Optimum sailplane performance in weak thermals

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Presented at the 10th OSTIV Congress, South Cerney, England, June 1965

Abstract

An analysis of the cross-country performance of current sailplane designs in weak thermal conditions is presented in this paper. The thermal conditions encountered in the area around Detroit are defined and classified as weak in the first part. The second section contains a brief review of the general theory relating sailplane design characteristics to optimum cross-country performance. In the final part, the performance of several different sailplanes in weak conditions is determined.

Introduction

The topic of achieving optimum cross-country performance in sailplanes has been treated comprehensively in many technical papers and articles during the past 15 years. Qualified writers, such as Carmichael, Cone, Lippisch, MacCready, and others have defined the specific sailplane performance characteristics and pilot techniques required to obtain optimum performance in specific thermal conditions. This paper evolved because the author wanted to determine how well current sailplane designs reflected the success of their designers in applying this information. The measure of success was to be the cross-country speed that the sailplane could achieve in the thermal conditions normally found in the Detroit area.

Local thermal characteristics

The first task in this study was to define, in quantitative terms, the strength and size of the thermals in the local area. Once the thermal characteristics were defined, the performance of sailplanes in these conditions could be determined.

Thermal data were obtained for 31 cross-country flights that originated from the Detroit area. The flights studied represent a random sample of the cross-country flights made by 6 members of the Vultures soaring club during the years 1961–1964. The sailplanes flown were an L-Spatz and 4 Ka-6 models. The soaring experience of the pilots averaged more than 300 hours, and all now have at least Gold C distance, with flights up to 400 miles having been made from the area. The distribution of flights by month was as follows:

Month	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*
Flights	1	9	3	9	5	2	2

With the exception of the small number of June flights studied, this distribution has a high correlation with the general thermal conditions in the area. The months of July and August are normally the best months for cross-country flights.

The barograph traces from these flights were analyzed by the procedure described by Carmichael in his analysis of Dick Johnson's record flight (Ref. 1). Table 1 summarizes the data of these flights. A number of interesting items are obtained from an analysis of each climb and glide cycle. Carmichael states "that the positive slopes of the barogram represent the rates of ascent of the sailplane in the thermals encountered".

Table 1: *Summary of flight data*

Item		*Average*	*Min.*	*Max.*
Distance	miles	212	56	264
Duration	hours	4:43	1:46	7:03
Average speed	mph	25.8	17.3	43.6
Maximum altitude...	feet AGL	5280	4000	7600
No. of thermals		21	7	39
Miles per thermal ...	miles	6.4	3.2	12.2
Average rate of climb	m/s	1.06	0.64	1.56
Rate of climb (individual thermal)	m/s	1.06	0.25	3.25
Average circling time	minutes	5.8	3.9	8.4
Per cent circling time		46	39	56

Each ascent was approximated with a straight line to obtain the average rate of ascent since this is pertinent to the analysis of cross-country techniques. The true thermal strength is found by adding the circling sinking speed to the rate of climb. The distribution of thermal strengths is plotted on probability paper to see if they follow a known distribution law. The time spent climbing in each thermal allows both actual cross-country efficiency and ideal cross-country efficiency to be determined. The ratio of effective ground speed for a given climb and descent to the speed used in the glide, or descent portion, is known as the efficiency factor. This is equal to the ratio of time spent in the glide to the sum of climbing and gliding time.

In the ideal case where thermals are very plentiful and a safe initial altitude is assumed, optimum cross-country performance could be obtained by always losing the same altitude in the glide as was gained in the last thermal. By equating these altitudes, we can express the rates of ascent or descent inversely proportional to the times for ascent and descent. The efficiency expression then becomes the ratio "rate of climb in the thermal" to "the sum of this rate plus the rate of descent in the glide".

Figure 1 shows the distribution and cumulative frequency of the rates-of-climb in the 645 individual thermals. The true thermal strengths are also shown by Figure 1 on the lower scale on the abscissa. This scale was established by adding the sinking speed in turns, of the sailplanes, to the rate of climb figures.

Dr. Lippisch analyzed the performance of sailplanes in circling flight (Ref. 2).

