CHAPTER 20

SPEED AND EFFICIENCY

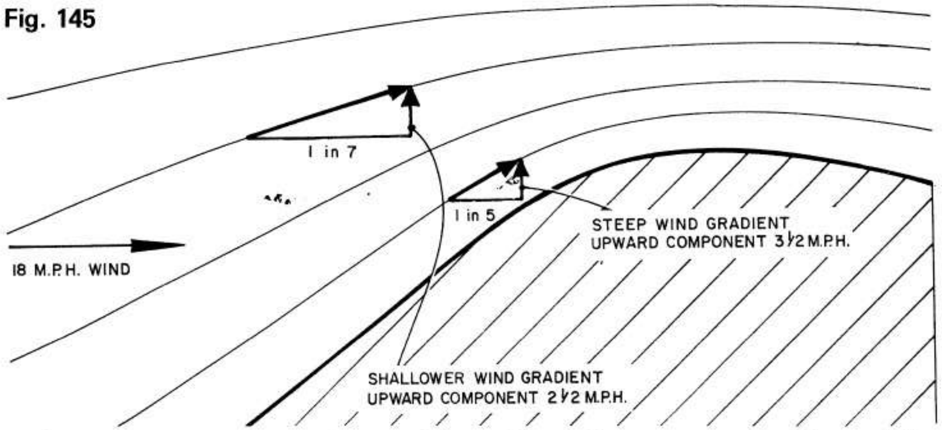
IF, at an early stage in the curriculum, you and mathematics cheerfully agreed to go your separate ways, then you'll certainly have developed compensatory talents, and modellers are especially good at getting the feel of what they want to know. So, don't be put off by the appearance of my presentation. In the interests of getting at the facts concerning weight, speed, glide angle, etc., I've resorted to some technical stuff. What I've done is to take a handful of separate factors, all of which you know vaguely to be of some consequence, and end up with numerical answers which speak for themselves. The bit in the middle, where these things are mathematically expressed and manipulated, is only the means, not the end, so the subject matter should still be comprehensible without dwelling on the detail of how it was done.

What's the problem?

The problem is the real-life one of "wind," and the remedy is not as easy as "Keep taking the tablets." In the two main categories of gliding, namely slope soaring and thermal soaring, the *effectiveness* with which a model can be operated is very dependent on the wind strength, though for different reasons. It is true to say that each change of environment defines its own "ideal" small range of flying speeds, to which the model should be matched for best performance, or for which a model should be selected. As explained elsewhere, a wind blowing up the slope is essential for hill soaring; without it, and in the absence of thermal lift, the model can only descend to the valley. The wind close to the hill goes upwards at the same angle as the surface slope, but further away from the hill its inclination is less, so the useful region of upward-inclined wind lies upwind of the crest. For a 1 in 5 hill, the upward component of the wind close to the surface must be one-fifth of the speed, say 3½ m.p.h. for a wind of 18 m.p.h. A model flying safely upwind of the ridge would experience less than this, say one-seventh or 2½ m.p.h. (Fig. 145). If the still-air sinking speed of the model is no worse than 2½ m.p.h., then it can maintain or gain height, *provided* that its flying speed is neither so fast that it moves out into less helpfully inclined air, nor so slow that it blows back downwind of the ridge. Excess speed is no problem, as a margin is desirable for manoeuvres, and the model can hold station by tacking. An increase of wind speed to twice as much, 36 m.p.h., will give twice the upward component, which sounds fine, but the model then has to be capable of a much higher flying speed in order to make headway. It is found in practice that retrimming a lightly loaded model, to cope with stronger winds, generally results in a performance no better or even distinctly worse than it would normally manage, in spite of the greater upward component of the wind. So the first problem is that of looking for reasons and remedies for unhappy matching of model speed to wind speed, for slope soarers.

The case for the thermal soarer is different, because wind is neither necessary nor desirable. The object is to achieve the maximum duration from a given starting height, and to this end the model will be flown as slowly as possible, and will in any case be lightly loaded to minimise its slowest speed, as explained in my "Downhill . . ." Chapter. The less the wind blows, the longer the model stays in sight, and the easier it is to bring it back to the landing spot. A stiff wind necessitates a fair turn of speed from the model, if only for that part of the

Fig. 145



flight spent in getting back to base, and the problem is how to arrange for this capability without undue sacrifice of the ability to glide at a shallow descent angle.

For any given model, the only way of controlling the airspeed *in flight* is by use of the lift-trimming system, *i.e.* the elevator, and flaps if fitted. Drag-producing devices may be used on occasion to spill off excess speed, so that a slower trimmed state can be resumed without undue zooming after a burst of high speed, but otherwise such devices function to steepen the glide, not to reduce the speed. As a premeditated step *before* flight, there is, in addition to trim changes, the alternative of adding ballast, to raise the wing loading. This *may* be done by the addition of weight ahead of the centre of gravity, in which case it serves the two purposes of increasing the total weight and also balancing the model more nose-heavy, but for the purpose of comparing separate effects, any reference in this article to ballast means weight installed *exactly* on the c.g. Thus, there are two alternative ways of adjusting the airspeed, and the relative merits are a point of controversy. The interdependence of speed, weight, glide angle, and state of trim, etc., is often only too obvious, especially when one wants to penetrate a headwind without the model sinking like a lift, but the answers are not to be found from casual, and often misleading observations. It's a case for "paper-work," not everyone's cup of tea, and for that reason the area in which I can usefully contribute something.

Sorting it out

Using nothing more complicated than the basic aerodynamics dealt with in the previous article, it is possible to derive a relationship between the state of trim, speed, and Lift/Drag ratio of a given model, the last item being a measure of the glide angle. The relation between speed and total weight, at a fixed trim, is a simple one. By taking a well-known model as a specimen, I've produced some comparative figures for the effect of the two alternatives, ballasting or retrimming, on the glide angle and sinking speed, over a wide range of forward speeds. From these particular results, I've drawn some general conclusions, applicable to the two modes of flying.

Also, because the same analysis can readily be extended to cover it, I've looked separately at the effect of modifying the design to a higher aspect ratio. This shows not only that the percentage benefit can be calculated, but that the value of such an "improvement" is very dependent on the type of flying undertaken.

Victimisation?

The chosen specimen model is Dave Hughes's *Soarcerer,* and it may appear from some of my deductions that a criticism of its versatility is implied. This is in fact a compliment, because the *Soarcerer* is specifically intended to be an aerobatic slope soarer and, as will

become apparent, the nature of this activity emphasises different qualities in a model. In its intended rôle, its universal popularity is a measure of the designer's success in achieving a good balance of many conflicting requirements. Its performance as a *thermal soarer* may be shown to be inferior to that of a model designed specifically for that purpose, but of course it was never intended for that type of flying. By examining it in this rôle, however, the reasons for, and merits of the different design approaches used for the two classes of model become more clear. The *Soarcerer* has a moderate wing loading, so it makes a good starting point for examining the effect of added ballast; also, the aspect ratio is quite low, so the effect of a change to a more sailplane-like A.R. should be significant.

The *Soarcerer* statistics are: Span 52in., Chord 7·5in., Wing area 386sq.in. (2·68sq.ft.), and Aspect ratio 7·0. At a typical weight of 26·8oz., or 1·675lb., the wing loading is 10oz./sq.ft.

At this stage, we can now launch into the incomprehensible.

The Lift/Drag characteristics

The notation, and the relation between Lift, Drag, Weight, etc., in steady flight, has already been set out in the earlier "Downhill" chapter. To attempt to predict the performance of any model "from scratch" would be totally unrealistic, because the conventional approach needs reliable, wind-tunnel measured data, on the lift and drag characteristics of the various components of the aeroplane, which we do not have. Full-scale data is just not relevant, because at the lower speeds and chords of our models there is a serious deterioration of lifting ability and an unavoidable rise in drag coefficient. However, part of the total drag is due to the generation of lift, and this "Induced Drag" is calculable quite accurately *without* reference to measured data. So, if we know the *real* Lift/Drag ratio of our model at just one speed (as distinct from the grossly optimistic value which an estimate from full-scale data would give), then we can calculate the *changes* of Induced Drag which would occur if the model were retrimmed to fly at other speeds, and thus derive the L/D ratio versus speed relationship.

As explained earlier, the trimmed state of a model is regulated by the incidence difference between wing and tailplane, and is thus susceptible to elevator movements. This defines the incidence at which it settles in steady flight, and the lift coefficient at which the wing operates. Since the Lift equals the Weight, the speed adjusts itself to suit the trimmed Lift Coefficient in accordance with the relation:- Lift $= C_L \times \frac{1}{2}\rho v^2 \times S =$ Weight.

Thus, a low C_L implies low incidence and high speed, and vice versa. The method of getting at what we want, then, is to relate the Drag Coefficient to the Lift Coefficient, and translate the latter into the corresponding airspeed.

Ideally, we should start from a measured value of the Lift/Drag ratio of the *Soarcerer* at a typical flying speed; as I don't have this information, all I can do is to make a fair guess at it. This is not too important for the main purpose of this article, which is to make comparisons rather than accurate predictions. A reasonable guess at the L/D value would be about 12, occurring at an incidence near, but not at, the stall, where the C_L value is 0·75. The corresponding speed comes from the equation relating C_L and wing loading "w," the latter being 0·625lb./sq.ft. in this case.

$$v = 29\sqrt{\frac{w}{C_L}} = 29\sqrt{\frac{0{\cdot}625}{0{\cdot}75}} = 26.4\text{ft./sec. (18 m.p.h.)}$$

Since $C_L = 0{\cdot}75$ and $L/D = C_L/C_D = 12$, then Total $C_D = \frac{0{\cdot}75}{12} = 0.0625$

But Total $C_D = C_{DP} + (C_L^2/3{\cdot}14A)$ = Profile Drag + Induced Drag, where A is the wing Aspect Ratio.

The Induced Drag coefficient for *Soarcerer,* at A = 7, is thus 0·0256. Hence $C_{DP} = 0{\cdot}0625 - 0.0256 = 0{\cdot}0369$.

We now have the means of calculating the total drag for any chosen value of C_L, using the above derived value of the Profile Drag coefficient of 0·0369, and adding to it an Induced

Drag coefficient of $C_L^2/3.14A$. Then, at each chosen C_L, the value of C_L/C_D follows, and the final step is to calculate speed from $v = \frac{22.9}{\sqrt{C_L}}$

The sinking speed $v_s = v \div C_L/C_D$

A set of calculations is tabulated below:—

C_L	C_{Di}	C_{D_P}	C_D	C_L/C_D	$\sqrt{C_L}$	v	v_s
0.90	0.0369	0.0369	0.0738	12.22	0.949	24.1	1.97
0.75	0.0256	0.0369	0.0625	12.00	0.866	26.4	2.20
0.50	0.0114	0.0369	0.0483	10.35	0.707	32.4	3.13
0.375	0.0064	0.0369	0.0433	8.66	0.612	37.4	4.32
0.1875	0.0016	0.0369	0.0385	4.87	0.433	52.9	10.85

These are illustrated as L/D v. C_L in Fig. 146, v against C_L in Fig. 147 and v_s against C_L in Fig. 148. At this stage, the most obvious thing to emerge is the rapid deterioration of L/D as C_L is reduced, this implying a steepening of the glide angle as speed is increased. The other feature is that the best obtainable glide angle, at maximum L/D, would occur at a C_L of 0·9, *if* it were possible to reach this incidence without flow breakdown. It is unlikely that the *Soarcerer* section could achieve much above $C_L = 0{\cdot}75$, however, so the 2% improvement indicated is not realisable in practice. Discussion of the relation between L/D, v_s, and speed, as obtained by these trim changes, will be made later, after examining the effect of ballast.

The weight-speed relation

This is a very simple matter, requiring no assumptions or guesses. If the only change made to the model is the weight, with no change of c.g. position, or wing and tail settings, then the trimmed C_L remains the same, and the speed increase will be proportional to the square root of the weight increase, in accordance with the equation $v = 29\sqrt{\frac{W}{S}\frac{}{C_L}}$

Thus $\frac{v_2}{v_1} = \sqrt{\frac{W_2}{W_1}}$

This is illustrated in Fig. 149, as a general curve applying to any model. The particular

Fig. 146

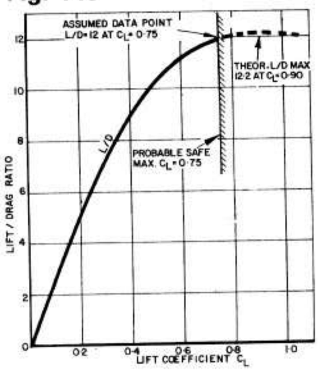


Fig. 147

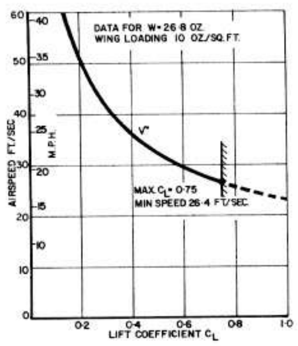
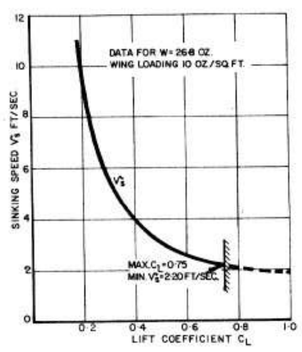


Fig. 148



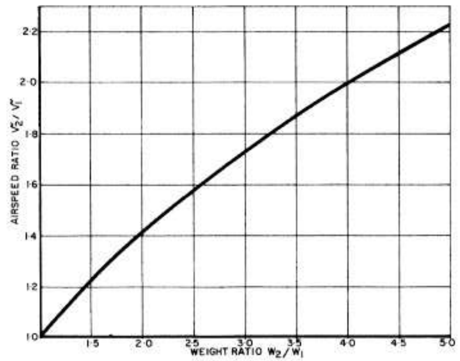


Fig. 149

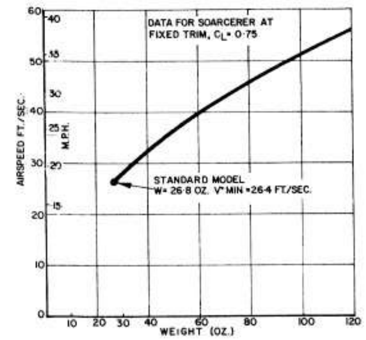


Fig. 150

version of this, applying only to our *Soarcerer*, is shown as Fig. 150, based on a speed of 18 m.p.h. at a weight of 26·8oz. The striking thing about it is the large amount of ballast needed to produce a worthwhile increase in speed; in simple terms, doubling the weight (of any model) only increases its speed by 41%. What is not revealed by these results, however, is that these speed increases have been obtained *without* any deterioration of the glide angle; the C_L was not altered, so the C_L/C_D ratio still remains at the value of 12. The sinking speed is always one-twelfth of the forward speed, for the "fixed trim, ballast at the c.g." case.

Ballast or trim?

We can now compare the performance of *Soarcerer* over a range of speeds obtained by the alternative methods of retrimming and ballasting. In Fig. 151, the L/D ratio which results from retrimming with down-elevator is shown plotted against the corresponding forward speed; for comparison, the constant L/D of 12, which would be retained if the speed were raised by ballasting only, is also shown. Likewise, the sinking speeds for the two cases are shown in Fig. 152. The most strikingly obvious feature is that for the speed range shown, the advantage of using ballast, as compared with the effect of trimming for high speed, rises

Fig. 151

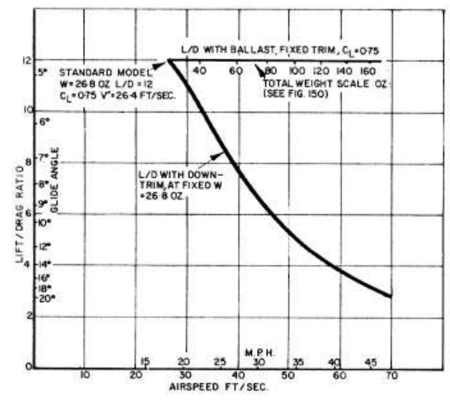
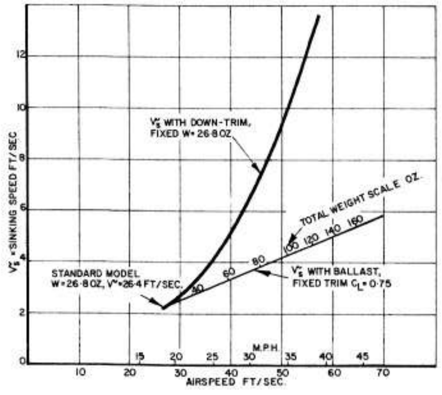


Fig. 152



so rapidly that there is a factor of *three* between either the glide angles or the sinking speeds obtained by the two methods, at 40 m.p.h.

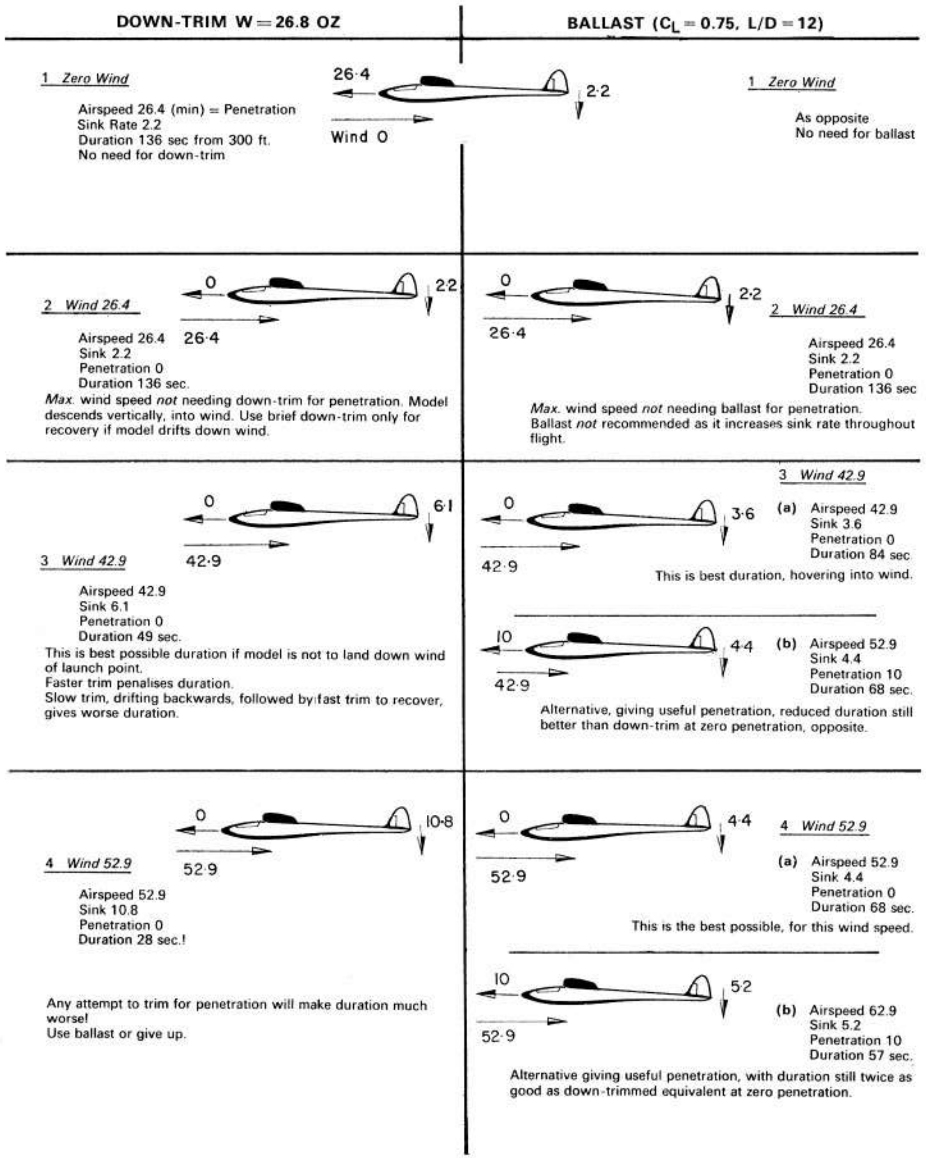
(a) *Slope Soaring.* There are too many variables to permit a concise but adequate appraisal of the situation; for each hill slope there is a different envelope of wind speed—model speed—model trim combinations within which successful operation is possible. All increases of airspeed are accompanied by an increase in sinking speed, an effect which is unavoidably worse when down trim is used rather than ballast. "Penetration" may be defined as the ability to make headway upwind, *i.e.* airspeed exceeds wind speed, and we note also that climb occurs when the model sinking speed (relative to the air) is less than the upward component of the wind speed. Then the ideal situation is when the model penetrates and climbs; it is also OK when it climbs at zero penetration, because temporary down trim may then be used to build up speed when you can afford to lose height. But if zero climb occurs when the model is trimmed to L/D max., this is a threshold condition, whether there is penetration or not, because the model sink rate cannot be reduced further to get a climb.

