STATIC MARGIN CONTROL FOR TAILLESS FLIGHT

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A new view on Tailless Flight

Tailless flight has been with us since the first days of human aviation. A great variety of tailless designs have shown their viability[1,2,3] but the idea gradually lost ground to the tailed or Penaud type aircraft. Better performance and handling of the tailed configuration has made it the dominant design.

However, tailless flight has great performance potential. The lower wetted area and higher wetted aspect ratio should be reflected in its performance. Junkers, Lippisch and the Horten brothers, to name a few, have shared this thought. More recently the Akaflieg Braunschweig has dared to enter the scene of the modem high performance sailplane with a tailless design. In-spite of all these efforts the tailless design can still not be considered successful in the low speed, high performance scene. Success would be reflected in the number of off-spring resulting from a good design.

This might not seem surprising but it is noteworthy that aircraft designs differ significantly in configuration from nature's high efficiency designs (Figure 1). It can be observed that large high efficiency birds like the Wandering Albatross *(Diomedea exulans)* are not equipped with aerodynamically efficient controlling tails. Furthermore, in normal flight their tails are not spread and therefore cannot account for much controlling action.

The high-efficiency birds under consideration do have tails but these rather take the function of flaps or area-increasing devices for take-off, soaring and landing enhancements[4,5,6]. Most such tails are inefficient as control mechanisms and therefore not generally used as such. From an aerodynamic point of view such birds can be considered tailless. This suggests that evolution has found tailless flight to be beneficial. Why has the development in human aviation led to a different conclusion?

Tailless flight can evidently be successful yet it seems to have some shortcomings in human aviation. These are attributed mainly to the cost of trimming. The traditional rigid tailless design uses wing section-modification for primary as well as trimming control. As a result, the lift distribution is adversely affected when trimming for low speed. This causes an early stall and efficiency is lost due to higher induced drag.

Since aerodynamic stability stands in conflict with efficiency in the tailless design, the cost of trimming can be reduced by making the aircraft less stable or even unstable[7]. It could be argued that birds are more efficient as they may be less stable or even unstable. Their

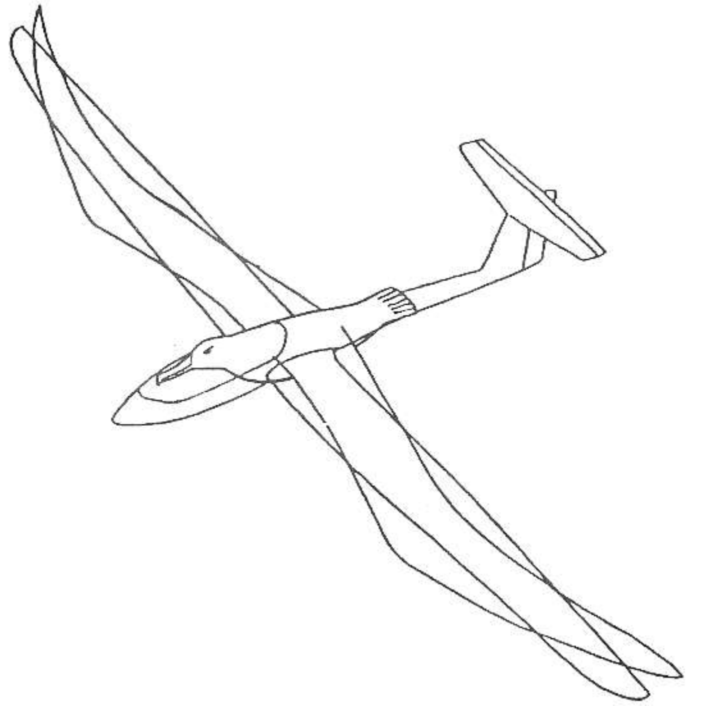

FIGURE 1. Superimposed on a figure of a modern high-efficiency sailplane is that of an albatross. From an aerodynamic point of view, comparing tail configurations, it should seem reasonable to refer to such birds as "tailless".

superior flight control system can provide the responsiveness required for unstable flight. However, as this requires higher vigilance it seems reasonable to assume that tailless birds can fly stable, while in some way reducing the negative implication of trimming. It seems more appropriate to argue that the better efficiency is the result of variable stability since the bird is in no way rigid. It can indeed be observed during gliding flight of most birds that configurational changes are taking place. Wing twisting seems not to be used for trimming control, at least not at low speed. Instead, some form of weight shift or variation of wing sweep seems to be employed[4,8].

