POSSIBILITIES OF DRAG REDUCTION ON SAILPLANES.

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I. INTRODUCTION.

The writing of a paper on this subject is invariably conducted with some misgivings. The subject is absolutely guaranteed to draw a cross fire of criticism from two extremes of the aeronautical profession. If one writes in a speculative manner reaching out toward those concepts dimly seen at present, one draws the ridicule of that group of conservative engineers who revel in the joy of proving that we are already at the limit of our endeavour. These meticulous proofs are invariably based upon the experience of the past. If one writes in a conservative manner to please the above group, one justly draws the condemnation of the research aerophysicist. The above reasoning persuades the writer to present a speculative type paper. In spite of the lack of data to aid in the speculation it will be considered justified if for each 100 criticisms received, one individual is stirred to contribute to the advancements which surely await a conscientious study of the problem. It will be interesting to review this paper a few years hence when many of the missing data shall be available. This paper will discuss the various sources of drag, seek to indicate the theoretical lower limits of these drag contributions, and estimate the resulting improvement in sailplane performance as the drag is progressively reduced.

II. SOURCES OF AERODYNAMIC DRAG.

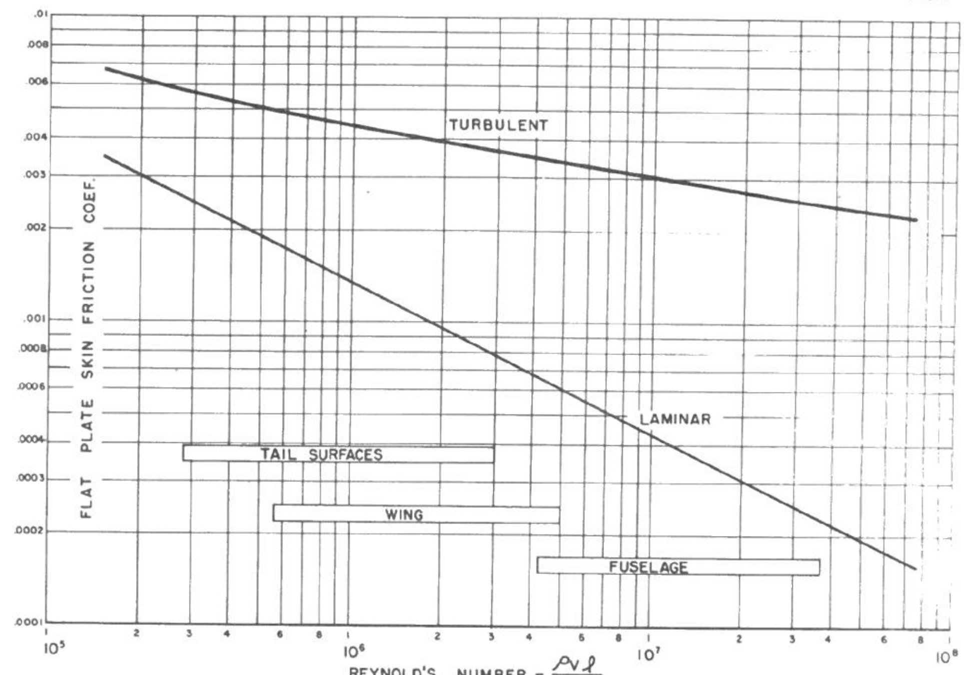
A. INDUCED DRAG - C_{D_I} It seems very unlikely that any new process will be discovered whereby induced drag will be removed from the picture. As long as lift is produced aerodynamically by changing the direction of the oncoming momentum of the air such that a vertical component is established, the reduction in the horizontal component will remain with us as „induced" or drag due to lift. What then are the possibilities of reducing this contribution to a minimum? If we are limited to a given aspect ratio it behooves us to make the entire span work as efficiently as possible. This implies a careful treatment of the wing fuselage intersection to avoid a lowering of the lift distribution in this area, a carefully designed tip to insure as large a spanwise displacement of the tip vortex cores as possible, and the avoidance of flow separation anywhere on the wing at moderately high lift coefficients. Now, what are the possibilities for increasing the geometric aspect ratio while still meeting structural requirements? The following suggestions are advanced without detailed discussion since each would comprise a lengthy design study in itself.

1. A return to external strut bracing using flight developed intersection fairings, thinner strut thickness ratio's, and possible provisions for strut incidence change in flight.
2. The use of thicker airfoil sections in cantilever wings since boundary layer control may well overcome the large drag penalty associated with these sections in the past. (See section on profile drag for further comment on this).
3. The use of some form of automatic load relief on the wing which would effectively prevent attaining normal load factors in excess of 3.