As an example, I've considered a 1 in 7 wind gradient and various wind speeds, and compared the extreme cases where the model speed is obtained *wholly* by trim or ballast; in practice, a bit of both would be better for various reasons. In Fig. 153, both versions start equal at a threshold wind speed which just permits height to be held. As the wind speed rises, we find that the ballasted model can rise faster for the same penetration, or penetrate faster at zero climb. The limit comes for the trimmed model at 42.9ft./sec., where the glide angle has deteriorated to 1 in 7, it cannot penetrate without losing height, and to climb it must retreat. The ballasted version can climb at 2·6ft./sec. at zero penetration, or penetrate at 30·3ft./sec. at zero climb, so it's quite happy. From this point on, the trimmed model cannot cope, as to penetrate faster winds or even "hold its own" it can only sink: no such upper limit applies to the ballasted model, which has an even bigger range of climb or penetration and can take full advantage of the higher wind component.

The figures used are solely for this model, on this particular slope. The implications are quite general, however, in the sense that the model which is speeded up by trimming alone must inevitably glide more steeply, and cannot be flown into winds which exceed the flying speed at which the glide angle becomes as steep as the wind inclination. For a steep hill, the problems are few; for a shallow hill, the operational band of the retrimmed model gets narrower, but the ballasted version flourishes on high winds.

(b) *Thermal soaring.* The best wind is none at all, as the model may then be flown in the trim for least sinking speed, at the least weight. There's always *some* wind, and if this is as great as the airspeed, then straying downwind poses a need for penetration, to get the model back to the launch point. Unless there is a good chance of thermals elsewhere, it may be best to hover the model into wind, when you can still get the still-air duration. Brief periods at a faster airspeed carry some penalty in sinking speed, so the allowable distance downwind is not much. Ballasting the model to ensure penetration imposes a penalty in sinking speed which acts throughout the flight, so it seems better to leave it to trimming (and judgement!). For windspeed well *in excess of* the normal airspeed, the result is different. Retaining the normal trim, the model will retreat rapidly, and will very soon have to be trimmed to a much higher speed to get back; this introduces a very high rate of descent. It is still best to hover the model, though the efficiency soon drops as the excess of wind speed over normal airspeed rises. Examples shown in Fig. 154. Ballasting the model now becomes increasingly effective, because if it is necessary to *double* the airspeed in order not to drift backwards, the rate of descent is only twice that of the normal model, whereas it would be almost *five* times as bad if the airspeed had been doubled by retrimming. As before, the actual figures are for this model, but the nature of the result is of universal application, as the deterioration of L/D with increase of speed is inevitable for all models, whatever the aerofoil.

To sum up, there is an advantage in ballasting for wind speeds above a certain level in relation to the normal flying speed of the model considered. For particularly strong winds, in the case of slope soarers over hills lacking steepness, it becomes essential to ballast in order



SUMMARY Trim for min. speed, max. L/D. For wind speeds *up to* flying speed, use no ballast, only brief trim when required. For *higher* wind speeds, *ballast is better than down-trim*, but never fly in a down-wind direction.

Fig. 153 SOARCERER AS A TOWLINE GLIDER. BALLAST v TRIM AT VARIOUS WIND SPEEDS.

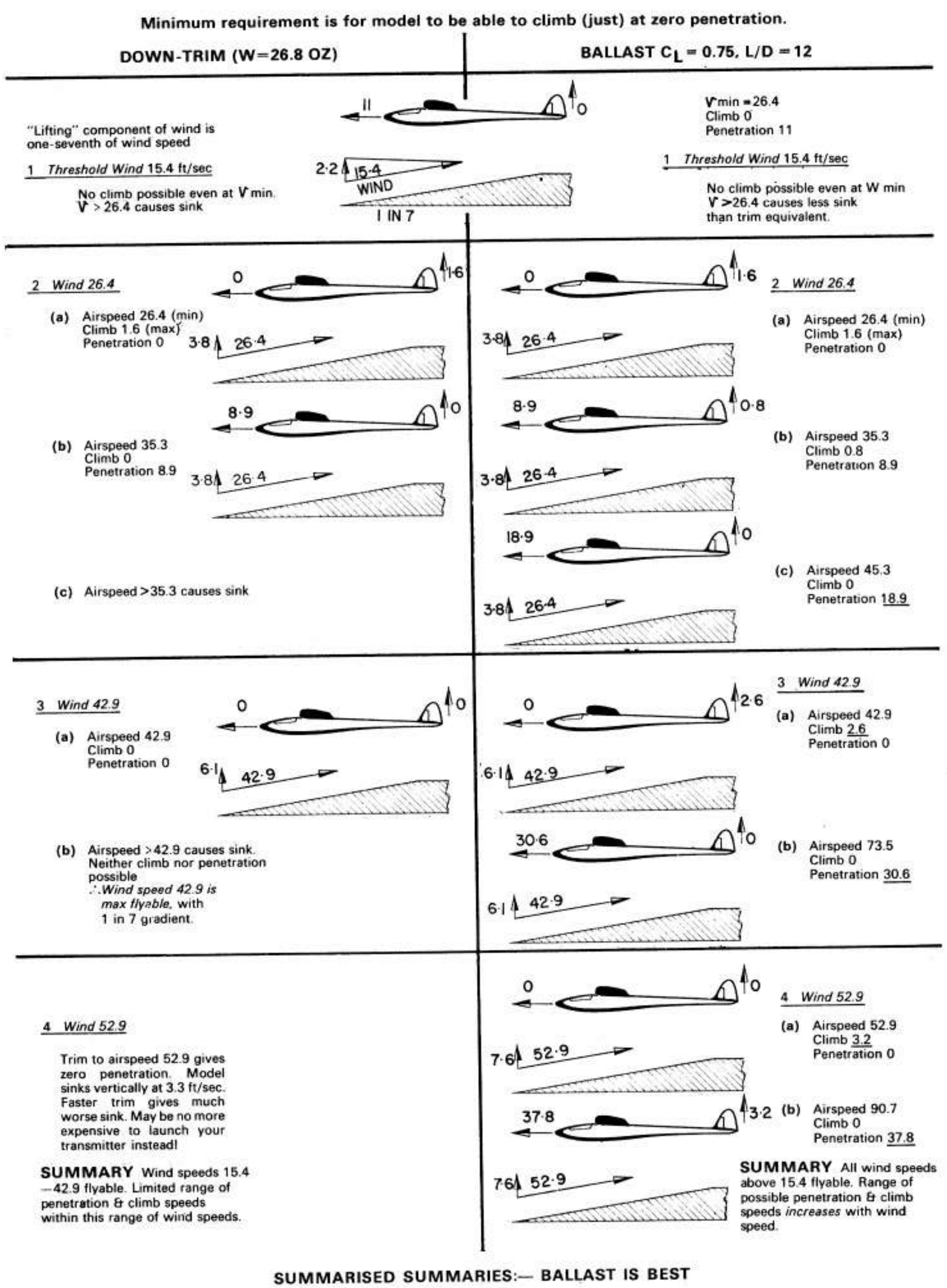


Fig. 154

SOARCERER PERFORMANCE ON 1 IN 7 SLOPE. BALLAST v TRIM AT VARIOUS WIND SPEEDS

to fly. For thermal soarers, in winds exceeding normal flying speed, ballasting greatly aids duration and recovery.

More efficiency?

A more efficient model is one with less drag, or to be more exact, a better Lift/Drag ratio. The above considerations have been of the *effectiveness* with which it is flown, with regard to external considerations such as wind gradient, etc. The inherent qualities of the model clearly influenced the numerical answers we got, and it's reasonable to look into the pros and cons of using that conspicuous feature of the "classical" sailplane, the high aspect ratio wing.

Taking the sample, *Soarcerer*, and revising the wing to 65in. span and 6in. chord, gives the same area of 386sq.in., but an aspect ratio of 10·94, say 11. The same calculation process follows, substituting $A = 11$ where it was previously $A = 7$ when calculating the Induced Drag: no other changes are necessary, and it is assumed that such a modification can be made without adding weight. Some results are tabulated below:—

C_L	C_{Di}	C_{D_P}	C_D	C_L/C_D	C_L	v	v_s
1.00	0.0291	0.0369	0.0660	15.15	1.00	22.9	1.51
0.75	0.0164	0.0369	0.0533	14.07	0.866	26.4	1.88
0.375	0.0041	0.0369	0.0410	9.14	0.612	37.4	4.09
0.1875	0.0010	0.0369	0.0379	4.95	0.433	52.9	10.66

The effect of the higher A.R. on the aerodynamic qualities is shown in Figs. 155 and 156, and the new relation between L/D and speed, and between sinking speed and airspeed, appear in Figs. 157 and 158. The increased efficiency of the aeroplane occurs not as a result of any change in lifting ability, but as a result of drag reduction at a given lift. In Fig. 155 it is clear that at the same "max. usable" $C_L = 0.75$ as the original wing, the version of A.R.= 11 has a net model L/D of 14·1, which represents a 17% improvement. At half this C_L, the improvement is only 5·5%, and at quarter C_L it is only 1·6%. The second feature is that the L/D curve is still rising at $C_L = 0{\cdot}75$, and *if* it were possible to persuade the wing to keep working to a higher incidence, giving $C_L = 1{\cdot}13$ then we could realise a L/D of 15·3, which is then a 27% improvement over the original wing best L/D of 12. The same percentage improvements apply to sinking speed at the same C_L's, but *if* we could attain $C_L = 1{\cdot}13$, then

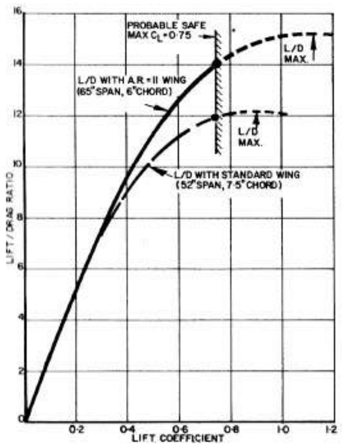


Fig. 155

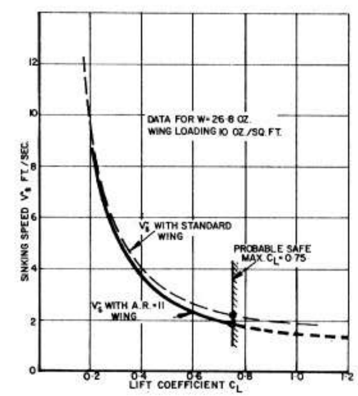


Fig. 156

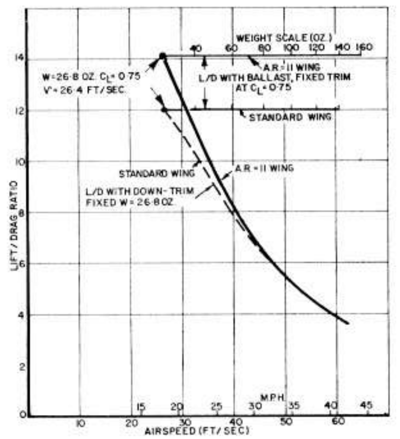


Fig. 157

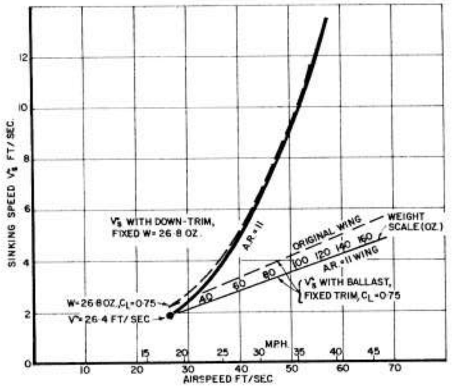


Fig. 158

the additional benefit of reduced forward speed would augment the effect of increased L/D to give a sinking speed of 1·42ft./sec., which represents a 55% improvement in still-air duration! This is out of reach with the existing aerofoil, but it gives an idea of the *potential* benefit.

From the graphs relating L/D and sinking speed to the model flying speed, it is apparent that the benefits are worth having at low speed, but the percentage benefit of high aspect ratio becomes negligible when the model is trimmed to higher speeds.

Soarcerer on the slope

In its intended rôle of aerobatic intermediate slope soarer, the *Soarcerer* has many virtues; the modest a.r. ensures a low roll inertia and thus enhances the speed and accuracy of response. At the chosen A.R. the sums show that there would be no advantage in L/D from using an aerofoil capable of a higher C_L, and in fact such an aerofoil would be inferior to the one used, in its ability to operate inverted. An increase in A.R. would barely improve the ability to penetrate strong winds by use of down trim, and would be detrimental to the handling qualities, so it seems that when there's a good "blow" to permit aerobatics, there's no merit in increasing the A.R. When there's not much slope or wind, and the problem is one of staying airborne, then a higher A.R. might make the vital difference. The advantage of using ballast rather than down trim for penetration increases rapidly with the wind speed for the standard model. The L/D when *trimmed* for high speed is hardly improved by use of a high A.R. wing, but the L/D ballasted may be 17% better than the standard model, so the advantage of ballast over trim is even greater. For fast flying aerobatic models, it is generally better to concentrate on the top end of the speed range, and reduction of *profile* drag is profitable. For example, a "slenderised" *Soarcerer* would have only 13% better L/D at low speed if the profile drag were reduced by 20%, but at high speed, where the retrimming causes a severe drop in L/D, there is a 24% improvement of this inherently poor L/D, which helps to reduce the "sink like a brick" effect.

The quantities of ballast needed in our examples are alarming; in practice it would be better to use both ballast and down trim, if only for the fact that speed obtained by ballast alone cannot be "turned off," and a model weighted to fly into a gale would move downwind like a rocket. The other problems are in finding room for ballast around the c.g., and ensuring that the model is strong enough to carry the dead weight. All this is not to imply that the standard *Soarcerer needs* a lot of alterations in normal circumstances; on the contrary, it is a versatile performer in a wide range of conditions, and using it as a "guinea pig" in this study serves to indicate the relative merits of different ways of extending the ability of

this, or any model, to cope with wind and slope conditions ranging from "too much" to "not enough."

Soarcerer as a thermal flier

Add a tow-hook, and your *Soarcerer* will serve you well enough as an introduction to the launching and flying techniques of tow-line gliding. You'll have fun, but if you match it in calm conditions against a specialised design, you'll wonder what's wrong. Nothing's wrong; you're asking it to do something for which it wasn't designed, and the features which make it so good at its intended purpose are not conducive to a high, still-air duration. This is a universal rule, not just a criticism of a particular design. I'll set out the lines of thought in an imaginary "let's make it better" exercise, and you'll see that most of the modifications which would make it a better thermal soarer would detract from its capabilities as an aerobatic slope soarer.

The first change to think of is an increase of aspect ratio, because in this class of flying, a model is flown at the highest C_L possible, *i.e.* at minimum speed, on the verge of stalling; the improvement to L/D is greatest under this condition. A change to A = 11 would then give about 17% improvement to L/D and thus to duration, say about half a minute added to a three-minute flight. This assumes a 65in. span, 6in. chord wing of the same section, flying at the same C_L. The next change could be to a more highly cambered aerofoil section, capable of reaching a higher C_L before stalling. For the standard *Soarcerer*, there is no significant improvement of L/D at C_L values above the normal 0·75, so the only advantage in getting a higher C would be in the reduced forward speed at the same angle of descent. However, the full benefits of *increased A.R.* may be realised if one can persuade the wing to "hang on" to a higher C_L; from Fig. 155 it appears that if C_L= 1.13 can be reached, then the increase of A.R. to 11 which gave 17% improvement of L/D with the standard aerofoil C_L of 0·75, will give 27% better L/D if the more cambered section is used. The forward speed *and* glide angle have been reduced by this joint change of section and A.R., with a net benefit to duration of 55%, adding over 1½ mins to what would have been a three-minute flight. While you're changing the aerofoil, you could go for something thinner, reducing the profile drag, a technique long favoured by the free-flight exponents. Incidentally, an A.R. of 11 would be considered low by A/2 standards* where 13 to 16 is normal practice, and some leading exponents have used even higher figures, though strength and weight problems then become disproportionately high for the small benefits to duration.

Thus, an alternative wing for thermal flying would bring marked benefits, using the same area but a higher aspect ratio, and a more cambered and possibly thinner aerofoil. The final stage in this line of reasoning is:— why not make the above changes but increase the area? This will reduce the wing loading and lower the flying speed still further, and because the parasitic drag of fuselage and tail is "spread" over a larger wing area, the resultant L/D of the whole aeroplane will be better. If the original chord of 7·5ins were retained, and the span extended to about 82ins., the A.R. would be 11, but the area would be more than 50% greater. After allowing for the extra wing weight, the benefit in terms of reduced wing loading would still be large. A performance at least twice as good as the standard *Soarcerer* should be obtainable. This last suggestion is not practical as it stands; you've gone too far, and the result is a lot too much wing for a properly proportioned model. So you stretch the fuselage by a foot or so, then the light dawns. You've arrived at Dave Hughes's *other* design, the *Ascender*! That's the one that *was* designed for thermal flying, and it's just as good at that, as the *Soarcerer* is at gyrating over the windy slopes. If you'd *started* with an *Ascender* and subsequently wanted to go chucking models off hills, then you'd probably end up reversing the process described, sawing off lengths of wing and so on. The *Ascender* would make a good reserve model for the near-windless conditions which ground the normal breed; its aerobatic abilities would be poor, but at least you could enjoy some relaxing flying.

A point to bear in mind, concerning a specially designed thermal flier, is that in stiff

* The A/2 is an international specification for free-flight gliders, first introduced over 20 years ago. Models in this class are now highly refined and developed.

breezes the advantage of slow flying speed can easily be thrown away if one has to use excessive downtrim to penetrate, because the glide angle then goes to pot. Use ballast for most of the extra speed that the conditions demand.

In conclusion. No need to go through all that again! The conditions under which various features of a design become important have been discussed, and the essential difference between the two methods of influencing flying speed has been illustrated. When all's said and done, there comes a time when you chuck the slide rule away, and go flying. The figures are only to show what to expect and why, and what to do about it. The remaining 90%, *i.e.* how to be a good designer/flier, is *your* problem.

CHAPTER 21

AEROFOIL SECTIONS

WHETHER or not you chose to follow the arguments of my previous chapters, we can agree on one thing: wings are indispensable. Those of us who have made the "not more than once per model" practical test of this proposition are generally keen *not* to seek further proof. As we've observed earlier, the Lift = Weight relationship is what distinguishes flight from a ballistic trajectory, and wings are by far the most *effective* way of providing lift. Also, whilst anything that looks remotely like a wing will work, even an unshaped plank, it makes sense to give some thought to the *efficiency* with which this lift is generated.