As the layout of birds such as the seagull or the albatross evidently holds great potential for tailless flight, the option of developing a full-scale glider of that form was investigated in a research project[9] at the University of Pretoria. To quantify the speculation about bird stability and control strategy, a simplified conceptual tailless layout resembling that of the sea-gull or the albatross was studied. A three-dimensional inviscid panel method[10] was used to model a low wing-loading full-scale tailless aircraft based on this gull-wing shape (Figure 2). The pressure distribution over swept wings with or without control surface deflections could be closely simulated. The computational model allows hinged movement of the outer wing portions in the horizontal plane to study the effect of trimming control by variable wing sweep. This was compared to trimming control by means of the traditional wing-based control surfaces like elevons.

It was found that the gull-wing layout can indeed be stable, not only in the longitudinal plane but also laterally, without the need for any dedicated tail surfaces. Fur-

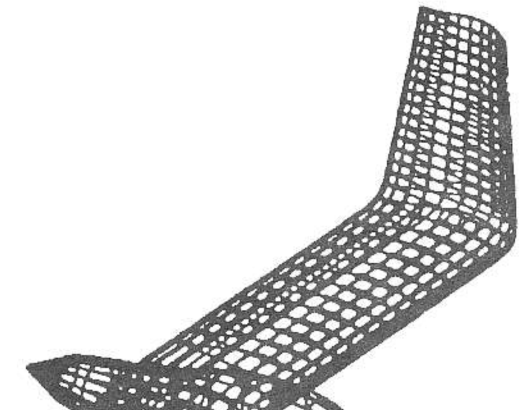

FIGURE 2. Shows the grid of a low wing-loading full-scale tailless glider based on the gull-wing shape. This was used in the three-dimensional inviscid panel method model.

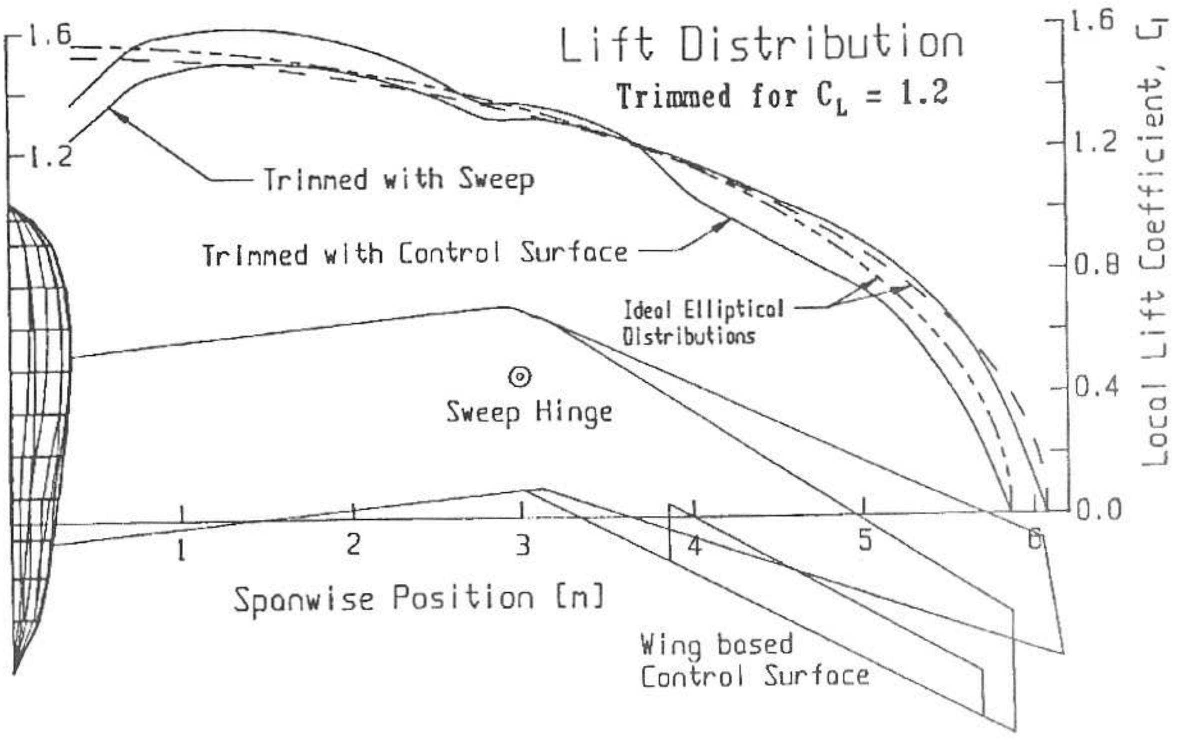

FIGURE 3. Shows the layout of the full-scale gull-wing shaped aircraft which was modelled numerically. The respective spanwise lift distributions for the different trim strategies are presented at a high aircraft lift coefficient, C_L. The control surface notably disburbs the lift distribution. As a result, induced drag increases significantly and the stall sets in early. The respective ideal elliptical distributions are also indicated. The conventional wing-based control surface is indicated. (The effect of wing twisting as used by birds is comparable to that of a control surface.) The sweep position corresponding to the given trim condition is also shown.

