AN EXAMINATION OF THREE SAILPLANE CONFIGURATIONS

by Gary Weir

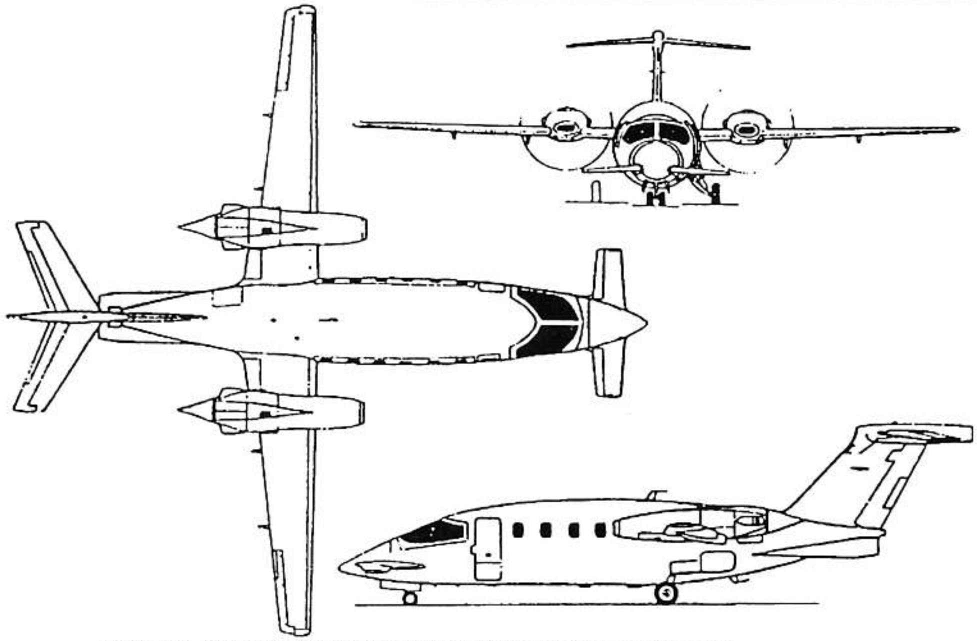
1.0 Introduction

The purpose of this paper is to examine different possible configurations for sailplane design. As an alternative to the conventional layout, a number of people have tried canard designs in the quest for improved safety and efficiency. A conventional sailplane frequently has a negative load on the tailplane, particularly at high speed. A canard, on the other hand always has positive loads on both surfaces. This is one of the attractions that canards have always had for people, creating the belief that this should lead to greater efficiency. The other attraction to canards stems from the fact that since the canard surface must always stall first, the canard aircraft can be made stall proof. Since nearly two thirds of sailplane accidents are of the stall/spin variety, this would be a very attractive feature. The nature of sailplanes is such, however, that performance is very important and most people would not want to sacrifice very much performance to obtain this safety benefit. Probably the most famous canard sailplane design is the Solitaire. It appeared to have good performance in a straight line, but not in circling flight. It will be interesting to try and understand why this might be so.

A third possible configuration is that of the three surface aircraft; that is one with both a canard surface at the front and a conventional horizontal tail at the back. Over the past ten or fifteen years there have been a number of papers in the literature examining this configuration as a possibility for powered aircraft (References 1-4). Some of these theoretical studies suggest that the three surface aircraft could be more efficient than conventional or canard aircraft, while others suggest just the opposite. One aircraft of this configuration that has been constructed is the Piaggio P180, a drawing of which is reproduced from Jane's in Figure 1. To the author's knowledge no sailplane has yet been built with this configuration.

2.0 Analysis Tools Used for the Study

Thus the objective of this study was to consider the relative merits of all three configurations. From the various studies on the three-surface aircraft, it is clear that quite different results can be obtained depending on the type of analysis used. After considering the various studies, the author came to the conclusion that the only way to obtain a meaningful result was to construct fully three dimensional models of the sailplanes. The program that was used for the aerodynamic analysis was a multi-panel analysis program that also included the ability to do boundary layer



Piaggio P. 180 Avanti corporate transport (Jane's/Dennis Punnett)

FIGURE 1.

analyses over the entire surface of the aircraft. This is important in establishing the profile drag of the aircraft. The one thing the program will not do is calculate the viscous interaction effects between the fuselage and the wing and control surfaces. This is normally thought to contribute between five and 10 percent of the total drag. Because of this uncertainty, it was decided to begin by constructing a model of a sailplane of conventional configuration.

3.0 Analysis of a Conventional Sailplane Configuration

The sailplane that was used as a baseline for the conventional sailplane configuration was the Discus. This was chosen because it was widely known, successful, and because the lack of flaps greatly simplified the analysis.

