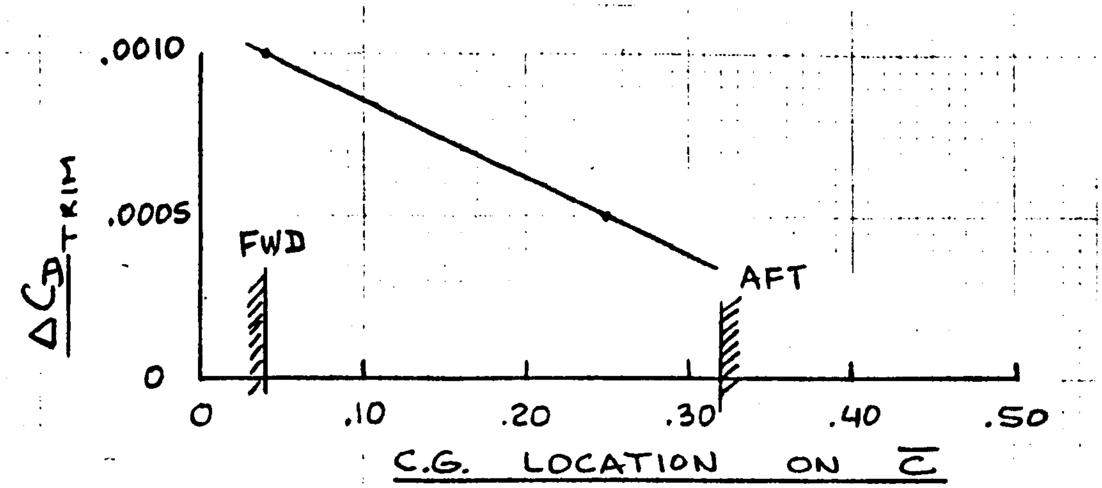

Figure 1. Example of Trim Drag Variation with Center of Gravity Location

Table 1. Fuel Flow due to Trim Drag as Function of Center of Gravity Location

Center of Gravity (See Fig. 1)	Fuel Flow due to Trim Drag (lbs./hr.)
FORWARD LIMIT	39
MID	19.5
AFT LIMIT	12

Table 2. Economic Importance of Trim Drag

	Aft C.G. extra gallons burned due to trim drag	Fwd C.G. extra gallons burned due to trim drag
1 airplane 1000 hours	1832	5954
500 airplanes 1000 hours each	916,000	2,977,000

The Trim Drag Problem in Propeller Driven Airplanes

Illustration of the Problem - It would seem that the designer, when trying to minimize drag, including trim drag is confronted with many unsolved problems. To illustrate the complexity of the design problem when including trim drag, consider Figure 2 and the following equations which need to be satisfied:

$$C_m = C_{m_0} + \frac{\partial C_{m_0}}{\partial T_c} T_c + C_{m_\alpha}\alpha + \frac{\partial C_{m_\alpha}}{\partial T_c} T_c \alpha + C_{m_{\delta_E}}\delta_E + \frac{\partial C_{m_{\delta_E}}}{\partial T_c} T_c \delta_E + C_{m_{i_H}} i_H + \frac{\partial C_{m_{i_H}}}{\partial T_c} T_c i_H \qquad (1)$$

$$C_L = C_{L_0} + \frac{\partial C_{L_0}}{\partial T_c} T_c + C_{L_\alpha}\alpha + \frac{\partial C_{L_\alpha}}{\partial T_c} T_c \alpha + C_{L_{\delta_E}}\delta_E + \frac{\partial C_{L_{\delta_E}}}{\partial T_c} T_c \delta_E + C_{L_{i_H}} i_H + \frac{\partial C_{L_{i_H}}}{\partial T_c} T_c i_H \qquad (2)$$

$$C_D = C_{D_0} + \frac{C_{L_{WBV}}^2}{\pi A e|_W} + \frac{C_{L_H}^2}{\pi A e|_H}\frac{q_H}{q}\frac{S_H}{S_W} \qquad (3)$$

