VARIABLE GEOMETRY SAILPLANES MINISIGMA

by D.J. Marsden, University of Alberta, Canada
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INTRODUCTION

Variable Geometry for sailplanes refers to the use of some mechanical method of changing the effective wing area to provide a better compromise between the requirements for circling flight and cruising flight. Some of the earliest examples of this concept[1] were the BJ-3, BJ-4 series of aircraft built by Beatty and Johl in South Africa. These aircraft featured a Fowler flap that allowed high wing loading for cruising flight and high lift for circling. In addition to the disadvantage of complex mechanisms, the BJ-4 had too much drag at high speed due to fixed slots on the ailerons. Too much drag at high speed proved to be a recurring problem with other Variable Geometry sailplanes.

The British Sigma[2] was perhaps the best known Variable Geometry Sailplane. It was very heavy with it's 21 meter, aspect ratio 36 wing constructed in aluminum alloy. It featured a slotless Fowler flap with 36% extension of chord using two wing sections[3] designed specifically for this aircraft by Professor Wortmann. The empty weight was 1325 lbs. with a resulting wing loading of about 11.75 lbs/ft^2. Although the stall speed with flaps extended was a suitably low 37 knots, it had weak lateral control at low speed. Spoilers were used to supplement aileron control, but detracted from soaring capability. Performance at high speed was disappointing, at least partly because of the poor fit of the flaps when retracted.

The flap system was rebuilt by D. J. Marsden to use a slotted flap actuated by a single mechanical control lever. This version had excellent lateral control, and reasonably good soaring capability. Although the best glide ratio improved from 42 to 47, it still had high speed performance much less than theoretically possible.

The two place variable geometry sailplane, Gemini[4], built in Canada in 1973 had a 30% chord slotted flap full span on it's 18.4 meter, aspect ratio 30 wing. This aircraft had a wing loading of 9.3 lbs./ft^2 with two pilots, and proved to have climb capability comparable to contemporary aircraft such as the Open Cirrus operating at much lower wing loading of about 6 lbs/ft^2. The low speed performance of this aircraft was very satisfactory, but again the high speed performance was a disappointment, probably because of the poor sealing of the fuselage to wing connections, and other imperfections that could not be corrected on this prototype aircraft.

The SB-11 built by the University of Braunschweig Akaflieg[5] was the most successful variable geometry sailplane, in that it won the 15 meter class World Championship in 1978. It represented an excellent effort in design and construction, using a Sigma type slotless Fowler "Wortmann flap" with a 25% extension in chord. Carbon fibre was used to provide stiffness required to maintain a good fit on the moveable flap. This aircraft achieved it's predicted performance at both high and low speed. However, it was not put into production. A likely reason that it was not taken up is given on the first page of designer Martin Hansen's 1978 OSTIV paper[5]; "When the Wortmann flap is retracted, the SB-11 hardly differs from a conventional flapped glider of the 15 meter unlimited class."

Performance at low speed with the flap extended was indeed better than other 15 meter sailplanes, and this contributed to winning the 1978 championship, but the aircraft was not designed to take advantage of the real edge that a Variable Geometry sailplane should have, super performance at high speed with a very high wing loading.

The lateral control in circling flight was less powerful than would have been desirable. Helmut Reichmann[6] mentions that nearly full opposite aileron was needed to control bank in circling flight and he felt he could have circled with steeper bank if he had had better aileron control. The original Sigma had the same problem. Flight test reports[7] indicate that full opposite aileron was needed with only 30 degrees of bank.

The design philosophy behind the new "Minisigma" variable geometry sailplane is to obtain superior high speed performance through the use of a high wing loading while retaining the best features of Sigma and Gemini, namely excellent low speed performance and handling. High wing loading can be achieved without excessive weight because of the relatively small area of the aspect ratio 27 wing.

THEORY

Sailplane design presents the classical aeronautical design problem of how to compromise between the large wing area desirable for low speed flight operations, and the small wing area needed for efficient high speed flight. Variable geometry provides a way to widen the operating speed range, either by literally varying wing area, or by increasing the effective wing area by means of increased camber. There are obvious practical limits on the amount the actual wing area can be changed. To be effective a variation of wing area of the order of 2 to 1 would be desirable. The slotted flap can nearly double the lift of the basic wing section while only having to move out a modest 7% of the wing chord, which is easily accomplished with mechanical track mechanisms.

Cruising Flight

The high speed cruise configuration is very much the conventional sailplane design problem, and should be easy to accomplish given the current state of knowledge. The capability to use high wing loading is the major advantage of the variable geometry sailplane. Potential energy stored in the mass of the sailplane (and water ballast) is used to supply power to overcome flight drag. The higher the ratio of mass to surface area the lower the sinking speed for a given flight speed. High aspect ratio is not important at very high speed, but it is desirable in providing a better glide ratio at intermediate speeds. For a given span, 15 meters in this case, small wing area dictates a high aspect ratio. Aspect ratio is limited by consideration of Reynolds number effects as well as by structural considerations.