The voice of experience

Ask any seasoned modeller what an aerofoil section is for, and he'll tell you "To fill the gap between the leading and trailing edges," or alternatively "To keep the top and bottom of the wing from touching." Concise and true. The only embellishment I would add is that the wing needs thickness in order to have strength, and it is customary to streamline the cross-section, if only to reduce the drag. All that remains to be said is that it is known that variations of the thickness and shape of the streamlined section, between something resembling a pear drop and something more like a banana, influence both lift and drag. If you suspect that this is oversimplifying things, I'll give you a reference to a 700-page book* which will make you sorry you asked.

How it works.

It is not enough to provide wings; they must be persuaded to operate at an incidence to the airflow in order to generate lift. The symmetrical, zero-rigged example of Figs. 144 (a) and (b) in Chapter 19 cannot generate lift, and the wings serve no useful purpose until the tail setting is changed to hold them at incidence. All wings, regardless of the aerofoil section used, generate lift by deflection of the airflow. In steady flight, the lift force is an upward reaction on the wing due to imparting a downward momentum to the air molecules. You can't have lift without some inclination of the zero-lift datum to the airflow, and the generation of lift always produces a "downwash" in the airstream as it leaves the trailing edge. There's more to it than the simple momentum analogy, however, otherwise we might all be using flat plates. The total lift from a typical streamlined section may be evaluated from a measurement of its pressure distribution, when it is found that most of its lift comes from suction on the upper surface, and of this, most is concentrated over the forward part of the chord, say from the L.E. back to about one-third. The term "suction" means only a small reduction in pressure from the surrounding atmosphere, not a vacuum. For a wing carrying one pound per square foot loading, the *average* pressure drop must be of this order, whereas normal atmospheric pressure is 2116lb./sq.ft. So it is only an insignificant change in the static pressure of the airstream, but a vital one.

* *Theory of Wing Sections* by Abbott and von Doenhoff; 700 pages, of which 400 are aerofoil ordinates and characteristics, and there are 160 references to further reading. It's a paperback by Dover Publications, great value for money if only one could understand it.

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Fred's frustrated

The most important aspects of performance may be studied in terms of the characteristics C_L and C_D for the whole aeroplane. It should be possible at the design stage to define the required aerofoil characteristics, and by studying the C_L and C_D figures of a range of sections, make our choice "scientifically." It should be, but it's not possible, because the data don't exist. I would be happy to launch off into reams of technical stuff, explaining how to interpret and apply aerofoil characteristics, but without reliable measured data this would be no more use than swimming lessons in the Sahara. So you're spared the clever stuff, as we're all in the same boat, except that I regret it more because I've got a headful of equations, with no prospect of ever using them.

Scale effect

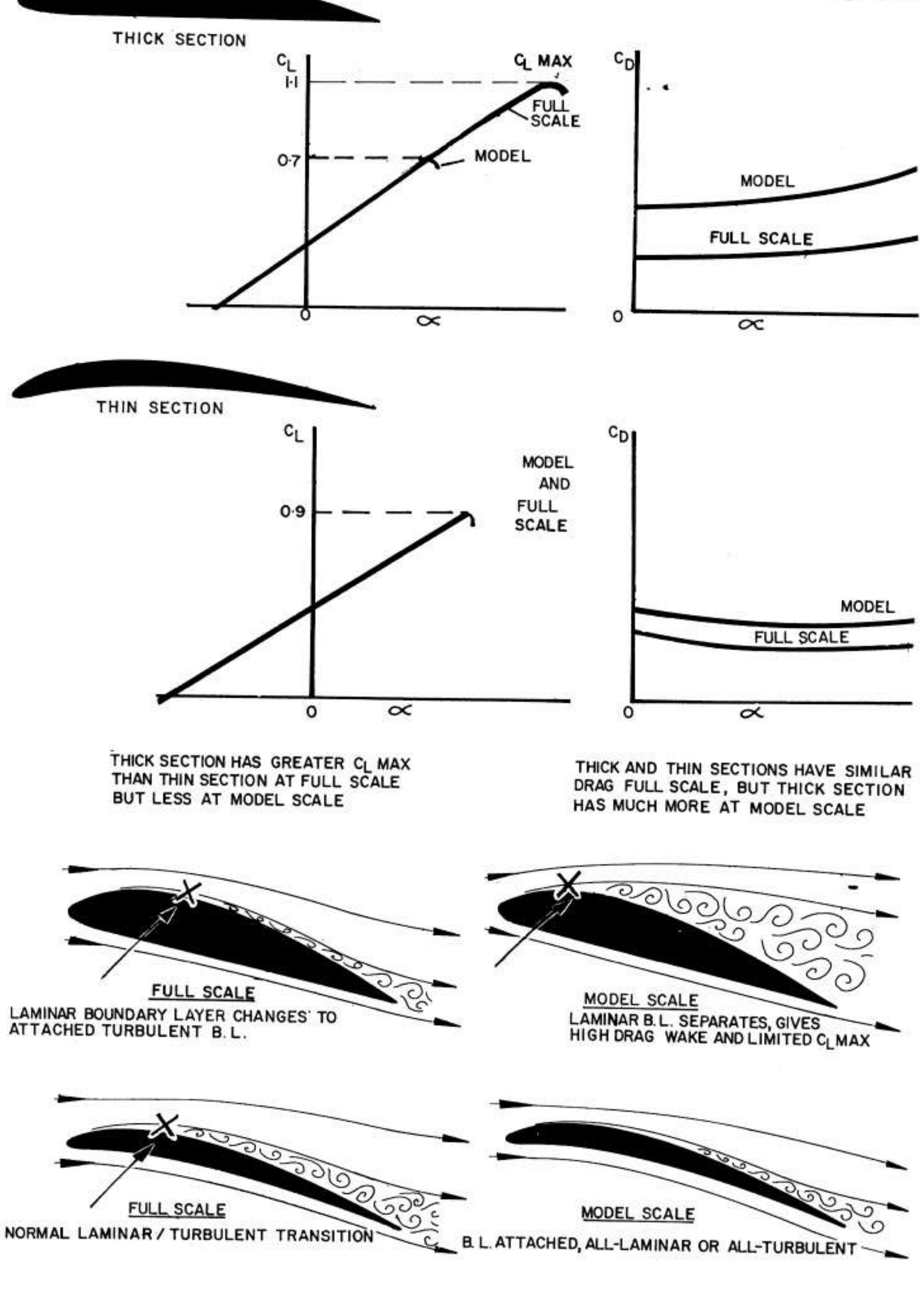
The equations such as $L = C_L \frac{1}{2}\rho v^2 S$ are convenient approximations. In full scale practice, they are valid for the range of flight speeds of which a plane is capable. If we make a model of that plane, however, it may be one-eighth scale, operating at half the speed, and this will cause a change in the coefficient values. The *equation* may still be valid for the range of speeds of which the *model* is capable, but we may well be operating in a region of low energy flow which gives markedly different values to C_L and C_D. A factor of *two or three* on drag coefficient is quite possible, for example, and the maximum lift coefficient may be seriously reduced. Model glider performance calculations based on full scale data are misleading rubbish. The criterion which determines where a wing is operating on the "aerodynamic scale" is Reynolds Number. This is essentially the product of airspeed and chord, VL, together with an allowance for viscosity and density which need not concern us. The sea level value is 6400 VL, where V is in ft./sec. and L is in ft. For R above about 0.2 million, the characteristics are "supercritical," and only change *very* slowly with further increases of R. Below this figure is where we operate, and there is a broad band of totally unpredictable behaviour between about 80,000 and 160,000 (VL between 12 and 25) where the behaviour may remain supercritical, may be subcritical, or may alternate between the two according to incidence and speed for a given model. There is very little evidence on the subject, and there are very few test facilities in the world capable of providing it.

The air adjacent to the aerofoil surface is stationary, a litle further out it has some velocity, and so on, till at some small distance from the surface it has the free stream speed. This envelope of slower-moving air is the Boundary Layer. Over the front portion of an aerofoil, it is normally "Laminar," a smoothly sliding layer with a minimum of associated drag. Somewhere along the top surface, it normally undergoes a transition to "Turbulent" flow on a full scale wing, a self explanatory term which implies a higher local drag from these regions. The energy level is too low on many model wings for this to occur; the boundary layer air can't make headway against the rising pressure (less suction) as it goes aft, and the result is *separation* of the airflow. This is the essential feature of subcritical flow—separation instead of transition (Fig. 159).

You can't possibly use Reynolds Number to factor full-scale data; the change from supercritical to subcritical may occur anywhere in the range mentioned, and it is discontinuous, not progressive. It is possible for one aerofoil which is inferior to another, full-scale, to retain its characteristics down to a low speed × small chord value at which the "better" section has undergone separation and become much inferior for model use. The many years of free-flight model development have demonstrated that the thin, slender-nosed sections work well down to low R, and the thick, bluff-nosed sections, especially the biconvex ones, are very poor. With our faster and larger R/C models, we seem to be in an intermediate region where the distinctions are less obvious, and in any case the emphasis is not always on maximum efficiency and minimum flying speed.

It's clearly not worth reproducing full-scale data for a range of sections, because the comparisons will be affected by the low R of our applications. Experience shows that many of the *qualitative* characteristics are similar under model conditions, however, and it is possible to indicate the *type* of lift-drag-incidence relationship to be expected from the principal types of aerofoil, without giving numerical values. If you want order-of-merit data

Fig. 159



on sections of a given type, you'll have to conduct careful flight tests in which the *only* variable is the aerofoil. The results will only be valid for the chord and speed at which you test, so unless the job is done comprehensively, it won't resolve the conflict of opinions and experiences which prevails at present. Plenty of scope for a collective effort, or on a smaller scale for the individual to develop a particular model by experiment.

Think about it

We're all looking for that aerofoil with unlimited lifting ability and no drag. Meanwhile, back at the drawing board, we may as well make the best of our lot—sub-critical or otherwise—and decide first *which* particular aspects of performance are of most importance to us for our proposed new design. It is possible to make a *good* all-rounder, but *excellence* has to be paid for by sacrificing one quality to gain another. The choice of the right *type* of aerofoil is important, but the full benefit will not be achieved unless the geometry, loading, and trim of the plane are also right for the type of flying we are attempting. The mechanics of gliding flight have been covered already, but to reiterate briefly:

airspeed is $v = 29\sqrt{\frac{\text{Wing loading}}{\text{Lift Coefft}}}$, Glide angle is $\tan\delta = \frac{\text{Drag Coefft}}{\text{Lift Coefft}}$, and sinking speed is $v_s = v \sin\delta \doteq v\, C_D/C_L$.

For the thermal flying class of model, we need minimum sinking speed. This suggests minimum forward speed in conjunction with maximum Lift/Drag ratio, so a light wing loading is called for. The aerofoil should be one capable of achieving a high lift coefficient without stalling, and its profile drag should be low *at high* C_L. The wing aspect ratio should be high to reduce the induced drag associated with operation at high C_L; a "high lift" aerofoil on a low aspect ratio wing may only reduce forward speed at the expense of a steeper glide angle.

For a fast-flying slope soarer, as we've seen, the most efficient way of achieving speed is by using a high wing loading, and operating the wing at a reasonable C_L, where the model L/D ratio is satisfactory. Operating a lightly loaded model at a low C_L *inevitably* results in a poor glide angle. However, one must have the ability to penetrate when required, and this puts the emphasis on aerofoils having low profile drag. At low C_L, the induced drag is a much lower fraction of the total, so the wing aspect ratio is less important, and reduction of profile drag has thus a relatively greater effect on the overall L/D ratio.

Aerobatics impose special considerations. Loops and banked turns require lift in excess of the weight; this is achieved by trimming to a lower C_L than the maximum (shoving on down elevator), till the speed builds up, when restoring the incidence gives the required extra lift to pull the plane round in a curved path. The ability to perform outside loops as well as inside ones dictates an aerofoil with adequate, or even equal, lifting ability in the negative direction. Profile drag should not be too large at low C_L, when diving for speed, nor should it be excessive at high C_L when performing manoeuvres. Response to control about all axes is enhanced by compactness, so modest aspect ratios are generally preferred.

Thus, admitting that the ideal aerofoil section doesn't exist, we've taken the step of putting an order of priorities on the qualities to be sought, in accordance with the type of plane and the performance required of it.

Geometric properties of aerofoils

There are various terms used in describing aerofoil sections, and it is important to know and use them correctly, and to have an idea of how the characteristics may be expected to depend on them. In particular, thickness and camber are separate parameters which are sometimes confused.

The simplest aerofoil is a flat plate, which is inefficient and has no strength. Adding a symmetrical fairing round it makes it a practical proposition (Fig. 160). This is the "Thickness Form," "Profile," or "Fairing shape." The maximum top-to-bottom depth is the section *"Thickness,"* normally expressed as a percentage of chord. The thickness, its location chordwise, the general profile of the fairing, and the nose radius all affect lift and drag characteristics.

The above is a special case. In general, the fairing may be added to a *curved* datum,

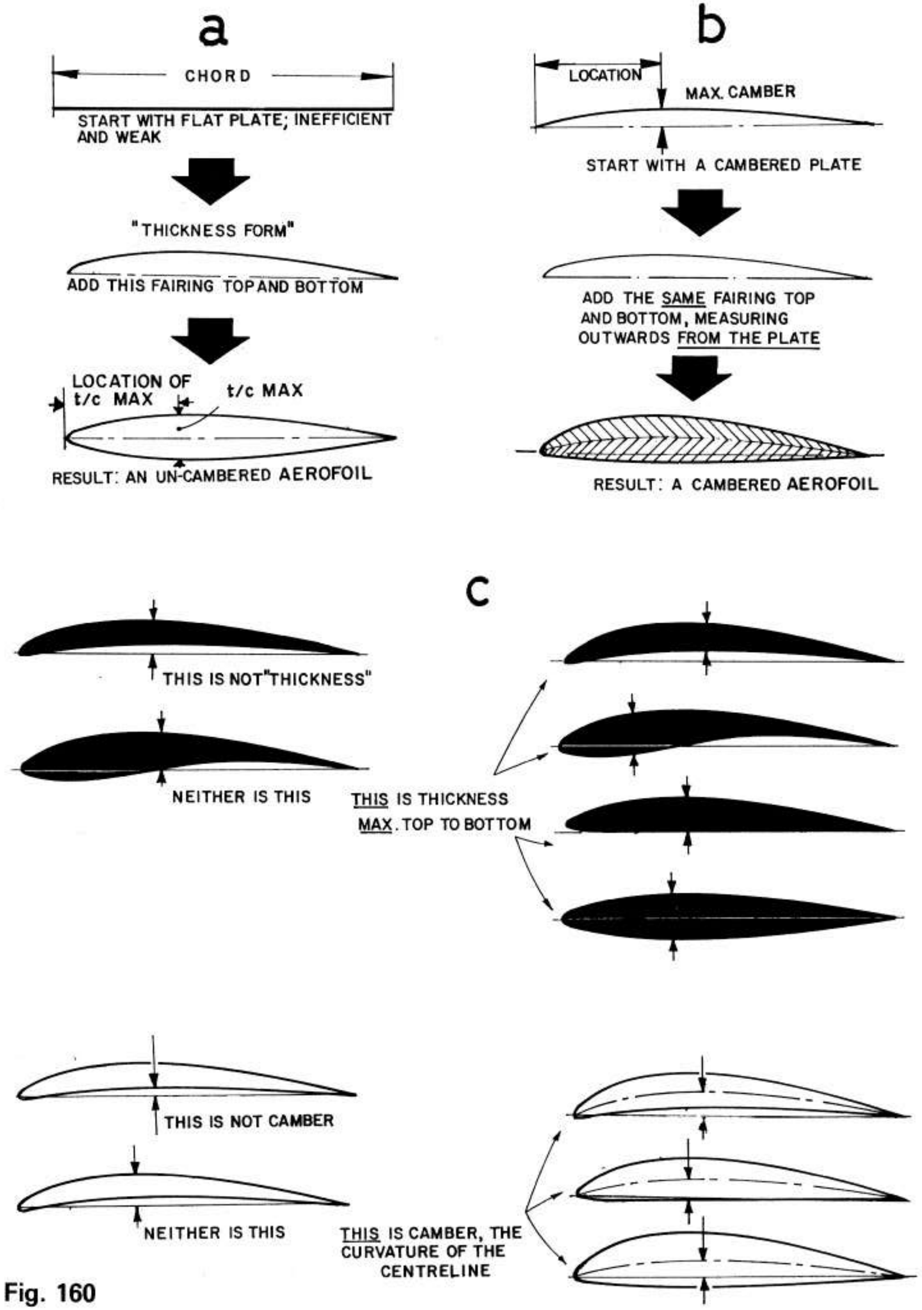


Fig. 160

and the maximum deviation of the bent *datum* from a straight line joining leading edge and trailing edge is known as the *camber*, also expressed as a percentage of chord. The amount of camber, location of the maximum (chordwise), and shape of the camber line all affect lift and drag.

The distinctions between camber and thickness are illustrated in Fig. 160. Reversing the process, the test for camber is to plot the *centreline* of the profile, because an aerofoil section consists of a *symmetrical* fairing plotted about a datum line. If the aerofoil centreline is bent, you have a cambered aerofoil.

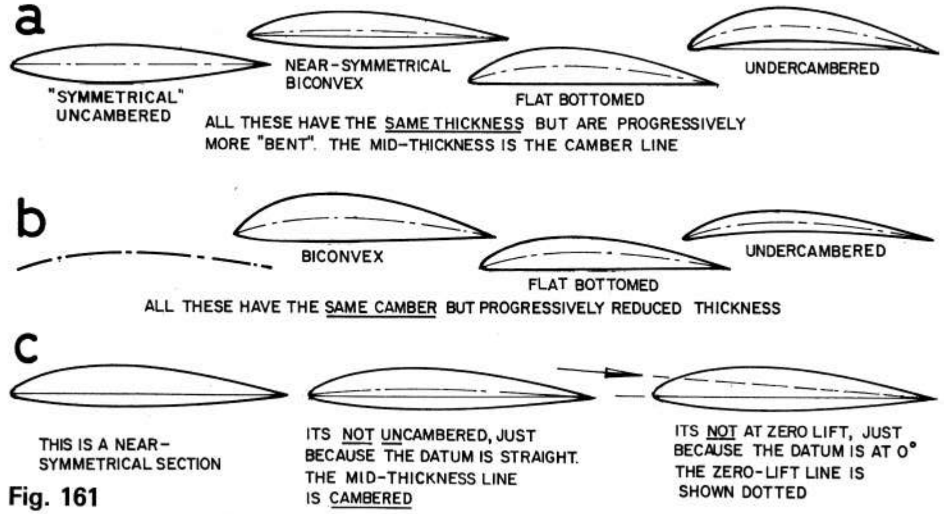


Fig. 161

It follows, allowing that all practical sections have thickness, that there are only *two* sorts of section—those with camber and those without! For convenience in visualising the actual section appearance, four groupings are used, namely symmetrical, "semi-symmetrical," flat-bottomed, and undercambered. The second term is totally meaningless and used only in the model world; such a section is *asymmetric* about the datum used for plotting, *symmetric* about its camber line, and not semi anything. A better term would be "near-symmetrical," or "(low) cambered biconvex." Starting with a given thickness form, it is possible to "bend" it to any of these aerofoil sections by plotting it about suitable camber lines. Likewise, one may take a given cambered line and plot various thickness distributions about it, to give undercambered, flat-bottomed, or biconvex sections. The *real* parameters, which govern aerodynamic behaviour, are not the visual appearance of the whole section, but the separate values of its components, namely camber and thickness.

The reference line used for plotting the section is generally used as a datum for incidence. This gives rise to some confusion, because undercambered and flat-bottomed sections are often plotted from the tangent to the lowest extremities, whereas biconvex sections use a line from the T.E. to the centre of the nose radius. The *only* case where the datum is of aerodynamic significance is the *uncambered* symmetrical section, where obviously zero incidence will give zero lift. The slightly cambered (near-symmetrical) section is effectively at positive incidence, giving positive lift, when the trailing edge-to-nose datum is at zero incidence to the airflow. The geometric datum is purely a matter of convenience and bears no relation to the aerodynamic "zero lift line," see Fig. 161.