B. PROFILE DRAG - C_{D_0} The remaining drag contributed by the wing after the induced drag is accounted for is known as the profile drag. While the induced drag follows from simple potential flow theory, the profile drag is present due to the viscosity of the air. Since the profile drag constitutes a major portion of the total sailplane drag at zero lift, reductions in it promise the largest gains in performance. Profile drag is made up of the drag due to the viscous shearing between the skin and the free airstream, and the form drag due to the refusal of the pressure at the trailing edge to return to as positive a value as exists at the leading edge. An extreme case of form drag found on very blunt bodies at all attitudes, or even on fine bodies at high angles of attack occurs when the principal flow separates toward the rear of the body. The resulting negative pressures in combination with the high positive pressures at the nose lead to a large drag increment.

The value of the skin friction coefficient has two widely varying values depending upon whether the flow in the boundary layer is laminar or turbulent. For each type of flow the value decreases with increasing airspeed and body length in the flow direction. The laminar coefficient becomes a smaller percentage of the turbulent as the airspeed length product (Reynolds number) increases. The attractive gains at high RN have proved elusive for it has been found increasingly difficult to maintain laminar flow at the higher Reynolds numbers up to the present. Thus, although the low operating Reynolds numbers of sailplanes may not lead to as high gains due to laminar flow as are available at the higher RN, we can console ourselves with the thought that we have a better chance of maintaining laminar flow. The values of the skin friction coefficient for both types of flows have been derived theoretically and experimentally substanciated for flat plates. These curves appear in Figure 1

FIG. I



together with an indication of the RN range for various components over the range of speeds and sizes common to contemporary sailplanes. The problem facing the performance predictor is just how to modify these flat plate curves to account for the effects of finite thickness. It is obvious that an increase comes due to the higher velocity (predicted from potential flow theory) at the outer edge of the boundary layer. The form drag mentioned previously will also cause an increase. It is reasonable to expect that the separation drag of thick sections will be overcome with boundary layer control. However, due to their larger super-velocities, their skin friction drag should remain somewhat higher than the thinner sections. There is a small amount of experimental evidence to the effect that the modifying factor decreases with increasing RN and rearward location of boundary layer transition. While some of these effects will be deliniated at the Aerophysics Department of Mississippi State College in the coming year, it is believed conservative to apply the factors derived by Hoerner in reference I for this study. A proper investigation of this problem requires transition detection in flight on both upper and lower surfaces together with momentum measurements in the wake. The manner in which the transition on both surfaces shifts with changes in angle of attack makes performance prediction even more difficult. An outstanding example of changes in profile drag with attitude is given in Figure 2. Here we see actually two variations depending on the direction of change of attitude. The discrepancy in profile drag of .004 across the hysteresis loop at the same lift coefficient is astounding but lends credence to the old pilot's story about putting an airplane „on the step" by overspeeding and then easing back to cruise speed.