Heavy wing loading raises some safety concerns. The maximum flight mass of the open class was limited to 750 kg due to concerns about the capability of tow aircraft even though higher mass was known to produce better performance in strong weather conditions. There has been some discussion of limiting wing loading to 9 lbs/ft^2 in the 15 meter class because of launch safety considerations and the temptation to overload a sailplane beyond safety limits to obtain a competitive advantage. Even though it is somewhat more difficult to regulate, a stall speed limitation would more directly address the safety problem.

The slotted flap wing section can allow substantially higher wing loading for a given stall speed. In addition it may have a particularly safe stall characteristic in that from the beginning of flow separation the lift will continue to increase slightly for an additional increase of about 8 degrees of incidence, while aileron control is maintained because the flap section is still not stalled.

Glide Polars

Calculated glide polars are based on a quadratic polar using the methods of reference 8.

$$C_D = C_{DO} + KC_L^2 \tag{1}$$

The calculated polar uses the known aircraft geometry together with wind tunnel data on the wing section, and gives good results because the major contributors to performance, wing span, wing loading, wing section characteristics and Reynolds number are accounted for. Average values based on area are taken for the less well defined fuselage and tailplane contributions to drag. Calculated polars for known sailplanes agree with flight test measurements within a few percent. The advantage of using calculated polars is that wing loading can be easily varied including the effect of Reynolds number.

Wing profile drag can be represented by the following

$$C_{Dwp} = C_{DO'}/(R^*)^{0.5} + BC_L^2/(R^*)^{0.5}$$

where R^* = Reynolds number when $C_L = 1.0$ based on mean wing chord.

$C_{DO'}$ and B are constants derived from wind tunnel data.

The value of R^* depends on wing loading and chord allowing performance calculations to take into account Reynolds number effects.

For example, Figure 1 shows a comparison of the calculated and measured polars[9] for the Nimbus 3.

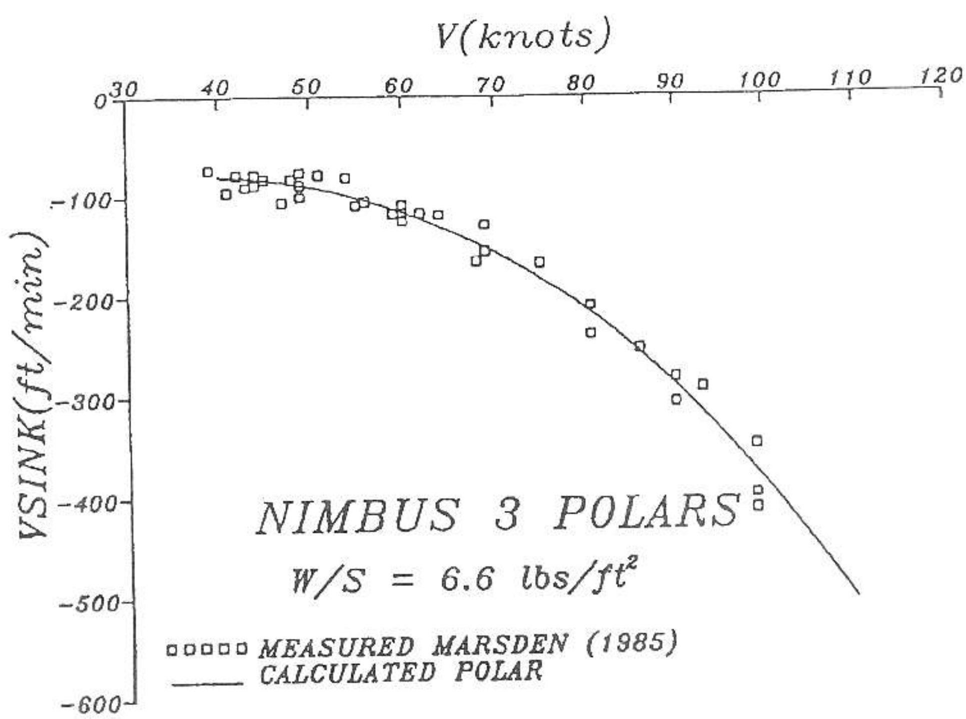

FIGURE 1. Nimbus 3 polars.

Climbing Flight

Sink rate in circling flight[10] is given by the following;

$$V_z = \frac{C_D}{(C_L \cos \phi)^{1.5}} (2W/\rho S)^{0.5} \tag{2}$$

where: W/S is wing loading;
ρ is air density;
ϕ is bank angle.