Aerodynamic properties of aerofoils

An idealised example of an *aerofoil* characteristic is shown in Fig. 162. The lift is zero at a negative incidence of the datum line, it continues in a straight line till, at just above

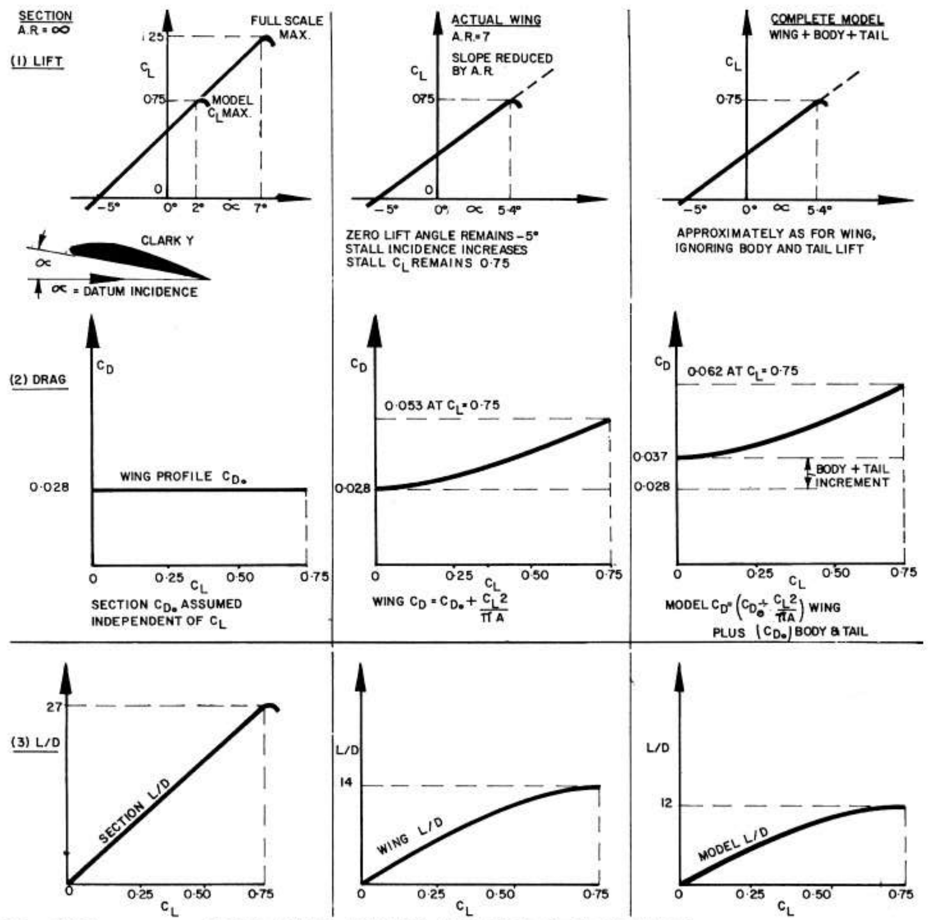


Fig. 162 LIFT AND DRAG CHARACTERISTICS

These characteristics are for the "Soarcerer" calculations in earlier chapter.

$C_L = 0.75$, it falls off at the stall. The drag has been assumed to remain constant with incidence α, and the L/D curve reproduces the shape of the C_L v α curve. This is the *section* characteristic of our *Soarcerer* example. When applied to the *actual wing*, the slope of the C_L curve is reduced due to the effect of aspect ratio. Lowering A.R. necessitates more incidence for the same C_L, but does not affect the achievable C_L value. Also, induced drag appears, and must be added to the profile drag, introducing a variation of *total* drag with incidence and C_L. Finally we add something for fuselage and tail profile drag, to end up with a L/D ratio of 12 at $C_L = 0.75$, having started with a *section* L/D of 27 at infinite A.R. At full-scale Reynolds No. the L/D could have been as high as 100 for the section.

The zero lift angle for the Clark Y section is −5 degrees, using the lower surface of the section as a datum, or −3 degrees if the line from L.E. to T.E. is used. If a highly cambered section were substituted, its zero lift angle might have been −8 degrees, and its C_L v curve as shown in Fig. 163, reaching a higher C_L value at the stall. But if the curves are replotted

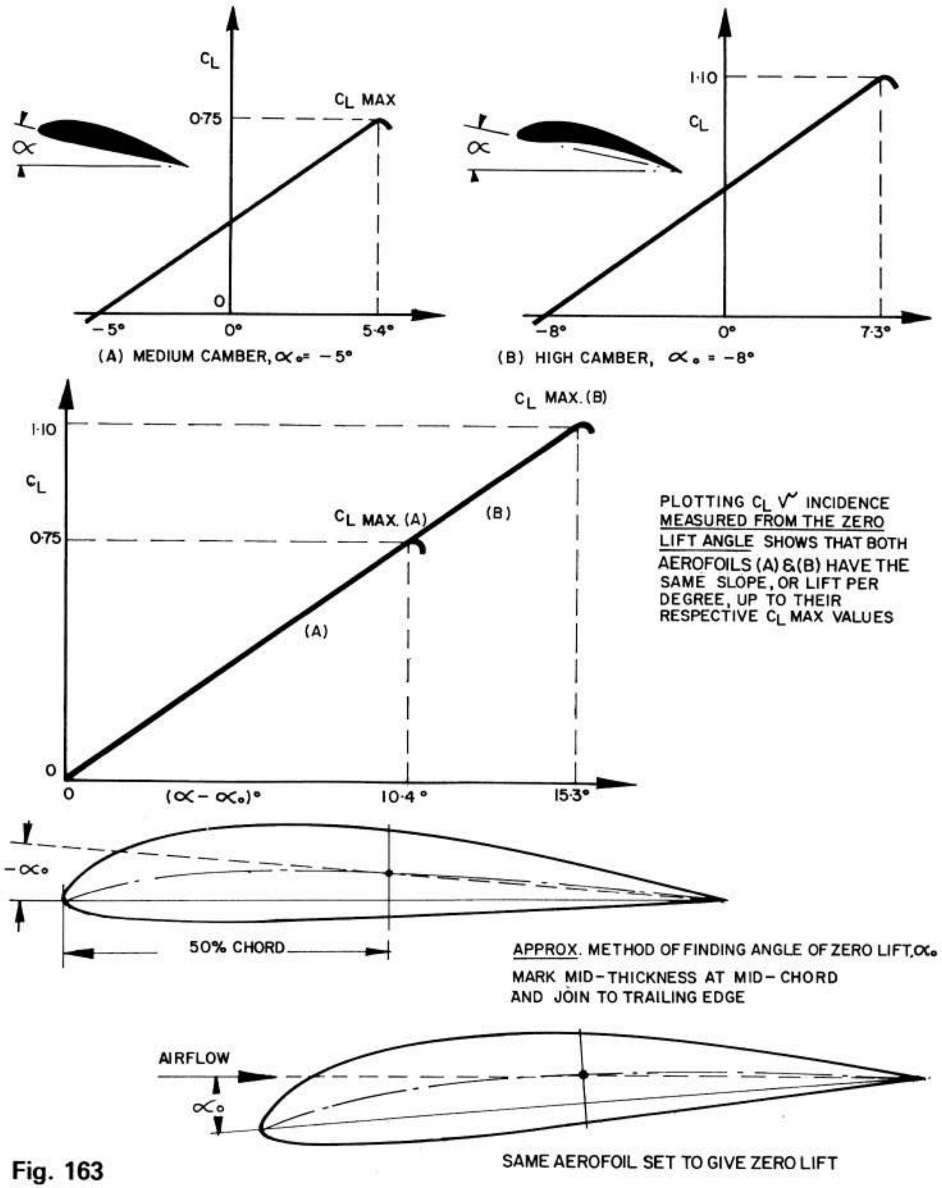


Fig. 163

by measuring incidence in each case from that at which $C_L = 0$, then they are superimposed, because (within plus or minus about 10 per cent) *all* sections produce lift at the same rate with incidence measured from their starting point, or zero lift angle. The fact that the high-cambered section gives more C_L at 5 degrees incidence of its datum line than does Clark Y doesn't make the former more "efficient," because the datum could have been

drawn anywhere. The zero lift line has to be found by experiment, but as a *very rough guide*, if you join the T.E. to a point at mid-chord on the mid-thickness (camber) line, then the slope of this line gives a fair visual indication of the airflow direction which will give zero lift.

From correlated full-scale test data, reasonably well-defined trends have been established for the separate influences of camber, thickness, etc., on the lift and drag properties of aerofoils. Experience with models bears out the validity of most of these, as long as they are accepted as generalisations.

Firstly, it must be admitted that the assumption of a *fixed* profile drag, independent of C_L, is only a convenient approximation (used in my *Soarcerer* sums). In general, there is a minimum value of C_{Dp} occurring at a modest C_L, and at incidences above or below this the profile drag will be higher. This increase may only be a *very* small fraction of the *total* drag of a real wing-body-tail combination, but it can be important for off-design operation, such as flying a model at very low C_L for penetration, when a rise in profile drag can lead to undesirably steep descent.

The *thickness* of an aerofoil, and its shape and distribution, mainly affect the profile drag. As some of this drag is skin friction, which remains unaffected by increases of thickness, the profile drag does not increase in direct proportion to thickness. Full-scale, one may double the t/c from 12% to 24% and experience only about 25% increase in profile drag.

The *camber* mainly affects the maximum achievable lift coefficient. The rate of increase of C_L with incidence is unaffected, but the curve goes a bit higher with each increase of camber, *i.e.* the stall is delayed. The other effect of increasing camber is to shift the minimum drag point to a higher C_L, without necessarily altering the amount of minimum drag, so high camber suits slow flight.

The nose radius mainly affects drag, but also has some influence on the incidence at which the section stalls, and the severity with which it does so. One may expect less drag from a sharper L.E., but stall behaviour is less predictable; the blunt L.E.s inherited from power fliers have no merit from any point of view, as they are capable of violent stalling and have excessive drag, but at the same time it *may* be a mistake to use an almost sharp entry. It is possible for a sharp L.E. to act as a turbulator on a small-chord, slow-flying section, giving a more stable and efficient flow than the separated laminar flow which might otherwise prevail. It is also possible for a sharp L.E. to induce premature stalling, a trick which may be employed to get a design to spin more readily.

There is a common belief that thick sections "give more lift." This is not supported by the masses of full-scale evidence, though it is true if one considers the range of low thicknesses from 6% to 12%. Going to 15% offers no consistent advantage, and above this thickness the stall occurs at a *lower* C_L. If you scale up the ordinates of a flat-bottomed section, such as Clark Y, measuring from the lower surface and increasing the ordinates by say 30%, the result will be a section of 15% thickness compared with the original 11.7%. It may well function as a "higher lift" section, but this will be because this method of increasing its thickness has *also* increased the *camber* from 3.6% to 4.7%. If the original thickness form had been retained, but "bent" to an undercambered shape, at least the same increase in C_L max. would have resulted, but *without* an accompanying drag rise.

Regarding the location of the maximum thickness and camber in the chordwise sense, it may be said of both that a forward location may give a higher C_L max., but the stall when it comes is more violent. Also, forward location of the max. thickness (at 20%-30% of chord) tends to give more drag. A more aft location of these maxima, at say 35%-55% chord, tends to give a milder stall at the expense of a small reduction in the C_L max. at which it occurs, and an aft position for max. thickness naturally gives a more slender entry and less profile drag.

In the light of the above, one may get a pretty good idea of what to expect from a section, or how one section compares with another, purely from appearances. It must be stressed that even on the basis of available full-scale data, these are sweeping generalisations to which there are numerous detailed exceptions. For models, the position is much worse, because different sections are affected differently by Reynolds Number, and there is in any

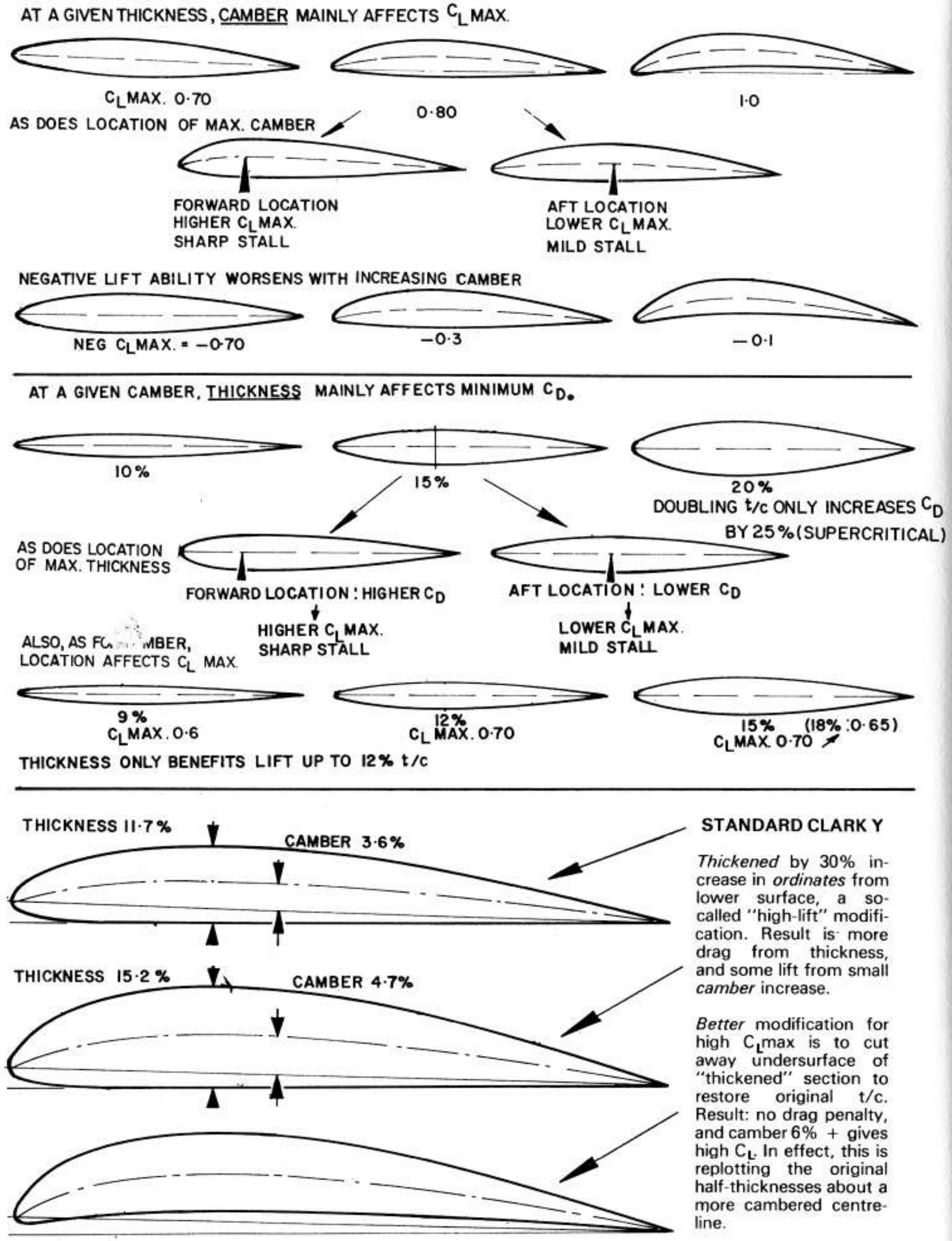


Fig. 164 SEPARATE EFFECTS OF CAMBER AND THICKNESS

case an almost total lack of measured data. However, on the basis of experience and observation, the foregoing is a very good foundation, on which may be built your own understanding of how model sections behave.

Particular classes of aerofoil

(1) Symmetrical (Uncambered)

If you must have equal performance upright and inverted, use this. It gives the highest possible *negative* C_L for outside loops and slow inverted flight, but the *positive* C_L obtainable (equal in magnitude) is less than for any other type of section. There is no other advantage, and for every other application than slope soaring aerobatics, there is no worse aerofoil. The minimum drag is at zero lift, and rises with the application of lift in either direction. For a thick section, the "face" presented to the airflow ensures high drag at high incidence. The stall comes quite early, especially with thin sections. Good for fast models flown at low C_L, where symmetry of manoeuvring is important and slow flight and shallow descent angle are not!

(2) Near-symmetrical

Generally a good bet for all-round performance in the aerobatic field. A better positive C_L max., with some slight deterioration in the negative lifting ability, according to how much camber is used. The optimum performance is biased towards cruising flight at some *moderate* value of C_L, where the minimum drag will occur, so that penetration and the building up of speed for manoeuvres do not entail too much height loss. The drag rise at high C_L will also be less than for the symmetrical section.

(3) Flat-bottomed

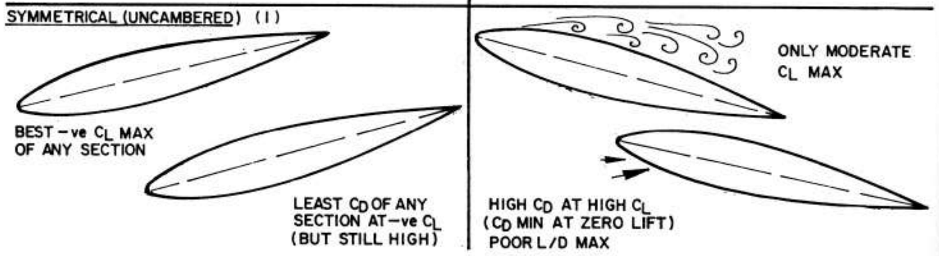
As above, only more so. This is the great "All-rounder" category. In fact, they're not particularly good at anything and in various *single* respects can easily be outclassed by other sections, but they do combine a very fair measure of all the qualities and are much favoured for multi-purpose models. The practical virtues of easy rib cutting, flat assembly without jigs and packing pieces, and ease of covering and aligning ensure that the 57 varieties of Clark Y will be the most popular section till long after old Virginius E. Clark, who designed it in 1922, is forgotten. By now, the effect of camber begins to become obvious on the inverted performance as the inverted stall occurs at quite a small negative C_L. The drag in inverted flight will have risen well above the minimum, which now occurs at a higher C_L than for the near-symmetrical sections. Penetration abilities are less, in the sense that the accompanying drag is higher. Slow flying with a flat glide path is improved, not only by the higher C_L max. but by the lower drag at high C_L than the near-symmetrical section. This type of section may be used on any category of model, though it has no place at contest level as a rule. Depends on the contest and the opposition!

(4) Undercambered

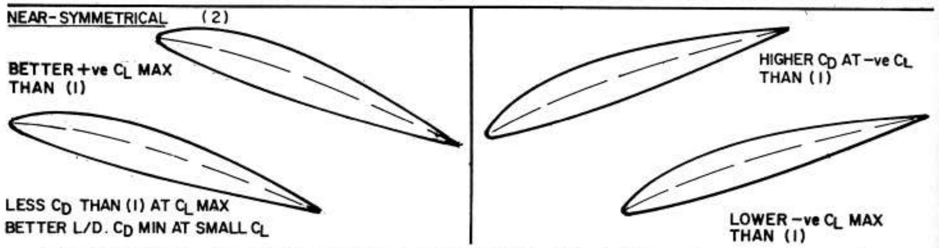
These are the truly high performance sections, for models where high efficiency is the requirement. The presence of a high *camber* is of multiple benefit to models where minimum sinking speed is the primary goal; it provides a high C_L max. which alone ensures slow flight, it enables the full potential of a high aspect ratio design to be realised because it enables the wing to attain the extra high C_L at which the L/D ratio has a maximum value, and it also ensures that the minimum profile drag occurs at a high C_L. Provided that the thickness is kept moderate, the amount of profile drag need be no more than for a less "bent" section, and it will occur closer to the minimum flying speed than for any other class of aerofoil. Let it be clear that the *camber* of the centreline is responsible for the high lift capability, and that there is no early limit to the amount which gives benefits, as with thickness. Camber may be raised to an absurd amount in the interest of obtaining high C_L and low stalling speed, but the drag may begin to suffer, and the effectiveness of camber increases in raising C_L max. is less if the thickness is raised above about 10%-12%.