thermore, trimming by means of variable stability (wing sweep in this case) proved to have a dramatic consequence. As stability is quantified by the static margin of an aircraft, this mode of control can be described as static margin control. The static margin is defined as the distance, relative to the mean aerodynamic wing chord, between the center of gravity (CG) and the neutral point of that aircraft. Static margin control can thus be done by either changing the position of the CG or by changing the position of the neutral point, for example through wing sweep. Both strategies can be observed in nature, often wisely combined.

Forward sweeping reduces the static margin and thus stability. The flier will be in trim at a higher coefficient of lift (lower speed) without disturbance of the lift distribution. The direct advantage of this approach becomes apparent if the lift distributions associated with the different control strategies are compared (Figure 3). As a secondary advantage the wing-aspect-ratio increases, further reducing losses to induced drag. Fur-

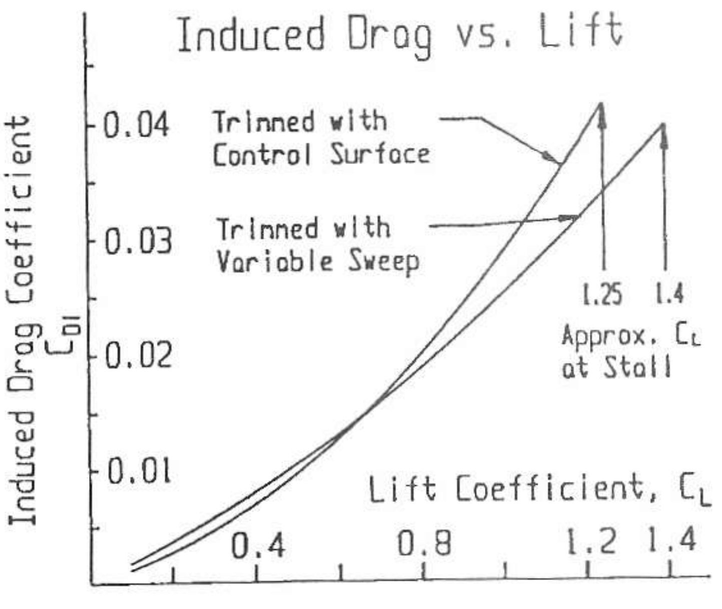

FIGURE 4. Shows the induced drag polar to compare the relative cost of trimming associated with the different control strategies for tailless aircraft. The respective lift coefficients at which the stall can be expected are also presented. The difference in maximum achievable lift coefficients is of great significance since wing sizing is predominantly driven by this coefficient.

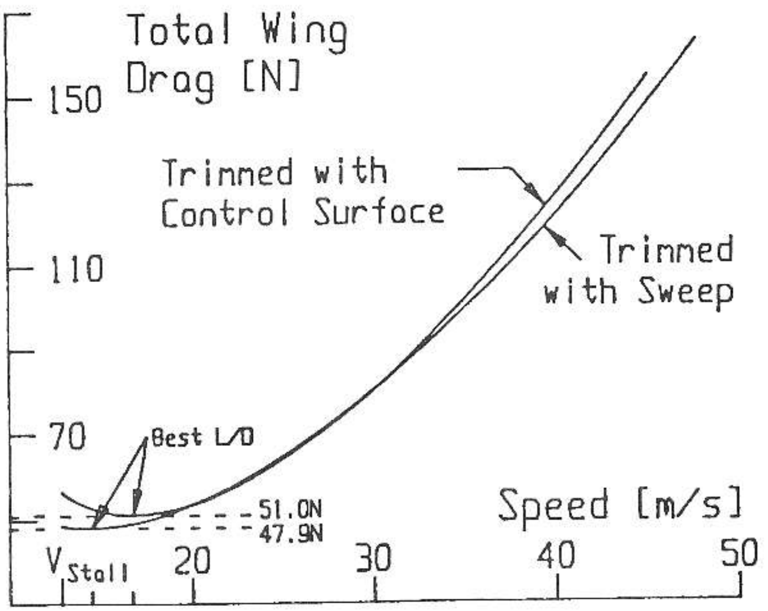

FIGURE 5. A tailless aircraft using static margin control can rely on a smaller wing to give it the same stall speed as its traditional rigid counterpart. The consequence of wing size reduction on total wing drag can be seen in this figure. The lower cost of static margin control at high speed is the result of less friction drag. At low speed, it is the result of lower induced drag. The minimum drag (also indicated) relates directly to the best lift-to-drag ratio and is better if static margin control is used to trim the tailless aircraft. This is true even though the computational model disregarded viscous effects like friction and separation caused by the deflected control surface.

