A Further Case for Variable Geometry

W.A.T. 'Fritz' Johl
watjohl@iafrica.com
Constantia, South Africa

Abstract

Today, all sailplanes in any particular class look and perform more or less the same. This gives credence to the view that the necessary compromises in design and sailplane technology have reached a limit. Sailplane development is on a sort of plateau. Further, apart from, perhaps, boundary-layer control, there appears to be nothing in the foreseeable future that promises any significant improvement in performance. It is the purpose of this paper to, once again, encourage interest in Variable Geometry and address the controversies which prevailed in abundance during the 1970s and which apparently still survive today.

Nomenclature

W	all up weight (kg)
S	wing area (m^2)
b	wing span (m)
W/S	wing loading (kg/m^2)
W/b	span loading (kg/m)
AR	aspect ratio (geometric)
ARe	aspect ratio (effective)
$C(w)$	mean wing chord (m)
$M.A.C.$	mean aerodynamic chord (m)
Clt	lift coefficient in turn
$Cdi(e)$	induced drag coefficient at ARe
Cdo	profile drag coefficient
Cdp	parasite drag coefficient
Cd	total drag coefficient
ρ	density of air (kg/m^3)
g	acceleration of gravity (m/s^2)

In thermal climb

R	thermal radius (m)
Tr	minor thermal radii (m)
Tso	thermal strength at core (m/s)
Tsr	thermal strength at radius Tr (m/s)
r	radius of turn (m)
Vdt	rate of descent at radius of turn (m/s)
Vct	rate of climb in turn (m/s)
Vt	true air speed in turn (km/h)
Vet	equivalent air speed in turn (km/h)
Bank	Angle of bank in turn (degrees)

In straight glide

V	true airspeed (km/h)
Vc	achieved rate of climb (m/s)
Ve	equivalent air speed (km/h)
Vav	average cross country speed (km/h)
Vave	equivalent average speed (km/h)
Vd	rate of descent in straight glide (m/s)
q	dynamic pressure = $(\rho/2 \times Ve^2)$

History

In May 1968 the magazine *Soaring* published an article by Pat Beatty and the author, 'A case for variable geometry.' Now, apart from sporadic cases, to the best of the author's knowledge, no serious efforts have been made to pursue this subject any further into series production. The author finds this surprising, as it would appear to him that variable geometry (VG) is an obvious way to go if the object is to improve the performance of the modern sailplane. There are those who may, perhaps, argue that, just as there is little purpose served in researching golfing equipment in an effort to make the ball travel further and faster, so too no useful purpose will be served by any efforts made to improve the potential performance of sailplanes beyond today's norm. If the reader has this view he need not read further — others can for themselves consider counter arguments. During the years 1945 to 1970 the author and Beatty built, entirely in South Africa, a series of high performance research sailplanes (BJ-1, 2, 3 and 4) designed to improve the soaring and gliding capabilities of sailplanes by exploiting the aerodynamic advantages resulting from the use of efficient high lift devices, in particular, the Fowler flap [1]. These original concepts were later confirmed [1–3] (The BJs were developed from the author's Pelican II 1946 design with wing profile NACA 23012 and external aerofoil flap.)

The author notes that in numerous publications some flap systems have been incorrectly named Fowler flap systems. To qual-

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ify as a Fowler flap system the flap itself must be a separate retractable surface with a recognisable profile — a mini wing as it were. In the retracted condition it must be fully absorbed within the basic wing profile. When deployed it must do so to its fullest chord dimension and its leading edge must be located relative to the basic wing trailing edge so as to form a slot. The location of the flap leading edge and the size of the slot are critical if the optimum benefit of the system is to be realised. The deployment of the flap to its full chord and the slot are the essence of the system and unless these conditions are fulfilled the system can not rightly claim to be a Fowler system (Fig. 5, inset)

In determining the wing aerodynamics for the BJ projects, extensive use was made of various wind-tunnel test reports — NACA Reports — on external aerofoil flap systems that were available for the appropriate Reynolds Numbers. Later on data was obtained from the publication Theory of Wing Sections (Abbott and von Doenhoff). The choice of the radical wing profile (NACA 66_1-212) for the BJ-3 evolved by in effect working backward from data published by Bruce Carmichael [3], and establishing the configuration, within our constructional facilities and capabilities to optimise the average cross country speed when relating this to the assumed summers day thermal activity in South Africa.

From 1960 to 1970 the BJ-2, 3 and 4 won every South African National Championship and set up numerous new World records resulting in these machines being recognised throughout the world as the first and most advanced sailplanes to employ VG principles. These successes created a flurry of interest throughout the gliding world in VG and encouraged extensive research by aerodynamicists particularly at establishments in England and Germany into VG aerodynamics and technology. The fact that all the records were flown by ordinary pilots on standard competition tasks further vindicated the faith that Beatty and particularly the author had in a VG system employing the Fowler flap principles, a faith it must be said that often ran contra to the opinions of their peers.

At that time and even still today, there are some who attributed these successes to the strong thermal activity that the South African air is noted for. As the SA air was what the BJ-s were specifically designed for, their success under these conditions is not surprising. It is true that when the BJ-s were later flown in more marginal conditions their performance was disappointing. But the BJ-s were only the first VG sailplanes and certainly did not represent the ultimate. There were many issues that had not been solved — particularly, in the expanded configuration, the broken span lift distribution due to the change in wing chord at the wing tips

The BJ partnership was dissolved in 1970 and Beatty continued to research VG on his own and up to his tragic death in a car accident in December 1991 designed, built and flew in competition the B-5, 6, 7 and 8. All these aircraft, by most innovative mechanical solutions, employed VG principles in that the wing profiles could in flight be altered both in depth and camber. For reasons best known to himself at the time, Beatty never again employed the principle of an area increasing flap in his designs. It may perhaps have been that no satisfactory solution presented itself for solving the problem of lateral control with a full span Fowler flap. Beatty over a period of some 30 years had built, flown, and later designed eight highly sophisticated high performance sailplanes all of which 'set the pace' and could, at the time, hold their own in competition. This effort must alone stand as a record of sorts.

Further VG projects

Other notable VG projects undertaken from those years to today are:

In England:

in 1966 a team led by Nicholas Goodhart designed a SIGMA project.

In Germany:

1975 the fs29 by the University of Stuttgart
1978 the SB-11 by the University of Braunschweig
1979 the Mü-27 by the University of Munich
1981 the D-40 by the University of Darmstadt
1981 the M2 'Milomei' by Michael Lorenz Meier, Hamburg
1992 the fs32 by the University of Stuttgart

The 'Sigma', SB-11, Mü-27 and M2 all used an unslotted system originally suggested and researched by F.X. Wortmann, which today, in his honour is designated the 'Wortmann flap'. In this system the wing surface at the trailing edge is expanded a constant percentage over the whole span.

The D-40 also used an unslotted system with the expansion varying from full expansion at the wing root to zero at the tip — a so called 'pocket knife' flap system.

The fs29 project used a system of span expansion from 13.3 to 19m. The pilot could set the desired span during flight to the configuration required for any particular flight phase. (Presumably the higher aspect ratio expanded wing was intended for the thermal climb phase. If this is so, it is in sharp contrast with the findings of the author as given in this manuscript.) The practical application and solving of the complicated mechanics and kinematics required for this system must have caused many a headache.

The fs32 system had no significant wing area changes but the profile camber could be changed from an unslotted trailing edge flap to a slotted flap.

Worthy of note also is the work done on VG by David Marsden in Canada who from the early 70s to late 90s devoted considerable time on various VG projects mostly using one or other form of slotted flap. In 1979, Sigma was moved to Canada and Marsden carried out various modifications among which was the removal of the problematical mechanical VG flap system that apparently had led to inferior aerodynamics. In the modified form Sigma broke the US 300km triangle record in 1997 at 151km/h.

In 1978 Helmut Reichman flying the SB11 came first in the 15m class at the World Gliding Championships at Chateauroux France [4]. Apart from this performance none of the projects mentioned fully lived up to the designers and constructors expectations. Worthy of note is that none of the projects listed used the Fowler flap principle. Perhaps there is a lesson to be learnt from this?

Variable geometry

Although the subject matter of sailplane design and construction and the various compromises that have to be made to produce the desired overall performance have been amply documented in various publications over the years, it may be worthwhile again to consider these more specifically as applied to VG.

Variable geometry in the context of this paper means the changing of the wing configuration and, hence, the wing aerodynamic characteristics by changes in the wing area either by changes in the wing chord dimension or in the wing span dimension. (The author is of the opinion that unless there is a change in either of these two dimensions the system cannot claim to be VG. The definition also specifically excludes purely camber changing systems as applied today to the FAI 15m class sailplanes and, especially, the open class, the 'Formula 1' in soaring). A further consequence of either of these actions is that the wing aspect ratio and the wing area, and consequently the wing loading for a given aircraft are changed.

Further, the following analysis applies only to the flight of sailplanes as applied to cross-country flying using thermal up currents as the source of energy. Limiting the analysis to this method of soaring only may encourage some to argue that with the improved technology and knowledge available to sailplane pilots today, energy sources other than thermals are used on soaring cross country flights and to now concentrate on the thermal climb performance particularly is a waste of time. Such arguments seem to be pointless as any pilot flying a variable geometry sailplane is of course not precluded from still using any other method of soaring. Further, one only needs to follow on the Internet the individual flight patterns of competitors on gliding championships to have it confirmed that, in spite of everything, all competitors still do spend considerable time on a cross country flight gaining height in thermals.

Classically, a soaring cross country flight using thermal currents consists of the repetition of a cycle comprising of a climbing phase during which the aircraft is turning within the confines of a thermal up current followed by a straight inter-thermal glide phase that continues to the base of the next thermal. The only really interesting flight performance question is the time taken to complete this cycle and the distance flown — the average cross country speed, (*Vav*). This, then, is the basis of analysis in this paper. To increase the *Vav* under any specified set of atmospheric conditions requires either an increase in the rate of climb, or an increase in the speed between thermals or if possible an increase in both — and this is the challenge in the design of a VG sailplane. It is truly a case of 'what is gained on the swings is lost on the round-a-bouts'.

To increase the speed of any aircraft requires an increase in power. Weight being the only source of power available to the sailplane an increase in this, or more specifically the wing loading, will produce much higher speeds on the straight glide phase between thermals. However, on the thermal climb phase the increased wing loading drastically reduces the thermal climb performance. Wing loadings can be changed by carrying water ballast when strong thermal activity is anticipated so increasing the inter-thermal flight speeds. But this is a 'once off' solution. You either have it or not. Far better is it to alter the wing loading to suit the specific requirements for a particular phase of the flight by altering the wing area either by changes in the wing span or alternative, changes in the wing chord. Hence variable geometry.