The thin, high-cambered section is the "end of the line" where specialisaton is concerned. Its deficiencies in other respects are very marked. The lower the C_L, the higher the profile drag, so penetration is at the expense of a steep descent. The inverted

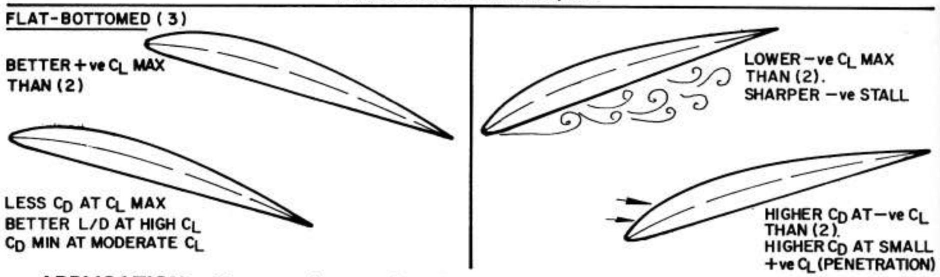
GOOD POINTS — **Fig. 165** — **BAD POINTS**



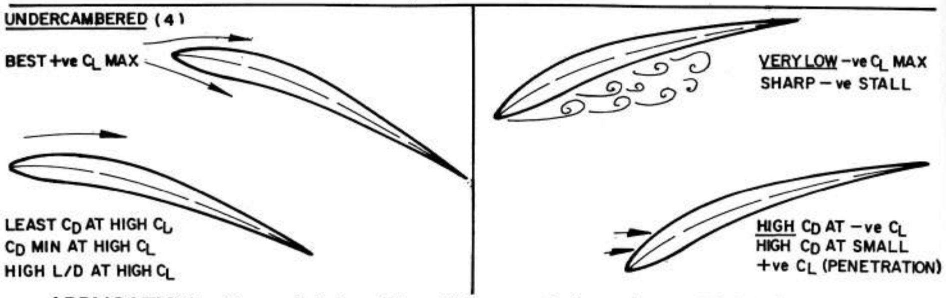
APPLICATION: Fast aerobatics, upright and inverted. Fair penetration. Slope soarers only



APPLICATION: Aerobatics and good penetration. "Upright" performance better than (1), at cost of inverted perf.



APPLICATION: Compromise section for slope/thermal flying. Fair C_L, L/D, and penetration



APPLICATION: Thermal flying. Slow flying on shallow slopes. High L/D at high C_L gives min. sinking speed. Good "load carrier." No inverted perf.!

N.B. The foregoing are generalisations; there are overlaps and exceptions, depending on shapes, thicknesses and Reynolds No.

These 2 graphs summarise the trend to better C_L and lower C_D as camber is increased.

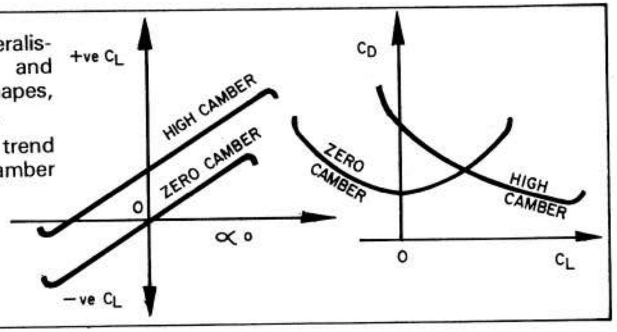


Fig. 165a

performance is very limited indeed, as the inverted stall occurs violently at a very low negative C_L, and drag is excessive in these regions.

For a load carrier, as with aerial photography, where a light wing loading is hard to achieve, but slow flight is required, lots of camber is what you need. Thickness will be a matter of structural strength, the less the better for performance. For all duration flying activities, including slope soaring in marginal winds or from shallower slopes than usual, there are benefits to be had from employing well-cambered sections which are not too thick, and the need for penetration may often be met better by using ballast. For small, light models, the combination of fairly high camber and low thickness gives an improvement which is exaggerated by the fact that the flat-bottomed moderately thick sections deteriorate to sub-critical behaviour at a much higher Reynolds Number, whereas the thin cambered ones work well down to very low R.

Specimen aerofoils

Ordinates are given for a number of "proprietary" aerofoils in each category. No attempt is made to present the sections in any order of merit, nor is there any implication that this selection is the best of the many hundreds available. The Hungarian sections by Dr. George Benedek, and the Swedish ones by Sigurd Isaacson were specifically designed for use on free-flight gliders, *i.e.* at low Reynolds Numbers, and the sharp L.E. is intended to promote turbulent flow. The German sections by Dr. Richard Eppler were also designed for model use, but intended to have attached laminar flow. The flattering published characteristics of these appear to have been computed, not measured, which impresses me not at all, after spending 15 years measuring the differences between theories and practice, in wind-tunnels. However, these sections are now quite widely used and have acquired a good reputation; their thinness and slender shape *look* efficient especially when compared with some of the "old faithfuls" used for years by conservative model glider exponents! Some of the latter sections are a hangover from the 1920's, when the structural problems of cantilever monoplane wings made thick sections desirable. The remaining examples given are all "full-scale" sections which have the right sort of camber and thickness to suit our purposes. The method of plotting from tabulated ordinates is given in Fig. 166.

If you don't want to be bothered about duplicating a particular section, try a spot of do-it-yourself with a french curve. From the outline given of the effects of thickness, camber, etc., you can forecast the sort of characteristics to be expected from any existing section, so you can apply the same concepts to creating your own section, and can in fact create a systematic series more easily than you can find a ready-made range of the type you are seeking. You may find success by combining various features; for instance, a near-symmetrical fore-portion helps inverted performance, and may be combined with a more cambered aft portion which has a flat, or even undercambered lower surface, which improves upright performance in comparison to that obtained with a conventional uncambered or low cambered biconvex section (Fig. 167). This sort of "tailoring" has been

(1) Start with a Table of Ordinates:—

X	0	5	10	15	20	30	40	…	100
Yu	0	5·36	7·58	9·18	10·34	11·65	11·80	…	0
YL	0	−1·99	−1·99	−1·67	−1·25	−0·38	+0·20	…	0

This is location of ordinate, % chord from L.E.
This is *upper* surface height, % chord, above datum line
This is *lower* surface height, % chord, above datum line.
(negative values lie below datum line)

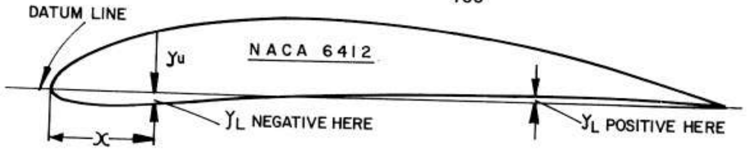
(2) Draw a blank table of three lines, with columns as for the table of ordinates. This is to be filled with ordinates and their locations *in inches,* for the particular chord chosen.

EXAMPLE: Chord = 7.5 inches. Take fourth column.

Ordinates are at $x = \frac{15}{100} \times 7.5'' = 1.125''$

Upper surface ordinate $y_U = \frac{9.18}{100} \times 7.5 = 0.689''$

Lower surface ordinate $y_L = \frac{-1.67}{100} \times 7.5 = -0.125''$



(3) Get a slide rule! Arithmetic is only done right by kids. Now go forth and multiply.

(4) Completed table looks like this:—

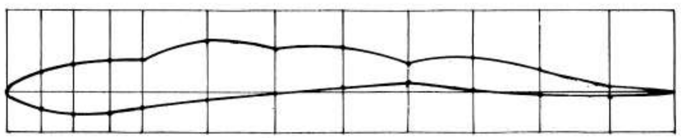
X"	0	0·375	0·75	1·125	1·50	2·25	3·00	…	7·50
Yu"	0	0·402	0·568	0·689	0·775	0·874	0·885	…	0
YL"	0	−·149	−·149	−·125	−·094	−·028	+·015	…	0

(5) Get some graph paper with 1/10 inch squares (available in 14" × 9½" pads). Mark ordinate stations on a chord line.

0 0·75" 1·5" 2·25" 3·0" → 7·5"
0 10% 20% 30% 40% → 100%

(6) Now plot! Use correct end of a hard, sharp pencil, not an old fibre-tip pen.

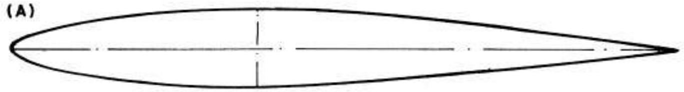
(7) Join plotted points with smooth curve.



If it looks like this, it's your rotten arithmetic. See step (3). Aerofoils never have 'umps.

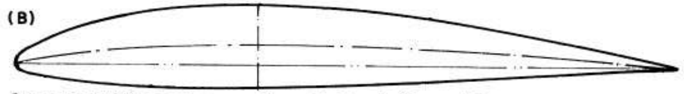
Fig. 166 PLOTTING AN AEROFOIL

(A)



Standard uncambered section. Limited L/D and $C_L$max. Good inverted performance.

(B)



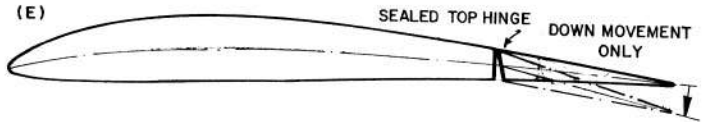
Standard 3% camber section. Better L/D and $C_L$max. Higher C_D and lower $C_L$max inverted.

(C)

Home-made hybrid. Front part of (A) ensures good negative lifting ability, delaying stall & drag rise. Rear part of (B) enhances normal flight, improving L/D both for cruise and penetration, compared with the uncambered section (A).
Note: no discontinuity of slope where the camber lines of the respective portions join.

(D)

(E)



Variable camber sections. For type (D), the movable "flap" endows the fully aerobatic model with an improved cruise L/D and higher manoeuvering C_L, without sacrificing symmetry of upright and inverted perf.
For type (E), a slender, low-camber section may be used on a thermal soarer to enhance penetration, and lowering the T.E. increases camber to provide high C_L and L/D for "lift-sniffing."
Avoid excessive movement, like a true "flap": high drag!

Fig. 167 WHY NOT EXPERIMENT WITH AEROFOILS?

done, and in my opinion, it's well worth pursuing. The design principles employed for the older sections were no more scientific, the understanding of camber and thickness effects was less than clear, and in any case they weren't designed for model conditions or requirements!

There is one further point worth mentioning; the simple explanation of longitudinal stability given earlier took the lift force as acting at quarter chord, but in practice the centre of pressure of a wing tends to move aft of this point at low incidence, by an amount which increases with the camber. The stability tends to diminish at high C_L for a model with a highly cambered wing, and the best way to reduce this tendency is to make the tail area a larger fraction of the wing area, so that the position of the *total* lift doesn't move too much.

These C.P. movements were a nightmare to the pioneer designers, leading to wing failures in a dive because of lack of torsional stiffness with the thin, undercambered aerofoils of those days, but for models it is the effect on stability that matters, and to deal with it is no problem.

Talking of tails . . .

There is an interchange between c.g. position and tail "volume" (*i.e.* Tail Area × Moment Arm), for a given amount of stability, and a shortage of arm or area can be compensated for by a forward movement of the c.g. The tail also provides *damping*, however, which is essential, and this does depend on tail area and moment arm. For this reason, and for the stability non-uniformity mentioned above, it is highly desirable that the high-cambered thermal flying model be provided with a good size tail a long way aft, so that it can ride steadily, finely trimmed to near the stall. Never be stinting with the tail volume; the stall will be less sudden, less violent, there will be less height loss, and it will damp out more rapidly. All these vices will appear with too small a tail, more than offsetting any small potential performance increase due to the drag saving.

Tail sections are not critical. A flat plate suffices for smallish models, but for extra strength and stiffness at little or no drag increase, a slender biconvex section is better, if you think it's worth the trouble. For thermal soarers, it is best in practice to trim with an aft c.g. so that the tail is contributing lift; thus it may as well have a "lifting section." By this we mean simply a cambered section, such as a thinned Clark Y, for convenience of rigging. There seems to be no need to employ a section capable of high C_L comparable with that of the wing, though I have heard tales of stability improvements resulting from such things. The main aim is to *avoid undue drag*, which is detrimental to performance and has no effect at all on the stabilising and damping properties of the tail, which are a function of its ability to provide *lift* forces.

Future Developments

I am convinced that (next to proportional R/C), the most significant recent innovation with the greatest potential for development, for all classes of glider, and for powered applications, is the *variable camber wing*. I've wanted to try it for years and am only now getting something "on the board," but I'm pleased to see that the aerobatic exponents who are pioneering the use of a "trimmable trailing edge" are finding that it's *the* way to *combine* the merits of a symmetrical section, for manoeuvres up or down, and a cambered section for cruising, gaining height, or landing slowly. Applying the same concept of a full-span "flap" of say 15% chord, or perhaps more, to a thermal soarer wing with a thin, flat-bottomed section, one should be able to deflect it to give high effective camber for the necessary high C_L to give minimum sink rate, and restore the flap to revert to the normal section for penetration without the high drag which the cambered section would have given at low C_L. Plenty of scope for experiment with proportions, movement range and preset, perhaps coupling to elevator, and flying techniques (Fig. 167).

On wing design in general, it seems to me that for fixed camber wings, the best way of producing a multi-role model (slope and flat field) is to provide alternative wings, as concluded in the previous chapter. For wide ranges of conditions in either mode, detachable panels would help in arriving at the right sort of wing loading, without using ballast in great quantities. The main thing is to recognise that whilst the section is important, *no* section will work miracles in curing shortcomings of design, trimming, and ballasting.

UNCAMBERED (SYMMETRICAL) SECTIONS

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Ordinate ± y	0	1.50	2.50	3.12	3.60	4.35	4.80	4.92	5.00	4.90	4.60	4.10	3.50	2.65	1.50	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Ordinate ± y	0	1.74	2.37	2.80	3.12	3.56	3.83	3.96	4.00	3.87	3.53	3.04	2.44	1.75	0.97	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Ordinate ± y	0	1.74	2.41	2.92	3.32	3.95	4.40	4.71	4.91	4.97	4.61	3.94	3.04	2.04	1.03	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Ordinate ± y	0	2.02	2.79	3.36	3.84	4.58	5.13	5.53	5.81	5.99	5.61	4.80	3.72	2.50	1.26	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Ordinate ± y	0	2.41	3.26	3.96	4.55	5.49	6.20	6.73	7.12	7.50	7.27	6.39	5.06	3.45	1.74	0

This selection of profiles is given in order of increasingly aft location of max. thickness, from 28% chord to 42%. All may be scaled to greater or lesser thickness, as required. No need to retabulate the percentage ordinates, simply calculate thicknesses as if for a larger chord. The thickness ratio of the section as presented is given by the last two digits.

LOW-CAMBERED BICONVEX SECTIONS

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	2.41	3.42	4.17	4.77	5.67	6.28	6.67	6.88	6.84	6.36	5.58	4.55	3.30	1.82	+0.10
Lower y	0	−1.93	−2.48	−2.81	−3.02	−3.23	−3.28	−3.23	−3.13	−2.84	−2.47	−2.02	−1.55	−1.07	−0.59	−0.10

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	2.99	4.13	4.96	5.63	6.61	7.26	7.67	7.88	7.80	7.24	6.36	5.18	3.75	2.08	0.13
Lower y	0	−2.27	−3.01	−3.46	−3.75	−4.10	−4.23	−4.22	−4.12	−3.80	−3.34	−2.76	−2.14	−1.50	−0.82	−0.13

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	1.90	2.69	3.29	3.79	4.59	5.20	5.66	5.98	6.27	6.01	5.32	4.31	3.04	1.55	0.02
Lower y	0	−1.47	−1.96	−2.32	−2.60	−3.03	−3.34	−3.55	−3.69	−3.72	−3.35	−2.72	−1.94	−1.17	−0.57	−0.02

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	3.61	4.91	5.80	6.43	7.19	7.50	7.60	7.55	7.14	6.41	5.47	4.36	3.08	1.68	0.13
Lower y	0	−1.71	−2.26	−2.61	−2.92	−3.50	−3.97	−4.28	−4.46	−4.48	−4.17	−3.67	−3.00	−2.16	−1.23	−0.13

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	2.20	3.40	4.20	4.90	5.90	6.60	7.20	7.50	7.65	7.10	6.00	4.60	3.15	1.60	0
Lower y	0	−1.20	−2.00	−2.40	−2.70	−3.00	−3.10	−3.20	−3.25	−3.20	−2.95	−2.60	−2.15	−1.50	−0.80	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	2.23	3.15	3.85	4.43	5.36	6.06	6.58	6.96	7.27	6.94	6.10	4.90	3.43	1.75	0.03
Lower y	0	−1.80	−2.42	−2.87	−3.24	−3.80	−4.20	−4.48	−4.66	−4.71	−4.28	−3.50	−2.54	−1.56	−0.77	−0.03

The above are low/medium thickness sections of moderate camber. The "64" series, and Eppler, offer less drag than their conservative equivalents 23012 and the "24" series, at slight cost in C_L max. Scaling any set of ordinates to give different max. thickness may be done, but it will also result in a change of camber.

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	3.71	5.07	6.06	6.83	7.97	8.70	9.17	9.38	9.25	8.57	7.50	6.10	4.41	2.45	0.16
Lower y	0	−2.86	−3.84	−4.47	−4.90	−5.42	−5.66	−5.70	−5.62	−5.25	−4.67	−3.90	−3.05	−2.15	−1.17	−0.16

Ex power fliers may feel more at home with the appearance of 2415, and the glide angle!

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	2.71	3.83	4.68	5.39	6.51	7.35	7.98	8.42	8.77	8.31	7.26	5.78	4.02	2.05	0
Lower y	0	−2.29	−3.11	−3.71	−4.20	−4.95	−5.49	−5.87	−6.12	−6.21	−5.65	−4.65	−3.42	−2.15	−1.07	0

If you *must* use thick sections, you must accept more drag, unless you embody a slim entry as on 64_2A215. Any lift advantage is unlikely, compared with a 12% section.

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	7.18	9.70	10.70	11.35	11.84	12.52	13.00	13.10	13.14	12.48	11.42	9.80	7.74	5.40	2.92	0.12
Lower y	7.18	4.72	3.74	3.10	2.58	1.72	1.14	0.70	0.44	0.12	0.02	0.10	0.22	0.32	0.24	0.12

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	2.46	3.54	4.38	5.06	6.14	6.93	7.50	7.87	8.06	7.58	6.56	5.15	3.49	1.74	0
Lower y	0	−1.72	−2.28	−2.69	−3.00	−3.45	−3.75	−3.92	−3.98	−3.78	−3.16	−2.28	−1.27	−0.31	+0.33	0

These are sections "biased" towards upright performance without undue sacrifice of inverted performance. The RAF 31 is like our suggested "home-made hybrid," and the $63_1$412 shows the characteristic lower surface concavity which results from bending a section which has a slender, cusped tail.