$$C_{L_H} = a_H\left(\alpha + i_H + \alpha_\delta \delta_E - \varepsilon - \frac{\partial \varepsilon}{\partial T_c} T_c\right) \qquad (4)$$

$$C_L = C_{L_{WBV}} + C_{L_H}\frac{q_H}{q}\frac{S_H}{S_W} \qquad (5)$$

It is noted that all coefficients and derivatives in equations 1 through 5 are functions of the shape of the configuration (including fuselage camber) and the location an angular orientation of the thrustline. The question which needs to be answered is how to optimize L/D. In view of potential importance of trim drag and the interaction of associated design decisions with the handling qualities of the airplane, some theoretical (methodological) research into this area seems needed. Certainly no solution to this problem is readily available today, except perhaps in the case of pure jet airplanes.

In nearly all current propeller driven general aviation airplanes, trim drag is ignored, so that the entire problem of trying to minimize it as part of the overall drag does not come up.

Illustrations of the Effect of Nacelle and Propeller Location on Trim Drag - Reference 1 shows the importance of thrust coefficient on C_{M_0} of different airplane configurations. Figure 3 illustrates the favorable effect increasing thrust coefficient can have on C_{M_0}. At the same time, Figure 4 shows how decreasing wing height

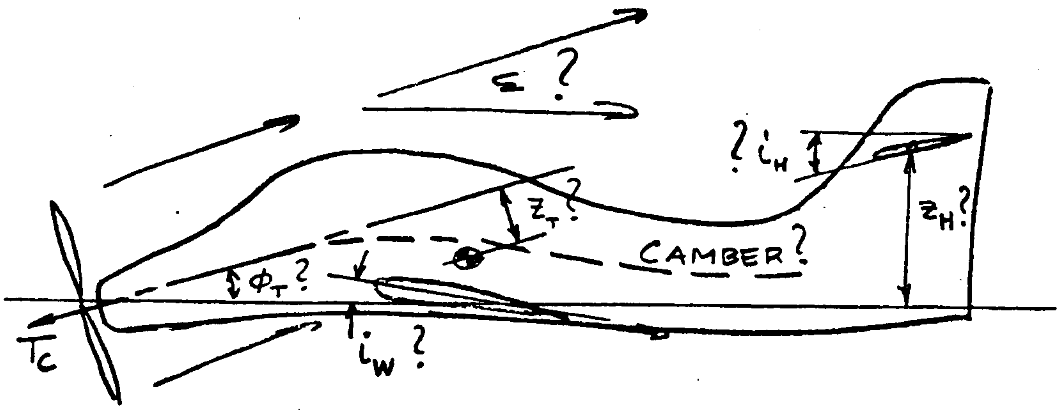

Figure 2. Illustration of Design Choices Affecting Trim Drag

can have an unfavorable effect on C_{M_0}. (A change in C_{M_0} of $|.10|$, using $C_{M_{\delta E}} = -.02$ means a 5 degree change in elevator required for trim.)

Reference 2 shows that a downward tilt of 5^o of the propeller axis of a typical WWII fighter configuration can cause an aft shift in a.c. of 5 to 10 percent, while also causing very large changes in C_{M_0}. Even though the aft shift in a.c. may be desirable to attain satisfactory longitudinal stability on high horsepower configurations the effect on trim drag is unfavorable.

These illustrations are meant to show the importance of considering the complicated interactions of these factors. No simple, reasonably accurate preliminary design procedures exist to account for them. Evidently there is a need to develop them.

A Method for Predicting Trim Drag of Jet Airplanes

Figure 5 illustrates the relation between WBV-lift and H-lift vectors. Note that it is not immediately clear from Figure 5 whether overall lift-to-drag ratio improves or deteriorates with c.g. movement. This depends to a large extent on the L/D of WBV in its untrimmed state relative to the value of $L/D|_{max}$ of WBV. It evidently also depends on whether the tail is uplifting or downlifting to achieve pitching moment balance. (These comments also apply to propeller driven airplanes.) Figure 6 illustrates the possibilities and Figure 7 shows the potential outcome.