Turn radius is given by:

$$r = \frac{1}{gC_L \sin \phi} \left(\frac{2W}{\rho S}\right) \tag{3}$$

$$g = 32.2 \text{ ft/sec}^2$$

From equations (2) and (3) it appears that increased lift coefficient will produce lower sink rate and smaller circling radius, all else being equal.

If flight test results are available, the optimum value of C_L and C_D can be selected at the lowest speed that can be flown before the sink rate starts to increase on the "back side" of the polar curve. Thus sinking speed as a function of turn radius is easily calculated from equations (2) and (3).

From the practical point of view, some speed greater than stalling speed must be maintained to avoid increased sink near stall and to retain control in rough air conditions. The speed that can be used in circling flight will depend on whether the lift is smooth or rough, narrow or wide, and it will depend on the aileron control power of the sailplane. An arbitrary rule of 1.1 times stall speed can be chosen for minimum circling speed for the purpose of this study. In the case of the Nimbus 3 for example $C_{Lmax} = 1.35$ (from flight tests) and therefore circling $C_L = 1.11$ with a corresponding value of $C_D = 0.020$, also derived from flight test results. For comparison, the slotted flap version of Sigma has a maximum $C_L = 2.5$ and circling $C_L = 2.07$ giving $C_D = 0.063$, also derived from flight test data. A comparison of circling polars at a wing loading of 9 lbs/ft² for both aircraft is shown in Figure 2.

Note that for a 30 degree bank angle the Nimbus 3 has nearly twice the circling radius with about the same rate of sink. This comparison shows the effectiveness of high lift coefficient even though the drag coefficient was more than three times as high at this high C_L. Flight experience with Sigma showed that it could easily be flown in thermals at a lift coefficient of 2 due to its very effective aileron control.

No attempt will be made to estimate cross country speed based on rate of climb in assumed models of thermals because such models are considered to be unreliable. While thermal updraft speed does generally increase toward the centre of the thermal, the implied assumption that the increased rate of climb due to flying closer to the centre will be maintained during a complete climb is probably not correct.

In any case, the correct strategy for variable geometry sailplanes is to use very high wing loading to gain an advantage in cruising flight. Wing loading can be increased until the circling performance is just equal to that of the competition. Since wing loading will be achieved with water ballast, the variable geometry sailplane would have exceptional operational flexibility. For example, if thermals prove to be very narrow on a particular day, wing loading can be adjusted to take advantage of the capability for flying very narrow circles.

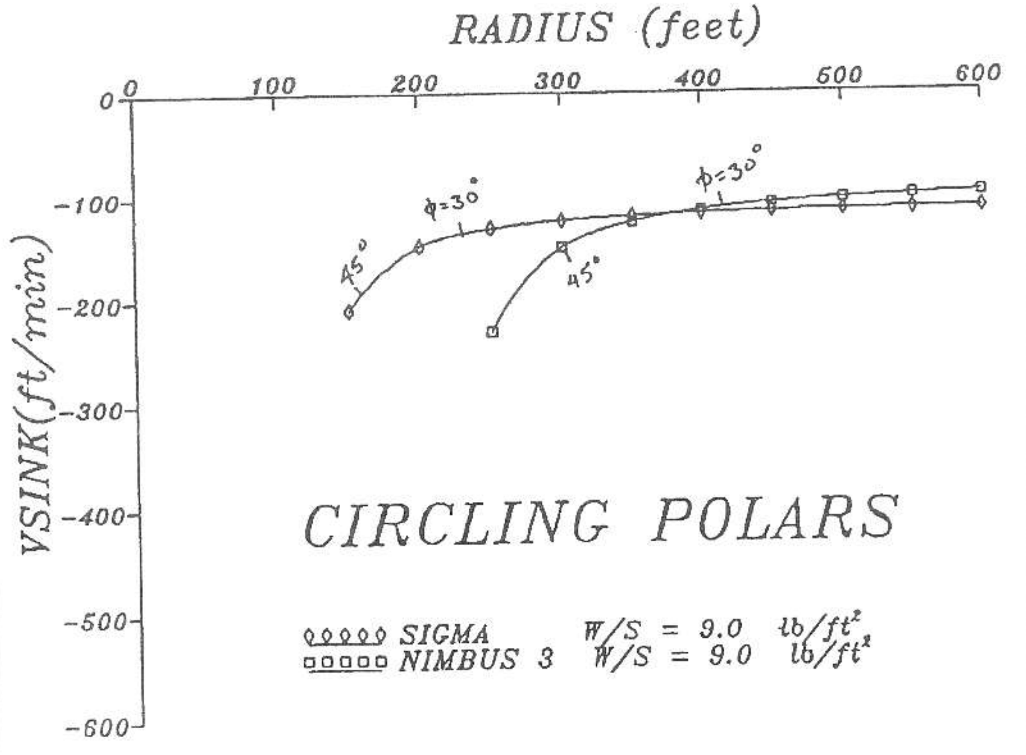

FIGURE 2. Comparison of Sigma and Nimbus 3 Circling Polars.

