SAILPLANE PERFORMANCE ESTIMATION

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SUMMARY

The estimation of the performance of a modern sailplane should be easy because of the relative simplicity of the sailplane configuration and the generally good quality of aerodynamic surfaces used. Evaluation of the glide performance of a sailplane essentially consists of an estimation of drag as a function of forward speed. In this paper, the parameters contributing to drag have been separated out. Some of these are easy to evaluate on theoretical grounds, while others, such as wing-body interference drag for example, are very uncertain. Fortunately, the largest contributions to drag are the ones that can be evaluated with good accuracy, and if average values based on analysis of the performance of known sailplanes are assumed for the more uncertain parameters, quite good glide polars can be obtained for any sailplane with not much more input data than is usually given in sales promotion literature. One of the advantages of the drag equation presented here is that it identifies the parameters contributing to drag in such a way that the relative importance of each of these is shown. This equation is particularly useful in the analysis of flight test results because it makes it possible to spot the most likely sources of excess drag if the performance is not as good as it should be.

An analysis of the published flight test data for a number of modern sailplanes is presented in order to establish average values for the more uncertain parameters and to show the probable scatter in value of these parameters to be expected. Some further examples of the analysis of flight test data are given.

INTRODUCTION

Estimation of performance is an important part of the aerodynamic design process for any aircraft. Sailplane performance estimation should be particularly easy because of the relative simplicity of the sailplane configuration and the generally good quality of aerodynamic shapes and surfaces used. Performance is, however, easily spoiled by quite subtle effects such as wing-body interference or air leaks around canopies.

The problem of calculation of sailplane performance is essentially that of calculating drag coefficient, C_D, as a function of lift coefficient, C_L. The usual graphical display of performance given by the glide polar is completely determined if C_D is known in terms of C_L, and the wing loading is known.

The quadratic polar given in Equation 1 below has generally been used for prediction of sailplane performance, and flight test results indicate that it does indeed "fit" most sailplanes for values of C_L from about 0.2 to 1.2.

$$C_D = K_1 + K_2\, C_L^2 \tag{1}$$

The glide polar, sinking speed against forward speed is easily obtained from Equation 1.

Since $C_L = L/\tfrac{1}{2}\rho V^2 S = W/\tfrac{1}{2}\rho V^2 S$ (for flight at 1g) and

$$C_D = \text{Drag}/\tfrac{1}{2}\rho V^2 S$$

$$V = \sqrt{2W/\rho S\, C_L} \tag{2}$$

$$V_{sink} = V\, C_D/C_L$$

giving

$$V_{sink} = \frac{C_D}{C_L^{1.5}} \sqrt{\frac{2W}{\rho S}} \tag{3}$$

where W = aircraft weight
S = wing planform area
ρ = air density
V = forward speed

The constants K_1 and K_2 can be estimated from an analysis of the factors contributing to drag of the sailplane, or they can be determined experimentally from flight test results. An analysis of the many excellent flight test polar curves now available for current sailplanes will be helpful in making estimates for the parameters involved in constants K_1 and K_2 for new sailplanes. Alternatively, the drag equation can be used together with flight test results as an aid in localizing sources of drag on prototype sailplanes, or even ones that have been in service for some time.

This paper presents an expanded form of Equation 1 which can be used to give a good estimate of sailplane performance, and discusses the factors contributing to sailplane drag. Some examples are presented of the use of the drag equation for analysis of flight test results.

Wing Drag

Performance of a sailplane is mainly determined by wing aerodynamics. Wing drag arises from two sources; wing profile drag due to "skin friction" and the lift-induced drag due to the trailing vortex system.

Wing profile drag can be obtained from the published wind tunnel data for the wing section chosen. Since profile drag is a function of both lift coefficient and Reynolds number, the data which is normally given as a function of C_L for constant Reynolds number will have to be replotted to take into account change of Reynolds number with forward speed. Figure 1 shows a plot of profile drag against C_L for the wing section FX 62-K-131/17 derived from Reference 1 assuming C = 2.4 feet and wing loading W/S = 7.05 lbs/ft^2. Since this wing section is equipped with a camber-changing flap it has been assumed that the flap is in its optimum position for each value of C_L.

