EFFECT OF STABILIZER LIFT ON SAILPLANE PERFORMANCE

Major Judson T. Bauman
Beale Air Force Base
Marysville, California

Presented at the 12th OSTIV Congress
Alpine, Texas, U.S.A., 1970

ABSTRACT

Since the sailplane represents a highly optimized aerodynamic form, the influence on performance of small effects such as stabilizer lift is worth considering. This paper analyzes the induced drag of the stabilizer and its effect on sinking speed. An equation is derived relating the fractional increase in sinking speed to the stabilizer lift coefficient and the aircraft's shape parameters. The equation for aircraft pitching moment in steady flight is introduced in order to obtain the relation between fractional increases in sinking speed and airspeed and center of gravity location. Data from a Schleicher K-8B is used to illustrate the resulting formula. It is concluded that non-zero stabilizer lift increases sinking speed and for a K-8B the greatest effect is with a forward C.G. position and a high airspeed.

INTRODUCTION

Concerted efforts by sailplane designers over the years have resulted in craft with highly optimized aerodynamic forms. Therefore, small effects which may be ignored for other aircraft are of interest to sailplane designers and pilots.

This paper is an analysis of the effect of stabilizer lift on sailplane sinking speed and the effect of C.G. position in establishing that stabilizer lift and attendant performance loss.

The effect of stabilizer lift on aircraft performance has rarely been investigated. Monson (Ref. 1) analyzed the effect but made some errors. Monson concluded that positive stabilizer lift improved performance. In Ref. 2, Dr. Hoerner advised that stabilizer lift decreases performance and that the effect is greatest at high wing lift coefficients, that is, in the climb. The subject is also briefly mentioned by Irving (Ref. 3), but he reaches no conclusion in regard to performance effects of stabilizer lift.

This paper concludes that performance decreases with increasing stabilizer lift but that the effect is greatest at low lift coefficients.

ANALYSIS

Symbols

$A \quad = \frac{b^2}{S}$ Aspect Ratio

$b \quad =$ Wing Span (ft)

$C_L = \frac{L}{\frac{1}{2}\rho V^2 S}$ Aircraft Lift Coefficient

$C_D = \frac{D}{\frac{1}{2}\rho V^2 S}$ Aircraft Drag Coefficient

$C_{L_W} = \frac{L_W}{\frac{1}{2}\rho V^2 S}$ Wing Lift Coefficient

$C_{L_t} = \frac{L_t}{\frac{1}{2}\rho V^2 S_t}$ Stabilizer Lift Coefficient

$C_{D_{P_e}}$ = Aircraft Effective Parasitic Drag Coefficient (Drag at zero lift with parabolic polar)

$C_M = \frac{M}{\frac{1}{2}\rho V^2 S \bar{c}}$ Aircraft Pitching Moment Coefficient

$C_{M_{0_W}}$ = Pitching Moment Coefficient of Wing Fuselage Combination

$\bar{c}$ = Mean Aerodynamic Chord (ft)

C.G. = Center of Gravity

D = Drag (lb)

e = Oswald aircraft efficiency factor (effectiveness of aspect ratio)

h = Location of C.G. aft of leading edge of $\bar{c}$ as a fraction of C.

h_{n_W} = Location of wing aerodynamic center aft of leading edge of $\bar{c}$ as a fraction of C.

L = Net lift of whole aircraft (lb)

L_W = Wing Lift (lb)

L_t = Stabilizer Lift (lb)

l_t = Distance between C.G. and aerodynamic center of stabilizer (ft)

M = Moment (ft-lb)

S = Wing area (ft^2)

S_t = Stabilizer area (ft^2)

T = Thrust (lb)

V = Airspeed (ft/sec)

V_s = Sinking speed (ft/sec)

$V_h = \frac{S_t \, l_t}{S \, \bar{c}}$ Horizontal Tail Volume Coefficient

ϵ = Downwash angle measured positive clockwise in Fig. 1 (radians)

ρ = Atmospheric Density (slug/ft^3)

θ = Glide angle measured below horizontal (radians)

Subscripts

$(\ )_o$ = Zero Lift Tail

$(\ )_t$ = Lifting Tail

$(\ )_w$ = Wing only.