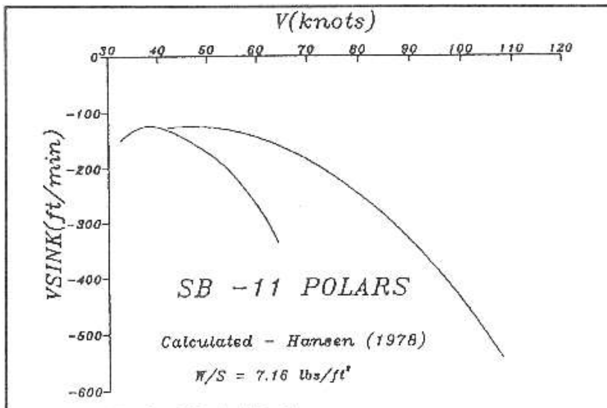

FIGURE 3b. SB-11 Polars.

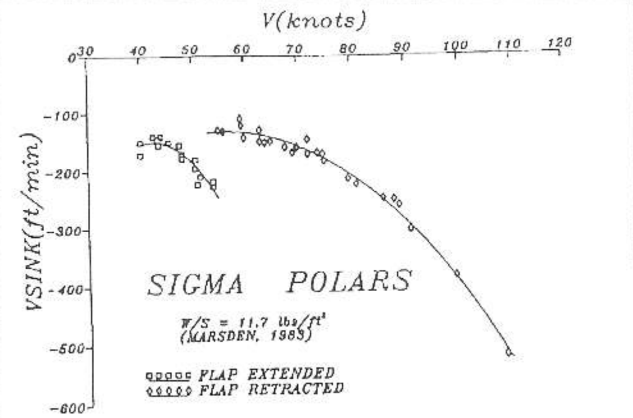

FIGURE 3a. Measured Sigma Polars.

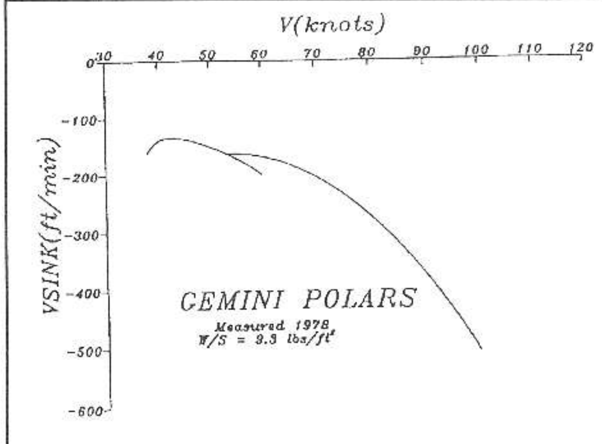

FIGURE 3c. Measured Gemini Polars.

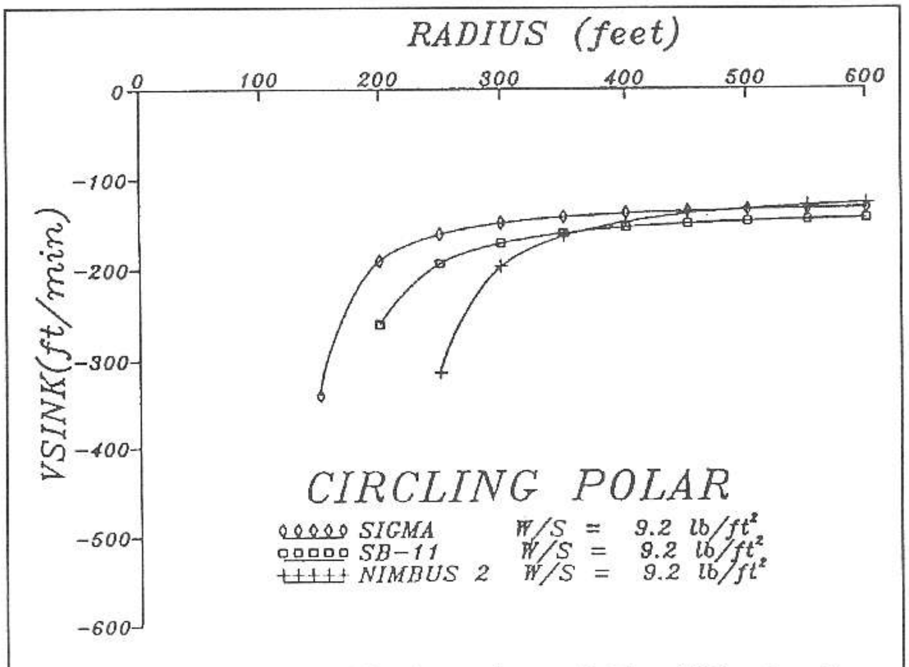

FIGURE 4. Comparison of Circling Polars with Equal Wing Loading.