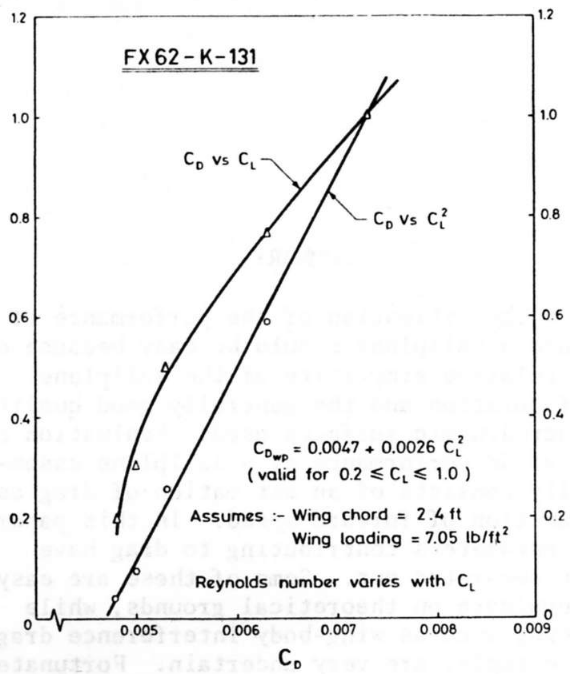

FIGURE 1. Wing Section Profile Drag

Values of C_D against C_L^2 have also been plotted in Figure 1 and it can be seen that they give a reasonably good straight-line fit. Taking the intercept at $C_L^2 = 0$ as C_{D_o}' and the slope $dC_D/dC_L^2 = B$, the wing profile drag can be represented to a good approximation by the quadratic equation,

$$C_{D_{wing\ profile}} = C_{D_o}' + BC_L^2 \tag{4}$$

In this case $C_{D_o} = 0.0047$ and $B = 0.0026$.

Induced drag can be estimated with good accuracy by the equation,

$$C_{d_i} = (1 + \sigma)\, C_L{}^2/\pi A, \qquad (5)$$

if it is a fairly conventional sailplane wing without discontinuities such as might be caused by partial-span flaps, for example. In Equation 5 A is aspect ratio and σ is a factor depending on planform shape and wing twist. An exact value of σ can be calculated (Reference 2) if the wing geometry is known. Most sailplanes have a double-tapered planform approaching the ideal elliptical shape and not more than a few degrees wing twist. This being the case a value of $\sigma = 0.05$ would be suitable for our estimation of induced drag coefficient.

Fuselage Drag

The fuselage can be assumed to be a streamlined body, but it is usually longer than the optimum 3.5:1 fineness ratio. It also contains disturbances caused by canopy and wheel door joints, possible leaks at these joints, wing-root junction and sundry total-energy probes and radio aerials. The wing-body junction is particularly difficult to deal with because the overall pressure field around the wing will affect fuselage drag but the magnitude of such an effect is not easy to predict. Wing-body interference drag may be as much as 50% of the drag of the fuselage alone (Reference 3). A further factor to be considered is the size of the fuselage relative to the wing area. Since the size of pilot is the factor controlling fuselage size, fuselage drag will be relatively less for a sailplane having more wing area.

For purposes of estimating sailplane drag, the fuselage drag coefficient will be taken to be:

$$C_{D_{fus}} = C_{D_\pi}\,(1 + K_3 C_L{}^2)\, AF/S \qquad (6)$$

where C_{D_π} is drag coefficient based on maximum fuselage cross-section area, AF, and the factor K_3 multiplying $C_L{}^2$ is to account for the dependence of wing-body interference drag on lift coefficient.

Values of C_{D_π} can be derived from flight test results for current sailplanes. The value of C_{D_π} chosen for performance estimation can be based on an average value and perhaps adjusted to reflect the expected quality of fuselage aerodynamics.

Tailplane Drag

Tailplanes generally operate at low values of C_L throughout most of the flight range. It is possible to calculate the induced drag contribution if the complete characteristics of the sailplane are known, but since induced drag is small and nearly constant it will be simpler to just add it in with profile drag for the tailplane. An approximate value of tailplane drag is given by:

$$C_{D_{tail}} = 0.008\ SE/S$$

where SE is the area of the entire fin and rudder and horizontal tailplane.