FLAT BOTTOMED SECTIONS

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	2.4	4.5	5.5	6.2	6.6	7.3	7.7	7.9	8.0	7.8	7.1	6.2	5.0	3.6	2.0	0.2
Lower y	2.4	1.1	0.6	0.4	0.25	0.15	0.05	0	0	0	0	0	0	0	0	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	2.0	4.5	5.6	6.5	7.2	8.3	9.2	9.7	10.1	10.2	9.5	8.3	6.8	5.2	3.6	2.0
Lower y	2.0	0.8	0.6	0.5	0.5	0.5	0.7	0.8	1.0	1.4	1.7	2.0	2.2	2.3	2.3	2.0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	3.74	7.40	9.17	10.37	11.25	12.53	13.34	13.60	13.80	13.34	12.27	10.63	8.53	6.12	3.40	0.25
Lower y	3.74	1.28	0.69	0.35	0.18	0.03	0	0	0.05	0.17	0.27	0.33	0.35	0.27	0.13	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	3.50	6.50	7.90	8.85	9.60	10.68	11.36	11.60	11.70	11.40	10.52	9.15	7.35	5.22	2.80	0.12
Lower y	3.50	1.47	0.93	0.63	0.42	0.15	0.03	0	0	0	0	0	0	0	0	0

Some of the "easy-build" sections for undistinguished performance, mainly inherited from obsolete full-scale practices of 50 years ago. Not worth detailed consideration, as by scaling Clark Y up or down one arrives at all the others, near enough. The exception is Eppler 387; this is not a flat-bottomed section, and the common practice of ignoring the concavity may well take the edge off its high-lift performance, but its reputation is undoubtedly due to the modern slim profile and moderate thickness, which give it a marked drag advantage over those fat old Göttingen relics.

UNDERCAMBERED SECTIONS

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	5.80	11.60	13.60	15.10	16.20	17.70	18.60	19.00	19.20	18.60	17.15	14.80	11.90	8.46	4.50	0
Lower y	5.80	1.70	0.50	0.10	0	0.60	1.40	2.45	3.60	5.90	7.45	8.00	7.80	5.90	3.25	0

We're not serious! This archaic notion of a glider section, used in the 1920's, gave an amazing C_L and a deplorable L/D, even at full-scale. For slow flight with a heavy model, lots of camber is what you need, but don't wrap a shape like this round it.

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	2.45	7.05	8.55	9.65	10.50	11.60	12.25	12.60	12.75	12.05	10.70	9.00	7.10	4.90	2.60	0.10
Lower y	2.45	0.80	0.50	0.30	0.15	0	0	0.10	0.25	0.65	1.05	1.35	1.50	1.35	0.45	0.10

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	3.80	5.36	6.57	7.58	9.18	10.34	11.10	11.65	11.80	11.16	9.95	8.23	6.03	3.33	0
Lower y	0	−1.64	−1.99	−2.05	−1.99	−1.67	−1.25	−0.82	−0.38	+0.20	0.55	0.78	0.85	0.73	0.39	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	2.96	4.30	5.42	6.31	7.78	8.88	9.58	10.13	10.35	9.81	8.78	7.28	5.34	2.95	0
Lower y	0	−1.11	−1.18	−1.08	−0.88	−0.36	+0.17	0.70	1.12	1.65	1.86	1.92	1.76	1.36	0.74	0

Three long-time favourites from free-flight days. 532 is one of the less dramatic looking Göttingen sections, used on the R.M. *Ascender.* NACA 6412 appears on many published designs, including R.M. *Slinky,* and the 6409 has a long history of contest wins for duration performance.

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	2.0	4.6	6.0	7.1	8.0	9.2	10.2	10.9	11.4	11.8	11.2	10.1	8.5	6.6	4.6	2.0
Lower y	2.0	1.2	1.2	1.3	1.4	1.8	2.3	2.8	3.1	3.6	4.1	4.4	4.4	4.1	3.5	2.0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	2.0	4.1	5.2	5.8	6.6	7.6	8.3	8.8	9.2	9.7	9.6	9.3	8.5	7.2	5.2	2.0
Lower y	2.0	1.5	1.5	1.6	1.8	2.5	2.8	3.2	3.6	4.3	4.8	5.1	5.0	4.7	3.9	2.0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	2.32	5.00	6.42	7.55	8.42	9.75	10.70	11.10	11.40	11.00	10.00	8.67	6.95	4.93	2.79	0.25
Lower y	2.32	0.72	0.28	0.12	0	0.28	0.73	1.10	1.50	1.75	1.72	1.53	1.22	0.92	0.50	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	1.00	3.90	5.40	6.50	7.45	8.60	9.35	9.75	9.95	9.70	8.95	7.90	6.45	4.65	2.90	0.70
Lower y	1.00	0.10	0.35	0.55	0.75	1.10	1.40	1.80	2.10	2.55	2.90	2.80	2.40	1.85	1.00	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0.90	3.95	5.60	6.60	7.40	8.55	9.20	9.55	9.65	9.30	8.60	7.70	6.65	5.40	3.95	0.50
Lower y	0.90	0.10	0.45	0.80	1.00	1.50	1.95	2.40	2.80	3.40	3.80	3.75	3.40	2.65	1.60	0

The refinements necessary to obtain truly high still-air performance bring structural problems. The Eppler 385 has a very thin T.E.: the E 59 has in addition a particularly thin profile, so its use is limited to small, light models—outside practical limits for present-day R/C. The E 385 should be a good thermal-flying section. The Benedek sections are not normally used thicker than 10%, and the lower drag thin variants have T.E. problems; the special 7406-f shape is a great help in meeting the strength requirements of R/C work with these successful free-flight sections. The first number is t/c, the second pair are location, the last is camber.

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	2.6	4.6	5.9	7.0	8.5	9.6	10.1	10.5	10.5	9.7	8.3	6.7	4.8	2.7	0.2
Lower y	0	−0.5	−0.6	−0.5	−0.3	+0.2	0.6	1.0	1.3	1.8	3.0	2.0	1.8	1.3	0.6	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	3.0	5.0	6.4	7.6	9.0	9.9	10.2	10.3	10.0	9.2	8.0	6.5	4.6	2.7	0.40
Lower y	0	−0.4	−0.4	0	+0.4	1.2	2.0	2.5	3.0	3.5	3.4	3.0	2.3	1.4	0.4	0

Station x	0	2.5	5	7.5	10	15	20	25	30	40	50	60	70	80	90	100
Upper y	0	3.0	4.6	5.75	6.7	7.7	8.3	8.6	8.7	8.4	7.8	6.6	5.3	3.7	2.0	0.3
Lower y	0	−0.5	−0.4	−0.2	0	0.7	1.2	1.4	1.6	1.8	1.8	1.5	1.2	0.6	0.1	0

The Sigurd Isaacson sections are similar to the Benedek; the numbering system is reversed, so that 73508 has 7% camber at 35% chord, and 8% t/c. The sharp L.E. is particularly intended to suit small slow models, and can easily be rounded off if this suits your application. The use of turbulator strips is common, and might repay careful experiment; enough thickness and no more is the key, otherwise you create more drag.

APPENDIX I

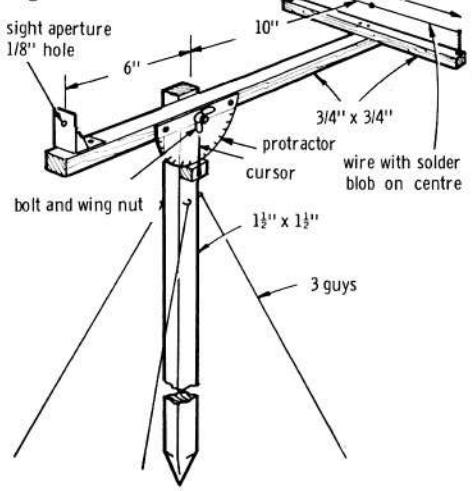
HOW HIGH IS IT?

IN those idyllic days when there is plenty of lift about, and our models suddenly seem very much smaller, as we lie on our backs and watch them circle overhead, we've all found ourselves wondering just exactly how high they really are. Some of the guesses to be heard from fellow modellers, as to the heights of *their* craft are obviously very wild indeed, but the estimates we make about our own are likely to be on the conservative side. Of course.

Why not, then, devise a proper means for computing a model's actual height with a fair degree of accuracy? John Beer has done just this, originally with a view to instituting height-gain competitions and, although the idea has not so far been taken up by any contest organisers, the system in itself was felt to be well worth recording here, even if to be used by groups of individuals for their own enjoyment, rather than for organised contests.

The basis of the system is a pair of sighting devices, as shown in Fig. 168. These should

Fig. 168



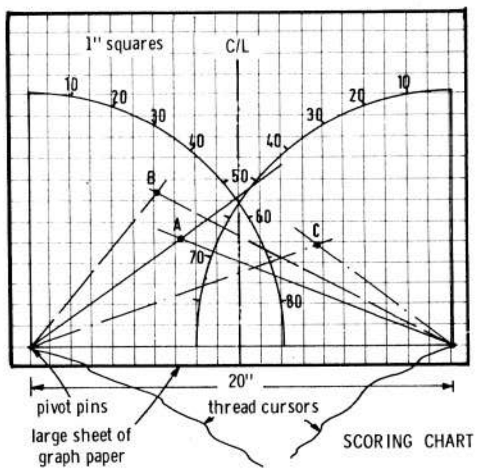


Fig. 170

be easy enough to make from wood, for anyone who builds models. And sighting up the models with these gadgets and reading off the angles to the horizontal is easy enough, too. The working out of the height, from the readings, however, is rather more tricky, and time-consuming, so the following scheme was devised.

Let us say (assuming we're using it for a competition) that the competitor is given two minutes in which to get his model as high as he is able, finding lift wherever he chooses. Within another period of time he must pass behind the sighting line and head up across the line, after calling his attempt. (See Fig. 169.) The sighters could transmit their readings either verbally, by blackboard and chalk, or by field telephone—according to how sophisticated the club's facilities. The two readings would then be transferred on to the scoring chart (Fig. 170), using the cursors from each corner to the appropriate quadrant

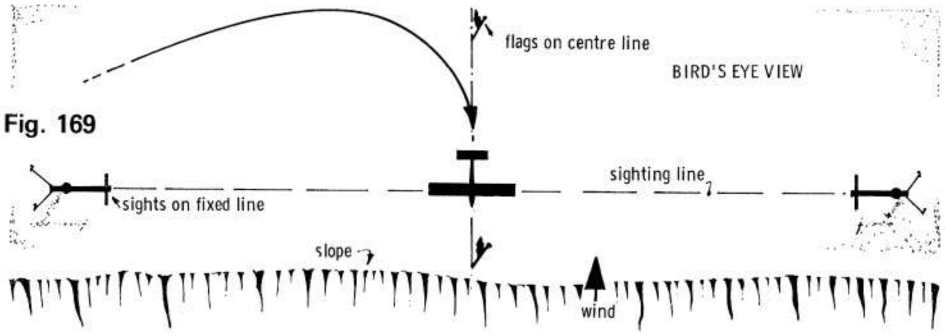
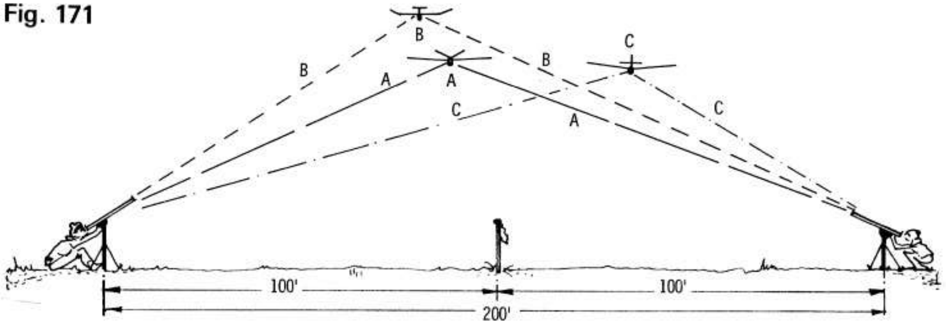


Fig. 169

marked on the chart. The intersection of the cursors could then be pinpointed, marked with the competitor's number or tabulated on a separate sheet.

It will be noted that it is suggested that the sights be placed 200ft. apart. This would give a direct reading of the height in feet. (Fig. 171). A further "task" could be incorporated into the flight, if it were desired to make it more interesting, inasmuch as points could be deducted for the amount by which the model was off the centre-line position.

Fig. 171



More mobile . . .

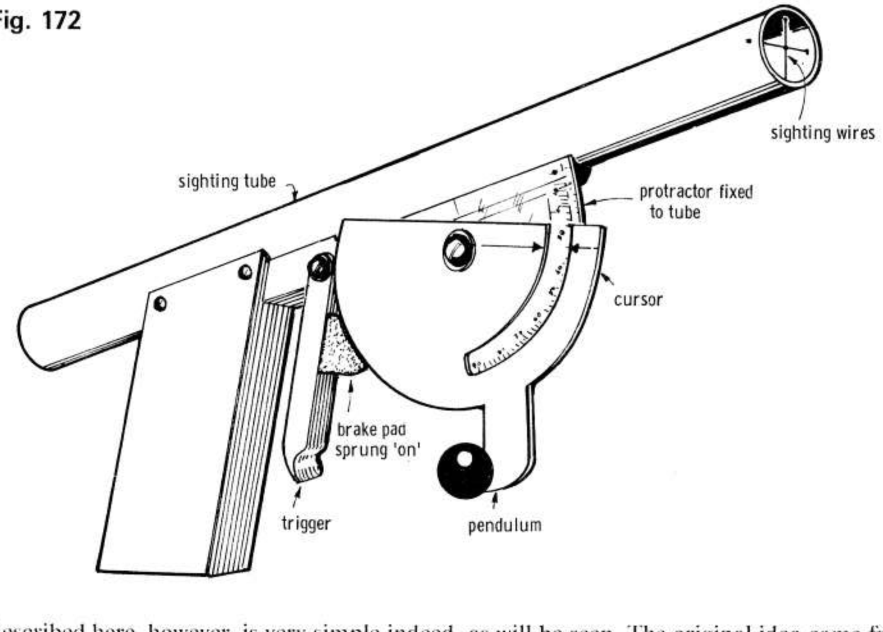
A refinement of the foregoing system involves the fabrication of a pair of portable sighting "guns". (Fig. 172). These take the place of the ground-based devices and avoid the need for the sighting men to lug around poles, tent-pegs and mallet. The guns are perhaps more tricky to make than the wooden sighting devices previously illustrated, but should be within the capabilities of those with a little metalworking ability. They incorporate small celluloid protractors, over which a metal cursor swings. This cursor has a pendulum to keep it vertical and is free to swing while the trigger is held in against its spring.

On sighting the model in the crosswires, the spring-loaded trigger is released and locks the cursor in position, when the angle may be read off the protractor. The two marshals or "sighters" would release their triggers at the sound of a whistle blown by the contest director or—if this is being done by a group merely for their own interest—by whoever is appointed to do the job.

Or airborne—an altimeter.

An entirely different way to find a model's height, of course, is by fitting a recording altimeter. Mention of this will conjure up thoughts of aneroid barometer type devices, tricky to make, to say the least, if not quite beyond the bounds of the less experienced. The device

Fig. 172



described here, however, is very simple indeed, as will be seen. The original idea came from Norman Armstrong and was published in *Radio Modeller* several years ago.

While it is not intended that it should be looked upon as a highly accurate instrument, nevertheless it gives a very good indication of the maximum height achieved by the model to which it is fitted.

The basic principle is this: to an air container is attached a length of transparent pipe, which has been filled with a certain amount of water from its outlet end. As the altimeter is carried upwards, the air in the container expands and drives the water out of the outlet end of the pipe, to waste. As the altimeter comes down again, air in the container is compressed and sucks the water back along the pipe. Now, however, there is a length of water missing from the outlet end and this missing length is a measure of the expansion of the air when the altimeter was at its highest point. The ticklish part is in determining just what height this missing length of water actually represents. (See Fig. 173.)

Calibration

To find out, we hark back to our distant school days and dimly remember something about Boyle's Law and Charles's Law and the expansion of gases. We couldn't care less

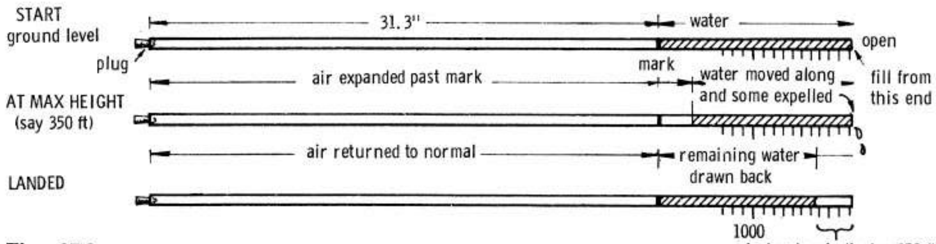


Fig. 173

then—because we hadn't got an application for them, but now we have. Further probing into the cerebral cobwebs reveals the equation:

$$\frac{P1 \times V1}{T1} = \frac{P2 \quad V2}{T2}$$

where P is pressure, V is volume and T is temperature in degrees absolute (Centigrade plus 273).

We can assume P1 (at sea level) to be 14·69lb./sq.in. (we can still use the device from any hilltop we like), and we can assume the temperature, T1, to be 15°C + 273 = 288 Abs. V1 we don't know yet. We want P2, V2 and T2 for greater heights.

If a graph is made of atmospheric pressure against height, the result will be a curve. However, the atmosphere goes up a long way and, if only the bottom 5,000ft. is taken, the curve is so near to a straight line that we can take it to be one and make our height scale linear. So, in the second half of the equation, we will put in the figures for 5,000ft. Thus: P2 = 12·23lb./sq.ft., T2 is ten degrees colder at 278° Abs., and V2 = ?

$$\text{So, } \frac{14.69 \times V1}{288} = \frac{12.23 \times V2}{278}$$

$$\text{Therefore, } 0.051 \times V1 = 0.044$$

$$\times V2 \text{ and the ratio } \frac{V2}{V1} = \frac{0.051}{0.044}$$

$$—1.16 \text{ (by slide rule)}$$

So Volume 1 at sea level becomes 1·16 times bigger when raised to 5,000ft. Owing to the "straightness" of the curve mentioned, V1 at 2,000ft. becomes (nearly) 1·16 times bigger when raised through 5,000ft. to 7,000ft.

For practical purposes, we can cut out the separate air container and use a length of small bore fuel tube instead. (This is the total cost of the device!) The inside volume of 2in. of this is—obviously—twice the volme of 1in., so the comparison of volumes now becomes much easier, in that it is now simply a comparison of lengths.

How long should the tube be made? Let us assume, for the moment, that we should like 1 inch on the scale to read 1,000ft., and, of course, 5in. 5,000ft. Then:—

(1·16 length minus 1 length) = 5in.

so 0·16 length = 5in.

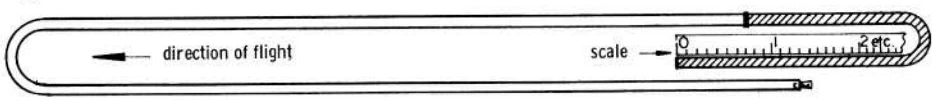
dividing by 16 $0{\cdot}01 \text{ length} = \frac{5\text{in.}}{16}$

Multiplying by 100

$$1 \text{ length} = \frac{500\text{in.}}{16}$$

$$= 31{\cdot}3\text{in.}$$

Fig. 174



This means that the air column part of the tube must be 31·3in. long and an extra length, say, at least 6in. should be added for water. One end of the tube is plugged, but the plug must be removable. If you can drive all the water out of that tube, you've beaten the world record, easily!

Mounting on the model

The length of tube may be mounted inside the fuselage or taped on to the outside, but the plug and water scale must be accessible. If the tube is kept straight, a hard launch or a sudden stop on landing may cause it to show a false height of 1,000ft. or more. The best way to mount the device has been found to be as in Fig. 174 so that sudden starts and stops have little effect on the water. Don't make the bends sharp enough to restrict the bore of the tube. Use the thinnest fuel tube you can get and make the plug really airtight. I use the tip off the shank of a fine painting brush.

The scale may be marked beside the tube, $\frac{1}{10}$ in. = 100ft. The point 31.3in. along from the plug should be well marked with a piece of sticky tape. For pouring water into the tube, a plastic bottle fitted with a suitable nozzle, is convenient. Colour the water with ink or dye for easy reading.

Using the altimeter

Remove the plug and fill from the other end until the water exactly reaches the 31·3in. mark; insert the plug tightly and check that the water is still at the mark. Now fly the model and, when you have brought it down again, measure the length of the water lost. Each tenth of an inch represents 100ft. The inside end of the water should be back on the 31·3in. mark. If it isn't, the plug is evidently leaking and the reading will be false.