The geometry for the analysis was largely taken from the report on the Discus in Reference 5. From the three views shown in Figure 2 the elliptical cross section of the fuselage could be generated. The planform of the wing and control surfaces could also be taken from the drawing, as well as the dihedral. The wing angle of attack and twist were not available, so assumptions were made. The angle of attack of the wing was assumed to be 2.5 degrees, and the twist of the wing was initially assumed to be 2.5 degrees, based on historical data. The airfoil coordinates were available . It is not known how the airfoil section varied along the wing span, so the airfoil section was assumed to be constant. The airfoil sections of the control surfaces were not known, so it was assumed that they were Wortmann FX 71-L-150, as these are widely used. No moveable portions were used on either of the control surfaces; the rudder because there was no deflection required. Because the incidence of the horizontal tail was not known, and for simplicity, the horizontal tail was treated as an all-moving one and was raised slightly above the true position at the tip of the fin so that it could deflect up or down without interfering with the fin.

From the geometry a grid of panels was constructed on which to do the analysis. A total of more than 6000 panels were used. The panels were not distributed evenly but in such a way as to have much closer spacing in areas of high curvature such as at the leading edges of the wings and control surfaces. Figure 3 is a close up of the wing fuselage junction which gives some idea of the variation of the spacing. The grid of panels on which the solution was carried out comprised not only the aircraft itself, but also the area behind the aircraft in which the wake is allowed to develop. It is essential to have a good description of the wake as this determines the accuracy of the induced drag calculation, and in a sailplane the induced drag is a very high fraction of the total. Figure 4 is

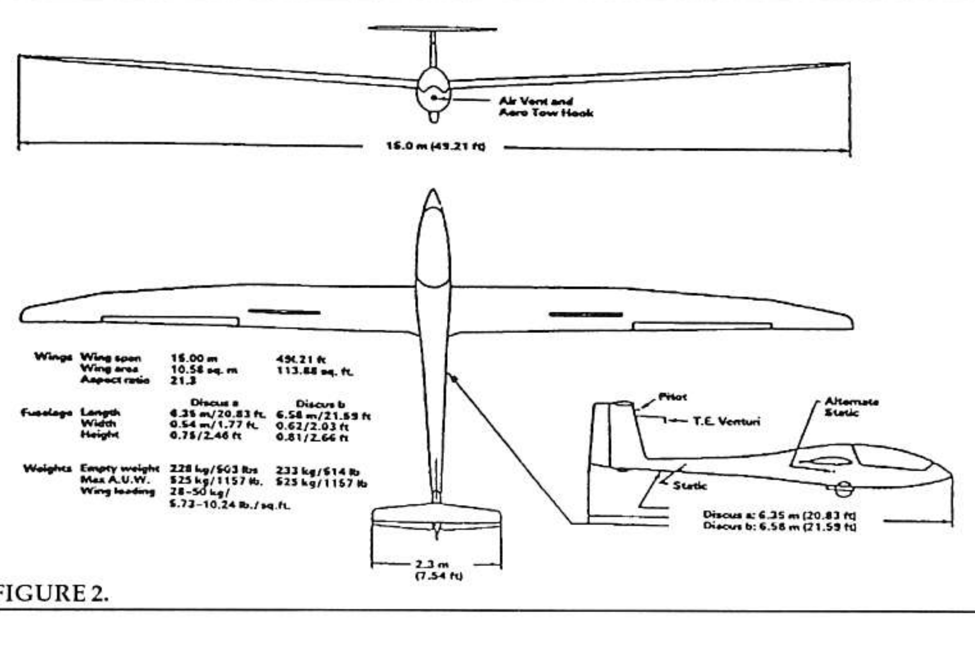


FIGURE 2.

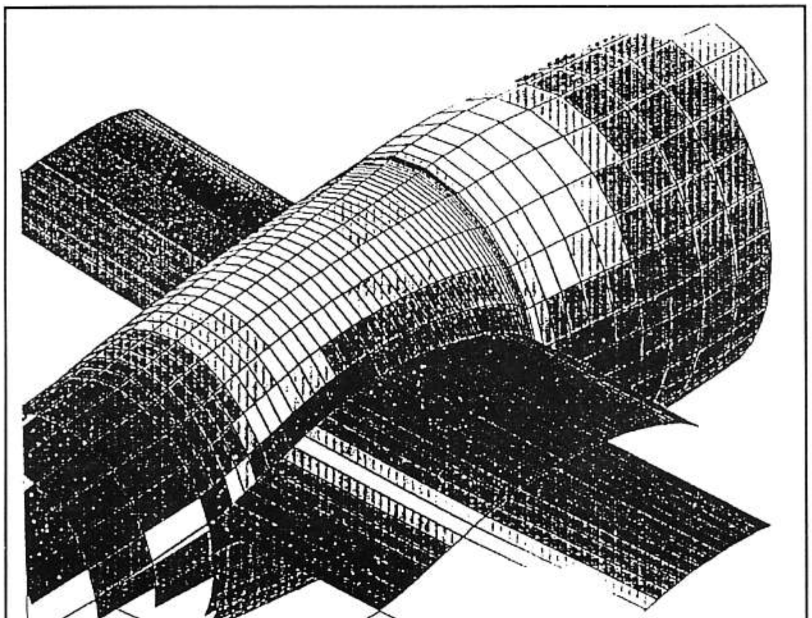


FIGURE 3.

a plot of the solution at one particular incidence. The pressures or velocities for every panel on the aircraft are represented by local variations of colour, which unfortunately cannot be reproduced here. Note the winding up of the vortices at the tips of wing and horizontal tail.