thermore, due to the lower stability, primary wing twisting control inputs need not be as large as for a more stable configuration at low speed.

Figure 4 shows the induced drag polar for the different control strategies as modeled on the simplified gull-wing layout. The lift coefficients at which the stall can be expected are also indicated. The increase in maximum lift coefficient achievable by avoiding lift shedding through control surface deflection is of even greater significance. Wing sizing is predominantly driven by stall considerations. Therefore, a flier using static margin control can do with a smaller wing. The mass and wetted area of the flier are both reduced. Thus not only low speed performance but also high speed performance is improved. Figure 5 shows the total wing drag for two gull-wing shaped aircraft having different wing areas to give the same stall speed. It can be seen that overall efficiency is better if static margin control is used.

It should further be noted that the gullwing layout closely resembles that of the most efficient crescent wing[11]. It is remarkable that this layout allows longitudinally and laterally stable flight without the need for dedicated tail surfaces. Are our most recent sailplane designs not also showing a tendency of evolution towards the crescent wing shape?

Have we not always been too conventional with our tailless designs by implementing conventional controls and wing shapes in our tailless aircraft? We could now argue that static margin control would be very complex to implement, but is it more complex than the elaborate tail structure of conventional aircraft?

The *Exulans*, a Prototype to test the Idea

To find answers to these questions the next step was taken. A full scale prototype of the glider which was analyzed in the theoretical feasibility study[9] was developed. It was named the *Exulans* as derived from the scientific name for the Wandering Albatross *(Diomedea exulans)*, the largest of the Albatross family.

The main characteristics of this research vehicle include the unconventional control strategy and wing planform. To allow comparison of control strategies the *Exulans* has both the option of variable static margin and eleven control. A hinge at the wing wrist allows sweep changes of the outer wing part in the horizontal plane for static margin control. The elevons are highly efficient. They are leak-free and will not contribute to drag in the undeflected position.

The ability to adjust longitudinal stability in flight also means that the stability can be adjusted to suit particular flight and weather conditions. Having both control systems on the glider gives the pilot the freedom to find a suitable compromise between performance and handling according to his circumstances. Uncomfortable stability characteristics can possibly be avoided altogether. Although stability is adjustable the glider is positively stable at all trimable sweep angles.

The *Exulans* is a research platform. However, it was decided to design it for a field in the gliding scene, in which it might compete with other state of the art designs. For this reason it was designed as a class 2 hang glider. It is therefore, required to be foot-launchable and foot-landable. In this field it will be able to compete against other recent designs and should thus have the potential to make its point.

As a commercial product such a glider has the potential to cater to the market gap which still exists between the conventional hang glider and the sailplane. For ease of transportation and storage, the wing can be disassembled into four sections. The fuselage acts mainly as a pilot protection structure. It includes two skids which allow sailplane launch and landing methods if foot-launches and landings are disliked.

The most important data of the prototype of the *Exulans* are as follows:

Wing Span:	12 m
Wing Area:	12 m

Aspect Ratio:	12
Mass Empty:	60 kg
Mass All-up:	160 kg
Wing Loading:	13.3 kg/m^2
Speed Max:	130 km/h ?
Best Glide:	25 : 1 ?
Maneuver factors:	-4.5 +6

The prototype of the *Exulons* is made entirely from composite materials. Skin structures are made from aramid fiber in a sandwich with Nomex honeycomb. Spar caps and shear webs are made from carbon fiber. The pilot protection structure uses carbon and aramid fiber. The entire glider was built in negative molds.

The *Exulans* still has to be tested. The test phase will be initiated as soon as funding for it can be mobilized. So far, the following questions remain: Can handling and performance simultaneously be improved? Can the benefits of tailless flight be realized practically in tailless aircraft by utilizing the strategies suggested by nature? Will high performance aircraft in the future be tailless with static margin control and crescent wing planform? This research project will provide the first answers to this new approach.

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