Sign Conventions

Lift coefficients positive upward.

Drag coefficients positive aft.

Moment coefficients positive clockwise in Fig. 1.

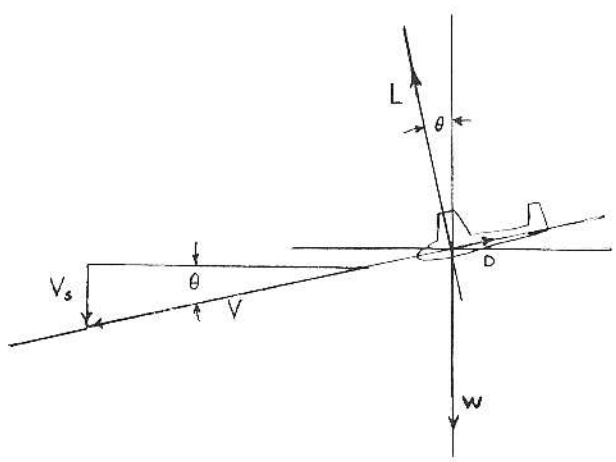

FIG. 1. Force and Velocity Diagram Aircraft in Gliding Flight

EFFECT OF STABILIZER LIFT

We use the customary analysis of steady gliding flight, assuming the glide angle θ to be small. From Fig. 1 we write

$$\tan\theta = \frac{D}{L} = \frac{C_D}{C_L} \qquad (1)$$

and the sinking speed is

$$V_s = V\sin\theta = V\frac{C_D}{C_L} \qquad (2)$$

We compare the sinking speeds of geometrically similar aircraft of equal weight which differ only in tail lift. The ratio of sinking speeds at the same airspeed is:

$$\frac{V_{s_t}}{V_{s_0}} = \frac{V\left(\frac{C_D}{C_L}\right)_t}{V\left(\frac{C_D}{C_L}\right)_o} = \frac{\left(\frac{C_D}{C_L}\right)_t}{\left(\frac{C_D}{C_L}\right)_o} \qquad (3)$$

Since C_L refers to the total lift coefficient it must be the same for both cases, so Eq. 3 becomes

$$\frac{V_{st}}{V_{so}} = \frac{(C_D)_t}{(C_D)_o} \qquad (4)$$

Similarly, for the thrust required ratio for level subsonic cruise

$$\frac{T_t}{T_o} = \frac{D_t}{D_o} = \frac{(C_D)_t}{(C_D)_o} \qquad (5)$$

Hence, the following analysis applies to level subsonic cruise as well.

The lift coefficient for the lifting tail aircraft is expressed as

$$L = L_W + L_t \qquad (6)$$

so that

$$C_L = C_{L_W} + \frac{S_T}{S} C_{L_t} \qquad (7)$$

We assume that the parabolic drag polar is sufficiently accurate to compare performance and note for the zero tail lift case

$$(C_D)_o = C_{D_{P_e}} + \frac{C_L^2}{\pi e A} \qquad (8)$$

For the lifting tail case, we add the induced drag of the stabilizer to obtain:

$$(C_D)_t = C_{D_{P_e}} + \frac{C_{L_W}^2}{\pi e A} + \frac{S_t}{S}\left[\epsilon\, C_{L_t} + \frac{C_{L_t}^2}{\pi e_t A_t}\right] \qquad (9)$$