It is popularly conceded that a high aspect ratio wing is necessary during the climbing turn to reduce the induced drag which is the greater part of the total drag, On the other hand, during the straight glide phase at high speed and low lift coefficients, the induced drag, being the smallest part of the total drag, a lower aspect ratio wing is acceptable. It is this concept that has led to the design of sailplane wings to be configured with ever higher aspect ratios and some to apply variable geometry to the changes of wing span and not the wing chord — that is, by using a base wing design for the climb and reducing the wing span for the inter-thermal glide.

In his research into VG the author had found (later confirmed [2]) that the reverse is the case. At any given span loading a low aspect ratio is required for the thermal climb and a high aspect ratio for the inter-thermal glide (see Figs. 1 and 2).

VG — The effect of aspect ratio

The basic idea of variable geometry is to 'tailor' the wing configuration to suit a particular phase of flight — to expand the wing for the thermal climb so increasing the area and reducing the wing loading and to contract the wing during the inter-thermal glide so increasing the wing loading and, consequently, the inter-thermal flight speed. There is nothing new in this. These matters are common knowledge to all who have anything to do with the flying or with the designing of sailplanes. The matter of contention has been how the wing geometry should be varied. To obtain a lower wing loading for the thermal climb, should the wing span be increased resulting in an increase in wing aspect ratio or the wing chord increased resulting in a decrease in wing aspect ratio.

Consider a sailplane of given wing configuration to be 'tailored' specifically for the thermal climb. To reduce the wing loading the wing area is increased by increasing the wing span. But the wing span can not just be increased indefinitely — other considerations eventually set a limit. If the limit arrived at is now considered as a base, a further reduction of wing loading still can be achieved by increasing the wing chord. So there does not seem to be much of a problem in making up one's mind on the matter. The way to go to specifically tailor the wing for the thermal climb is at any fixed wing span to expand the wing by increasing the wing chord so reducing its aspect ratio. When now, for the inter-thermal glide, the expanded wing is contracted, the

CONFIGURATION							
AR		**25**	**21**	**18**	**16**	**14**	**13**
W	kg	500	500	500	500	500	500
S	sq.m.	12.96	15.55	18.14	20.73	23.33	25.92
b	m.	18.00	18.00	18.00	18.00	18.00	18.00
W/S	kg/sq.m.	38.58	32.15	27.56	24.11	21.43	19.29
W/b	kg/m	27.78	27.78	27.78	27.78	27.78	27.78
MAC	m.	0.72	0.86	1.01	1.15	1.30	1.44
AERODYNAMICS							
ARe	Effective	21.15	17.63	15.11	13.22	11.75	10.58
Clt	max.	1.40	1.40	1.40	1.40	1.40	1.40
Cdo	at Clt	0.015	0.0150	0.015	0.015	0.015	0.015
Density Altitude		0	m				
PERFORMANCE							
Thermal			R = 100 m		Tso = 6 m/s		
Tsr		4.05	4.56	4.84	5.04	5.18	5.31
Vdt	m/s	-1.46	-1.38	-1.30	-1.26	-1.22	-1.23
Vct	**m/s**	**2.59**	**3.18**	**3.54**	**3.78**	**3.95**	**4.08**
Thermal			R = 150 m		Tso = 4 m/s		
Tsr		3.23	3.42	3.51	3.59	3.64	3.69
Vdt	m/s	-1.12	-1.10	-1.04	-1.03	-1.02	-1.03
Vct	**m/s**	**2.10**	**2.33**	**2.47**	**2.56**	**2.62**	**2.66**
Density Altitude		4000	m				
PERFORMANCE							
Thermal			R = 100 m		Tso = 6 m/s		
Tsr		3.31	3.14	3.77	4.19	4.44	4.67
Vdt	m/s	0.00	-1.97	-1.86	-1.78	-1.69	-1.67
Vct	**m/s**	**0.00**	**1.17**	**1.91**	**2.40**	**2.75**	**3.00**
Thermal			R = 150 m		Tso = 4 m/s		
Tsr		2.56	2.88	3.12	3.26	3.36	3.42
Vdt	m/s	-1.59	-1.47	-1.44	-1.40	-1.37	-1.34
Vct	**m/s**	**0.97**	**1.41**	**1.68**	**1.86**	**1.99**	**2.08**

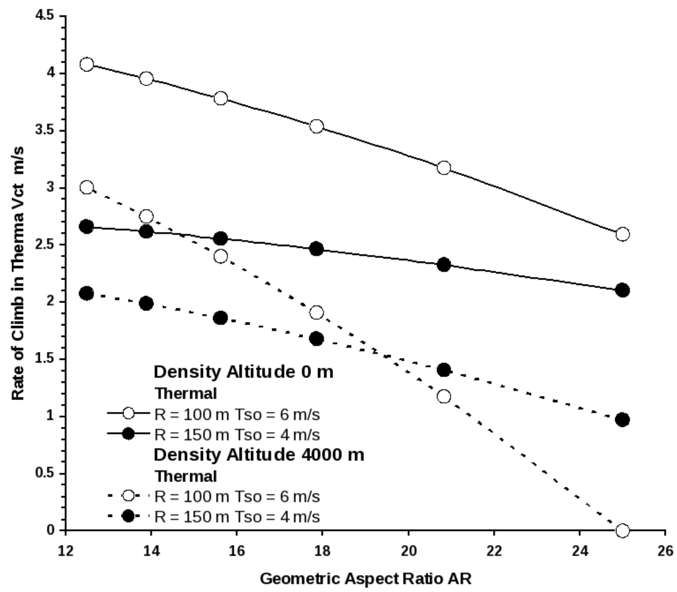

Figure 1 The effect of aspect ratio at constant span loading on climb performance with two specified thermal profiles and at two density altitudes.

chord and area reduced, the wing loading increased, the resulting higher aspect ratio will give greater aerodynamic efficiency at the higher wing loading. (Figs. 1 and 2)

The following are further factors in favour of changing the wing chord rather that the wing span.

Firstly — while it is possible with a bit of ingenuity to double the wing chord and hence the wing area, it is difficult, if not impossible to double the wing span. The best one can probably expect is to increase the span by a factor of 1.7 (this being the increase in span achieved in the magnificent VG sailplane project fs29 by Akaflieg Stuttgart.)

Secondly — when the wing chord is increased it is possible to change the shape of the wing profile and tailor this in the expanded condition, to a shape that produces aerodynamic characteristics more supportive of the requirements for the thermal climb. The profile can be shaped to give a lower rate of descent and better aerodynamic characteristics near the stall. The author does not see how this can be done when increasing the wing span The profile at best will have to be a compromise for high and low speed operation.

Thirdly — increasing the wing chord in the thermal climb increase the Reynolds number in proportion at the same speeds. This usually has a marked beneficial effect on the wing profile lift and drag characteristics at low speed and high angle of attack — close to the stall — conditions appertaining to circling flight in a thermal.

Fourthly — From a purely operational point of view, high aspect ratio wings are affected more by gusts than low aspect ratio wings — this has to do with the steeper Cl vs. alpha slope of wings with higher aspect ratios. Hence, a high aspect ratio wing is more 'gust prone' and can be induced to stall as a result of an up gust that would not have the same effect on a wing of lower aspect ratio. High aspect ratio wings make for a bumpy ride in turbulent weather when compared to wing of lower aspect ratio. This may also be a factor affecting the strength and hence weight of the sailplane.

It may serve good purpose at this point to be reminded that aspect ratio is only a convenient way for describing the shape of a wing and, as all aeronautical engineers know, enters into the calculation of a wing's drag coefficient. It is that portion of the wing drag which is directly attributed to the generation of the wing lift. It is a popular fallacy that aspect ratio is the determining factor in reducing the induced drag. It is generally assumed that high aspect ratios are good and low aspect ratios are bad. Many are inclined to ascribe almost magical properties to aspect ratio particularly when evaluating the potential performance of an aeroplane.

Aspect ratio does, of course, have a major part to play in the determining of the induced drag coefficient (Cdi) but a coefficient is only a convenient mathematical concept to compare data from various sources and for various purposes. It should not be confused with the actual force it represents.

In level flight the induced drag is

$$Di = \frac{1}{\pi q}\left(\frac{W}{b}\right)^2 \tag{1}$$

CONFIGURATION							
AR		**25**	**21**	**18**	**16**	**14**	**13**
W	kg	500	500	500	500	500	500
S	sq.m.	12.96	15.55	18.14	20.73	23.33	25.92
b	m.	18.00	18.00	18.00	18.00	18.00	18.00
W/S	kg/sq.m.	38.58	32.15	27.56	24.11	21.43	19.29
W/b	kg/m	27.78	27.78	27.78	27.78	27.78	27.78
MAC	m.	0.72	0.86	1.01	1.15	1.30	1.44
AERODYNAMICS							
ARe	Effective	21.15	17.63	15.11	13.22	11.75	10.58
Clt	max.	1.40	1.40	1.40	1.40	1.40	1.40
Cdo	at Clt	0.015	0.0150	0.015	0.015	0.015	0.015
Density Altitude		**0 m**					
Thermal		**R = 100 m**		**Tso = 6 m/s**			
PERFORMANCE							
Ve	km/h	198.0	190.3	183.8	178.2	173.3	168.9
V	**km/h**	**198.0**	**190.3**	**183.8**	**178.2**	**173.3**	**168.9**
Vct	**m/s**	**4.08**	**4.08**	**4.08**	**4.08**	**4.08**	**4.08**
Vav	km/h	**128.4**	**121.5**	**115.7**	**110.7**	**106.5**	**102.7**
L/D	at Ve	24.9	22.9	21.3	19.9	18.8	17.9
Thermal		**R = 150 m**		**Tso = 4 m/s**			
PERFORMANCE							
Ve	km/h	173.0	165.5	159.3	154.1	149.6	145.6
V	**km/h**	**173.0**	**165.5**	**159.3**	**154.1**	**149.6**	**145.6**
Vct	**m/s**	**2.66**	**2.66**	**2.66**	**2.66**	**2.66**	**2.66**
Vav	km/h	**110.3**	**103.9**	**98.5**	**94.0**	**90.1**	**86.7**
L/D	at Ve	31.8	29.1	27.0	25.2	23.7	22.4
Density Altitude		**4000 m**					
Thermal		**R = 100 m**		**Tso = 6 m/s**			
PERFORMANCE							
Ve	km/h	179.4	171.8	165.6	160.3	155.7	151.6
V	**km/h**	**219.5**	**210.2**	**202.6**	**196.1**	**190.5**	**185.5**
Vct	**m/s**	**3.00**	**3.00**	**3.00**	**3.00**	**3.00**	**3.00**
Vav	km/h	**141.0**	**132.9**	**126.2**	**120.6**	**115.7**	**111.4**
L/D	at Ve	29.8	27.3	25.3	23.7	22.3	21.1
Thermal		**R = 150 m**		**Tso = 4 m/s**			
PERFORMANCE							
Ve	km/h	161.6	154.2	148.2	143.1	138.8	135.0
V	**km/h**	**197.8**	**188.7**	**181.3**	**175.1**	**169.8**	**165.1**
Vct	**m/s**	**2.08**	**2.08**	**2.08**	**2.08**	**2.08**	**2.08**
Vav	km/h	**123.2**	**115.7**	**109.5**	**104.3**	**99.8**	**95.8**
L/D	at Ve	35.7	32.7	30.2	28.2	26.4	24.9