Reference 3 shows that the trimmed drag coefficient of a tail-aft configuration can be estimated from:

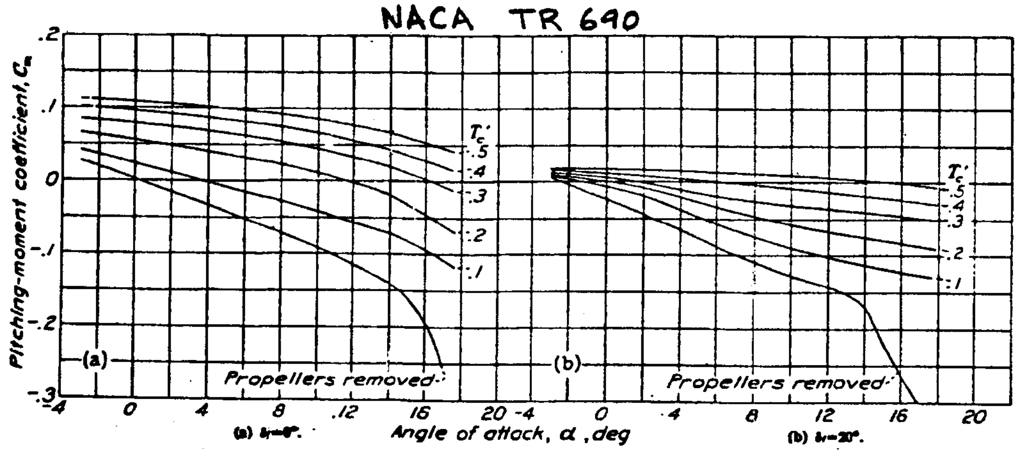

Figure 3. Effect of Propeller Operation on the Pitching-Moment Coefficient

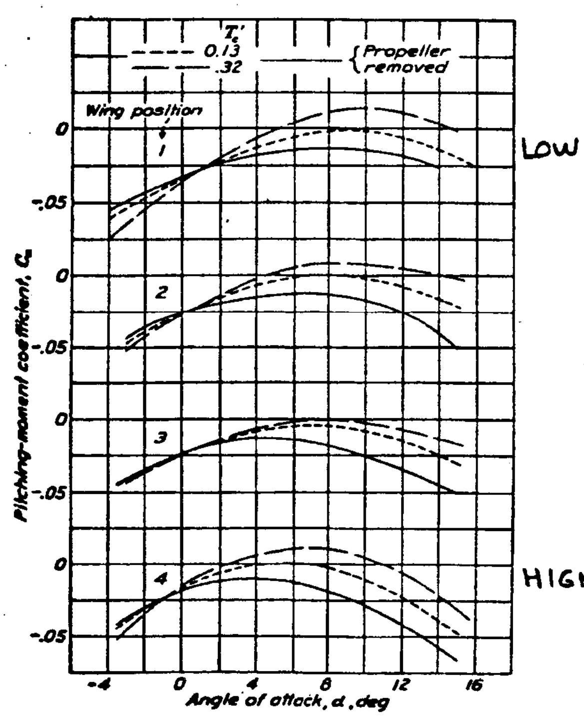

Figure 4. Effect of Propeller Operation on the Pitching-Moment Coefficient

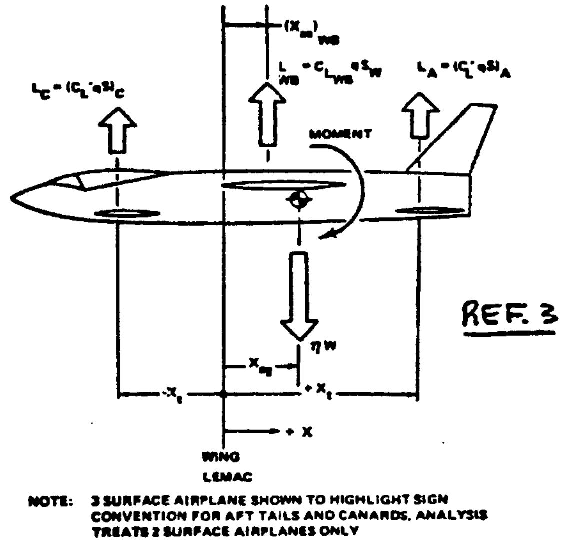

Figure 5. Coordinate System and Sign Convention