In this article, he explains the effect of the angle of bank and circling speed as they contribute to an increase of sinking speed and forward speed in circling flight. A summary of the derivation of the these effects is presented below:

$$Vzc = \frac{Vzs}{(\cos \varnothing)^{1.5}}$$

and $$Vc = \frac{Vs}{(\cos \varnothing)^{0.5}}$$

where Vzc = sinking speed in circling flight
Vzs = sinking speed in straight flight
Vc = velocity (true air speed) in circling flight
Vs = velocity (true air speed) in straight flight
$\varnothing$ = angle of bank

$\varnothing$ deg.	30	45	60
% increase in sinking speed	24	66	167
% increase in velocity	8	19	41

In calculating the above, the angle of bank was obtained from the equation

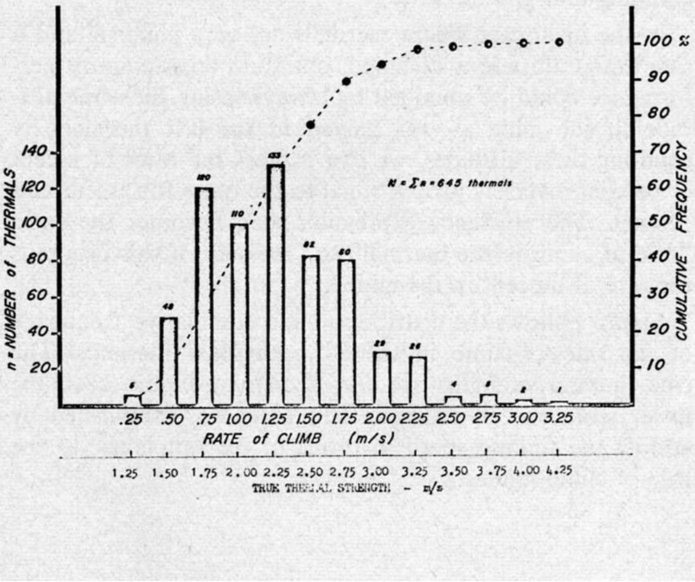
$$\tan \varnothing = \frac{Vzc^2}{g \cdot r}$$

where g = acceleration due to gravity = 32.2 ft./sec.^{2}
r = radius of turn in feet

Assuming an average circling time of 15 seconds, and that the sailplanes are flown at the velocity for their minimum sinking speed, R = 143 and 148 feet for the L-Spatz and Ka-6, the above equation gives ∅ = 37 and 39 degrees respectively, for the two ships. This information was used to determine the sinking speed in circling flight for the L-Spatz and Ka-6.

Sailplane	*Ka-6*	*L-Spatz*	*Average*
Average Rate of Climb . .	1.08 m/s	0.96 m/s	1.02 m/s
+ Sinking Speed in Turns . .	0.94	0.99	0.97
= Average Thermal Strength	2.02	1.95	1.99

THERMAL RATE OF CLIMB DISTRIBUTION (fig. I)

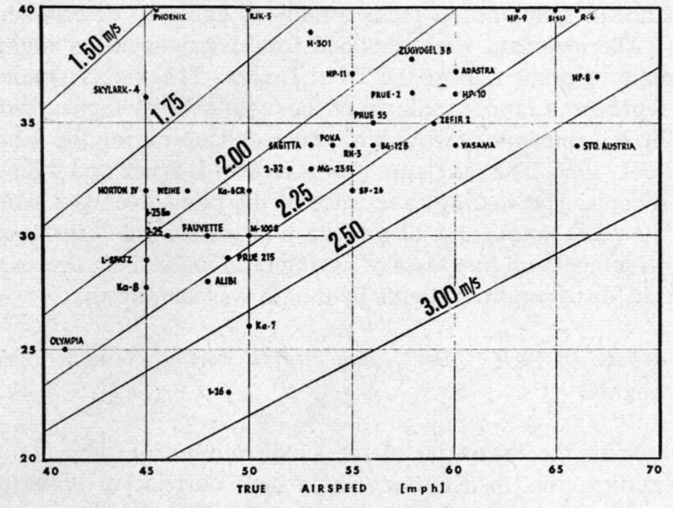


When this was done, and the data in Figure 1 were analyzed statistically, the average rate of climb was found to be 1.02 m/s, resulting in an average true thermal strength of 1.99 m/s, when the sinking speed was added to it. The standard deviation of the thermal strengths was 0.53 m/s, and the range of thermal strengths for various limits of standard deviations was as follows:

Standard Deviations	*% of Thermals*	*Range of Thermal Strengths*
± 1	68	1.5–2.5 m/s
+ 2, — 1	90	1.5–3.0 m/s
± 2	95	1.0–3.0 m/s

The average thermal strength of 2.0 m/s for the two sailplanes, at their normal circling radius of about 145 feet, correlates closely with Carmichael's definition of a weak thermal (Ref. 3). In his article, he states, "the weakest part of any such study as this is the necessity to make some assumption on the thermal size, shape, and strength. This study assumes 3 different types in an effort to make the results as general as possible. All are assumed to have a distribution of strength similar to a turbulent free jet. Core velocities of 10 and 20 feet per second were assumed as typical of weak and strong thermals, respectively. The strength was assumed to fall to half of the core value at a radius of 200 feet. An average thermal core value of 15 fps was assumed to fall to half value at a radius of 400 feet, to investigate the effect of a wide thermal. The shape and size of the thermals will certainly have a large effect on the outcome of any study of this type, and it is regrettable that more information on thermal structure is not available. The choice of strengths is based on analysis of barograms from fligths on weak and strong days with ships whose usual circling radii were approximately known. The shape is pure conjecture, but at least the qualitative experience of pilots does not refute the theoretical guidance given by the turbulent free jet."

A plot of the three model thermals defined by Carmichael is shown in Figure 2. The performance of the two sailplanes in local conditions is also shown, and supports the conclusion that the average thermals in the Detroit area may be classi-



OPTIMUM THERMAL STRENGTH (figure 3)

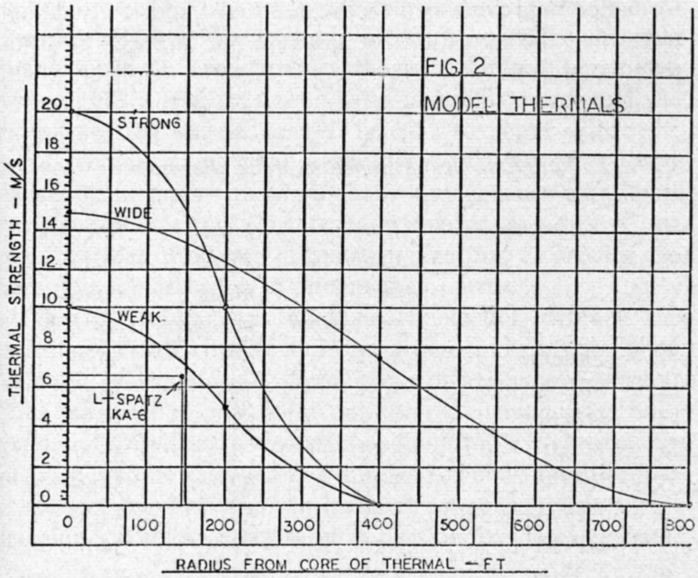


FIG 2
MODEL THERMALS

fied as weak. The figure also shows that differences in circling radii of various sailplanes will result in some having better performance in wide thermals than in strong thermals, and that there will probable be some whose rates of climb in these two types of thermals will be identical.

Now that we have determined the specific characteristics of the local thermals, we shall proceed to determine what constitutes optimum cross-country performance in these thermals.

Optimum performance in thermals

Carmichael, in Reference 3, shows that there is an optimum thermal strength for each sailplane design, and that it can be altered slightly by changes in wing loading. The optimum thermal strength for a particular sailplane occurs where the sinking speed at best glide-ratio speed is equal to one-third of the true thermal strength.

$$\mathrm{Wts} = (\mathrm{Wt} + \mathrm{Vcz})$$

$$\mathrm{Vza} = \frac{(\mathrm{Wt} + \mathrm{Vzc})}{3}$$

then $\mathrm{Wts} = 3\ \mathrm{Vza}$

Where Wt = rate of climb
Vzc = sinking speed in turns
Wts = true thermal strength
Vza = sinking speed at maximum L/D velocity

The optimum thermal strengths for a number of currently popular sailplanes are illustrated in Figure 3. Admittedly, the best thermal strength can be altered a fair amount by any discrepancy between published and actual glide ratio performances. The performance data used in this study were based on published information, conceded by some to be about 10% optimistic. However, it should be noted that if the best glide ratio of a sailplane is less than predicted, and it occurs at a slightly lower speed, the position, on Figure 3, of the design will probably be shifted parallel to the iso-thermal-strength lines, and the relationship will still hold. The relative position of the sailplanes on this graph along a particular iso-thermal-strength line is approximately linearly dependent on wing loading. This leads to the logical conclusion that sailplanes located further to the right, along a line, would be expected to average faster on a day when that thermal strength is encountered.