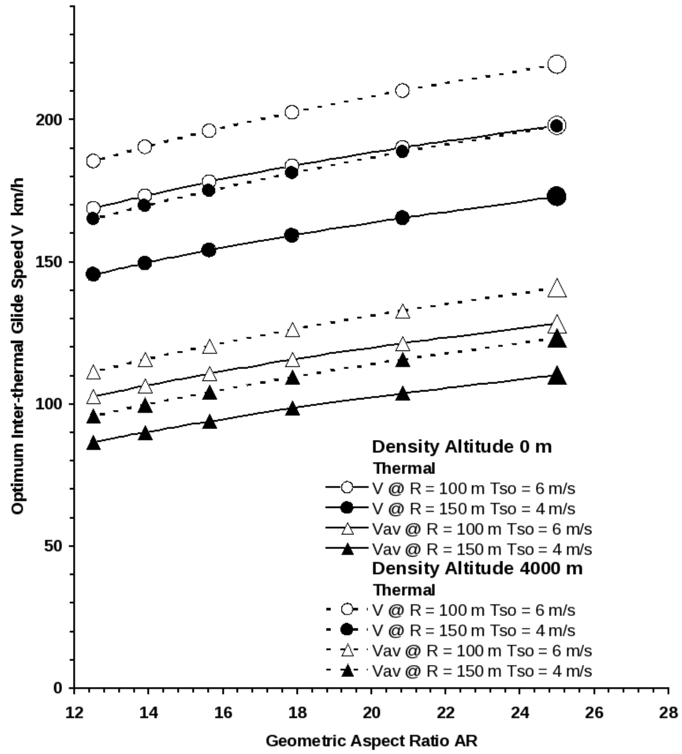

Figure 2 The effect of aspect ratio at constant span loading on the optimum inter-thermal speed for best *Vav* with two specified thermal profiles and at two density altitudes.

(see Appendix). In the real world it is the drag and not the coefficient that has to be overcome. In the real world it is the span loading and not the aspect ratio that determines how efficiently a wing performs its lifting function. Hence, all aeroplanes that have the same span loading have the same induced drag at the same equivalent air speed *Ve* irrespective of aspect ratio or the wing chord.

VG — General effect

Table 1 compares the general effect on the configuration and aerodynamics of an aircraft of given span loading when the wing chord is doubled or halved.

Just as a matter of interest, we see in nature that, without exception, all birds that soar using thermal up currents — eagles, vultures, condors, all have wings of low aspect ratio when compared to birds that soar using horizontal air currents — dynamic soaring — albatross, gulls and so forth. If it is argued that eagles and vultures are land based birds and have low aspect ratio wings because of the environment in which they operate, then one only needs to look at the pelican which is an excellent 'thermal' soarer. Yet sailplanes that soar using thermal air currents, are configured, for reasons that everyone knows, like an albatross — with high aspect ratio wings. If sailplanes are right, one can not help but wonder how nature could have got it so wrong?

The thermal climb

The rate of descent of a sailplane in a gliding turn is not in itself a satisfactory or realistic enough basis for predicting possible thermal climb performance. A sailplane may have a low rate of descent in a turn but when this is related to a specific thermal profile at any particular density altitude the picture looks a lot different.

Clearly therefore, any meaningful performance analysis of the thermal climb only can be done in relation to the up current strength and the distribution thereof. For this analysis the up current distribution is assumed to spread out radially from a central core with the strength reducing parabolically from the center out. The parabolic distribution has been chosen arbitrarily mainly because of the possibility of easier mathematical analysis. Two thermals are used as the standard — $R = 100$m, $Tso = 6$m/s and $R = 150$m, Tso=4m/s. Although these are in line with thermal profiles chosen by others in sailplane performance analysis, the author has found that the chosen radii and thermal strengths seem to be basically unrealistic. Knowing the aerodynamic char-

Table 1 Effect of doubling or halving wing chord on configuration and aerodynamics

Configuration		Wing Area Doubled	**Standard**	Wing Area Halved
Weight	W	1	**1**	1
Wing Area	S	2	**1**	0.5
Wing Span	b	1	**1**	1
Wing Loading	W/S	0.5	**1**	2
Span Loading	W/b	1	**1**	1
Aspect Ratio	AR	0.5	**1**	2
Wing Chord	C	2	**1**	0.5
Lift Coefficient	Cl	1	**1**	1
Aerodynamics		Wing Area Doubled	**Standard**	Wing Area Halved
Wing Reynolds Number	Re	1.41	**1**	0.70
Induced Drag Coefficient	Cdi(e)	2	**1**	0.5
Profile Drag Coefficient	Cdo	1	**1**	1
Parasite Drag Coefficient	Cdp	0.50	**1**	2.00
Equivalent Air Speed	Ve	0.71	**1**	1.41
Induced Drag at same speed	Di	1	**1**	1
Induced Drag at Ve	Di Ve	2	**1**	0.5
Profile Drag at same speed	Do	1	**1**	1
Parasite Drag at same speed	Dp	1	**1**	1

acteristics and configuration of actual sailplanes, if their actual performances at altitude are related back to what the up current strength must have been to produce these performances, then it appears that the standard thermals are not representative of what is actually the case. They all appear to be either too weak or too small. Further, the analysis done by others is normally related to sea level — zero density altitude — only. Sailplanes do not fly at sea level and the author has found that when climb performance is related to more applicable conditions the picture often looks a lot different.

Mathematically,

$$\begin{aligned} Vct &= \text{Rate of Climb in Thermal} \\ &= Tsr - Vdt \end{aligned}$$

where

$$\begin{aligned} Tsr &= \text{Thermal Strength at Radius R} \\ &= Tso - \left\{Tso(r/R)^2\right\} \qquad (2) \\ & \quad \text{Parabolic } r \text{ v. } Tsr \text{ distribution} \end{aligned}$$

(Fig. 3 Graph 1) and

$$\begin{aligned} Vdt &= \text{Rate of Descent in Turn of Radius } r \text{ (Ref. 2)} \\ &= Cd \div \left[Cl\sqrt{1 - 1 \div \{Cl^2(2W \div Sgr\rho)^2\}}\right]^{1.5} \ldots \\ & \quad \times \sqrt{2W \div S\rho} \qquad (3) \end{aligned}$$

The solving of the above equations for the maximum value of Vct at various aspect ratios of a sailplane of fixed weight and wing span and, hence, fixed span loading for any given thermal profile will give the maximum rate of climb for the sailplane configuration and aerodynamic characteristics under consideration. Figure 1 shows the result in tabular and graphical form of such evaluation when applied to a 'state of the art' sailplane for two selected thermal profiles at density altitudes 0 and 4000m. The table also shows the configuration and aerodynamics applicable to the analysis. The advantage of a low aspect ratio is self evident.

Some will consider this presentation (and also that in Fig. 2) to be manipulative and confusing in that the span loading is held constant and the improved performance attributed to the reduction of aspect ratio. The author has deliberately embarked on this approach — basing the comparison on aspect ratio — as this has been the main point of criticism during discussions on VG in general and more specifically, his J-5 Project. It was believed that when reducing the wing loading by increasing the wing chord, the resultant reduction in aspect ratio and increase in induced drag would more than offset the advantage of the reduced wing loading. As we see, this is not so. Those who are not able to support this approach should ignore it entirely but just judge the arguments on the merits of the comparative performance results presented below. If these are deemed to be credible, then the question still remains 'why has not more work been done on variable geometry?' After all, machines designed specifically to satisfy varying requirements are surely better than those designed as a compromise and that are neither ‘fish nor fowl’.

Graphical analysis of thermal climb performance

There is another interesting method to analyse the climb performance of sailplanes graphically (Fig. 3) (Note: Imperial Units, ft and ft/s).

The rate of descent in a turn Vdt may be related to the rate of descent in a straight glide Vd by the relationship

$$\frac{Vd}{Vdt} = \left(1 - \frac{Ve^4}{g^2 r^2}\right)^{0.75} \tag{4}$$

(see Appendix). Graph 1 shows how the up-current strength is assumed to vary with distance from the centre of the thermal (in this instance — parabolic). Graph 2 shows the rates of descent Vdt required at specified radii of turn r for the sailplane to achieve various rates of climb Vct in this particular thermal. Applying Eq. 4 to these values, a series of curves can be developed that relate any particular rate of climb Vct to the rate of descent Vd at various straight glide speeds Ve. The sequence of analysis is shown graphically (Graphs 3 and 4) for zero and 20ft/s rates of climb in the sample thermal. The envelope to this family of curves, then, gives curves for the rates of descent in the straight glide to produce zero and 20ft/s rates of climb Vct in the sample thermal, in this instance $R = 400$ft and, $Tso = 40$ft/s (Graphs 5 and 6). In this manner the analysis can be extended to produce a set of curves relating the straight glide speed Ve and rates of descent Vd to any selected series of rates of climb Vct in any thermal of selected radius R and strength Tso (Graph 6; Appendix).

When this evaluation is computerised and applied to the straight glide performance polar of any sailplane, the potential climb performance is immediately apparent, the only variables in the analysis being thermal R and Tso. A further extension permits complete performance analysis at any density altitude both in equivalent and true speeds and rates of descent. The graphical performance predictions of the J-5 project are presented below in this form.

The graphical analysis is further interesting as it indicates the importance of the low speed characteristics required in a thermal climb and shows that it is still possible to climb in thermals although the rates of descent close to the minimum flight speeds — at the stall — are high.