FLIGHT TEST RESULTS

There have only been a few variable geometry sailplanes built over the past 20 years and very few flight test results have been published. In fact, only results for the modified Sigma11 and estimated performance for the SB-11 are available[5], together with unpublished results for Gemini, shown in Figures 3(a),(b),(c) respectively. However, these are enough to provide some comparisons with conventional sailplanes to illustrate the advantages of variable geometry.

Sigma was designed and built in the late 1960's when composite construction was just starting to be used. Because of it's large span and high aspect ratio, the designers felt it was necessary to use metal structure for stiffness. It's empty weight of just over 1300 lbs resulted in a wing loading of nearly 12 lbs/ft². This was not too high for competition but ground handling and operational flexibility would have been improved if this heavy weight could have been achieved using water ballast.

Sigma's high speed performance was not as good as it should have been because of construction details that could be improved on a new aircraft but not on the original prototype. There were air leaks, the wing section was not accurate, the flaps did not fit as well as they might have. The result was that the zero lift drag coefficient was about 0.010 compared to 0.0078 for the comparable size Nimbus 2. For purposes of comparison, it will be assumed that an aircraft like Sigma could be built in modern composite materials with about the same weight as contemporary sailplanes so wing loading can be treated as a variable in comparing aerodynamic performance.

Figure 4 shows a comparison of the circling performance of Sigma with the Nimbus 2 and the SB-11, all at the same wing loading of 9.2 lb/ft2. Sigma is able to fly a much smaller radius circle than the Nimbus 2 due to it's higher lift coefficient, and is somewhat better than the SB-11 also.

Comparison of the SB-11 with the ASW-20 on the basis of using water ballast to make the climb performance equal is shown in Figure 5(a) and 5(b). Unfortunately, the SB-11 does not have water ballast capacity to achieve this wing loading.

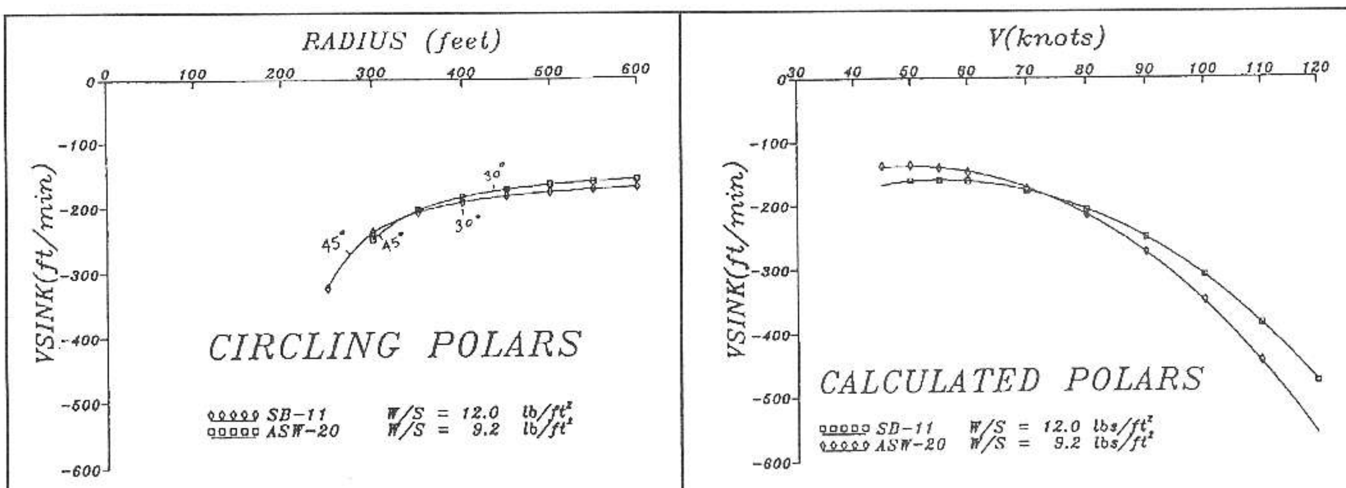

FIGURE 5a.

FIGURE 5b.