Total Sailplane Drag

Combining all the contributions to drag coefficient we have;

$$C_D = C_{D_o}{}' + C_{D_\pi} AF/S + 0.008\ SE/S$$
$$+ [(1 + \sigma)/\pi A + B + K_3 C_{D_\pi} AF/S]\ C_L{}^2 \qquad (7)$$

In terms of Equation 1

$$K_1 = C_{D_o} + C_{D_\pi}\ AF/S + 0.01\ SE/S$$

and

$$K_2 = (1 + \sigma)/\pi A + B + K_3 C_{D_\pi}\ AF/S$$

Evaluation of Constants

Some of the parameters in K_1 and K_2 can be determined fairly accurately from theory, while others are quite uncertain and untimately have to be determined by flight test. The value of $C_{D_o}{}'$ is known to good accuracy, and the assumed value of $C_{D_{tail}} = 0.008\ SE/S$ is reasonably accurate or can be estimated to good accuracy if more details of the tail are known. Thus a value of K_1 obtained from flight test results will essentially determine the value of C_{D_π}. In the case of K_2 both $(1+\sigma)/\pi A$ and B are known to good accuracy, and flight test results can be used to evaluate K_3. The value of K_3 is likely to vary widely since it arises from interference effects that depend on the wing-root geometry as well as a more subtle relationship between pressure fields of the wing and body.

Analysis of Flight Test Data

Table 1 shows an analysis of some flight test data by Bikle (Reference 4) and Johnson

(References 5-7) analyzed on the basis of Equation 7.

Values for the wing section profile drag were derived from data given by Althaus in the Stuttgarter Profilkatalog (Reference 1) making allowance for change of Reynolds number with flight speed. Most of the wing sections used on the sailplanes listed in the table gave good linear relationships between C_D and C_L^2 for the range $0.2 < C_L < 1.0$ similar to that illustrated in Figure 1. The one exception was FX67-K-170. The data for FX67-K-150 did form a straight line with a reasonable fit through the FX 67-K-170 data points as well, so the values of C_{D_o}' and B for FX 67-K-150 were used for those aircraft having an FX 67-K-170 wing section.

Values of C_{D_π} are in the range 0.038 to 0.068 with the one exception of 0.114 for the ASW-12. The reason for this exceptionally high value is not at all obvious. It may be partly due to the very long slender shape giving a larger wetted area to cross-sectional area ratio than the more optimal pod and boom fuselages now used on most sailplanes.

This higher-than-normal fuselage drag is especially ironical when pilots have squeezed into a rather tight and very reclined cockpit in order to reduce fuselage drag. It is worth reconsidering the assumptions made in arriving at this value. The measured value of $K_1 = 0.090$ is made up from three components.

$$K_1 = C_{D_o}' + 0.008 \, SE/S + C_{D_\pi} \, AF/S$$

The value of C_{D_o}' could easily be larger than the 0.0047 given by the wing section data for a number of reasons. The most obvious possibility is extra drag due to the inevitable roughness that occurs on real wings due to control joints, etc. In this respect, however, the ASW-12 is probably no worse than the other two open class ships.

Bikle (Reference 4) lists the wing section as FX 62-131KM, the M signifying that the designer has modified the shape of the wing section in some unspecified manner. The result of a minor change in shape can range from negligible effect to large increase in drag and loss of lift. In this case the designer probably increased the thickness chord ratio and this would likely cause an increase in C_{D_o}'. The value for the similar wing section FX 62-K-153 is $C_{D_o}' = 0.0053$ and $B = 0.0026$. If we assume these values, $C_{D_\pi} = 0.092$, which is still quite high.

Values of $C_{D_\pi} = 0.038$ for the Standard Cirrus and $C_{D_\pi} = 0.048$ for the Nimbus II are reasonably consistent in that these two sailplanes have very nearly the same fuselage. The relatively high value of 0.068 for the Libelle 201 is to be expected because of its old fashioned bubble canopy shape. Leaving out the two high values, the average value for $C_{D_\pi} = 0.052$.

The values of K_3 show rather more variation and in this case we can distinguish a difference between aircraft with shoulder mounted wings and those with mid-fuselage wing position. The Nimbus II, Standard Cirrus and Standard Libelle all have mid-fuselage mounted wings and rather high values of K_3, while the values for those aircraft with shoulder mounted wings are comparatively lower. For purposes of performance estimation a value of $K_3 = 1.0$ can be used for a sailplane with a mid-fuselage wing and a value of $K_3 = 0.25$ if it has a shoulder wing. Fortunately, the term $K_3 C_{D_\pi} AF/S$ only makes up about 10% of the value of K_2.