The inter-thermal glide — specific effect of VG

Quite apart from the effect on the average speed, it should be the aim to make the inter-thermal speed of a sailplane as high as possible. After all, the air does not only go up and so it is reasonable to suppose that in between up currents, there must be proportionate amount of air moving downward. Further, one supposes that the stronger and more frequent the up currents so also there must be an increase in the frequency and strength of air moving down and the faster one can traverse such areas so much the better.

$$\begin{aligned} Vav &= \text{Average Cross Country Speed} \\ &= \frac{VctCl^{-0.5}}{\left(\begin{array}{l} ((Cdo + Cdp)Cl^{-1.5})\ldots \\ + ((1 \div \pi ARe)Cl^{0.5})\ldots \\ + (Vct \div \sqrt{2W \div S\rho}) \end{array}\right)} \end{aligned} \tag{5}$$

where $S = b^2 \div ARe$. The solving of these equations for the highest Vav at the various aspect ratios of a sailplane of fixed weight and wing span and hence span loading for any given achieved rate of climb Vct will give the inter-thermal speed for the sailplane configuration and aerodynamic characteristics considered.

Figure 2 gives, the results of such evaluation, for the ‘state of the art sailplane’ with constant span loading but various aspect ratio at density altitudes 0 and 4000m. (Note that the Vct in the evaluation are the maximum values as determined in Fig. 1) The accompanying table shows the configuration and aerodynamics applicable to the analysis. The advantage of high aspect ratio for the inter-thermal glide is self evident.

The J-5 project

The J-5 project aims primarily at increasing the average cross-country speed (Vav) of sailplanes — this is the performance criterion.

The project started out as an investigation into the requirements for and the possibility of designing a sailplane with the potential to complete a 1000km flight on a triangular course with no wind in five hours and using only thermal currents.

The J-5 project extends the development of VG principle by expanding/contracting the wing chord at the leading edge as well as the trailing edge using the Fowler flap concept. The aim is to double or halve the wing area and to drastically change the wing profile to produce the configuration and aerodynamics required to specifically suit the requirements of the thermal climb phase and the inter thermal glide phase of a cross country flight performance cycle (a two-speed sailplane). Extensive performance analysis shows that, in this way, thermal climb abilities can be maintained at weights appreciably higher than those of most gliders today and that the performance gains in the order of 25% are theoretically possible.

J-5 configuration

Figure 4 shows the three-view of the proposed configuration of the 15m version of J-5. The wing is mounted on a slim pylon and the tips have anhedral. Mounting the wing on a pylon appears to be the only way to obtain an aerodynamically clean fuselage/wing joint particularly when considered in the light of the chord expansion system. For de-rigging the wing tips are removable and the wing/fuselage joint is half way up the pylon. All fuselage/wing control connections are by torque tube

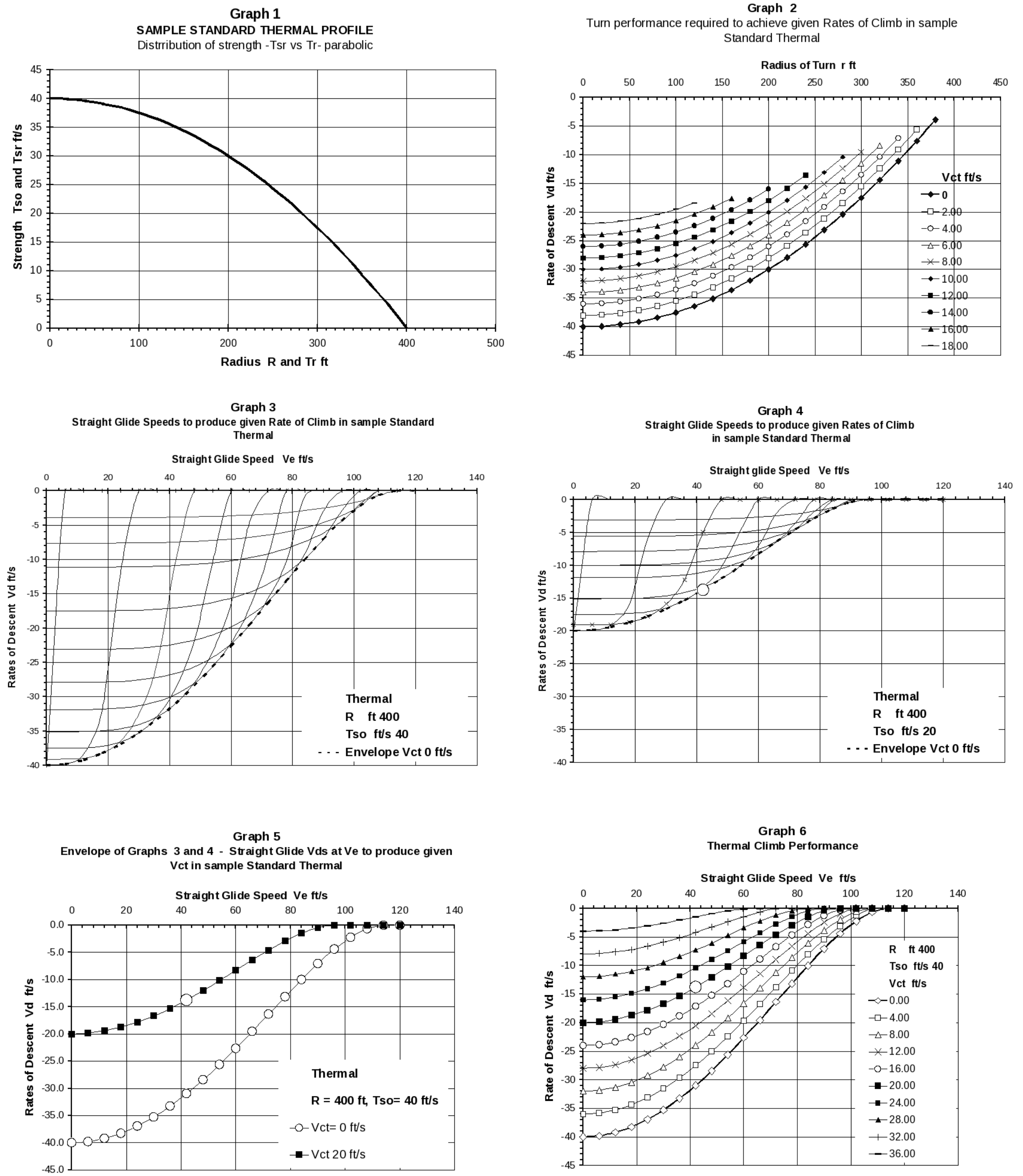

Figure 3 The sequence of evaluation for relating the straight glide performance of a sailplane to the climb performance in a thermal of given profile assuming the thermal profile to be parabolic.

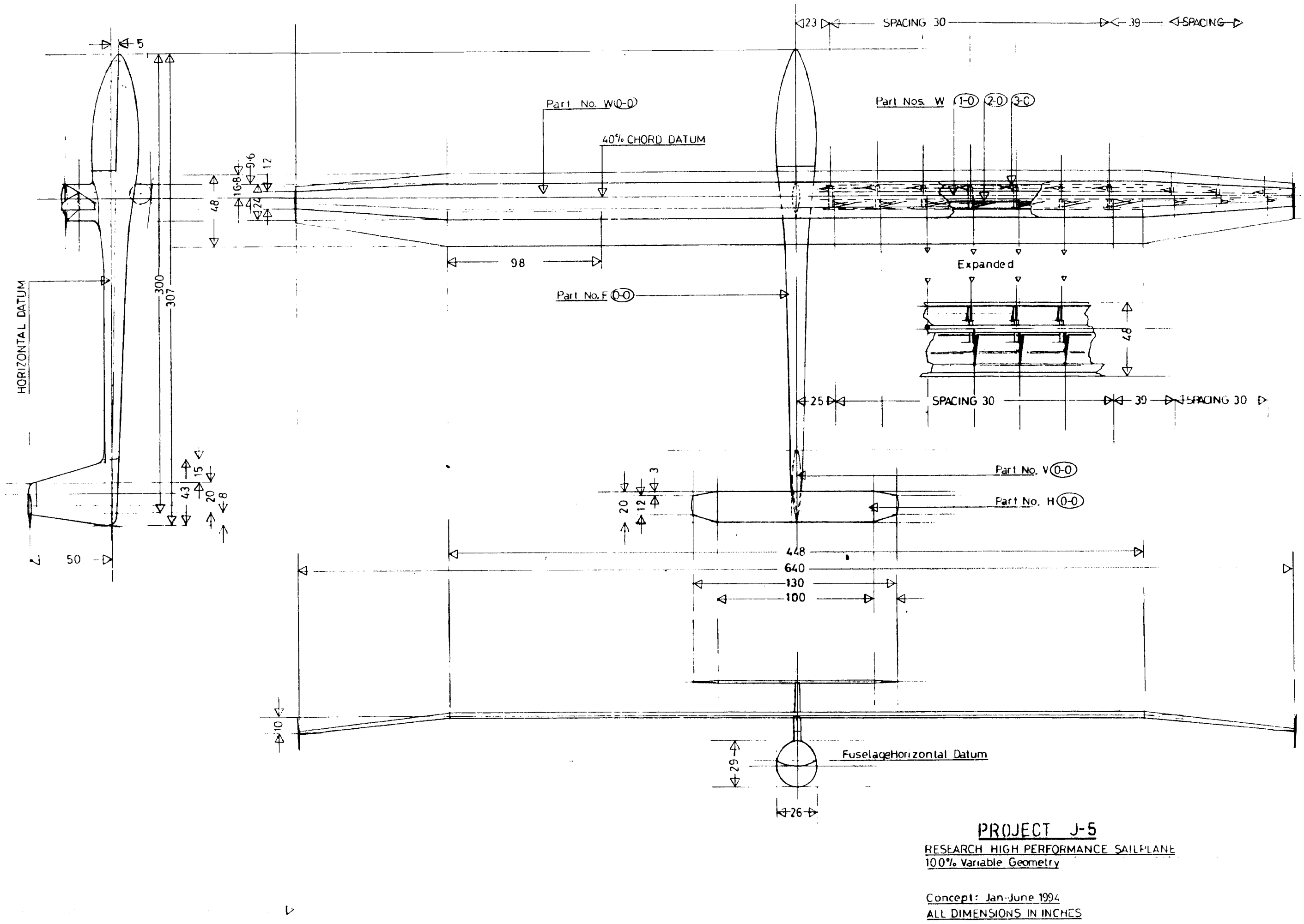

Figure 4 Three view layout of J-5 variable geometry high performance sailplane.

located in the pylon which automatically mate when the wing is mounted.

The wing tip anhedral (negative dihedral) is necessary to provide acceptable stability characteristics and also to afford protection to the expanded profile during operations on the ground. But what is more important is that it is not possible to expand leading or trailing edges of the wing as one spanwise unit unless the tapered portion of the wing has anhedral. The anhedral datum, when extended beyond the wing tips, ends at the apex of a cone of which the wing tip root is the base. The wing surface is a segment of this cone. Further, the author has a ‘gut feeling’ about the aerodynamic benefits of wings with anhedral encouraged in part by the observation of birds in flight. He would welcome any positive input in this regard.