FIGURE 5. Comparison Based on Equal Climb Capability

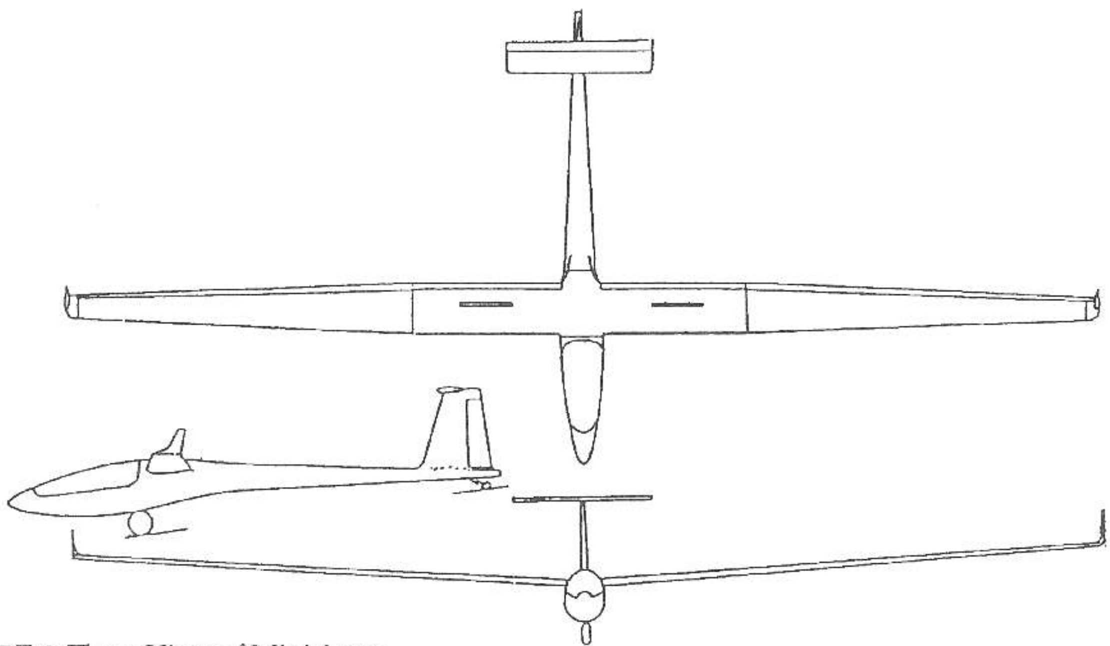

FIGURE 6. Three View of Minisigma.

MINISIGMA

Minisigma is a 15 meter variable geometry sailplane based on lessons learned from Sigma and Gemini. A three view is shown in Figure 6. The 15 meter class was chosen because it is the most competitive class, a small span sailplane is easier to deal with, and high wing loading can be achieved without excessive total weight. A moderate aspect ratio of 27:1 was chosen, partly to avoid problems with low Reynolds number associated with very small wing chord.

The Minisigma has a three piece wing like the original Sigma. This enables permanent seals between the wing and fuselage to be installed on the part of the centre section that mates with the fuselage. The three piece wing is also lighter for easier ground handling. Winglets will be fitted as these have proven effective on a number of other sailplanes.

The only other major feature of Minisigma is it's large water ballast capacity. High wing loading is necessary to take advantage of variable geometry, but large empty weight is not very desirable. The water ballast capability gives great operational flexibility, and the very low stall speed with the ballast gone is a useful safety advantage. Projected empty weight is 500 lbs, and water ballast capacity will be 500 lbs, providing a wing loading range from 7.45 to 13 lbs/ft^2 with a 180 pound pilot.

Wing Section

A modern low drag wing section is required for efficient high speed flight, combined with a slotted flap for high lift. A new section UAG91 169/SF was designed with a 25% chord slotted flap. This section is being tested in the wind tunnel, with particular emphasis on development of the slotted flap. Wind tunnel tests provide lift and drag data at the correct flight Reynolds number as well as such useful items as aileron effectiveness and hinge moment coefficients. Preliminary results indicate that the new wing section can be flown in the low drag regime up to a lift coefficient of 1.9 with profile drag coefficients less than 0.02 at a Reynolds number of 0.5 million. Comparable measurements for the slotted flap section used on Sigma showed section drag coefficient of 0.023 at Reynolds number of one million.

A cross section of the wing is shown in Figure 7 showing the slotted flap and aileron. A full span aileron is part of the flap such that when the flap is retracted the wing section becomes a normal flapped camber changing wing section. The full span aileron simplifies the control mechanisms in that it is simply driven from the fuselage. When the flap is

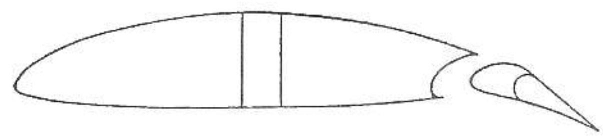

FIGURE 7. UAG 167/25SF Wing Section With Slotted Flap.