It is interesting to note the distinct separation, in Figure 3, of the group of record setting sailplanes, such as the Sisu, Standard Austria, HP-8, and R-6, as compared with the two sailplanes, RJK-5 and Skylark 4, which have been piloted by Dick Johnson to seven US National victories. Records are set in fast ships flying in strong conditions, where thermal strengths are somewhat above their optimum. Unfortunately for most pilots at contests, flights have to be made in weather conditions varying from downright poor to super days. Under these circumstances, Dick Johnson has shown that a more conservative performance sailplane is required to excel in long contests, where consistency of performance is important.

A more definite explanation of what is meant by optimum conditions and optimum performance is valuable to assist in interpreting Figure 3. Optimum cross-country performance for a given sailplane design occurs in conditions where the incremental increase in cross-country speed due to a specific increase in thermal strength is maximized. Certainly on days when thermals exceed the optimum value, any sailplane should average faster. But unless the wing-loading is changed so that best L/D occurs at a higher speed, in order to hold the value of $\mathrm{Wts} = 3\ \mathrm{Vza}$, the sailplane design limits the achievement of optimum performance in those conditions. In this case, some other sailplane design could be matching its optimum performance on this day and would, therefore, achieve a faster speed.

This discussion may be difficult to follow exactly, but in effect what we are saying is that the performance characteristics inherent in a given sailplane design determine its optimum performance. Unless the design incorporates means of altering the optimum thermal strength, through the use of ballast or airfoil changing devices such as flaps, it limits the adaptability of the sailplane to changing weather conditions.

The effect of wing loading may be illustrated by analyzing the change in performance required to shift the optimum thermal strength range of the L-Spatz and Ka-6 from the mean value of 2.0 m/s to cover the middle 50% of the thermals encountered in this study. This means that the optimum would have to range from 1.7 m/s to 2.4 m/s. The only thing that can be done to adjust performance for the 1.7 m/s condition is to eliminate all unnecessary equipment weight to obtain a lower wing loading. Since for a given angle of attack wing loading is proportional to the square of the speed, a weight reduction of about 40% would be required. A 200 lb. weight cut is clearly unobtainable in either of these ships. At the other end, for 2.4 m/s thermals, we find that the L-Spatz would require an additional 100 lbs. of ballast, and the Ka-6 125 lbs. This can nearly be achieved before gross weights are exceeded. Thus, it can be seen that these ships can compensate for only about 30–40% of the expected range of thermals, and adjustments can only be made on the ground before the flight.

The ideal sailplane would employ a combination of camber changing flaps and jettisonable ballast so that a wider range of thermals could be used as optimum thermals. Some of the current generation of new sailplanes are being designed to achieve this flexible performance range. The Schreder HP-14 appears to be one of the planes incorporating this approach in its design to the fullest extent. With provision for 360 lbs. of ballast, its weight and wing loading can be increased by over 60%.

Along with light empty weight and full span flaps, the ballast facility will result in a shift in optimum thermal strength over a range of 30%. This is obtainable in flight, and it should encompass a majority of the thermals found in the local area. The recently changed OSTIV rules allowing the use of flaps on standard class ships will allow other designers to pursue a similar course in improving the designs. This approach will increase the usefulness of these sailplanes to their owners, and should provide yet another means to assist pilots in continuing to steadily surpass existing soaring records.

This discussion of optimum performance in thermals leads us to an analysis of the performance of a number of sailplanes in the weak thermals encountered in the local area. It should be noted that the term "weak thermal" is relative, for the normal variation in conditions has resulted in flights of over 400 miles from this region.

Sailplane performance in weak thermals

The final objective of this paper is to determine the sailplanes that are best suited to soaring in weak thermals. The sinking speed in turns and the radius of turns for a 15 second circle were determined in the same manner as for the L-Spatz and Ka-6. This information, when compared to the model weak thermal (Fig. 2), gave the rate of climb of each sailplane in a weak thermal. No allowance for downdrafts was made, but this does not affect the final rankings of the sailplanes. Inter-thermal speed and average cross-country speed were then determined using the rate of climb and an approximation to the polar curve of each ship.