The high value of K_3 for the Standard Cirrus probably only applies to the earlier varsions of the type as some improvements at the wing root and introduction of wing twist

TABLE 1

NAME	WING SECTION	C_{D_o}	B	S(ft^2)	A	SE/S	AF/S	$1+\sigma/\pi A$	K_1	K_2	C_{D_π}	K_3
NIMBUS II	FX67-K-170	0.0056	0.0031	155	28.6	0.12	0.030	0.0117	0.0080	0.0161	0.046	0.94
ASW 17	FX62-K-131	0.0047	0.0026	158	27.2	0.20	0.029	0.0123	0.0079	0.0150	0.054	0.06
ASW 12	FX62-K-131	0.0047	0.0026	140	25.0	0.15	0.027	0.0134	0.0090	0.0163	0.114	0.09
PIK 20	FX67-K-170	0.0056	0.0031	107	22.5	0.20	0.043	0.0149	0.0098	0.0190	0.060	0.39
ST.CIRRUS	FX66-S-196	0.0068	0.0028	107	22.5	0.23	0.043	0.0149	0.0103	0.0214	0.038	2.23
ASW 15	FX61-163	0.0066	0.0028	118	20.5	0.21	0.039	0.0163	0.0106	0.0202	0.059	0.48
ST.LIBELLE	FX66-5-161	0.0070	0.0025	103	23.5	0.15	0.036	0.0142	0.0107	0.0193	0.068	1.06
ASW 15/17	FX62-K-131	0.0047	0.0026	118	20.5	0.21	0.039	0.0163	0.0087	0.0191	0.059	0.48

made around 1972 were said to have improved the climb performance.

A breakdown of drag as a percentage of total drag is shown in Table 2. Values for C_L = 1.0 are shown in Table 2(a) and for C_L = 0.4 representing typical cruising flight in Table 2(b).

The most striking feature is the very high percentage of drag that is due to the wing, approximately 80% at C_L = 1.0 and 65% to 75% in crusing flight at C_L = 0.4. The induced drag component is dominant at C_L = 1.0 but in crusing flight it is the profile drag that is most important.

Since profile drag only depends on the wing section, the choice of wing section is a very important decision in the design of a new sailplane. Fortunately, there are not too many restrictions on that choice. One consideration other than minimum profile drag is to have low profile drag at high lift. The thickness is also important for structural reasons.

As an example of the effect of choice of wing section on performance, some results are shown in Table 2 for an ASW-15 with the FX 62-K-131 wing section used on the ASW-17 substituted for its original FX 61-163 section. (Moving it from Standard Class to 15-metre Class.) This one change increases cruising L/D from 29.0 to 33.6, well ahead of the PIK-20.

Table 2(b) shows that fuselage drag accounts for 15 to 20% of total drag at cruising flight. The ASW-12 is badly penalized with 25% fuselage drag partly compensated for by its low wing profile drag. The low values of 12% and 13% for the Cirrus and Nimbus II obviously represent good aerodynamic design of the fuselage.

Tailplane drag in cruising flight is around 10% to 12% with the ASW-17 having the highest value of 15.5% and the Nimbus and Libelle low with 9.5%. A redesigned smaller tail could possibly give the ASW-17 a 5% edge over the Nimbus in cruising flight.

Performance Estimation

Having established typical values for the constants C_{D_π} and K_3 it is now easy to calculate the drag coefficient for any new

TABLE 2. DRAG BREAKDOWN IN PERCENT OF TOTAL DRAG

(a) C_L = 1.0

	WING		FUSELAGE		TAIL		
NAME	$\frac{1+\sigma}{\pi A} C_L^2$	$C_{D_0}' + B C_L^2$	$C_{D_\pi} \frac{AF}{S}$	$K_3 C_{D_\pi} \frac{AF}{S} C_L^2$	0.008 SE/S	C_D	L/D
Nimbus II	48.5	36.0	5.7	5.4	4.1	0.0241	41.5
ASW - 17	53.7	31.9	6.9	0.4	7.0	0.0229	43.7
ASW - 12	53.1	28.9	11.9	1.2	4.7	0.0250	39.6
PIK - 20	51.7	30.2	9.0	3.5	5.5	0.0288	34.7
ST.CIRRUS	46.2	30.2	5.2	11.7	5.8	0.0317	31.5
ASW - 15	53.0	30.5	7.5	3.5	5.5	0.0308	32.4
ST.LIBELLE	47.2	31.6	8.3	8.6	4.2	0.0301	33.2
ASW - 15/17	56.8	25.4	8.0	3.8	5.8	0.0287	34.8