Perkins and Hage (Ref. 4) give for the downwash at the stabilizer:

$$\epsilon = \frac{2\, C_{L_W}}{\pi e A} \qquad (10)$$

We will discuss this assumption later. The sinking speed ratio becomes

$$\frac{V_{s_t}}{V_{s_o}} = \frac{C_{D_{P_e}} + \frac{C_{L_W}^2}{\pi e A} + \frac{S_t}{S}\left(\frac{2\, C_{L_W} C_{Lt}}{\pi e A} + \frac{C_{Lt}^2}{\pi e_t A_t}\right)}{C_{D_{P_e}} + \frac{C_L^2}{\pi e A}} \qquad (11)$$

To eliminate C_{L_W}, from the equation, Eq. 7 is solved for C_{L_W}, both sides squared, and divided through by $\pi e A$. The resulting expression is substituted into Eq. 11 and, after some rearranging, we get

$$\frac{V_{s_t}}{V_{s_o}} = 1 + \frac{\frac{S_t}{S}\left[\frac{eA}{e_t A_t} - \frac{S_T}{S}\right]\left(\frac{C_{Lt}}{C_L}\right)^2}{\frac{\pi e A\, C_{D_{P_e}}}{C_L^2} + 1} \qquad (12)$$

From Eq. 12, we can conclude that for $(C_{L_t}/C_L) \neq 0$ and reasonable values of A/A_t and S_t/S that $V_{s_t} > V_{s_o}$. Furthermore, this expression leads to a trim criterion, namely for best cruise or glide performance; trim for zero stabilizer lift.

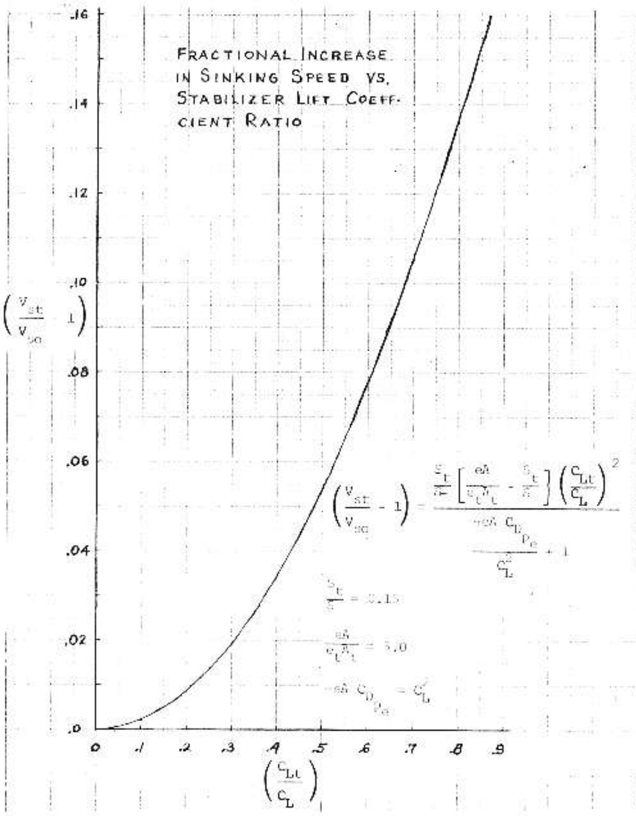

FIGURE 2

PERFORMANCE LOSS AS A FUNCTION OF C.G. POSITION

To establish the relation between the C.G. location and stabilizer lift coefficient, we employ the equation for aircraft pitching moment:

$$C_M = C_{M_{O_W}} + (h-h_{n_W})\, C_{L_W} - V_H\, C_{L_t} \qquad (13)$$

In using this expression, we are assuming:

1. Drag forces produce no significant moment about the C.G.
2. The stabilizer and elevator have no camber and the elevator is streamlined.
3. Flight is in the low Mach number regime, so compressibility effects are negligible.
4. Aeroelastic effects are negligible.