3.1 Discussion of Selection of the Wing Twist

As mentioned earlier, the geometrical twist in the airfoil section was originally selected to be 2.5 degrees based on a survey of older sailplane designs. The twist has two functions. The first is to help get as close as possible to the optimum elliptical lift distribution. With either single or double or even triple tapered planforms and the correct selection of twist, one can approach very close to that ideal elliptical lift distribution. The second effect of twist is to contribute to safety by making sure that the inboard end of the wing is more highly loaded than the outboard section and thus stalls first. The modern trend seems to be much lower values of twist and the ASW-24 (Reference 6) has only 0.85 degrees of twist.(the values are seldom published) The final value of twist chosen for the Discus calculation was 1.25 degrees. Figs 5 & 6 are for a wing with one degree of twist. Figure 5 is a plot of the lift distribution. There is approximately 0.1 variation in C1 between root and tip. The two dips in Cl at 45 and 80 percent span are at the locations of the kinks in the leading edge. Figure 6 is a plot of the lift distribution along the span of the wing compared to the ideal elliptical lift distribution. The two are not far different and in fact for this case the span efficiency is 96.5 percent; that is the induced drag is 3.5 percent more than that of a wing with the ideal elliptical lift distribution.

3.2 Discussion of the Boundary Layer Calculation

As mentioned earlier, a boundary layer analysis can be done over the entire surface of the aircraft, Figure 7 is a trace of the streamlines on the fuselage. On each streamline, a calculation is done assuming that the boundary layer starts out laminar and then transitions to turbulent according to some built in transition criteria. Figure 8 is a typical plot of the boundary layer development. Cf is the local skin friction coefficient, from which the drag is calculated. It drops steadily while the boundary layer remains laminar, rises sharply when transition to a turbulent boundary layer occurs, and then falls steadily again. The transition part of the program is not sophisticated enough for these low Reynolds numbers of sailplanes; it has no laminar separation bubble. So it is interesting to see if the predictions of transition are sensible. At a Reynolds number of two million, the transition is predicted to occur at about 55 percent on the upper surface

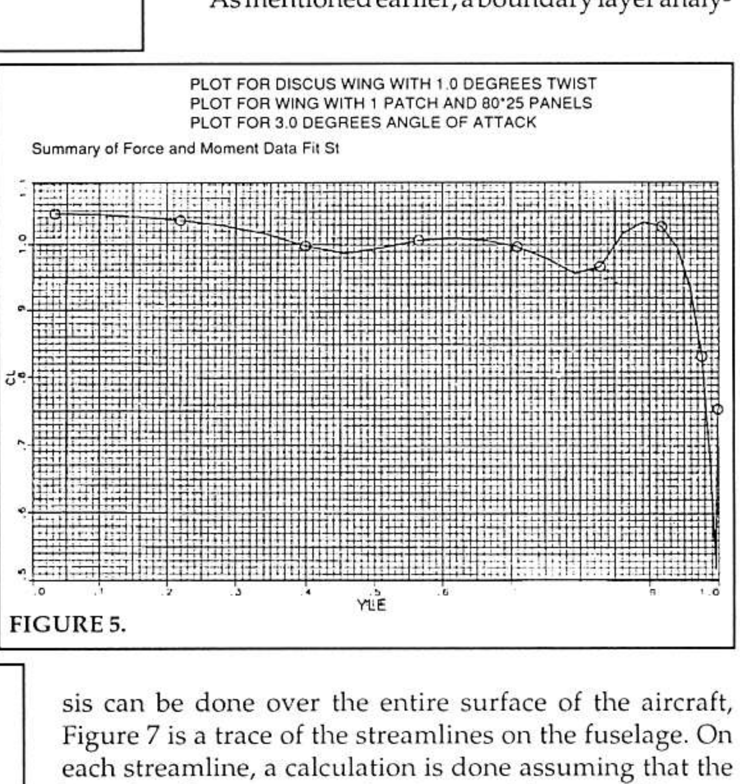


FIGURE 5.