If one wants to check the calibration, by taking the altimeter up and down hills in a car, it should be remembered that cars are heated, even when the heater is not in use, and the altimeter will over-read because of lack of temperature variation. Air temperature normally falls about 2°C per thousand feet.

There seems no reason why it would not be possible to arrange competitions for altitude, using commonly calibrated altimeters of this type. It would then be quite feasible to have six models airborne together for, say, a quarter of an hour, each with one fitted, and combined with a spot-time for landing. The models would obviously have to be launched at short intervals, rather than simultaneously, so as to avoid chaos when the time was up!

Even if the idea is not taken up for contests, however, the use of an altimeter on your model can be quite fascinating, and you will eventually become able to judge quite well, by eye, just how high your model really is, instead of hearing all the wild guessing that starts when the models get into really good lift.

THE BEAUFORT WIND SCALE

This is a standard scale for wind speed (expressed in terms of Beaufort Number), based on observed phenomena. The original scale is rendered in terms of the appearance of the sea; but the equivalent land observation is added in the following table, and wind speeds are given in miles per hour rather than knots.

Beaufort Number	Wind Speed m.p.h.	Wind Description	Observation, Sea	Observation, Land
0	Less than 1	CALM	Mirror flat.	Smoke rises vertically.
1	1—3·5	LIGHT AIR	Ripples on water.	Wind direction indicated by smoke drift, but wind is not strong enough to give proper indication by weathercocks.
2	4—7	LIGHT BREEZE	Small wavelets, crests have glassy appearance and do not break.	Wind strong enough to be felt on the face; leaves on trees begin to rustle; flags partially extended.
3	8—11	GENTLE BREEZE	Large wavelets with crests beginning to break: some scattered white horses.	A light flag will be fully extended; leaves and twigs on trees in constant motion.
4	12—18	MODERATE BREEZE	Small waves with frequent white horses.	Small branches waving on trees; dust and paper, etc., on ground lifted by the wind.
5	20—24	FRESH BREEZE	Moderate waves or more pronounced form: many white horses.	Small trees begin to sway.
6	25—30	STRONG BREEZE	Large waves begin to form, foam crests more extensive everywhere and probably some spray.	Larger branches on trees in continual movement; telephone wires hum.
7	32—38	NEAR GALE	Sea heaps up and white foam from breaking waves begins to be blown along in streaks with the wind.	Whole trees in motion; considerable resistance felt in walking against the wind.
8	39—45	GALE	Moderately high waves of greater length, with edges breaking up into spindrift. Foam blown in well-marked streaks.	Twigs and small branches broken off trees.
9	46—55	STRONG GALE	High waves with dense streaks of foam and flying spray.	Slates or tiles may be lifted off roofs; other minor structural damage likely.
10	55—65	STORM	Very high waves with long overhanging crests; large patches of foam with the whole sea taking on a white appearance.	Whole trees may be uprooted and houses damaged.
11	65—75	VIOLENT STORM	Exceptionally high waves, sea completely covered with foam.	Damage to trees and houses.
12	Over 75	HURRICANE	Sea completely white with driving spray; air filled with foam and spray.	Extensive damage to trees and buildings.

APPENDIX II

HOW FAST IS IT?
By GEORGE BUSHELL

OVER a number of years I frequently used to hear fellow modellers complaining that the wind was "too strong" but, when I took up slope soaring, the complaint was far more often that it was "too light." I decided that here was a subject on which, if more and positive information could be obtained, might be of invaluable assistance when applied to the design of future soarers.

Basically, the object of my analysis was to determine the percentage windspeed and direction for the months of the year, as applied to my own regular flying sites—Ivinghoe Beacon and the local playing fields. Ivinghoe is best used in west winds, and quite soarable in all but east winds. The local playing fields (for bungee launch, of course) are flyable in all wind directions, but producing best thermal conditions with a little east in the wind.

After close analysis during the winter, I built my new soarers and then attempted, by personal observation and weather forecasts, to assess how many *Sundays* were actually flyable using these models, either as slope or thermal soarers, whether or not I was prepared to venture out. The number of flyable days proved quite remarkable, and those Sundays of heavy rain or threat of rain could be "written off" as negligible. By flyable days I should say "comfortable"—if you take my meaning.

Where does one get the information upon which to make the analysis? There is a book, published by H.M. Stationery Office—ref. Met.0.792—which is the answer. It is called *Table of Surface Windspeeds and Direction over the United Kingdom.* The information used to compile these tables comes from weather stations throughout the U.K. and almost anywhere in the country would be in the same "weather pocket" as one of these stations. Similar tables exist for most other civilised countries, and it was on this basis that I was able accurately to predict that the world record for model glider duration flight would be broken at Sylt, N. Germany, about six months prior to its actually taking place.

The only serious drawback with these tables is that they do not provide information relating to daylight hours only. It is as well to bear in mind the following "rules," therefore, for interpreting them. On coastal sites the winds *tend* to be more on-shore during the day and off-shore towards evening. And, on inland sites, the wind reaches its maximum speed "just after lunch."

From the tables for Dunstable (p. 124-128) given in the book, we can extract the following useful information.

1. Windspeeds in all directions from 8-18 m.p.h. expressed as a percentage:

January	52·5	July	43·3
February	51·2	August	40·5
March	51·9	September	47·2
April	52.5	October	38.7
May	46·4	November	45.4
June	38.5	December	50·6

2. Windspeeds in all directions 18 m.p.h. and over, expressed as a percentage:

January	8·6	July	1·7
February	3·8	August	1·4
March	4·3	September	1·3
April	2·4	October	2·9
May	1.8	November	3·1
June	0.5	December	8·7

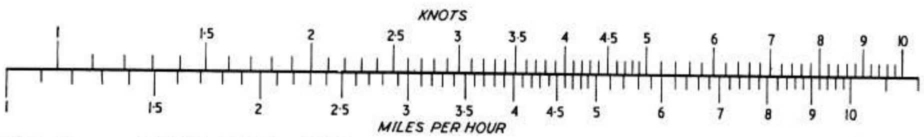
3. Wind direction 020°—160° (the poorest direction for Ivinghoe) expressed as a percentage:

January	17·80	July	23·20
February	25·90	August	20·20
March	40·00	September	29·90
April	31·00	October	18·40
May	33·20	November	23·30
June	20·00	December	19·60

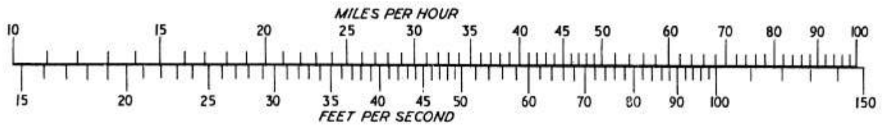
A study of the above figures shows a number of surprising aspects, and will make many modellers revise their ideas of just how many unflyable days there are in the year. Similar figures can be extracted for virtually any site in the United Kingdom, and a study of the book is to be thoroughly recommended. It may be purchased from H.M. Stationery Office, through any bookseller, or may, of course, be studied in your local reference library.

Speed Conversion Scales

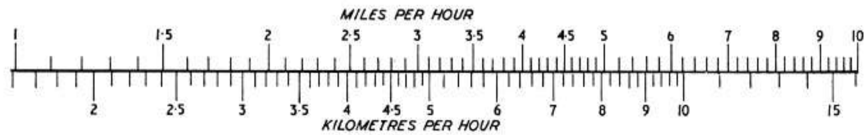
KNOTS to M.P.H.



M.P.H. to FEET PER SEC.



M.P.H. to KILOMETRES PER HOUR



K.P.H. to METRES PER SECOND

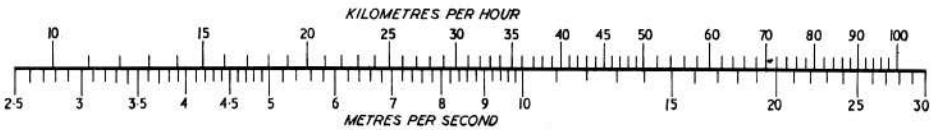
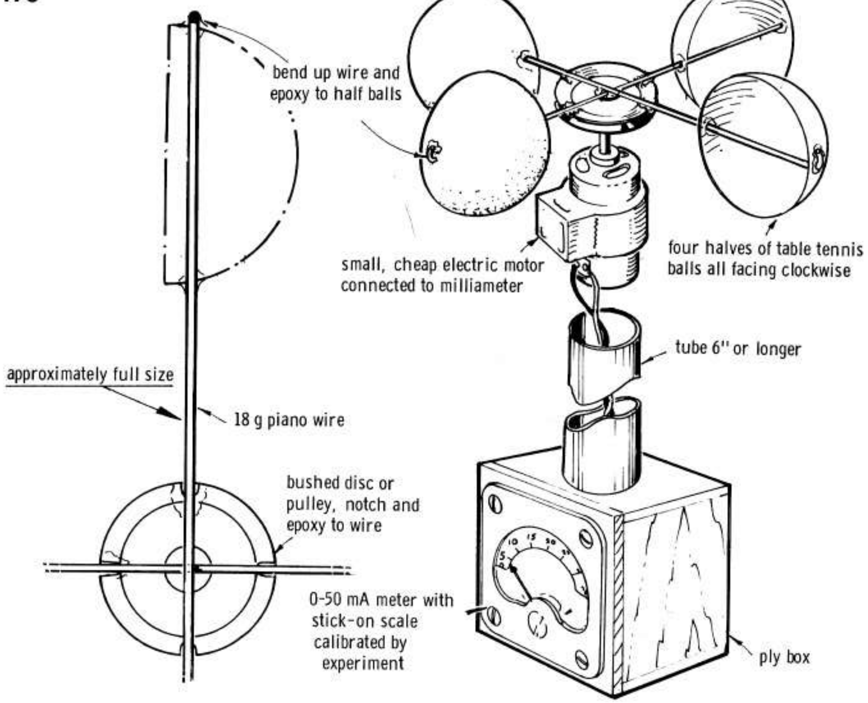


Fig. 175



A HOME-MADE ANEMOMETER

For those who live some distance from their hill-soaring slope, and need to keep a weather-eye on the wind speed, an anemometer will be a boon. Our sketch, Fig. 175, shows how one of these instruments may be easily constructed, using a small electric motor and a milliameter. This type of wind-speed meter is usually fixed to a workshop or shed roof, with the meter itself inside. Not only slope soaring enthusiasts, but also thermal soarers will find it useful to keep a check on wind velocities, and modellers may find it of interest to log weekend wind speeds for themselves, throughout the flying season.

For measuring actual wind speeds when on slope or field, the hand held pocket wind meter is invaluable, and two kinds of these are shown, photographically, elsewhere in this book.

APPENDIX III

CLOTHING AND EQUIPMENT FOR SLOPE SOARERS

WHILE one of the many happy aspects of slope soaring is that one can, in fine weather, wear "civilised" clothes instead of the oil-soaked jeans and sweater favoured by the power flier, one must bear in mind the changeable nature of the climate in these isles. It is essential to have at hand some outer garments for protection against the vagaries of the elements. The slope soaring enthusiast very soon finds that he acquires a special kit for his visits to the hills, and will always take it with him—no matter what the met. men say! To be caught in a thunderstorm, or even a summer squall, at the top of a hill, perhaps a mile or so from one's car, without some form of protection, is not an enviable experience, so don't let it happen to you.

A good set of oilskins, or PVC mack and overtrousers, are a sound investment. Also, even on the hottest day, one cools down very rapidly standing on a hill in a fresh breeze, so you will be glad of an anorak. A popular alternative to this is the lightweight waterproof, fluorescent coloured garment used by sailing enthusiasts. As well as these over-garments, a good thick fisherman's type of pullover with a polo neck is a good thing to have, in addition to whatever woollies you normally wear.

If your "thatch" is getting thin, you will be glad of some warm headgear—perhaps a woollen bobble-hat, but just a word of caution here. If you wear a bobble-hat, either wear the right colour for your radio frequency, or else something like a Paisley or stripe, that could not possibly be mistaken for one of the frequency colours. To wear, say, a red bobble-hat when flying on "blue" could result in your own and someone else's model being "shot down" because others thought you were on "red."

The same applies if you elect to wear one of those lightweight peaked caps, for those hot, almost windless days that always seem to happen when there is a contest! For cooler weather, a Balaclava or a trapper's type of hat, with ear flaps and under-chin fastening, can be very comforting. Have some gloves, or mittens, to be worn between flights if you are one of those who cannot abide wearing gloves of any sort while flying. A sheet of stout polythene, such as may be bought at cycle shops or camping outfitters, will come in very useful for a groundsheet—and may also be used for covering up a model, or several models, should it come on to rain. We have also seen these used as a sort of "personal tent" by mackless soarers who preferred to cocoon themselves to keep dry, and leave their models to the elements.

One usually has plenty of time to unpack the protective clothing and the ground sheet, since, as one is on a hill and looking into the wind, the rain or "precipitation" will often be visible when it is several miles distant. With practice (and you will get this, if slope soaring has really hooked you!) you will find that you will eventually be able to gauge fairly accurately just how many minutes the rain will take to arrive.

If a "personal tent" of polythene, why not a tent proper? This would seem to follow on, but, on many sites—particularly those belonging to the National Trust—the setting up of tents, or even windbreaks, is forbidden by the byelaws. It is as well to ascertain what is permitted, in this respect, before you consider buying one, therefore.

All the other items, plus your thermos flask and sandwiches, will have to be transported up the hill, so a good quality rucksack is a must (unless you have a well-trained wife!!)—and leaves the hands free for model and transmitter. Better still, hang the transmitter on a neck strap and have one hand free in case you should stumble, or need to support the model with both hands in a sudden gust of wind.

Finally, a good stout pair of hiking boots is generally preferable to wellingtons, even in wet weather, especially if there is much walking or climbing to do, from car to launching site. The soles of ordinary shoes will very soon become polished and slippery on the grassy or heather-covered hillside, especially in dry weather, so boots are best whatever the conditions. Don't drive in the boots but change into them, with an extra pair of socks, before you leave your car. In the same way, don't trudge up the hill in your full kit; keep it in the rucksack and don it when you reach the top, as and when you feel the need of it.

If you are one of those lucky ones who has found the kind of site where you can drive right up to the launch point, to "lob off" almost from the car, then you may choose, at first, to disregard all this advice on clothing, and take refuge in the car from the rain, or just to warm up. However, one of the most enjoyable aspects of slope soaring is visiting new and different sites around the country and, if you are going to experience this, then you would do well to be prepared in the way that has been described.

APPENDIX IV

AN AUTOMATIC ELECTRIC WINCH

ALTHOUGH the vast majority of modellers who go thermal soaring do so competitively, there are also those who like to fly this type of model sheerly for its own sake, at their local fields or parks. Some of them do so, probably, because they have no slopes within reasonable distance—others just because they prefer this more relaxed type of glider flying.

Methods of launching the models vary, from the hand-towing and bungee launches described in Section Two, to the use of electric powered, or even petrol-driven, winches. In addition, interest is increasing in the "aerobatics from a flat field" type of contest, for which an electric winch is a definite pre-requisite.

The winch described here was originally published in *Radio Modeller*, and was designed by J. Robertson and I. Barr. The original idea was to produce a launching system capable of launching any model in nil-wind conditions. This was because, being primarily slope soaring enthusiasts, they would go to the hills if there was any wind at all. An electric powered winch was chosen for its ease of control and simplicity of construction, the basis being an ordinary 12v. car starter motor. The original winch was simply a drum coupled to the shaft of the motor, whose speed was regulated by pulsing the current fed to it, by means of a micro-switch. This proved acceptable, but the speed and height of the launch depended too much upon the skill of the operator.

Further thought was put into the design and the system, as it now stands, was conceived. A "jockey wheel" measures the tension of the line and, by means of a reed switch, a transistor switch and the starter motor solenoid, *the motor is pulsed on and off automatically*. Thus, all the operator has to do to give a perfect launch, is to keep the master switch depressed. If it is considered desirable, the line may be run through a pulley, attached to a stake in the ground, so that the winch is at the release point—far better than relying on tiresome and usually ambiguous hand signals—and provision is made for remote operation of the master-switch, making possible even solo operation. Further, a brake drum driven by a bicycle freewheel unit, provides restraint, should the model "kite" up in a gust.

Construction

Construction of the winch is relatively simple, except that access to a lathe is necessary in order to install the bicycle freewheel unit in the metal drum. Very few of the dimensions are critical, but the important points are (1) the inner diameter of the drum which must be as shown, to produce the correct torque, and (2) the strength of the two springs, which have to be found by trial and error, as they are dependent on the leverage of the system.

Operation

Operation of this winch is very simple, and the sequence is as follows. The desired speed is selected on the toothed quadrant; the glider is attached to the line; the master switch is depressed, the glider launched and the master switch released when the model is at the "top" of the launch. The foregoing sequence causes the winch to go through the following

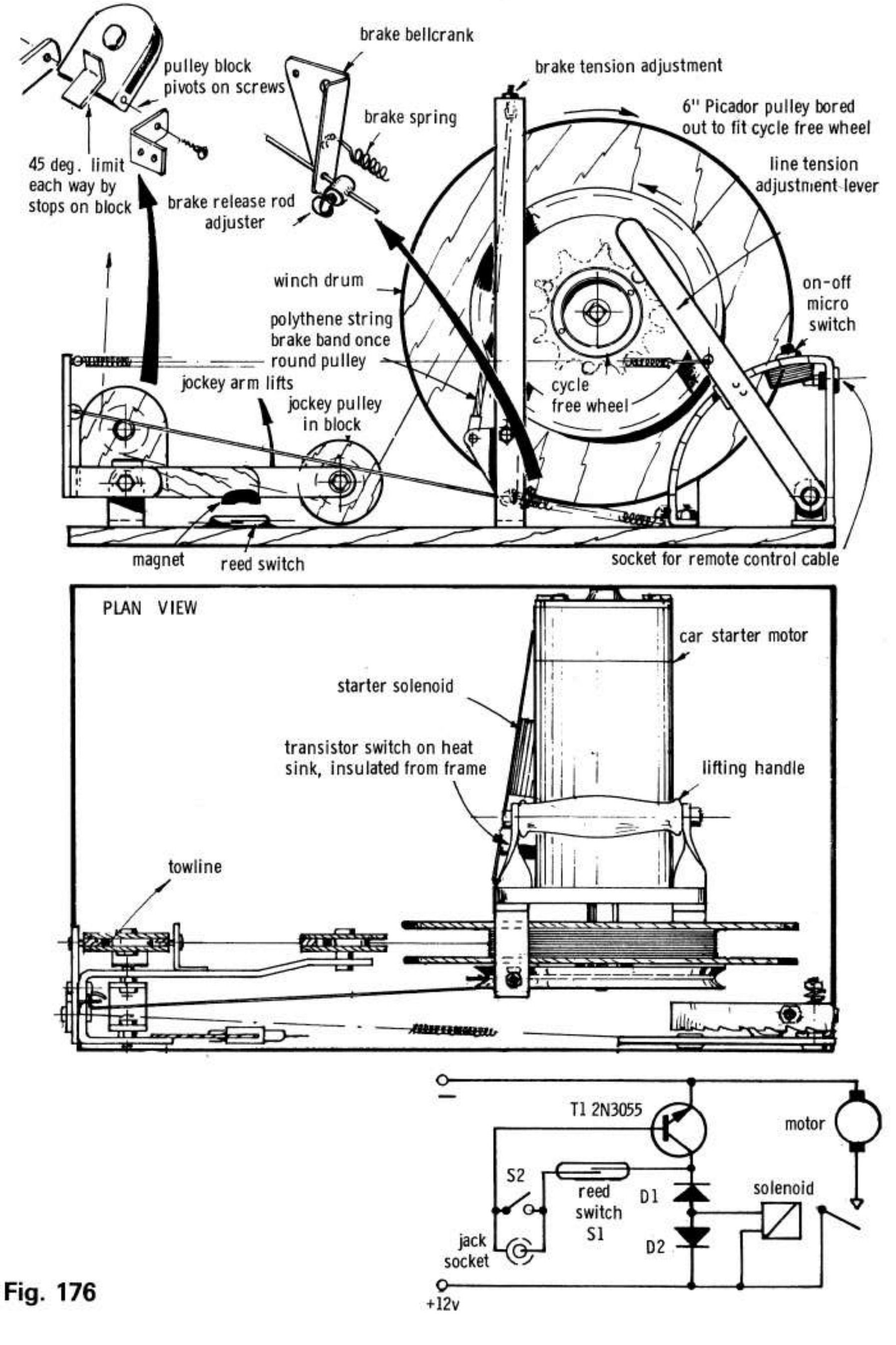
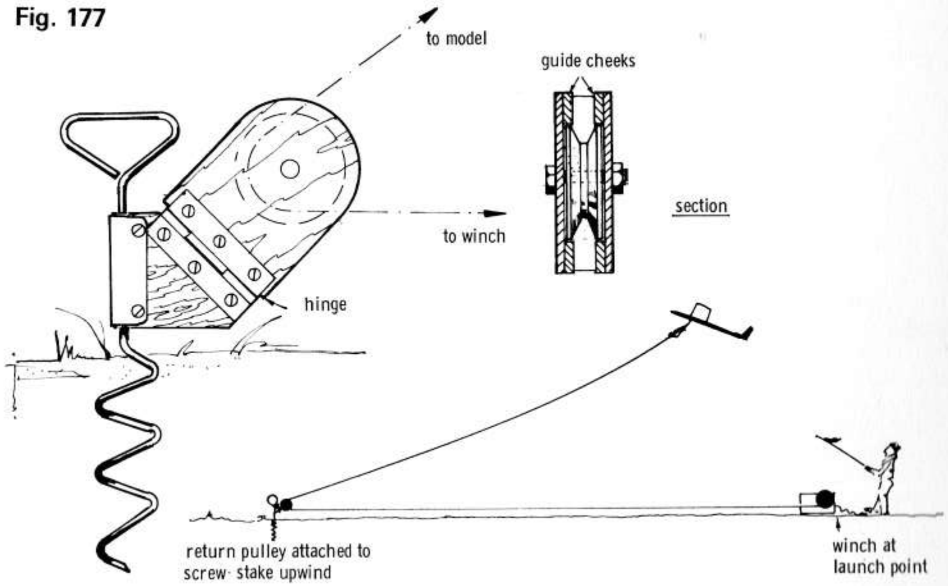


Fig. 176

Fig. 177



actions: the position of the lever on the quadrant sets the line tension (launch speed) that the winch will maintain. Depression of the master switch causes the line to be reeled in until the set tension is reached. The winch will then switch itself off until the model is launched. Initially, the man releasing the model runs forward until the line tension is lowered sufficiently for the motor to start. It will then maintain the correct tension all the way up the tow, by automatically pulsing the motor on and off.