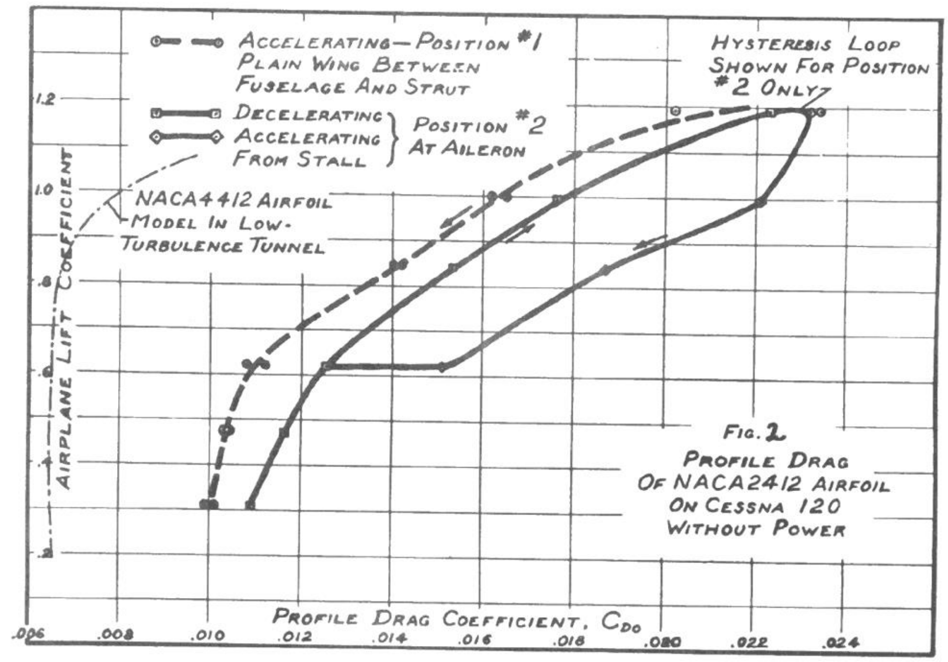


FIG. 2
PROFILE DRAG
OF NACA2412 AIRFOIL
ON CESSNA 120
WITHOUT POWER

C. PARASITE DRAG - C_{D_P} If the profile drag is subtracted from the zero lift drag, the remainder is known as the parasite drag. This generally contains the contributions of the fuselage, skid, wheel, canopy, tail surfaces including trimming drag, intersection drag, miscellaneous proturberences, and the drag of controls on the wing if not included in the profile drag. The tail surfaces may be handled in the same way as the wing profile drag. The emperical factors of Hoerner for three dimensional bodies may be applied to the fuselage and canopy (if it does not fair into the fuselage). A skid may be expected to increase the fuselage drag by about 10% and a wheel may have a drag coefficient as high as 2 based on it's own protruding frontal area. The parasite drag may also be a function of lift coefficient, particularly if the wing body intersection is clumsily handled or if the fuselage has other than a smooth elliptical cross section.

III. SAILPLANE PERFORMANCE.

In a paper of this type where drag is given the principal emphasis it is fitting that the performance comparisons be made in terms of pure aerodynamics. This implies the use of the maximum glide ratio which is to a first approximation independent of weight. Soon after the discovery of the theory of lift on a finite wing and the associated drag, it occured to many aerodynamicists that performance calculations could be markedly simplified if the drag of the airplane were expressed analytically by approximating the lift-drag polar with a parabola. The fit was remarkably good over the range of interest at that time. The principal conclusions of this method were that the maximum glide ratio occured where the induced drag equaled the sum of profile and parasite, that the lift coefficient at which this occured was equal to

$$C_{L_{OPT}} = \sqrt{\Pi e A\!\!R\, C_{Do}}$$

and that the value of max glide ratio was equal to

$$(\frac{L}{D})_{MAX} = \frac{1}{2} \sqrt{\frac{\Pi e A\!\!R}{C_{Do}}}$$

In 1937, Raushenbakh (reference 2) derived a method of optimizing the design for maximum glide ratio by dividing the drag back into it's three components. He reasoned that since the two dimensional airfoil reached its best glide ratio at some particular lift coefficient that there was one best aspect ratio where the sum of

$$C_{Di} / C_L \quad \text{and} \quad ¢\, C_{Dp} / C_L$$

reached its minimum at the same lift coefficient where the section had its best L/D. Unfortunately most airfoils reach their best L/D at a very high lift coefficient and this coupled with the low parasite drags of today's sailplanes lead to fantastic values of optimum aspect ratio.

Lippisch took a more realistic view of the situation as reported in a paper on the development of the FVA-11. He started out with a reasonable aspect ratio in the three term drag expression and solved for the optimum lift coefficient for the entire sailplane. To proceed in a purely analytical manner it is necessary to express the profile drag of the section as a function of lift coefficient. Lippisch was able to do this for the turbulent flow airfoils of that day. There is not yet enough data to do this for the laminar flow conditions treated in this paper and so we must reluctantly return to the simple parabolic curve fit for the remainder of this study. It should be remembered, however, that changes in profile and parasite drag with lift coefficient can cause large changes in the effective zero lift drag C_{Do} and effective aspect ratio e $A\!\!R$, as compared with the computed zero lift drag ($C_{Do} + C_{Dp}$), and aspect ratio. Only flight research can provide enough data to refine the art of performance prediction.

IV. ZERO LIFT DRAG PREDICTION.

The Reynolds number at sea level may be computed from the expression

$$RN = 9354 \; (V_{MPH}) \; (L_{FT})$$

where L is the cord length for wing and tails and total length for the fuselage. The laminar and turbulent flat plate skin friction coefficients may be read from Figure 1 at these RN's. The effective flat plate

$$C_F = (X) (C_{F_{LAM}}) \text{ plus } (I - X) (C_{F_{TURB}})$$

where X is the transition point in fraction of the chord. These values may be increased to account for finite thickness by multiplying by

$(I + 2 \frac{t}{C})$ for wings and tails and by $(I + 0.5 \frac{d}{L})$ for the fuselage.