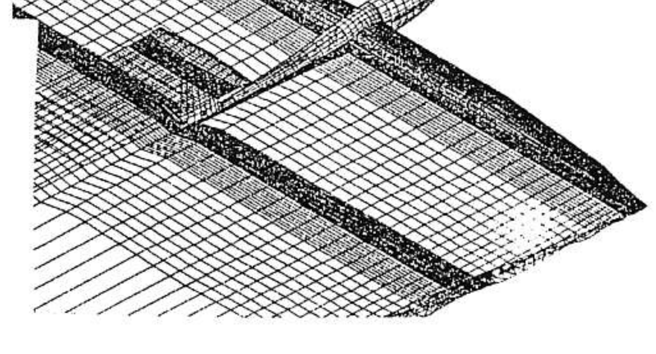


FIGURE 4.

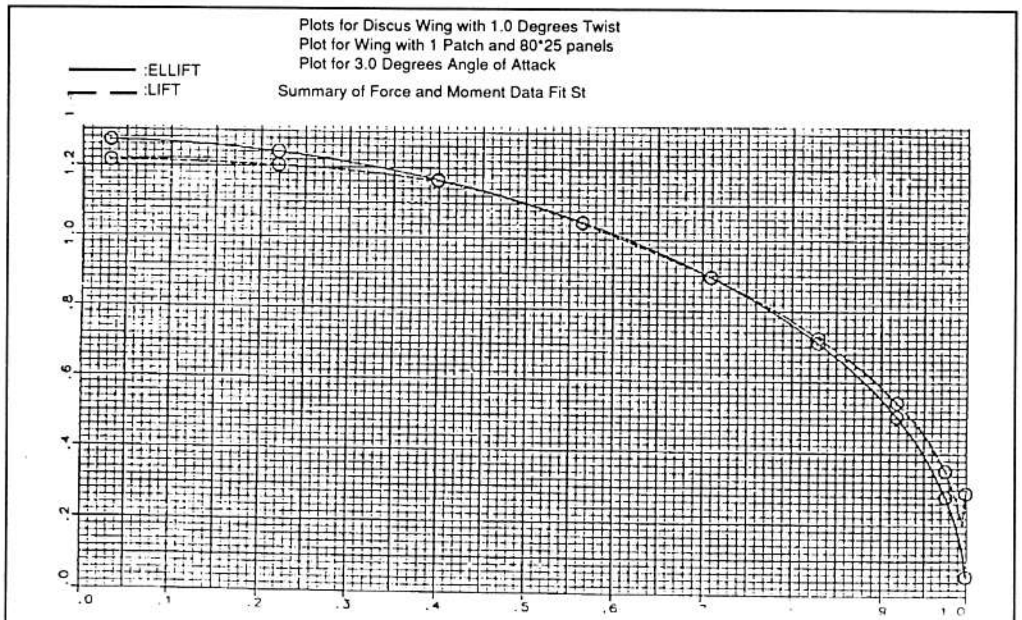


FIGURE 6.

of the neutral point. Since the most rearward possible position of the c. g. is generally taken to be about 10 percent forward of the neutral point, this gives a useful c. g. range of thirty percent of the m.a.c., which is quite good. Thus our initial choice of c. g. position is about 5 percent ahead of the most rearward position of the c. g. and is thus acceptable for the calculation.

3.4 Calculation Procedure

The calculations were all done for an assumed wing loading of 6.3 pounds per square foot and were done for seven different speeds. At each speed, the angle of attack of the aircraft was varied until the appropriate Cl was achieved. From the velocities the appropriate Reynolds numbers were input to the program. Then the angle of the tail was varied until the pitching moment about the assumed c. g. position was calculated to be zero.

3.5 Discussion of the Calculation Results

Before presenting the overall L/D results from the calculation, let us look at the breakdown of the components to see if the results appear sensible. The following table compares the drag breakdown by aircraft component from the present calculation against some numbers given in Reference 7 for a typical 15m sailplane.

and 70 percent on the lower surface. These numbers seem quite reasonable.

3.3 Discussion of the Selection of Center of Gravity Position

Since one of the things that effects the total drag of the aircraft is the load on the tail, then obviously the position of centre of gravity (c. g.) chosen for the calculations is sign)ficant. For the initial calculations on the Discus, the c. g. was chosen to be at 81.0 inches from the nose of the aircraft, which is 25 percent of the mean chord, based on c. g. location of similar aircraft. But for unconventional aircraft, one needs a general procedure, and it is best to try out that procedure. The first step in the procedure is to find the neutral point of the aircraft. That is defined as the point about which the pitching moment of the aircraft does not change with angle of attack. This can be found by simply trying different c. g. positions. For the Discus the neutral point was found to be at 85.0 inches from the nose. The second step is to move the c. g. forward until the tail runs out of control power(as determined by the limiting C1 of the tail) It is the size of the tail that determines the allowable c. g. range. For the Discus, the forward limit was found to be at 73.8 inches from the nose, or 40 percent of the mean aerodynamic chord(m.a.c.) forward