For steady flight, $C_M = 0$ so the expression for trim is:

$$0 = C_{M_{O_W}} + (h-h_{n_W})\, C_{L_W} - V_H\, C_{L_t} \qquad (14)$$

Again, using Eq. 7 to eliminate C_{L_W} and solving for C_{L_t}/C_L, we obtain:

$$\frac{C_{L_t}}{C_L} = \frac{(h-h_{n_W}) + \dfrac{C_{M_{O_W}}}{C_L}}{V_H + (h-h_{n_W})\dfrac{S_t}{S}} \qquad (15)$$

We substitute Eq. 15 into Eq. 12 and the result is:

$$\frac{V_{s_t}}{V_{s_o}} - 1 = \frac{\dfrac{S_t}{S}\left[\dfrac{eA}{e_t A_t} - \dfrac{S_t}{S}\right]\left[\dfrac{h - h_{n_W} + C_{M_{O_W}}/C_L}{V_H + (h-h_{n_W})\, S_t/S}\right]^2}{\dfrac{\pi e A\, C_{D_{P_e}}}{C_L^2} + 1} \qquad (16)$$

the fractional increase in sinking speed or thrust required as a function of C.G. position h.

CALCULATED PERFORMANCE LOSS FOR A K-8B SAILPLANE

The Schleicher K-8B sailplane was chosen for an example to illustrate Eq. 16 because it is widely known and the author had already made previous performance analysis of it.

Data from Ref. 6 gave: $W/S = 4.47$ lb/ft^2; $S_t/S = 0.138$; and $V_H = 0.568$. The quantity

$$\frac{eA}{e_t\ A_t} = 5.2$$

was estimated from two sources. From Ref. 6, wing loading and performance data were taken to estimate $C_{D_{p_e}}$ and e. A technique outlined by Hoerner in Ref. 2 was used to compute e_t. The values of A and A_t are given in Ref. 6.

The author did not have any data on $C_{M_{O_W}}$ for the K-8B nor on the Gottingen airfoils used so $C_{M_{O_W}} = 0.10$ was assumed and $h_{n_w} = 0.25$ was also assumed.

Departures of the above items from the estimated values will not change the qualitative conclusions reached. The resulting values are plotted in Fig. 3.

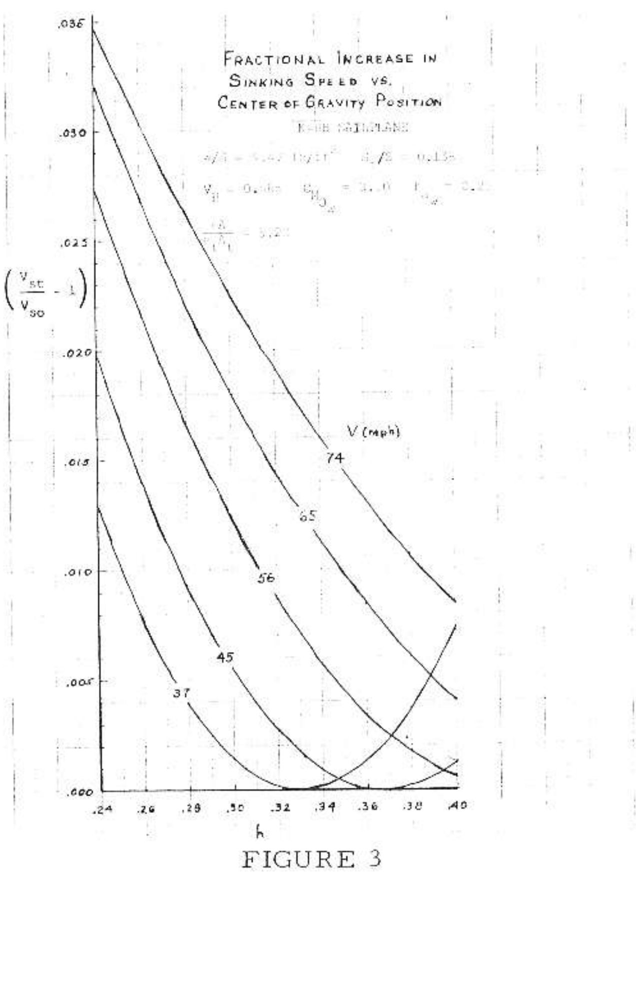

FIGURE 3

DISCUSSION

The result of the first part of the analysis, Eq. 12, is plotted in Fig. 2. The fractional loss in sinking speed is simply a parabola symmetric about the $C_{L_t}/C_L = 0$ axis so the function is plotted only for positive values of the argument. It is obvious then that only the magnitude of the stabilizer lift coefficient matters. Upward lift degrades performance just as much as downward stabilizer force.