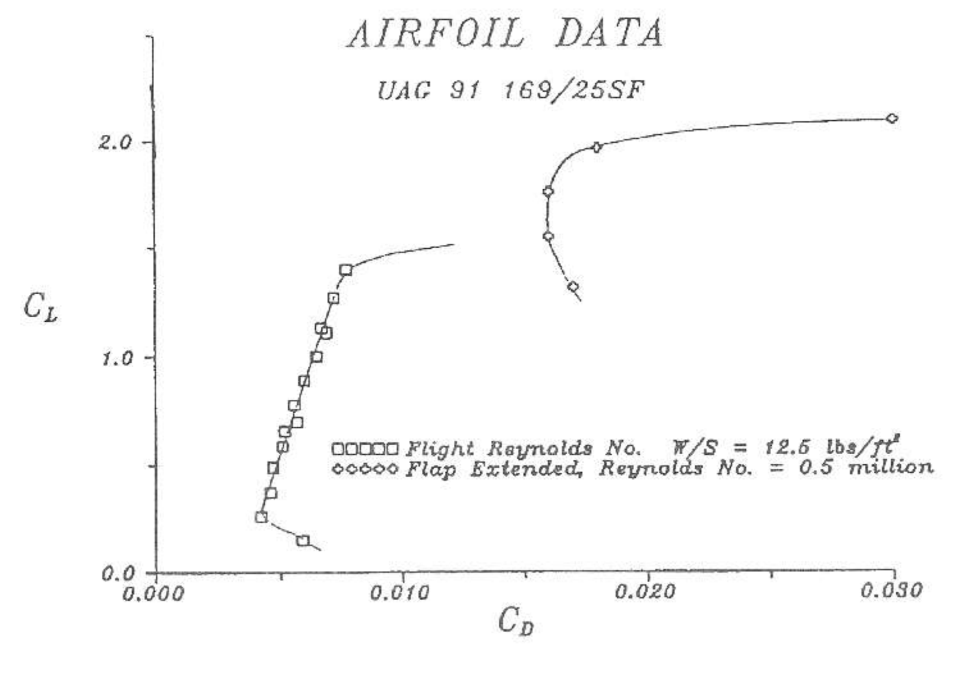

FIGURE 8. Preliminary Wing Section Data.

extended, the aileron moves with it and still operates as an aileron. For this wing section the flap only moves out 7% chord, and is carried on tracks that are fully contained within the wing. Some preliminary wind tunnel results for the new wing section are shown in Figure 8.

Performance Estimates

Calculated performance curves shown in Figure 9(a) are based on the geometry of Minisigma, together with measured wing section data, for two values of wing loading representing full ballast and empty. The corresponding circling performance, based on wind tunnel measured wing section drag with the flap extended, is shown in Figure 9(b). The significance of these results is best illustrated by comparison with some current sailplanes. A comparison with the Nimbus 3 is shown in Figure 10(a) and 10(b). These figures show that performance comparable to the current best open class sailplane is possible in this 15 meter variable geometry sailplane.

CONCLUSIONS

1. The slotted flap is the best solution for variable geometry. It provides nearly two to one increase in effective wing area, while maintaining effective aileron control power at low speeds. It has higher drag than the unslotted Fowler flap, but it's higher operating lift coefficient more than makes up for the difference.
2. Variable Geometry offers substantial performance gains for a 15 meter class aircraft without excessive

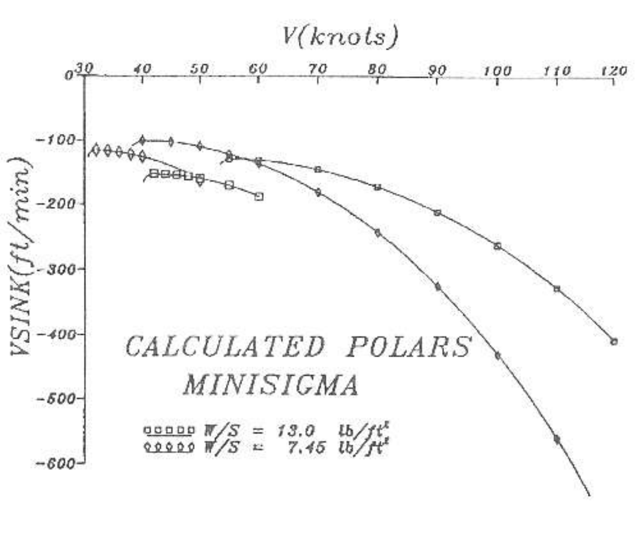

FIGURE 9 a.