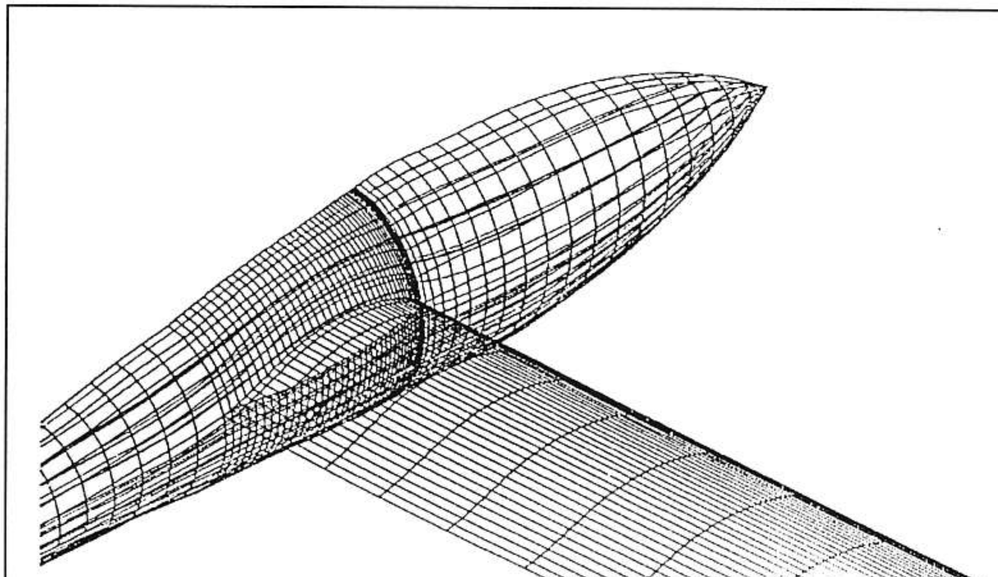


FIGURE 7.

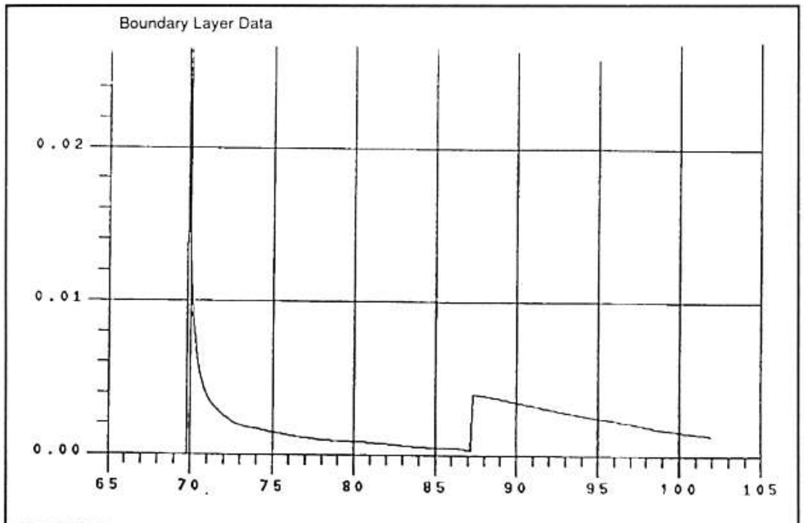


FIGURE 8.

Low Speed

% Drag	Discus (63mph)	Nicks (55mph)
Wing	76%	80%
Fuselage	20%	12%
Tail3%		5%
Other		4%

High Speed

% Drag	Discus (99mph)	Nicks (100mph)
Wing	70%	60%
Fuselage	22%	25%
Tail8%		10%
Other		5%

The drag can also be broken down by type:

Low Speed

	Discus	Nicks
Induced	62%	57%
Profile	38%	38%
Interference	5%	

High Speed

	Discus	Nicks
Induced	14%	10%
Profile	86%	85%
Interference		5%

Thus the calculated proportions for drag are at least sensible. At high speeds, the induced drag is very low and the drag of each component becomes nearly equal to its portion of the wetted area. (the wing has 64.5 % of the total wetted area and at high speed has 70% of the total drag).

Figure 9 is a plot of the overall L/D ratio at various flight speeds. The curve given by the manufacturer is compared with the current prediction, which is a bit optimistic. As mentioned in the introduction, this program cannot calculate the interference drag, and that is thought to be about 5 percent of the total. The third curve is the prediction with 5 percent arbitrarily subtracted from the results. It can be seen that this gives a fairly good prediction of the results and is just)fication for using this calculation method to examine the merits of the other configurations.

4.0 The Canard Configuration

The next configuration to be looked at was the canard. While the idea was to end up with something that looked like the Solitaire, the starting point was the Discus in order to have as close a comparison as possible.