The component skin friction coefficients may be converted in terms of drag coefficient based on wing area and summed with the following expression.

$$C_{D_{cl=o}} = 2\, C_{F_w} + 2.5 \frac{L_F \sqrt{S_F}}{S_W} C_{F_f} + 2 \frac{S_T}{S_W} C_{F_T}$$

where C_F is the skin friction coefficient, S_W is wing area, L_F is fuselage length, d =

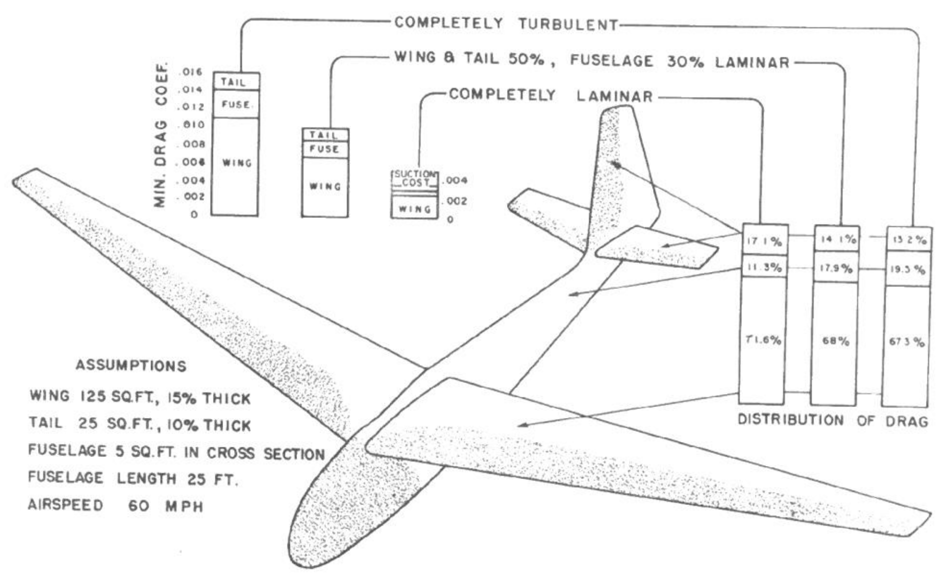
diameter S_F is fuselage cross-sectional area and S_T is tail area. Figure 3 shows a component breakdown of drag for a typical conventional sailplane. It is seen that the wing accounts for over 2/3 of the total zero lift drag. The bar charts at the right indicate that the wing and tail contributions increase slowly percentagewise as the extent of laminar flow increases, while the fuselage contribution decreases at a more rapid rate since it is operating at higher RN where the difference is more marked. The bar charts on the left give the actual values of the drag coefficients. A conventional airframe has been chosen with the relative size of the components an average of existing sailplanes. Three cases have been chosen for study:

1. Completely turbulent flow. The minimum drag coefficient of .0159 is comparable to many of the older sailplanes. While these ships may have had a small amount of laminar flow it was counteracted by the many small drag items not considered in this study.

2. Partial laminar flow obtained by geometry. Here it was assumed that the choice of low drag type airfoils and aerodynamic smoothing of all surfaces would produce 50% laminar flow on the wing and tail surfaces, and 30% laminar flow on the fuselage. The sketch shows a visual presentation of the laminar and turbulent areas as would be seen in flight using an evaporative method of transition detection. The total minimum drag coefficient has fallen to less than 0.01 and we now have a conventional sailplane with lower minimum drag than a flying wing with turbulent flow.