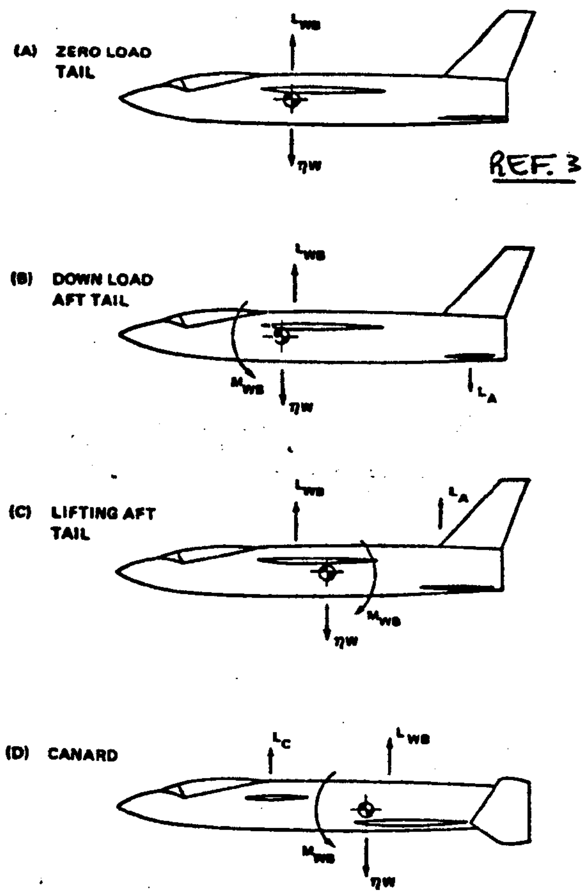

Figure 6. Effect of Center of Gravity and Wing-Body Aerodynamic Center Location on Lift Sharing $C_{M_o} = 0$.

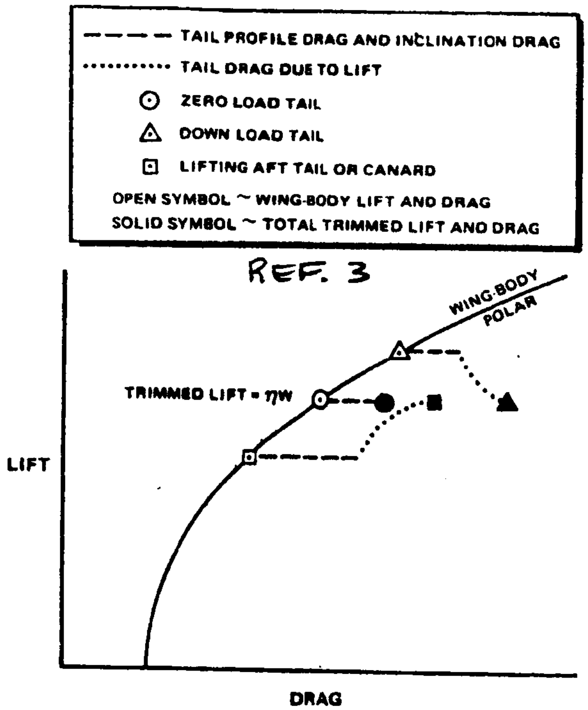

Figure 7. Trim Drag Elements

$$C_{D_{TRIM}} = C_{D_{o_{WBV}}} + C_{D_{o_H}} \frac{S_H}{S_w}\frac{q_H}{q} + \frac{(C_L - C_{L_o})^2_{WBV}}{\pi A e|_{WBV}} + \frac{C^2_{L_H}}{\pi A e|_H}\frac{S_H}{S_w}\frac{q_H}{q} \qquad (6)$$

Note the absence of thrust effect terms.