With the proposed expansion mechanics it is difficult to also incorporate a spoiler system in the wing. For this purpose a variable area parachute is considered. It is a much simpler system and although perhaps not as effective as spoilers located in the wing, can be used to advantage in other respects, for example spin recovery. (Note: The BJ-2 that flew unmodified from 1961 to 1996 employed an effective system of parachute brake). Another problem area is the provision of an acceptable and effective aileron control system. In this regard it is proposed to use an upper surface aileron/spoiler system the design of which is based on the details given by Wenzinger and Rogallo in their NACA Report [5].

Specific performance comparisons

The best way to analyse the advantages/disadvantages and effectiveness of VG is to compare the potential performance of a VG with that of a ‘state of the art’ sailplane. This has been done in the tables and charts in Figs. 5 and 6 to 11. The charts are selected results from a computer program devised specifically to enable comprehensive and rapid performance comparisons between two sailplanes of known or assumed basic configuration and aerodynamic characteristics and the effect of any changes in the base on the comparative performances.

In the tables in Figs. 5 and 6 to 11, the various items and

CLIMB CONFIGURATION		VG J-5	OTHER	Ratio
W	kg	**800.00**	500	1.60
S	sq.m.	**18.05**	12.96	1.39
b	m.	**18.29**	18.00	1.02
W/S	kg/sq.m.	**44.33**	38.57	1.15
W/b	kg/m	**43.74**	27.77	1.58
AR		**18.53**	25.01	0.74
ARe	Effective	**16**	21.16	0.74
AERODYNAMICS DURING CLIMB				
Clt		**1.90**	1.40	1.36
MAC	m.	**0.99**	0.72	1.37
RN	1.00E+06	**1.57**	1.33	1.18
Cdi (e)		**0.0733**	0.0295	2.49
Cdo		**0.0250**	0.0150	2.00
Cdp		**0.00189**	0.0023	0.82
Cd		**0.10018**	0.0443	2.26
INTER-THERMAL STRAIGHT GLIDE CONFIGURATION				
W	kg	**800.00**	500	1.60
S	sq.m.	**10.31**	12.96	0.80
b	m.	**18.29**	18.00	1.02
W/S	kg/sq.m.	**77.58**	38.57	2.01
W/b	kg/m	**43.74**	27.77	1.58
AR		**32.43**	25.01	1.00
ARe	Effective	**30.81**	23.76	1.00
C[w]	m.	**0.56**	0.72	0.78

Cdo ESTIMATES

PROFILES	**For the thermal climb**
VG J-5	NACA NLF 415F with 0.25Cw L.E. and 0.5 Cw flap extended = **(Expansion Ratio 1.75)**
OTHER	NACA NLF 415F
	For the inter-thermal glide
BOTH	NACA NLF 415F

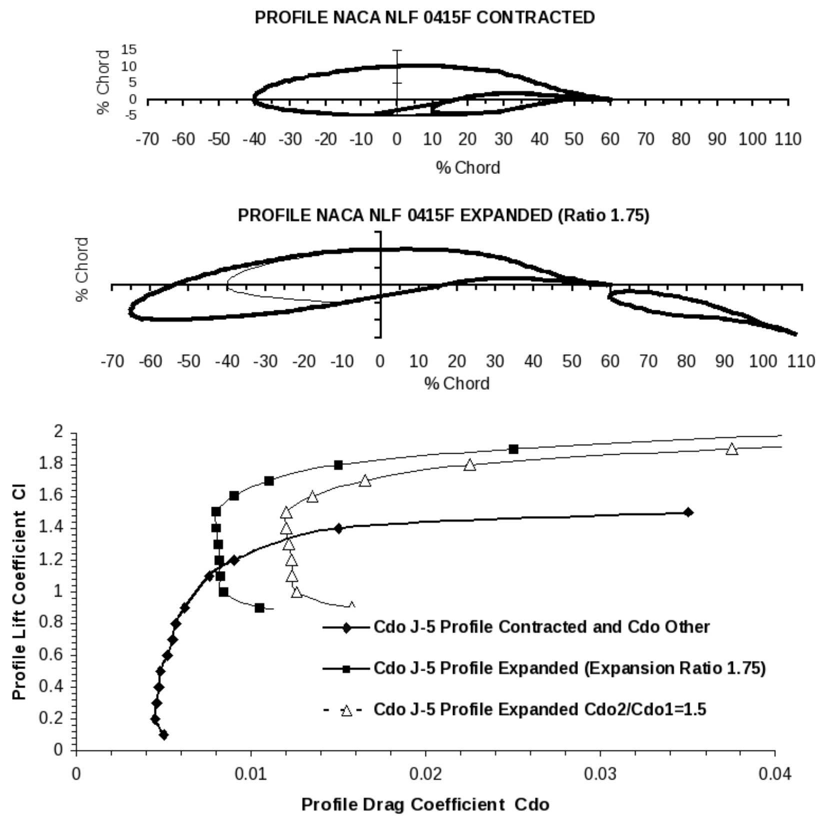

Figure 5 J-5 and OTHER sailplane configuration and basic aerodynamic assumptions.

their units are listed. The values have been determined mathematically independently of the values shown in the graphical presentation. The three columns marked "J-5", "OTHER" and "RATIO" give the comparative figures and the ratio of their differences (Ratio = J-5/OTHER). The "OTHER" column in these cases is representative of a 'State of the Art' sailplane. Performance comparisons are presented at selected thermal diameter and strengths at sea level, and at density altitude 3000m. The relative performance is presented graphically also in the usual way, as is also the performance in the thermal. The up-current distribution in the thermal is assumed to be parabolic.

Figure 5 shows graphically and in tabular form the configuration and aerodynamic characteristics on which the performances are based. In the expanded condition the coefficients are based on the expanded wing area. (Note that the expansion ratio has been limited to 1.75).

Figures 6 to 9 show the comparative performances at sea level and density altitude 3000m in the standard thermal and Figure 10 shows the performance in a very strong thermal The performance comparisons are comprehensive, complete and sufficiently detailed to require no further comment except perhaps in the case of Fig. 11 where the profile drag *Cdo* of J-5 has been increased on the climb phase by a factor of 1.5 over the whole range of lift coefficients, this to allow for possible wing surface imperfections with the wing in the fully expanded condition.

Figure 12 compares — in a comprehensive series of graphs — the performances of J-5 and 'State of the Art' sailplanes, the rate of climb Vct, the optimum inter-thermal glide speed V and the average speed Vav, for density altitudes 0 and 3000m and for a range of thermal radii *R* from 50 to 200m and selected thermal strengths $Tso = 3, 4, 5, 6$ and 7m/s.

Referring specifically to the performance figures of the J-5, these show the performance with the wing either fully expanded (Expansion Ratio 1.75) for the climb or fully contracted for the inter-thermal glide — there is nothing in between. As shown, the J-5 performance is truly a two speed sailplane only. Judging from the performance figures it would appear that the minimum rate of descent of the J-5 would be appreciably higher than that of the 'state of the art' sailplane. This means that the pilot, 'loitering', looking for thermals in conditions of weak thermal activity would have less time to do so and this is of course not acceptable. The stronger the up currents, the more vigorous the thermal activity, the less it is necessary for pilots on a cross country flight to fly at speeds for minimum rate of descent, looking for areas of high lift. It is only necessary for them to fly straight at the optimum computed inter-thermal speed and use thermal currents as they present themselves. (This gives credence to the opinions on the BJ performances in the 1950 to 70s that they

DENSITY ALTITUDE			0	metres.
THERMAL	Radius	R	100	metres.
	Strength	Tso	6	m/s
THERMAL CLIMB				
Expansion Ratio		1.75		
PERFORMANCE		VG J-5	OTHER	Ratio
W/S>>>kg/sq.m.		44.34	38.57	1.15
R	m	100.0	100.0	1.00
Tso	m/s	6.0	6.0	1.00
Tsr	m/s	4.4	4.1	1.06
r	m	52.0	56.0	0.93
Vdt	m/s	-1.8	-1.4	1.26
Vct	**m/s**	**2.6**	**2.7**	**0.96**
Vet	km/h	146.5	170.0	0.86
Vt	km/h	146.5	170.0	0.86
Bank	deg	47.0	53.3	0.88
STRAIGHT GLIDE				
PERFORMANCE		VG J-5	OTHER	Ratio
W/S>>>kg/sq.m.		77.58	38.57	2.01
Ve	km/h	216.3	173.3	1.25
Vave	km/h	136.7	110.6	1.24
V	km/h	216.3	173.3	1.25
Vav	**km/h**	**136.7**	**110.6**	**1.24**
Vd at Ve	m/s	-1.5	-1.5	0.98
L/D	at Ve	40.2	31.7	1.27
L/D Max		55.71	50.8	1.10
Ve for Max L/D		151.58	115.4	1.31
V for Max L/D		151.58	115.4	1.31
Cl at Inter-thermal V		0.34	0.26	1.29
R.N. at Inter-thermal V		2.30E+06	2.35E+06	0.98
Cdo Factor			VG J-5	OTHER
Glide		Cdo2/Cdo1	1.0	1.0
Climb		Cdo2/Cdo2	1.0	1.0

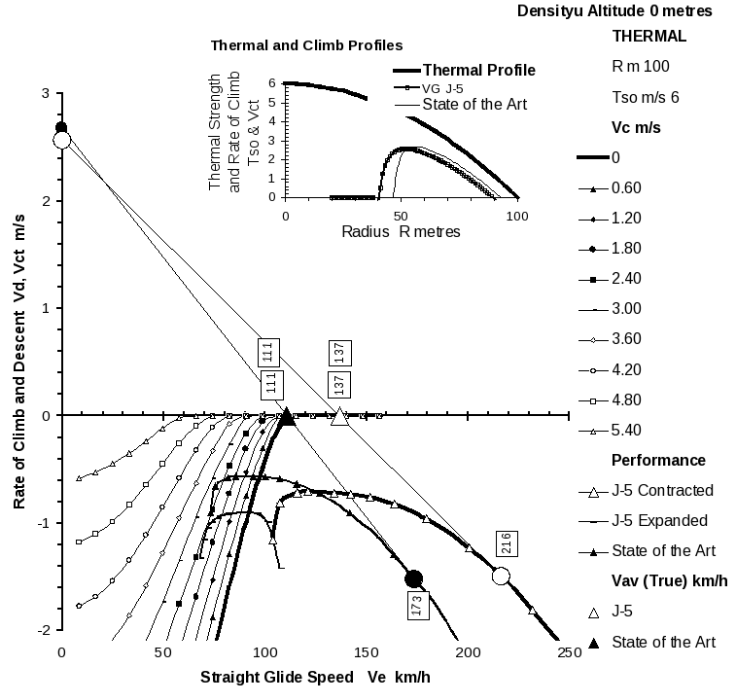

Figure 6 Performance comparison, density altitude = 0m, thermal $R = 110$m, $Tso = 6.0$m/s