So as a first step, the horizontal tail of the Discus was moved out several feet in front of the nose of the Discus. This gave a canard area of 8.4 percent of the wing area. Following the procedure described earlier for finding the neutral point of the aircraft, the neutral point was found to be at 72.5 inches from the nose(the wing leading edge is at 69.7 inches) If we assume the rearmost c. g. is at ten percent of the m.a.c. forward of the c.g., the rearmost c. g. is then at 69.7 inches. But at this position the aircraft cannot be balanced even with a canard Cl as high as 1.85. Thus this canard is simply too small to give any c. g. range. Next, the area of the canard was doubled to nearly 17 percent of the wing area. This gave a useful c. g. range of 12.5 percent from the most rearward point. Again this range was not large enough to be practical. (for reference, the stated c. g. range of the ASW-15 is 20 % of the m.a.c.). Then the canard area was increased to triple area or nearly 25 percent of the wing area. This gave a useful c. g. range of 15 percent forward of the most rearward position. One can see that the return rapidly decreases with increasing area and no further increase in area was studied. For the Solitaire the canard area was also about 25 percent of the wing area . In order to increase the efficiency of the design, the aspect ratio was increased to 10 (same as the Solitaire) and the canard was moved forward so that its leading edge was at 45 inches forward of the nose of the aircraft.

To achieve even this limited c. g. range required not only tripling the area of the tail but also asking for a much larger lift coefficient. the Solitaire used a GU225 section with a maximum lift coefficient near 2.0. The coordinates for this airfoil were not available, so those of the FX72- MS-150 were used. This also had a max lift coefficient near 2.0 A top view of the modified Discus is shown in Figure 10 compared to the Solitaire. For the Discus the nose of the fuselage was not lengthened to meet the canard and the tail was not shortened. This would have amounted to shifting

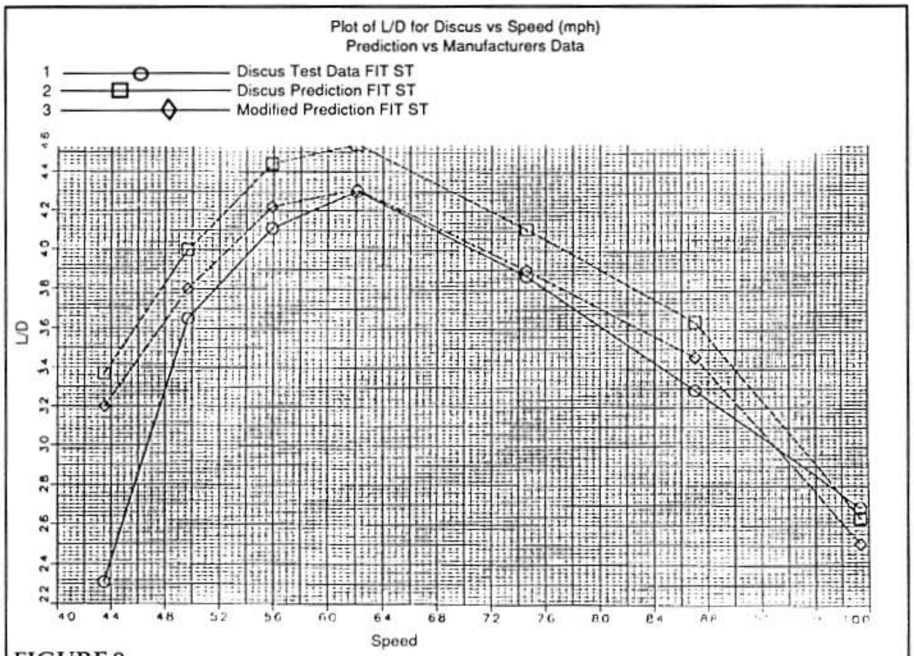


FIGURE 9.

Reynolds numbers.

5.0 The Tri-Surface Configuration

In the first attempt at laying out a tri-surface configuration, the horizontal tail at the rear of the aircraft was left where it was, but was duplicated for the canard, which was placed just slightly ahead of the nose of the aircraft. Thus both surfaces had 8.4 percent of the wing area. Using the procedure described earlier, the neutral point was found. There are many different ways to arrange the movement of the two control surfaces. To allow the forward surface to act as a stall limiter, its incidence was arranged to give a Cl just higher than that of the wing. Then the rear horizontal tail was used as a control surface. Then the c. g. was moved progressively forward. When the e.g. was 31 percent of the m.a.c. forward of the wing back in the fuselage.

As before, the calculations were done for seven different velocities, using the canard to balance the aircraft at each speed. The c. g. was chosen to be 10 percent forward of the most rearward e.g. location. This shows that the canard Discus is about 5 percent worse L/D at high speed and about 15 percent worse at low speed.