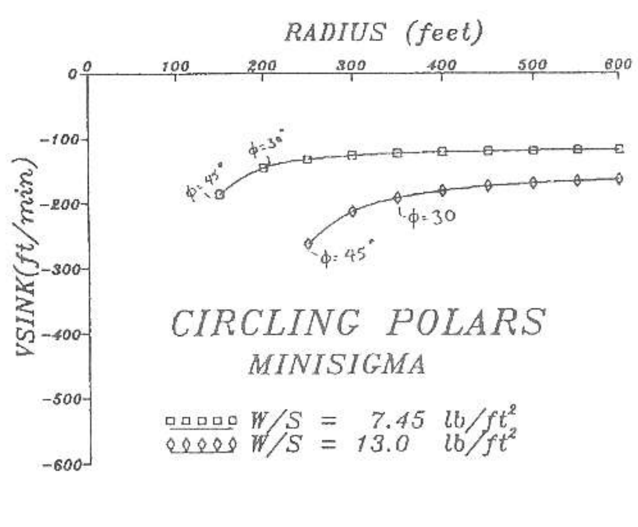

FIGURE 9 b.

FIGURE 9. Estimated Polars for Minisigma.

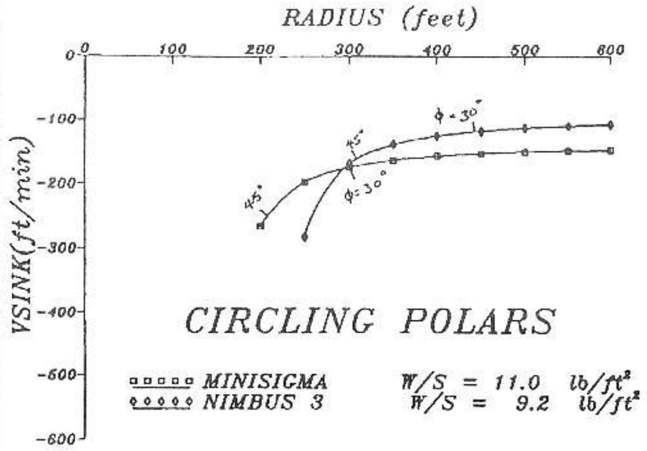

FIGURE 10 a.

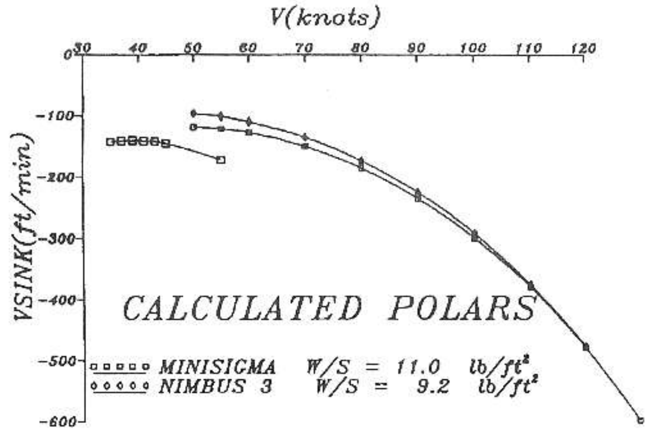

FIGURE 10 b.

FIGURE 10. Comparison with the Nimbus 3 Based on Equal Climb.

weight.

3. Safety does not have to be compromised for heavy wing loading, and in fact the slotted flap provides impressive gains in safe handling even in the case of full water ballast.
4. Variable Geometry can provide performance comparable to open class with the advantages of light weight and convenient handling typical of 15 meter class.

References

1.Beatty, P. and Johl, F. "The Case For Variable Geometry", *Soaring*, Vol. 32, No. 5,1968.

2.Goodhart, Nicholas "projectSigma", *Sailplane & Gliding*, Vol XX, No.2 (1969) pp 134 -137.

3. Wortmann, F.X., "Airfoils for the Variable Geometry Concept" *OSTIV Publication XI*, 1970.

4. Marsden, D.J. nGemini - A Variable Geometry Sailplane", *Canadian Aeronautics and Space Journal*, Vol. 21 March 1975.

5.Hansen, Martin, "Design and Construction of the SB - 11", *OSTIV Publication XV*, 1978.

6. Reichmann, Helmut, "New Horizons with an Unconventional Aircraft", *Sailplane & Gliding*, 1978.

7. BGA No.l Flight Test Group "Flight Tests to Assess the Handling Characteristics of the 'SIGMA' Glider", 1973.

8. Marsden, D.J., "Sailplane Performance Estimation", *OSTIV Publication XV*, 1978.

9. Marsden, D.J., "Sailplane Performance Flight Testing", *OSTIV Publication XVII*, Vol. IX, No. 1 (1985).

10. Marsden, D.J., "Circling Performance of Sailplanes", *OSTIV Publication XI*, 1970.

11. Marsden, D.J. "Flight Testing Sigma", Proceedings of SSA Convention, (1983).