DENSITY ALTITUDE			0	metres.
THERMAL	Radius	R	150	metres.
	Strength	Tso	4	m/s
THERMAL CLIMB				
Expansion Ratio		1.75		
PERFORMANCE		VG J-5	OTHER	Ratio
W/S>>>kg/sq.m.		44.34	38.57	1.15
R	m	150.0	150.0	1.00
Tso	m/s	4.0	4.0	1.00
Tsr	m/s	3.3	3.3	1.02
r	m	61.5	64.5	0.95
Vdt	m/s	-1.5	-1.1	1.34
Vct	**m/s**	**1.9**	**2.2**	**0.86**
Vet	km/h	136.4	155.1	0.88
Vt	km/h	136.4	155.1	0.88
Bank	deg	38.2	44.1	0.87
STRAIGHT GLIDE				
PERFORMANCE		VG J-5	OTHER	Ratio
W/S>>>kg/sq.m.		77.58	38.57	2.01
Ve	km/h	201.5	163.4	1.23
Vave	km/h	120.9	102.3	1.18
V	km/h	201.5	163.4	1.23
Vav	**km/h**	**120.9**	**102.3**	**1.18**
Vd at Ve	m/s	-1.2	-1.3	0.96
L/D	at Ve	45.1	35.1	1.29
L/D Max		55.71	50.8	1.10
Ve for Max L/D		151.58	115.4	1.31
V for Max L/D		151.58	115.4	1.31
Cl at Inter-thermal V		0.39	0.30	1.32
R.N. at Inter-thermal V		2.1E+06	2.2E+06	0.97
Cdo Factor			VG J-5	OTHER
Glide		Cdo2/Cdo1	1.0	1.0
Climb		Cdo2/Cdo2	1.0	1.0

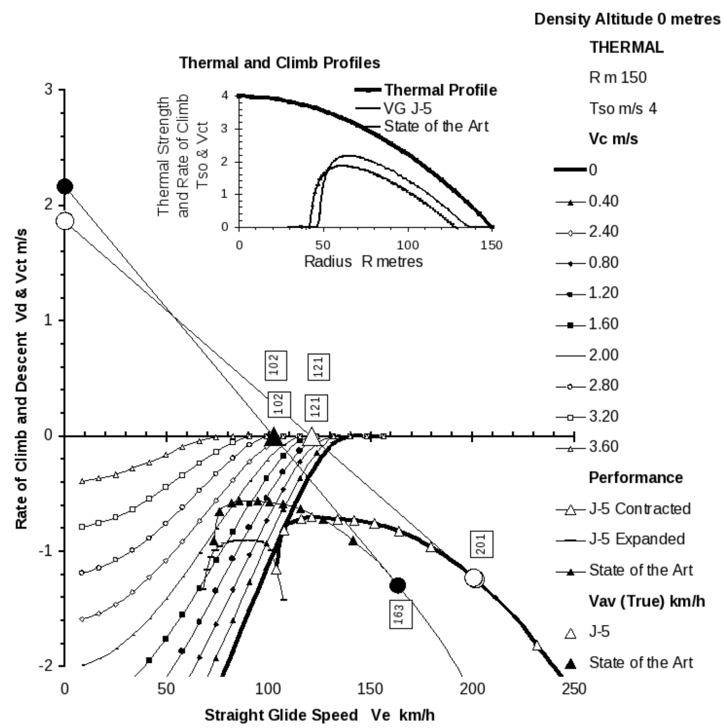

Figure 7 Performance comparison, density altitude = 0m, thermal $R = 150$m, $Tso = 4$m/s

AT DENSITY ALTITUDE			3000	metres.
THERMAL	Radius	R	100	metres.
	Strength	Tso	6	m/s
THERMAL CLIMB				
Expansion Ratio		1.75		
PERFORMANCE		VG J-5	OTHER	Ratio
W/S>>>kg/sq.m.		44.34	38.57	1.15
R	m	100.0	100.0	1.00
Tso	m/s	6.0	6.0	1.00
Tsr	m/s	3.4	2.8	1.21
r	m	66.0	73.0	0.90
Vd turn	m/s	-2.4	-1.9	1.28
Vct	**m/s**	**1.0**	**1.0**	**1.07**
Ve turn	km/h	177.0	204.2	0.87
V turn	km/h	205.5	237.1	0.87
Bank	deg	51.0	56.1	0.91
STRAIGHT GLIDE				
PERFORMANCE		VG J-5	OTHER	Ratio
W/S>>>kg/sq.m.		77.58	38.57	2.01
Ve	km/h	182.0	137.0	1.33
Vave	km/h	92.4	72.7	1.27
V	km/h	211.3	159.1	1.33
Vav	**km/h**	**107.3**	**84.4**	**1.27**
Vd at Ve	m/s	-1.0	-0.8	1.17
L/D	at Ve	51.3	45.2	1.14
L/D Max		55.71	50.8	1.10
Ve for Max L/D		151.58	115.4	1.31
V for Max L/D		176.02	134.0	1.31
Cl at Inter-thermal V		0.48	0.44	1.14
R.N. at Inter-thermal V		1.93E+06	1.82E+06	1.04
Cdo Factor			VG J-5	OTHER
Glide		Cdo2/Cdo1	1.0	1.0
Climb		Cdo2/Cdo2	1.0	1.0

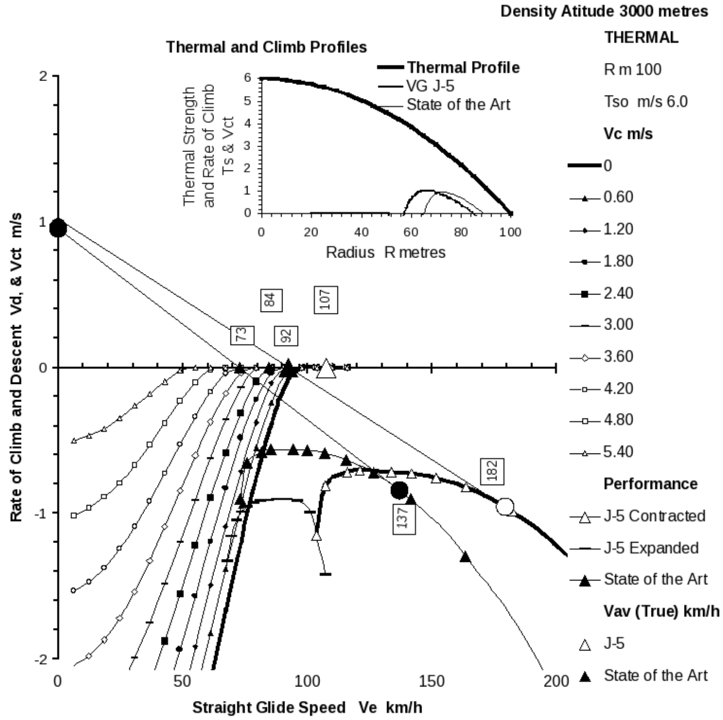

Figure 8 Performance comparison, density altitude = 3000m, thermal $R = 100$m, $Tso = 6$m/s

could only be achieved under condition of strong thermal activity as occurs in South African air). If VG is to be meaningful it is essential that every effort is made to maximise these two ‘in between’ performance criteria — the area in which the best gliding angle and, more importantly, the minimum rate of descent occur.

Integrity of the estimated performance figures

Sceptics may argue that the conditions on which the performance is based have been chosen specifically to ‘paint a rosy picture’. The computer programme permits extensive comparisons at an infinite variety of thermal radius and strength at any altitude as well as changes in the base configuration and aerodynamic assumptions. In most normal situations investigated the performance of the sailplane with VG outperforms that of the ‘state of the art.’ In general the calculated performance figures given in this paper are judged to be realistic. There is little doubt that, with the wing in the contracted configuration, the estimated performance for the high inter thermal glide speeds can be realised. However, no information could be found on the aerodynamic performance of a laminar flow profile with Fowler flap operating at the flight Reynolds numbers appropriate to the wing in the expanded condition as it would be during the thermal climb. Further, experience has led the author to believe that it is not possible to determine accurate Fowler flapped profile performances at the appropriate Reynolds numbers by the application of the usual theoretical computer analysis based on recognised aerodynamic theory. This applies particularly at the high angles of attack near the stall the condition appertaining to the thermal climb and of course, also the profile performance with partial expansion. With the Fowler flap in the expanded configuration, the relative location of the flap unit and the wing trailing edge and the slot formed between these two surfaces is critical. The airflow patterns are complicated and the calculated profile aerodynamics characteristics, consequently, unreliable. To verify the expanded wing performance and particularly the profile characteristics, a method of full scale tests using an existing sailplane is suggested. The wing of an existing sailplane could, for such tests, be modified by the addition of suitably fixed shaped foam surfaces to simulate only the profile and Fowler flap in the expanded condition. These tests would also form an excellent basis for the testing of the effectiveness of the lateral control system.