Expressions for $C_{L_{WBV}}/C_{L_{trim}}$ and $C_{L_H}/C_{L_{trim}}$ can be found by imposing the conditions that total lift equals airplane weight (level flight) and that the total pitching moment is zero:

$$C_m = C_{m_{o_{WBV}}} + C_{m_{\alpha_{WBV}}}\alpha + C_{m_H} \qquad (7)$$

where

$$C_{m_H} = - C_{L_H} \frac{\ell_H}{\bar{c}_w}\frac{q_H}{q} \qquad (8)$$

and

$$C_{m_{\alpha_{WBV}}} = \left(\bar{X}_{cg} - \bar{X}_{ac_{WBV}}\right) C_{L_{\alpha_{WBV}}} \qquad (9)$$

Reference 3 shows for fighter type configurations that this method gives accurate results. Results indicate that trim drag can affect the trimmed L/D of such configurations by $\pm$ 7 percent depending on overall arrangement and c.g. location.

From equation (7) it is evident that C_{M_o} can play a role in reducing adverse (i.e., down load on tail) trim requirements. It would be desirable to give the airplane a positive value of $C_{M_o} > 0$ by fuselage camber. What is not known today, is how the general aviation fuselage can be shaped in such a way that:

1. C_{M_o} is as close as possible to being positive
2. fwd visibility and windshield shape are compatible with $C_{M_o} > 0$ and low windshield drag
3. contour lines are not expensive to produce
4. aft fuselage shape does not violate take-off rotation requirements.

Some systematic research into this area may very well pay off. Perhaps a theoretical trade-off study of a wide range of fuselage camber shapes should precede a systematic windtunnel investigation.

The effect of wing mounted nacelles on C_{M_o} and C_{D_o} should also be investigated in a systematic manner. The latter in view of the fact that general aviation twins use widely varying wing-nacelle shapes not all of which can be particularly good. (See Reference 4.)

Summary of Research Needs in the Trim Drag Area

In view of the fact that trim drag can affect the cruise lift-to-drag drag ratio by up to seven percent, it would seem desirable to have procedures available to accurately account for it. For propeller driven airplanes these procedures do not seem to exist.

Because of the potentially large effect of C_{M_0} on trim drag, this quantity should be accurately predictable. It is not today.

The following research is therefore needed:

1. Development of a theoretical procedure to predict C_{M_0} including propeller thrust interactions;
2. Development of a preliminary design method for predicting trim drag of propeller configurations; and
3. Configuration research to see if perhaps other than conventional tail-aft configurations are capable of yielding better cruise lift-to-drag ratios.

References

1. Katzoff, S.; Longitudinal Stability and Control with Special Reference to Slipstream Effects; NACA TR 690, 1940.
2. Goett, H.J. and Delany, N.K.; Effect of Tilt of the Propeller Axis on the Longitudinal Stability Characteristics of Single-Engine Airplanes; NACA TR 774, 1944.
3. Goldstein, S.E. and Combs, C.P.; Trimmed Drag and Maximum Flight Efficiency of Aft Tail and Canard Configurations; AIAA Paper 74-69 presented at the AIAA 12th Aerospace Sciences Meeting, Jan. 30 - Feb. 1, 1974, Washington, D.C.
4. Roskam, J.; Drag of the Complete Configuration, Part II, Aerodynamic Considerations; Paper presented at the NASA/Industry/University General Aviation Drag Reduction Workshop; July 14, 15, 16, 1975, The University of Kansas.

7.2 Trim Drag Research Results

H. Chevalier
Texas A & M University

This paper was not submitted for inclusion in these proceedings.

Preceding Page Blank