Testing of the Solitaire showed a maximum L/D in straight flight of about 30, which is good for the span, but the performance deteriorated rapidly in circling flight. This should be shown by poor performance at high Cl's (i.e. low speed), but this is not seen in this analysis to the extent that the data would require. It is useful to speculate on a reason for this discrepancy. The first point is the very high Cl required of the canard surface. Such a section will not have the L/D ratio of a lower lift section designed for optimum L/D and will probably be accompanied by a separation which did not seem to be predicted by the program. A more sign)ficant effect, however, is the interference effect of the very large canard on the flow over the wing. Oil flow studies done in the testing (Reference 8) showed that the part of the wing behind the canard had a fully turbulent boundary layer at Cl's above about 0.9. There is probably no way to avoid this with such a large canard area and with a very high lift coefficient which would lead to a thicker canard wake impinging on the main wing.(without going to an impractical vertical separation). Flight testing did confirm a stall free flight envelope but it appears one is simply sacrificing too much efficiency in the canard layout at high Cl's which are so important to the operation of a glider. Note that 25 percent of the area and a greater fraction of the lift is in the canard, which has an aspect ratio only half that of the main wing. It is not possible to increase the aspect ratio of the canard without going to unacceptably short chords because of the

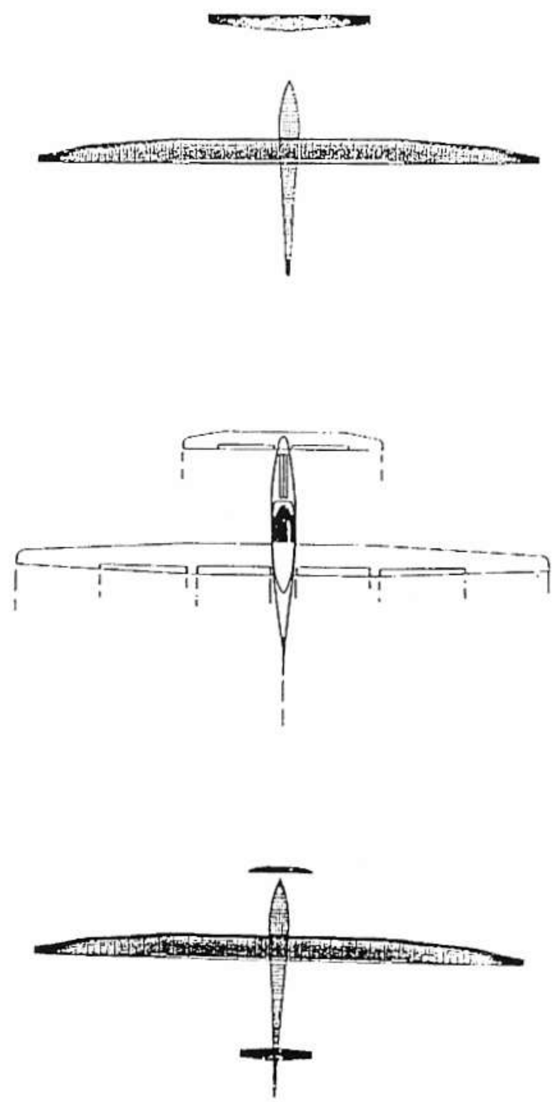


FIGURE 10.

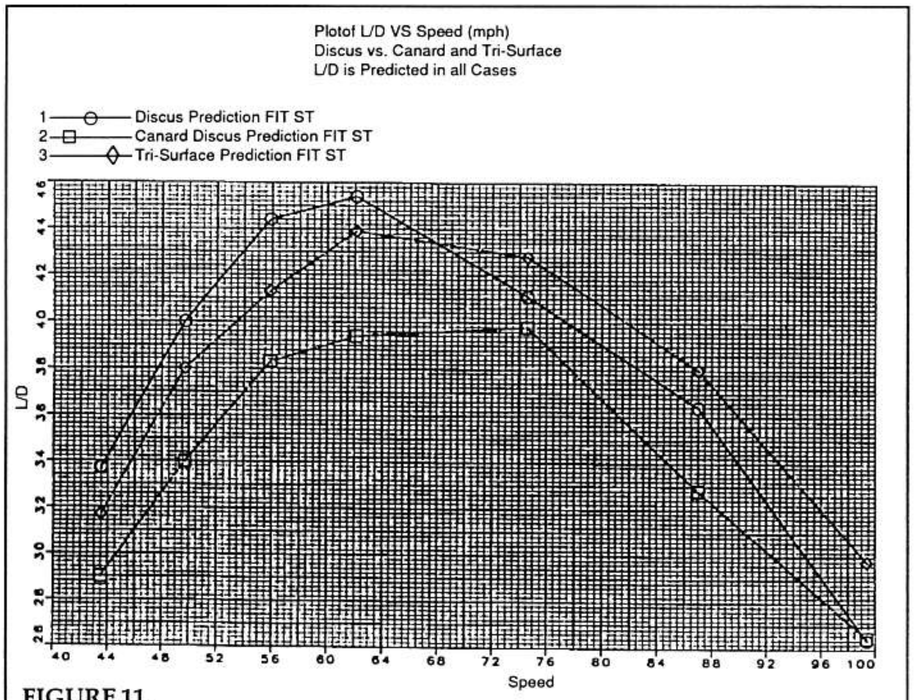


FIGURE 11.

the neutral point, the Cl of the tail was still only at -0.85. Thus it appeared that the total horizontal surface area was larger than required.