Of particular interest to sailplane performance is that Fig. 2 has been plotted for $C_L^2 = \pi eA\ C_{D_{p_e}}$. Therefore, the lift coefficient corresponds to $(L/D)_{max}$. The other arguments are purely arbitrary and do not necessarily reflect typical values for a sailplane.

The most important assumption in the derivation of Eq. 12 is Eq. 10. The use of Eq. 10 implies several things:

1. The flow field around and behind the wing is adequately predicted by inviscid flow theory.
2. The stabilizer is located at the centerline and directly in the wing wake.
3. The downwash angle is the same across the stabilizer span.
4. The fuselage does not significantly alter the flow field about the stabilizer.

Considering the assumptions in turn:

1. The viscous effects on downwash angles are small and the equation from Perkins and Hage has adequate justification from wind tunnel flow measurements.
2. According to the downwash graphs in Ref. 5 the influence of small amounts of vertical displacement of the stabilizer above (or below) the wing wake consists of small departures of ± 0.3 deg per unit lift coefficient or less. Since the downwash angle itself is on the order of 3 deg per unit C_L, the effect can be neglected. It is possible that positive stabili-

zer lift would produce a slight performance gain in a T-tail design where the downwash at the stabilizer is less than that predicted by Eq. 10.

3. Since the stabilizer span is small compared to the wing span, the difference between centerline downwash values and the average across, the stabilizer span can be considered negligible. The graphs of Ref. 5 , which were calculated using a stabilizer span of one-third the wing, do not depart more than 4 percent from centerline values tending to confirm the assumption.

4. However, assumption (4) can be quite erroneous. The fuselage has a large effect on downwash values. The effect can be thought of in terms of two sources. One is the interference with the spanwise lift distribution due to the fuselage-wing root configuration affecting the downwash pattern and the second is the interference with the resultant pattern by the presence of the fuselage at the stabilizer.

The magnitude of both effects depends on the relative size of the local fuselage diameter compared to the wing or stabilizer chord. Since typical sailplanes have comparatively small fuselage diameters, we expect the effect to be minimized. Also, in a T-tail configuration the stabilizer-fuselage interference effect should vanish.

Finally, the author has successfully predicted stabilizer incidence settings for glide trim in two competition glider models (FAI, A-2 Class) using the graphs of Ref. 5 . These models also have relatively small fuselage diameters compared to the wing chord.

Hence, a reasonable qualitative argument can be made in favor of accepting the validity of Eq. 10 for high-performance sailplanes.

The important conclusion from Eq. 12 is that there is an optimum trim condition of zero stabilizer lift.

The Effect of C.G. Position

Figure 3 shows Eq. 16 computed for several airspeeds throughout the certificated C.G. range of the K-8B sailplane. Several effects are noteworthy.

1. Increasing airspeed (reducing the lift coefficient) increases the loss for most of the C.G. range. This effect is contrary to Hoerner's statement that the stabilizer lift would be most adverse in a climb (high lift coefficient). Evidently, the K-8B's penetration is adversely affected by stabilizer lift.

2. The optimum C.G. position appears to be in the 0.36 to 0.40 region, well aft.

3. The effect is modest. The worst case calculated is C.G. at the 24 percent position and 74 mph airspeed. Schleicher literature gives L/D = 16.7 at 74 mph. The improvement to be expected by shifting from the 24 percent position to the 40 percent position is + 0.57 in the L/D. At the $(L/D)_{max}$ = 27, corresponding to 45 mph, the improvement would be 0.54.