MacCready (Ref. 4) calculates this information in constructing his Optimum Airspeed Selector – "a simple device that indicates the optimum speed at which a sailplane should be flown between thermals. For the derivation of the airspeed selector, one minimizes the time for the sailplane to reach a thermal and to regain the original height. The resulting equation may be solved graphically as follows:

1. Draw the performance curve of the sailplane.
   (Vzs sinking speed vs. velocity)
2. Construct tangents to the curve at 10 mph intervals which intersect the ordinate, and record the intercepts $\triangle$. The velocity for each tangent point is the speed to fly. The velocity at which the tangent line intercepts the abscissa is the average ground speed (ideal in zero wind).
3. Then plot Vzs + $\triangle$ vs. velocity on another graph to obtain values for preparing the airspeed selector table."

In the above quotation, the symbols have been changed to those used elsewhere in this paper. $\triangle$ represents the achieved rate of climb in the thermal.

This is a general description of the procedure. For determining performance in weak thermals, only one tangent had to be constructed. Table 2 shows a ranking of sailplane cross-country performance in weak thermals by average speed. It shows that the newer designs have obtained a performance improvement in weak thermals, and it also illustrates that the record setting ships do not fare well at all in these conditions.

Table 2: *Sailplane performance in weak thermals*

No.	*Sailplane*	*Rate of Climb feet per second*	*Cruise speed miles per hour*	*Average speed miles per hour*
1.	Phoenix	4.34	67	39.3
2.	Std. Austria ...	3.23	78	36.0
3.	HP-11	3.49	68	35.7
4.	H-301	3.42	72	35.5
5.	RJK-5	3.42	62	35.0
6.	Zugvogel 3B .	2.92	69	34.3
7.	HP-10	3.10	69	34.0
8.	1-23 H	3.83	68	33.0
9.	Phoebus	2.58	66	32.8
10.	Prue 2........	2.65	73	32.6
11.	Prue SS	2.96	67	32.5
12.	Ka-6CR	3.49	66	32.5
13.	M-100 S......	3.57	63	32.0
14.	Skylark 4	3.35	59	31.8
15.	Fauvette	3.64	62	31.0
16.	Ka-8	4.04	58	30.8
17.	L-Spatz	3.64	60	30.7
18.	2-32..........	2.92	66	30.5
19.	Sagitta	2.63	68	30.0
20.	BG-12 B......	2.42	65	29.8
21.	Vasama	2.50	67	29.5
22.	SF-27	2.65	64	29.0
23.	Prue 215......	3.02	62	29.0
24.	Foka	2.50	62	28.5
25.	MG-23 SL....	2.48	60	28.0
26.	Ka-7	3.11	66	27.5
27.	Kranich 3	1.93	66	25.2
28.	1-26..........	2.89	62	25.0
29.	Sisu-1A	1.35	67	23.8
30.	Adastra	1.08	65	19.0
31.	Zefir 2	1.10	66	19.0
32.	HP-8	0.89	65	17.0
33.	HP-9	0.37	66	8.0
34.	R-6	0.20	69	4.5

Summary

The specific thermal conditions normally encountered in the area around Detroit during the course of a soaring season have been analyzed and found to agree with the definition of a weak thermal. The general theory for determining optimum cross-country performance in thermals was reviewed briefly, and the performance of several sailplanes in weak thermals was calculated.

This study has indicated that the new class of sailplanes, such as the Libelle, Phoebus, and HP-14 are incorporating design factors that broaden the range of optimum thermal strength conditions that their performance can be adapted to. This approach to improving performance should lead to new records, but more importantly, it will result in sailplanes better suited for the varying weather situations met by contest pilots and by the majority of sailplane pilots who normally fly in an even broader range of thermal conditions throughout a soaring season. The capability to expand the useful soaring season, and to be able to better utilize the available conditions on a given day, is the type of progress in sailplane design that will have the greatest long term benefits for soaring. The recently revised Standard Class specifications are a step in the right direction to provide the incentive for designers to pursue this approach.

The type of analysis made in the section defining the existing thermal conditions in a particular region can yield valuable information for the sailplane owner or contest pilot. This information will point out the requirements for both pilot and sailplane, if successful and enjoyable cross-country soaring is to be achieved in a specific region. The procedure is straight forward, and can make an interesting winter project for a club, as every pilot is a valuable source of data.

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