In the contracted condition the top surface of the J-5 wing is broken only by a spanwise joint line at the 75% chord location so it should be possible to fully exploit the potential of the profile with regard to laminar flow. In the fully expanded condition however, there are small spanwise ridges formed at 55% and 70% chord location of the expanded wing — (Fowler flap chord excluded). It is believed that these ridges will not seriously affect the flight performance as flight with the fully expanded wing is at high angles of attack only where the transition point is in any

AT DENSITY ALTITUDE			3000	metres.
THERMAL	Radius Strength	R Tso	150 4	metres. m/s
THERMAL CLIMB				
Expansion Ratio		1.75		
PERFORMANCE		VG J-5	OTHER	Ratio
W/S>>>kg/sq.m.		44.34	38.57	1.15
R	m	150.0	150.0	1.00
Tso	m/s	4.0	4.0	1.00
Tsr	m/s	2.9	2.8	1.05
r	m	78.0	82.5	0.95
Vdt	m/s	-1.8	-1.4	1.31
Vct	m/s	1.1	1.4	0.79
Vet	km/h	161.8	185.1	0.87
Vt	km/h	187.8	215.0	0.87
Bank	deg	41.1	47.2	0.87
STRAIGHT GLIDE				
PERFORMANCE		VG J-5	OTHER	Ratio
W/S>>>kg/sq.m.		77.58	38.57	2.01
Ve	km/h	184.2	147.6	1.25
Vave	km/h	96.4	86.4	1.12
V	km/h	213.9	171.3	1.25
Vav	km/h	111.9	100.4	1.12
Vd at Ve	m/s	-1.0	-1.0	1.01
L/D	at Ve	50.7	41.1	1.23
L/D Max		55.71	50.8	1.10
Ve for Max L/D		151.58	115.4	1.31
V for Max L/D		176.02	134.0	1.31
Cl at Inter-thermal V		0.47	0.37	1.19
R.N. at Inter-thermal V		1.96E+06	1.98E+06	1.04
Cdo Factor			VG J-5	OTHER
Glide		Cdo2/Cdo1	1.0	1.0
Climb		Cdo2/Cdo2	1.0	1.0

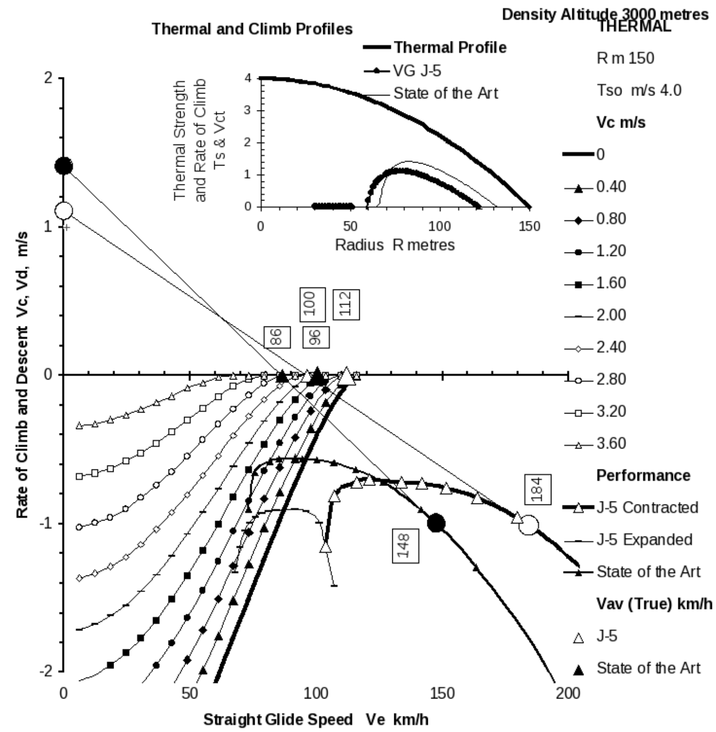

Figure 9 Performance comparison, density altitude = 3000m, thermal $R = 150$m, $Tso = 4$m/s

AT DENSITY ALTITUDE			3000	metres.
THERMAL	Radius Strength	R Tso	150 7	metres. m/s
THERMAL CLIMB				
Expansion Ratio		1.75		
PERFORMANCE		VG J-5	OTHER	Ratio
R	m	150.0	150.0	1.00
Tso	m/s	7.0	7.0	1.00
Tsr	m/s	5.4	5.1	1.05
r	m	72.0	78.0	0.92
Vdt	m/s	-2.0	-1.6	1.23
Vct	m/s	3.4	3.5	0.97
Vet	km/h	167.6	192.3	0.87
Vt	km/h	194.6	223.3	0.87
Bank	deg	45.4	51.0	0.89
STRAIGHT GLIDE				
PERFORMANCE		VG J-5	OTHER	Ratio
W/S>>>kg/sq.m.		77.58	38.59	2.01
Ve	km/h	232.1	187.8	1.24
Vave	km/h	150.7	121.4	1.24
V	km/h	269.5	218.1	1.24
Vav	km/h	175.0	141.0	1.24
Vc	m/s	3.4	3.5	0.97
Vd at Ve	m/s	-1.8	-1.9	0.96
L/D	at Ve	35.4	27.4	1.29
L/D Max		55.71	50.8	1.10
Ve for Max L/D		151.58	115.5	1.31
V for Max L/D		176.02	134.1	1.31
Cl at Inter-thermal V		0.30	0.22	1.32
R.N. at Inter-thermal V		2.47E+06	2.55E+06	0.97
Cdo Factor			VG J-5	OTHER
Glide		Cdo2/Cdo1	1	1
Climb		Cdo2/Cdo1	1	1

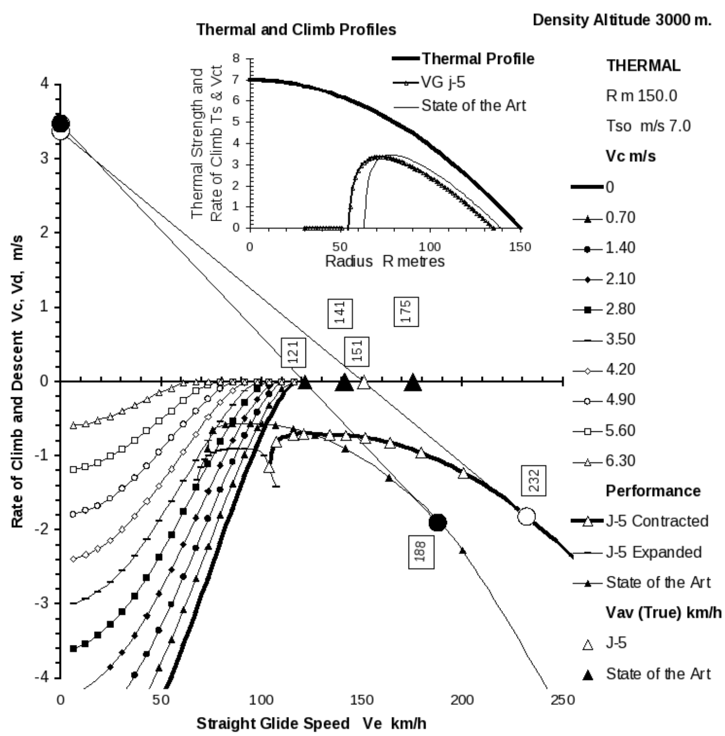

Figure 10 Performance comparison, density altitude = 3000m, thermal $R = 150$m, $Tso = 7$m/s

AT DENSITY ALTITUDE			**3000**	**metres.**
THERMAL	**Radius**	**R**	**150**	**metres.**
	Strength	**Tso**	**7**	**m/s**
THERMAL CLIMB				
Expansion Ratio		**1.75**		
PERFORMANCE		**VG J-5**	**OTHER**	**Ratio**
W/S>>>kg/sq.m.		**44.34**	38.59	1.15
R	m	**150.0**	150.0	1.00
Tso	m/s	**7.0**	7.0	1.00
Tsr	m/s	**5.3**	5.1	1.04
r	m	**73.5**	78.0	0.94
Vdt	m/s	**-2.2**	-1.6	1.35
Vc t	m/s	**3.1**	**3.5**	**0.90**
Ve turn	km/h	**165.9**	192.3	0.86
V turn	km/h	**192.7**	223.3	0.86
Bank	deg	**44.3**	51.0	0.87
STRAIGHT GLIDE				
PERFORMANCE		**VG J-5**	**OTHER**	**Ratio**
W/S>>>kg/sq.m.		**77.58**	38.59	2.01
Ve	km/h	**227.3**	187.8	1.21
Vave	km/h	**146.7**	121.4	1.21
V	km/h	**263.9**	218.1	1.21
Vav	km/h	**170.3**	141.0	1.21
Vd at Ve	m/s	**-1.7**	-1.9	0.90
L/D	at Ve	**36.8**	27.4	1.34
L/D Max		**55.71**	50.8	1.10
Ve for Max L/D		**151.58**	115.5	1.31
V for Max L/D		**176.02**	134.1	1.31
Cl at Inter-thermal V		**0.31**	0.22	1.37
R.N. at Inter-thermal V		**2.41E+06**	2.55E+06	0.95
Cdo Factor			**VG J-5**	**OTHER**
Glide		**Cdo2/Cdo1**	**1.0**	**1.0**
Climb		**Cdo2/Cdo2**	**1.5**	**1.0**

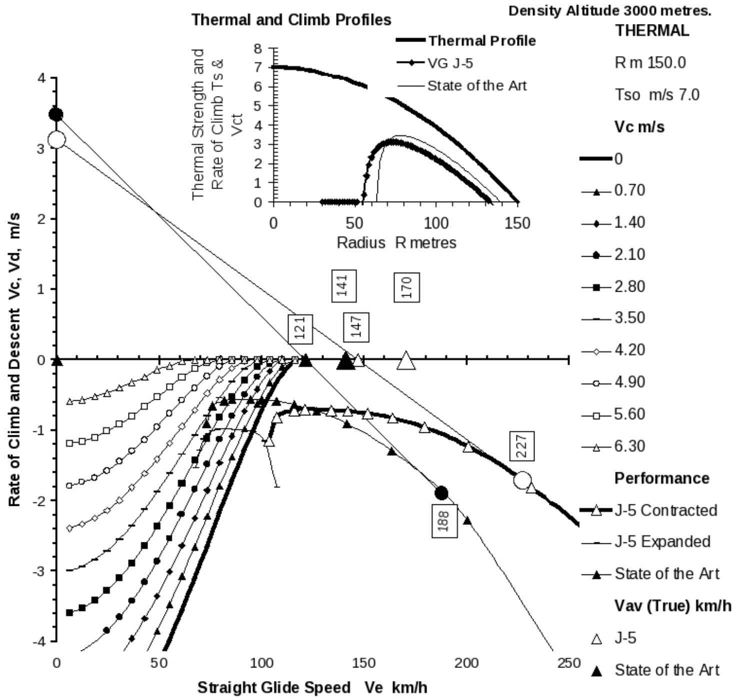

Figure 11 Performance comparison, density altitude = 3000m, thermal $R = 150$m, $Tso = 7$m/s, with J-5 Cdo on climb factored by 1.5.

event well forward near the leading edge.

Further research is necessary in the design of the expansion system to determine performance with the profile only partially expanded. This may lead to possible re-design of the method of expansion for the Fowler flap. It may be necessary first to increase only the area and then change the flap angle as was done on the old BJ-series instead of proportional angle change with expansion as at present.

The expansion/contraction of wing surfaces

It is of course one thing to consider the performance potential of VG but quite another to actually produce in practice the necessary changes in the sailplane configuration particularly if the aim is as drastic as to double/halve the wing area in flight. As it is essential that the static and aerodynamic balance and stability of the complete aircraft is maintained, it is considered necessary to also expand the wing forward.