A close look at Eq. 16 reveals that lower parasitic drag ($C_{D_{p_e}}$) increases the effect at high lift coefficients. Thus, we would expect cleaner higher performance sailplanes to be more sensitive to stabilizer lift and C.G. position at their $(L/D)_{max}$.

CONCLUSION

The effect of stabilizer lift on sailplane performance is to increase the sinking speed. The effect is dependent on the C.G. position which determines the stabilizer lift coefficient. On the Schleicher K-8B sailplane, forward limit C.G. positions and higher airspeeds are the most detrimental conditions.

For References, see p. 39.

ABSTRACT

Les Championnats Du Monde De Vol a Voile De Marfa (Texas) et la Préparation Médico Physiologique des Équipes. par G. Stedtfeld et J.P. Crance. Revue de Médicine Aéronautique et Spatiale. No. 36 1970

The World Gliding Championships at Marfa (Texas) and the Medico-Physiologic Preparation of the Teams.

Discussion and analysis, at the Colloque franco-allemand de Fayence, on the medical aspects governing the preparation of the French and German teams for this international contest are outlined.

Medical problems arise from the hot, dry climate of the semidesert region of southwest Texas. Team personnel are exposed to danger from dehydration, hyponatremia, and changes in hydroelectrolytic equilibrium. Such problems are monitored by determining body weight and corrected by a higher fluid intake and salt tablets.

German doctors recommend training to increase bladder capacity and reduce the problems of urination in long flights. Concentrated fruit juice is preferred to tea, coffee, or carbonated beverages as fluid intake, and drinking in-flight is undesirable. The French consider fresh water in-flight necessary to combat rapid dehydration. A fresh water emergency supply is required for possible off-field landings.

A nutritious, protein-rich, breakfast is the most important dietary item, and is consistent with American eating habits. Emotional stress and preoccupation with launch preparations result in a rapid intake of sandwiches and fruit at midday, causing danger of glycemia toward evening. In-flight eating ranges from cake, fruit, and dry food to nothing, regardless of recommendations.

Hypoxia is a danger at the flight levels used. Oxygen is necessary at greater than 4000 m. asl. Based on experience in South Africa, the Germans set 3000 m. asl. as the minimum altitude for oxygen use.

Rattlesnake bites are a hazard in field landings. Crews and pilots are trained in the symptoms, precautions, and the use of snake bite kits.

Good physical form is essential for pilots to withstand the long, tiring flights involving minimum muscle movement. The Germans recommend all forms of exercise, i.e., walking, cycling, swimming, skiing, plus twice-daily sauna treatments to increase resistance to temperature variations.

The team doctors are equipped to monitor body weight, blood pressure, and heart rate, and to handle minor surgery and dressings. More extensive medical facilities are provided on-site and in the contest area. Doctors are responsible for the physical health and morale of team members and need to appreciate hygiene and dietary problems as well as the spirit of soaring.

Translated and abstracted by Erica Scurr.

REFERENCES (Bauman)

(from p. 15)

1. Monson, Don, A Generalized Method of Optimizing Aircraft Performance with Emphasis on the Clipper Cargo Event, in 1959-61 Model Aeronautic Yearbook, Ed F. Zaic. Model Aeronautic Publications, N.Y., N.Y., 1961, pgs 221 through 227.

2. Hoerner, S.F., Fluid Dynamic Drag, published by the author.

3. Irving, F.G., All-Moving Tailplanes, in OSTIV Publication VII. Summary of the Lectures held during the IX Congress of OSTIV in Junin, Argentina, 11-21 February 63.

4. Perkins, C.P. and Hage, R.E., Airplane Performance, Stability, and Control, Wiley, 1949.

5. Etkin, B., Dynamics of Flight, Wiley, 1959.

6. OSTIV: Worlds Sailplanes II.