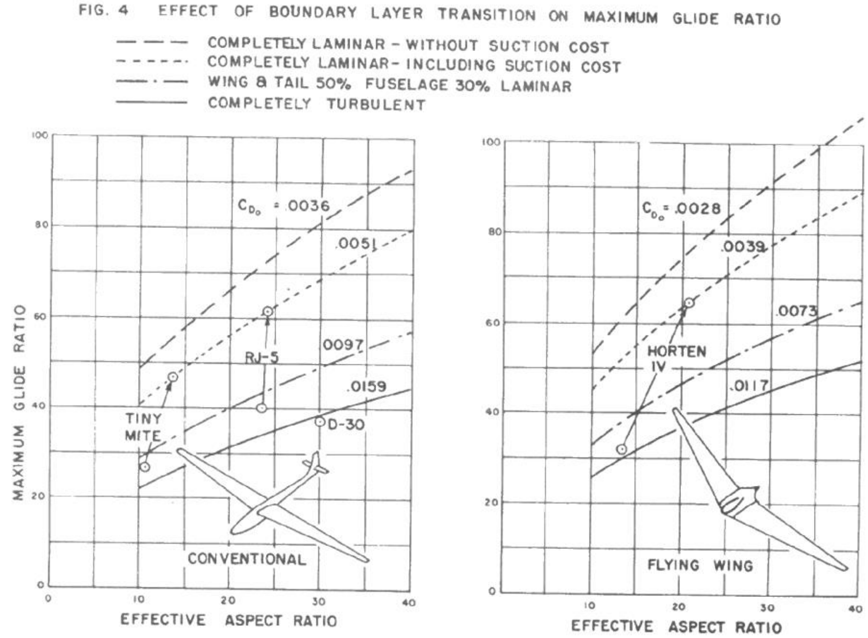
3. Completely laminar. Here it is assumed that the natural transition point of case 2 has been moved aft to the trailing edge by the application of suction through a perforated surface. If this could be obtained without cost the total minimum drag coefficient would drop to 0.0036 and the performance gain would be phenomenal. The laws of nature are not in the habit of providing something for nothing however so we must guestimate a drag cost to provide this suction. Reference 3 provides flight measurements where the upper surface transition was moved from its natural point to the trailing edge by suction through a perforated skin. When the flow quantity was converted to an effective drag coefficient it was

EFFECT OF BOUNDARY LAYER TRANSITION ON MINIMUM DRAG COEF.



found that 78% of the gain in external drag improvement still remained. Although 100% ducting efficiency was assumed, the distribution of porosity was probably not optimum and the low flow rates required indicate that 75% of the external drag gain may not be grossly over-optimistic for this study. One fourth of the difference in total minimum drag coefficient between natural transition and complete laminar flow has therefore been added to the latter as indicated on the bar chart of Figure 1.

FIG. 4 EFFECT OF BOUNDARY LAYER TRANSITION ON MAXIMUM GLIDE RATIO



V. RESULTING PERFORMANCE.

Figure 4 presents maximum glide ratio as a function of effective aspect ratio for the various cases of minimum drag coefficient worked out in the preceeding section. This has been done for both conventional and flying wing sailplanes. Since it is reasonable to expect some drag increment over the pure wing drag for the flying wing to account for fairing in the pilot and trimming the sailplane in pitch, 20% of the fuselage plus tail drag of the preceeding study has been added to the wing drag. It is seen that to approach a glide ratio of 40 with a conventional sailplane under turbulent flow conditions an extreme aspect ratio is required as attested to by the pre-war Darmstadt D-30. The required aspect ratio becomes much more feasible for a flying wing type craft. Now if partial laminar flow can be obtained through geometry the reduction in aspect ratio to reach a glide ratio of 40 is very marked as attested to by the performance of the RJ-5. Now if we raise our sights to a glide ratio of 57.3 or just one degree from the horizontal, we find it virtually unobtainable for complete turbulent flow, requiring very high aspect ratio for partial laminar flow, but for complete boundary layer stabilization it should be obtainable with moderate aspect ratio on a conventional sailplane, and even lower aspect ratio on a flying wing. Although glide ratio's of 70 appear quite feasible, a ratio of 100 would seem to require a flying wing of extreme aspect ratio, having complete boundary layer stabilization at very low cost.

Three types of existing sailplanes which are leaders in their class are spotted on the chart and their performance extrapolated toward complete laminar flow. Although their flight RN may differ from those chosen for this study their flight test L/D appear to match the curves by right order of magnitude. If suction b.l. stabilization were applied to the low aspect ratio Tiny Mite, its glide ratio of 27 would increase toward a value of 47. If applied to the RJ-5, its glide ratio would increase from 40 toward 62, and if applied to the Horten 4, its ratio would increase from 32 toward 65. In all cases it is assumed that b.l.c. not only reduced the drag but also increased the effective aspect ratio toward the geometric value.

VI. CONCLUSION.

In bringing this study to a close I can anticipate the questions in the mind of the reader for the same questions exist in my own mind. Can thicker sections be employed to increase the aspect ratio without large drag penalty when b.l. stabilization is applied? How will the profile and parasite drag values vary with lift coefficient under b.l.s.? Will stabilization through suction prove more or less costly than assumed for this study? The answer can only come through systematic and well instrumented flight studies.

VII. REFERENCES.

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