Serious work was started on possible systems in 1986. In the initial concept, the idea was to incorporate a free flexible wing surface — a folio — which was deployed during the expansion process. In the fully expanded condition, that is with the wing chord expanded 100% of its basic dimension, the free folio would cover 50% of the exposed wing chord. It was expected that its camber would be determined entirely by the aerodynamic local pressures as is the case in hang gliders. Extensive consideration was given to this system but at the end was discarded because of too many unknown factors requiring extensive research.

A further possibility was to deploy the folio over a 'false' wing surface which would be exposed during the expansion process. In this way the folio would be drawn over a preset solid surface and the shape would not depend on the local air pressures. Numerous test models were built of the system but each in turn discarded.

To attain 100% expansion another system investigated was one in which the front and top 70% wing chord surface is moved forward 20 to 30% of the chord and the back portion expanded in the form of a double Fowler flap for 70 to 80% of the original wing surface. It enables the important condition of laminar flow to be maintained in the high speed (contracted) configuration and also enables the application of effective lateral control surfaces. Suffice it to say that over a lengthy period of time many models of possible systems were investigated and it became largely a matter of going from failure to failure without losing enthusiasm.

With due consideration to all the factors involved, it was finally decided that a system that was realistic and could be satisfactorily accommodated by the proposed expansion mechanics was to limit the expansion of the basic wing chord to from 70 to 75% instead of the 100% — the leading edge expanded forward 20 to 30% and a 50% wing chord Fowler flap expanded backward with angle changed progressively in proportion to its ex-

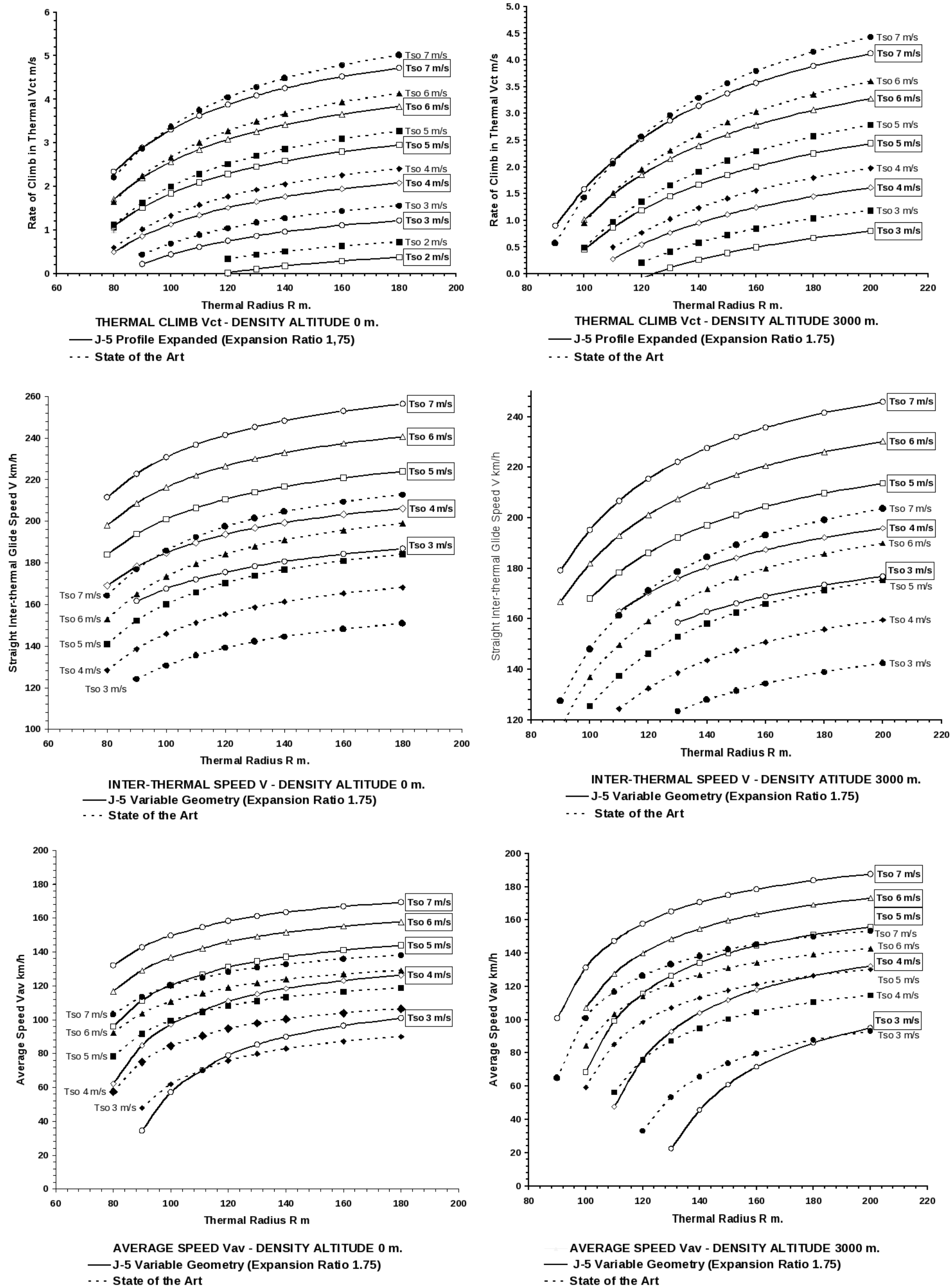

Figure 12 J-5 and OTHER sailplane configuration and basic aerodynamic assumptions.

pansion from being flush on the underside of the main wing surface when fully contracted to 20 degrees depressed when fully expanded. (Fig. 5) (Note: the J-5 performance figures in the performance comparisons Figs. 6 to 11 and Fig. 12 are for an expansion ratio of 1.75)

In these examples the choice of the NASA NLF 415 profile may seem drastic but if the principle of a two speed sailplane is accepted then there is little purpose served in selecting a basic profile that has been specifically designed as a compromise for the straight inter-thermal glide and the thermal climb. (In this connection it is interesting to note that the basic profile of the BJ-3 and 4 was the NACA 66_1-212. These sailplanes had poor thermal climb performance without the Fowler flap extended). The basic profiles on the J-5 project have been chosen at random. It may be better to design a profile specifically tailored for the VG concept.

Details of the proposed operating mechanism are beyond the purpose of this paper. Suffice it to say that the proposed operating mechanics to expand and contract the surfaces and accommodate the loads are actually relatively simple and can be contained entirely within the wing surface boundaries. If necessary, it can be arranged that the mechanisms in no way interfere with the load carrying structure of the wing. .

Conclusion

As pointed out at the outset, the J-5 project is intended purely as a research project but this should not distract from the possibility of this forming a basis for a marketable VG sailplane. The VG does not necessarily have to be 100%. But it does appear that, to reap the full benefits, it is necessary at least to expand the front as well as the back of the wing.

The author tends to strongly favour any system of VG which incorporates the Fowler flap principle. Apart from the effect of area increase the slot formed by the flap has a beneficial effect in ducting air from the high pressure area below the wing to the top so re-energising the air flow over the upper wing surface at high angles of attack. The BJ-2, 3 and 4, with flaps extended were plagued by poor span-wise lift distribution at the wing tips created by the change of wing chord dimension at the transition from flap to aileron. This could have been overcome by a more sophisticated flap/aileron linkage which would allow the flap and aileron in the contracted configuration to move as one unit. When expanded, the normal aileron would be locked in the neutral position whilst the Fowler flap would, then, act as an external aerofoil aileron.

In the expanded condition, the increase in the Reynolds number of the expanded wing has a comparatively large beneficial aerodynamic effect. This has not been taken into account in the performance analysis in this paper. It is clear that the criticisms raised during the BJ era regarding the detrimental effect of the low aspect ratio during the climb are largely unfounded. It is important to recognise that the parameter minimum rate of descent in a turn is in itself not a good indicator of the climb performance in a thermal. The Vct in the thermal not only depends on the Vdt(min) in the turn but also at what radius of turn this occurs. In the level flight performance analysis, the stall speed and rate of descent of a sailplane close to the stall are good indicators of its ability to climb.

Finally, if, as the author hopes, he has managed by this paper to encouraged further debate and interest for research, into VG, research particularly with regard to the application of the Fowler type flaps and associated aerodynamic characteristics at low Reynolds numbers, then the effort has been well worth while. He invites comments and criticism on any of the issues raised and hopes that, rather than being accused of 'flogging a dead horse,' he has managed to revive it.

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Appendix

Induced drag:

$$\begin{aligned} Di &= Cdi\frac{\rho}{2}SV^2 = \left(\frac{Cl^2S}{\pi b^2}\right)\frac{\rho}{2}SV^2 \\ &= \frac{Cl^2\frac{\rho}{2}^2S^2V^4}{\pi\frac{\rho}{2}b^2V^2} \\ &= \frac{L^2}{\pi\frac{\rho}{2}b^2V^2} \end{aligned}$$

and in level flight L is substantially equal to the W.

Therefore:

$$\begin{aligned} Di &= \frac{1}{\pi q}\left(\frac{W}{b}\right)^2 \\ (A) &= \left[1-\left\{Ve^4 \div (gTr)^2\right\}\right]^{0.75} \\ (B) &= \left\{Tso(Tr \div R)^2\right\} - (Tso - Vct) \end{aligned}$$

Sequence of evaluation for relating the straight glide performance (Vd/Ve) curve of a sailplane to the achievable Vct in a particular thermal:

Evaluation of Formula (A). Prepare a table:

1. Horizontally list a series of selected values of straight glide speeds (*Ve*) values from 0 to at least the anticipated average speed of sailplane (*Vav*).

2. Vertically list a series of selected values of thermal radii (Tr) from thermal radius 0 to R.

3. Complete the table by evaluating (A) for each Ve vs. Tr.

Evaluation of Formula (B). Prepare tables:

4. Horizontally list the same values of selected straight glide speeds (Ve) as in 1.

5. Vertically list a selected series of rates of descent in the straight glide (Vc) for which each selected Vct is to be drawn. (A separate table for each Vd. Note $Vd = -Vct$.

6. Evaluate (B) for each selected Vct (10 Vcts then 10 separate tables).

Consolidation.

7. Horizontally list the same values of Ve as in 1 and 4 above.

8. Multiply each Ve by the minimum value of each Vd as evaluated in 6 for successive values of Ve.

When the values obtained in 8 are graphed then each curve will represent the Vd vs. Ve required to produce a given Vct.

Note — if the variables are all related to unity then the analysis is applicable to any changes in radius of thermal R and thermal strength Tso. When the graphical results are superimposed on the straight glide performance Ve vs. Vd of any glider, it enables immediate analysis of the climb performance Vct and hence, v and Vav at any density altitude.