(b) C_L = 0.4

	WING		FUSELAGE		TAIL		
NAME	$\frac{1+\sigma}{\pi A} C_L^2$	$C_{D_0}' + B C_L^2$	$C_{D_\pi} \frac{AF}{S}$	$K_3 C_{D_\pi} \frac{AF}{S} C_L^2$	0.008 SE/S	C_D	L/D
NIMBUS II	17.6	57.5	13.2	1.9	9.5	0.0106	37.8
ASW - 17	19.0	49.2	15.2	0.9	15.5	0.0103	38.6
ASW - 12	18.3	44.5	26.2	0.4	10.4	0.0114	34.9
PIK - 20	18.6	47.4	20.2	1.2	12.4	0.0128	31.1
ST.CIRRUS	17.5	52.5	12.1	4.4	13.4	0.0137	29.2
ASW - 15	18.9	51.1	16.1	1.2	12.2	0.0137	29.0
ST.LIBELLE	16.0	53.8	18.2	2.9	9.1	0.0137	29.0
ASW - 15/17	21.9	43.0	19.4	1.5	14.1	0.0119	33.6

sailplane using Equation 7. Polars have been calculated for the seven sailplanes listed in the tables, using wing section parameters derived from wind tunnel data and the mean values for C_{D_π} and K_3 suggested above. The calculated polars mostly agree quite well with the measured polars, as might be expected, except for a case like the ASW-12 where the real fuselage drag is substantially higher than what could be expected for a good modern fuselage design. Comparisons between calculated and measured polars are shown in Figures 2 and 3. In general the estimated

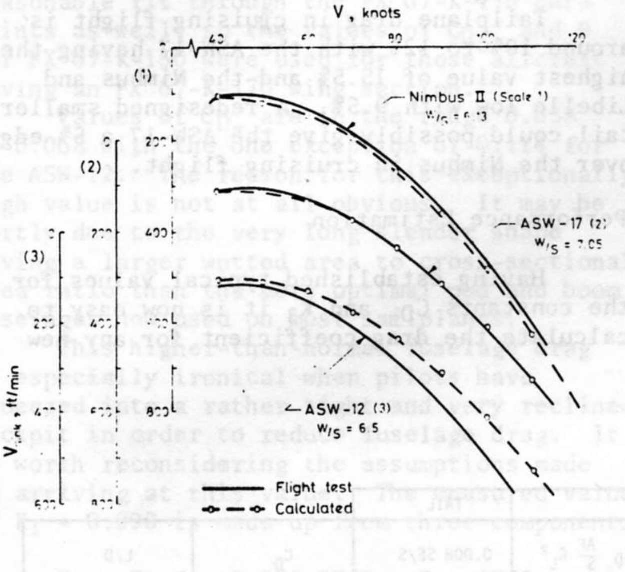

FIGURE 2. Calculated and Measured Glide Polars

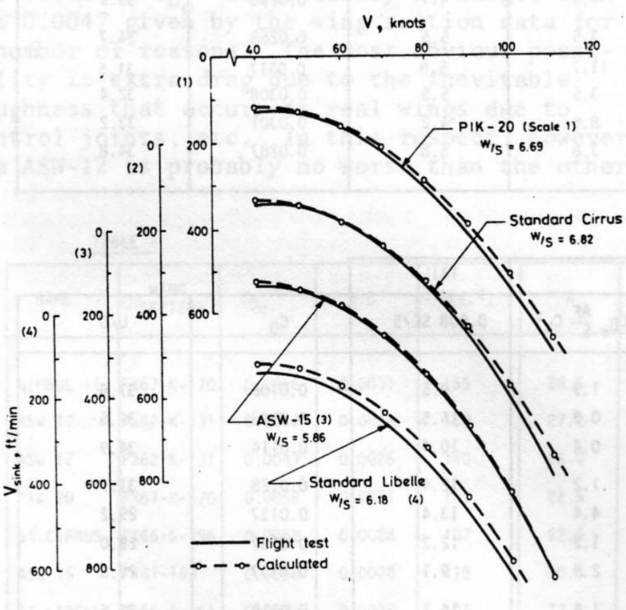

FIGURE 3. Calculated and Measured Glide Polars

polars for new aircraft should show similar good agreement as long as the assumptions made in deriving values for the constants in Equation 1 are correct.

CONCLUSION

An equation for drag coefficient is presented that separates out the various parameters contributing to drag and suggests realistic approximations that lead to quite good estimates of the drag polars of real sailplanes. The equation provides a framework for more accurate estimates where more detailed information is available, and also provides a useful basis for the analysis of flight test results.

Absolute values for performance are uncertain because they are so easily upset by hard to predict effects such as wing-body interference drag. Comparisons to see the effect of varying one parameter at a time should be quite reliable, however, and this drag equation should be useful to the sailplane design engineer in that respect.

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