In the next step, the size of both surfaces was reduced to 5 percent of the wing area. This time the calculations showed there was 25 percent m.a.c. movement between the neutral point and the most forward allowable c. g. position. Allowing 10 percent static margin for the most rearward point, this gave an allowable c. g. range of 15 percent, which was thought to be a good starting point.

The c. g. was then fixed at 10 percent forward of the most rearward location, and a series of runs was done at different velocities, as had been done for the baseline Discus and for the canard. The predicted L/D was worse than the baseline Discus everywhere except at the highest speed.

It was thought that because the canard incidence was set high to limit stalling, that the efficiency might be suffering as a result. Therefore, the incidence on the canard was lowered by two degrees and the calculation repeated for the lowest speed. The L/D changed from 31.1 to 31.3, not a very large effect.

The results were examined in more detail. At high speeds, the canard and tail have roughly equal and opposite Cl's, but they are both very small; i.e. there is little negative moment to counteract. At low speeds, however, both canard and tail have high Cl's which hurts the L/D. The wing aerodynamic center is thus too far behind the c.g. Since shifting the c. g. is not very practical, one wants to find a better compromise between the high and low speed performances. Moving the tail rearward or making it larger moves the aerodynamic centre rearward, reducing the balancing moment required at low speed. In essence, by changing the relative size of the canard and tail, one can bias the characteristics of the aircraft more towards the conventional or canard layout, and thus favour the high or low speed regime.

The next step was to reduce the canard area to 4 percent of the wing area and to increase the tail area to 6 percent of the wing area. This moved the neutral point rearward by 4.0 inches. Another series of runs was made at different speeds with the c. g. set at 20 percent of the m.a.c. ahead of the neutral point. A top view of the configuration is shown in Figure 10. The predicted results are better everywhere than the previous case. They are shown in Figure 11 compared with the predicted results for the canard and the predicted results for the Discus. They are also predicted to be better than the Discus above about 65 mph. This seems to be a fairly good result and there is no point in pursuing a greater difference in area between the canard and tail. At this point the tail area was 50 percent greater than that of the canard, but the difference in moment arms was such that the volume of the tail was twice as large as that of the canard. One possible way of making use of the high speed performance is to increase the wing area slightly, improving the thermalling performance. A view of the layout is shown in Figure 10. Again the calculations were done at a high canard incidence. A couple of extra runs were done at lower canard incidence and did show a small improvement in overall results. Further work would have to be done to optimize the relative settings of the two surfaces.

Finally one must consider whether these results are likely to be obtained in the real world, or whether the configuration is likely to suffer some of the same problems as the canard layout. The largest problem that the canard layout faces is that at high lift, the canard seems to force transition on the main wing. In Reference 9 a study was done on a canard layout with three different sizes of canard. At the two larger sizes, some pitchup was encountered at low speeds, but this was not encountered with the smallest canard (7%) The conclusion the authors reached was that the two larger canards were forcing transition on the main wing, but the smaller one was not. Thus the very small canard arrived at here (4%) should not be expected to cause transition problems with the main wing. However, there are two separate horizontal tails and the interference drag would most likely be larger than for the conventional layout. In addition, there is the question of Reynolds number. By dividing the tail area in two, the chords are going to be less for a given aspect ratio or the aspect ratio is going to be less for a given chord. Either way, there will be an efficiency penalty. Thus the results in Figure 11 are likely to be slightly optimistic for the tri-surface layout. But the difference should not be large as the total tail area is only 10 percent, or slightly more than that of the baseline

Discus.

Note that the canard in this case does not require very large lift coefficients; in fact the same section was used as for the wing. The symmetrical section was left in place for the tail, but in fact an upside down section would probably provide a benefit.

6.0 Summary and Conclusions

An analysis has been done of three different sailplane layouts, conventional, canard, and three surface. The predicted results for the canard are worse than thse for the baseline Discus at all speeds. Testing tells us that the real world results are even worse than the prediction because of the harmful effect of the very large canard (25% of wing area) on the boundary layer of the main wing. 'I'he predicted results for the tri-surface layout are better than those for the baseline at high speed but worse at low speed. The difference between the real world results and the prediction is likely to be slightly worse for the tri-surface layout than for the baseline because of extra interference and low Reynolds numbers, but it should not suffer the same problems as the canard.

In conclusion, the canard layout seems to be markedly worse than the conventional one. The trisurface layout seems to be close to the conventional layout in terms of efficiency, but it is not at all clear whether one can use the small canard as a stall limiting feature. Thus there is no clear aerodynamic advantage in choosing the tri-surface layout; but on the other hand there is no significant penalty if that layout is chosen for other reasons.

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