The winch will keep the tension correct, even in strong winds as, in these conditions, it will—again automatically—*pay-out* the line, thus kiting the model. At the top of the launch, the master switch should be released, thus cutting off the power to the winch and releasing the model. If the model does not free itself, the control lever may be set to a lower position.

To pull out the line to the launch point, the quadrant lever is first set at the lowest tension. The initial launch should be made with the lever set at the "average speed" position, and subsequent launches made at faster or slower speeds as is felt desirable for the particular model. Reeling in the line after the last launch calls for some caution, as it comes in surprisingly fast. Power should be switched off when the end of the line (visible by its parachute) is still some 20 yards distant. The parachute used should be similar to that used with the bungee method of launching, described in Chapter 16 (Fig. 123) and may be either home-made or of the commercially available type. A home-made parachute can be quite a simple affair, cut from a square of silk or nylon, about 16in. on a side, with a line at each corner, and bound at the centre, round a "pinch" of the material. There is no need to make an elaborate round 'chute, with its numerous triangular-shaped panels, though this is more elegant, of course.

GOLDEN RULES FOR SLOPE BEGINNERS
by Chris Pullen

(1) Visit a known site and enquire about suitable models for training. (Although many model shops can give good advice, relatively few of them know much about soaring.)

(2) Having built the model (and acquired your r/c licence), ask someone who is obviously a good flier (not the showoff, but a good, consistent flier and lander!) to trim the model out for you. Never attempt to fly it on your own to start with. This could be a risk both to the model (and the radio you've just paid out for)—*and* to bystanders and other fliers.

(3) If the flier who checks out your model is agreeable, get him to teach you the basics of controlling the model and landing—or to recommend someone who will. (It can take quite a lot of a pilot's time up to get a newcomer to the "safe to solo" stage, but there are those who enjoy doing it, reckoning they are putting back into r/c modelling a little of what they've got out of it, over the years.)

Do's and Don'ts

Do check the procedure used at the site concerning frequency control (pegboard, etc?)

Do ascertain the local conditions—*e.g.* turbulent areas to avoid, safe approach areas and any particular hazards of the site.

Do ask for help if you are not sure of your capabilities.

Do always have a high regard for other people and their property (not only modellers and models, but farmers, land-owners and so on, and their walls, gates, fences—and animals).

Don't risk it if you're not *sure.*

Don't switch on your radio before you are ready to fly (*e.g.*—don't check it in the car park!)

Don't "hog" the frequency (*i.e.*, make your flight of reasonable length, if there are others waiting for your "colour").

Don't fly your model over people, unless unavoidable (such as to avoid some sudden hazard).

Don't land your model close to other models, or people. Choose your intended spot well beforehand, and keep a lookout for changes in people's positions, or other models landing, while you're lining up.

Most of the problems arising at well-frequented sites are caused by, (a) people attempting to fly models for the first time and without sufficient knowledge, (b) people not prepared to take advice from experienced fliers, (c) people flying their models too low, and colliding with other models or—worse—people and (d) attempting to land their models alongside parked models, and ending up ploughing into them.

APPENDIX V

READING THE WEATHER

by GEOFF MEAKIN

FURTHER OUTLOOK

WEATHER-WISE, the further outlook may often be determined locally, with some degree of accuracy, by the intelligent use of a moist forefinger held high above the head combined with a keen pair of eyes and a fundamental knowledge of cloud formations.

At first sight, the wide range of strange sounding Latin names used by the meteorologists appears confusing and not immediately meaningful. Put more simply, however, a study of the clouds can prove fascinating when it is realised that all cloud formation is water vapour, which is always present in the atmosphere, condensed into tiny floating globules of liquid water, or crystals of snow or ice, depending on height and therefore temperature.

There are two main types of cloud formation—the *cumulus* or heaped clouds, and the *stratus* or stretched or layered group. *Cumulus* are short termed, developing rapidly, changing shape, sometimes perceptibly and, except in summer, thundery weather producing only heavy showers. *Stratus* clouds are often associated with warm fronts, with streaks of higher cloud banking up into denser formations and later bringing drizzle and sometimes more continuous rain. In the winter they also form in warm moist air, turning into heavy grey sheet type cloud and again bringing drizzle or heavier rain.

There are ten main classifications of cloud formations but, before considering them individually, it will be as well to study some of the more common Latin terms used to describe different combinations of cloud names. . . .

* * *

Cumulus. This means a mound or heap of cloud appearing as cotton-wool like, heavily massed groups resembling small mountains slowly changing shape (Fig. 178).

Fig. 178

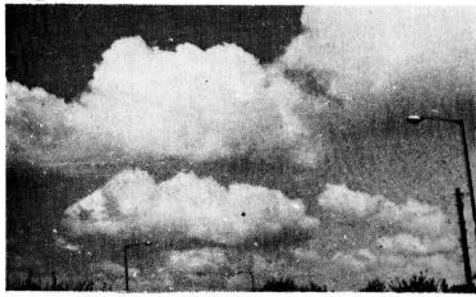


Fig. 179

Stratus means stretched or layered cloud (Figs. 179, 180 and 181).

Cirrus means curled and light and airy—and these clouds are therefore often found

Fig. 180

Fig. 182

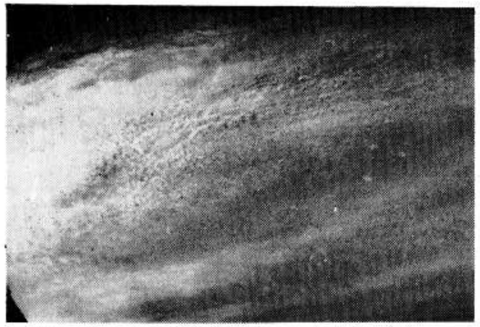


Fig. 181

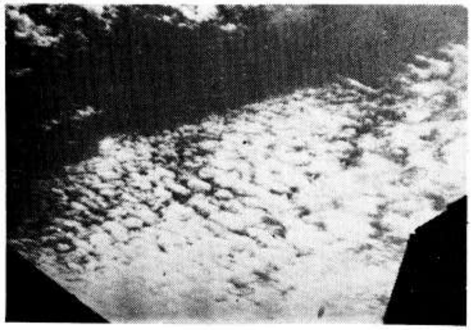


Fig. 183

at the greatest heights—about 30,000ft. above sea level.

Alto stands for "height" which, in the cloud sense, can range from anything below *Cirrus* down to about 5,000ft.

Nimbus means "rain-maker" and generally appears at heights of from 2,000ft. down to 500ft. or perhaps lower, when viewed from the lofty perch of some slope soaring site.

Starting, therefore, at the highest altitude and descending gradually to ground level, let us now look at the ten major classifications of cloud formation. . . .

1. **Cirrus.** Very high. Detached, delicate and fibrous formation, white in colour with no shadow. (Fig. 182).

2. **Cirro-cumulus.** Very high. Small, round, white and flakey. Seen in groups or lines—or ripples rather like sand formations on a beach. (Fig. 183).

3. **Cirro-stratus.** High. Thin and veil-like, with a whitish milky wash effect. (Fig. 180).

Next come the *Alto* group, below the *Cirrus* group. . . .

Fig. 184

4. **Alto-cumulus.** Rounded or rolled masses, fairly large, in groups or lines, or rows following one another in one or two clear directions. (Fig. 184).

5. **Alto-stratus.** Greyish white or grey veil with sun showing behind, dimly outlined as if seen through ground glass. (Fig. 181).

Then follow the *Stratus* group, below the *Altos*. . . .

6. **Strato-cumulus.** Large, lumpy, irregular masses forming large grey undulating cloud banks. (Fig. 179).

7. **Stratus.** Uniform layer of fog-like cover but well above ground level. (Figs. 179 and 180).

8. **Nimbo-stratus.** The rain-maker. Lower layer of structureless rain bearing cloud, heavy and sultry grey towards black, with a threatening appearance. (Fig. 185).

And then, finally, the *Cumulus* group. These may vary considerably in both height and size. . . .

9. **Cumulus.** Thick, dense and dome-shaped, with turrets rising rapidly. Form changes, sometimes quite perceptibly. Short term, bringing heavy showers. Base of cloud often flat and horizontal—like lumps of cotton-wool pressed onto a sheet of glass. (Fig. 186).

10. **Cumulo-nimbus.** Great masses of mountainous tower shaped cloud, often with "anvil shaped" tops and dark black centres and bases. Sometimes the centres of electrical storms, bringing heavy rains and thunderstorms. (Fig. 187).

Fig. 185

Fig. 186

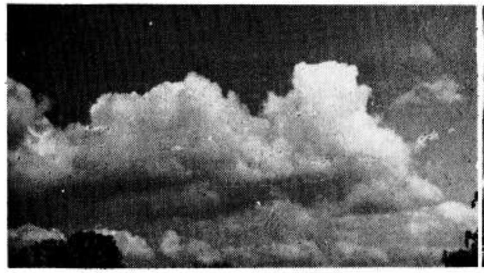


Fig. 187

Fig. 188

Soaring pilots are shrewd judges of the speed and direction of the wind and, from the advantageous heights of the slopes, it is often possible to see approaching and departing weather for several miles around.

Perhaps those who don't already know may, after a study of the foregoing basic information, with its accompanying illustrations, be able to assess the "further outlook" more accurately, and decide either to keep their models aloft or to bring them down before the storm breaks! Normal rain fronts travel, on average, at about 25 mph, and storm fronts sometimes considerably faster, so give yourself time not only to land satisfactorily, but also to get packed up and safely under cover of the car or whatever shelter may be available.

* * *

A CLOSER LOOK AT THERMALS

A CAREFULLY blown smoke-ring, fumes and heat released by a garden bonfire or the dense billowing smoke and searing heat generated by a burning building; all these produce artificial thermals. They differ, however, from natural thermals in that they carry upwards with them tiny, but collectively visible, particles whereby some of their form and movement may be seen, whereas, at source, natural thermals are almost completely invisible. Nevertheless, both types of thermal carry water vapour in varying degrees and this only becomes visible when it condenses out in upper and cooler surroundings.

Air bubbles

Most natural thermals are invisible at source because they are generated by radiant heat from the sun striking local areas of the earth's surface which accumulate the heat received. These "hot-spots", in turn, raise the temperature of the air immediately above them until a type of invisible hot-air-bubble is formed, which may either take off in still air on its own accord, or is assisted by gentle air currents at ground level in finally breaking free.

Depending on the nature of the ground being heated, the strength of the sun's rays and the speed of any wind at ground or the upper levels then, one of two phenomena may occur: either an intermittent series of hot-air-bubbles will be formed which will take off at more or less regular intervals *or*, a fairly continuous stream of air-bubbles will be generated, forming into a kind of processional column rising at a steady speed.

In relatively still air the intermittent series of bubbles will rise almost vertically, as will the processional column but, in light breezes which may be travelling at differing speeds in ascending heights, then both the intermittent bubbles and the continuous stream will rise either in a diagonal line from ground source or in the form of a gentle parabola to something like 500ft. above ground level. (See Figs 189 and 190). At this height, the surrounding air will be less dense and considerably cooler than at ground, and the stream of ascending hot-air-bubbles will start to condense out their contained water-vapour which will show itself, at first in the form of a wispy white mist and then later as the more clearly defined embryo form of the *cumulus* cloud.

In near still air, the intermittent stream may gradually accumulate themselves into one largish cumulus cloud, increasing gradually in both size and buoyancy. Similarly, the more or less continuous stream of bubbles may more quickly form into a cumulus cloud of considerable size and strength.

Alternatively, if the air at the 500ft. altitude is moving directionally faster than the air below it, then the intermittent stream of bubbles will form a horizontal procession of small

Fig. 189

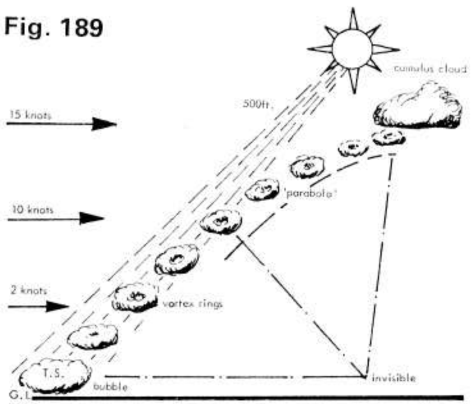
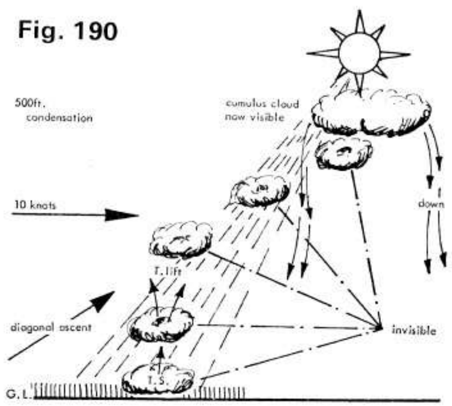


Fig. 190



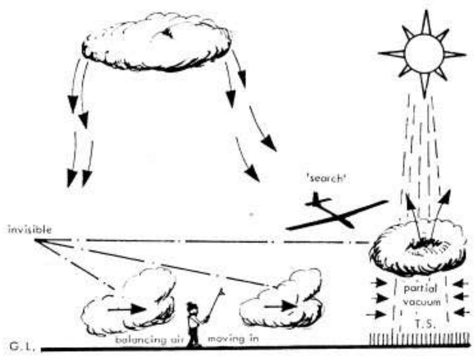


Fig. 191

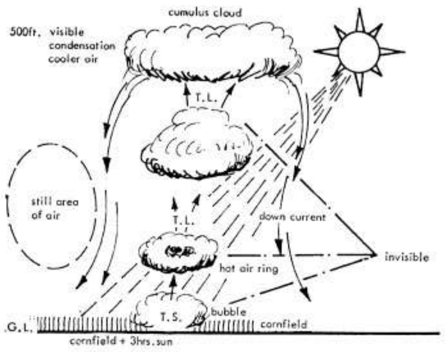


Fig. 192

cumulus clouds travelling at wind speed in what is sometimes known as a "cloud street". Under similar conditions the continuous upward thermal column will tend to generate a series of somewhat larger cumulus clouds, bunched more closely and travelling also in a "cloud street" downwind of the ground thermal source (see Fig. 188, Page 263).

So, whilst the formation and ascent of the hot-air-bubbles is not generally visible at ground level, the phenomena may be detected by the formation of cumulus clouds at somewhere around 500ft. At the same time, further phenomena are taking place, some of which are partly visible whilst others have to be imagined. As the water vapour in each forming cumulus cloud condenses into minute droplets, these are held in suspense by the hot air beneath them. But every droplet tends to combine with its nearest neighbour forming larger droplets which, being heavier, sink to the bottom of the cloud and then, being denser they appear darker than those above them. Hence the flattish, darker coloured base of almost every cumulus cloud.

Ups and downs

These heavier and now considerably cooler droplets can no longer be fully supported by the up-rising hot-air-bubbles and they therefore fall as a down-current of cooler air, mainly on the outsides of the uprising current, when they travel back towards ground into the generally warmer air below, either completely evaporating or partly arriving as short sharp showers of light rain, on the earth-bound soarer "pilots" below.

One of the first truths about thermals, therefore is that, for every up-current there is a balancing down-current. Looked at more optimistically; if a glider wing is seen to dip suddenly then somewhere, very close by, there is some positive "up-lift" to be found. But, before moving on, and from ground level again, it is necessary to examine two more phenomena. One of these can only be sensed or physically felt. The other only becomes visible in the upper atmosphere—sometimes quite majestically.

Because nature will not tolerate imbalance and since the hot-air-bubbles taking-off from the ground leave a partial vacuum, nearby air moves in sharply sideways to take their places. So, on a relatively still summer day, a hopeful soarer pilot may feel a short-lived brisk cool breeze going past him followed by a more gentle and slightly warmer breeze. He may then know that he has just missed one ascending hot-air-bubble but happily, if he looks in the direction of the breeze travel, he may know that he could be standing very near the centre of a ground thermal source. (See Fig. 191).

But what happens to the hot-air-bubble as it actually leaves the ground and travels upwards? It does not remain in the form of a bubble (see Figs. 190 and 192) but, because its centre is more "active" than the perimeter, the bubble will tend to form into an invisible hot-air-and-vapour ring and, in the same way as a smoke-ring, it will entrain more air as it travels up and so increase in size, gathering strength and speed as it goes into the more rarefied air above.

On encountering the under-side of an embryo cumulus cloud, the "newcomer" will tend to break through the centre part of that existing formation, so creating an even larger aerial vapour-ring which will now become visible as the water vapour condenses.

Additionally, at this point, the latent heat stored within the uprising vapour ring, before it took off from ground level, will be released as the condensation begins and this released heat will add to the general up-lift within the forming cumulus causing a type of secondary thermal which may show itself as a sort of central "crown" on top of the general billowy shape of the cloud. Probably the truly classic example of this may be seen when watching the formation of a cumulo-nimbus or thunder cloud. (See previous article "Further Outlook", Fig. 187).

The centre of such a formation will break out of the top of the cumulus and lift with quite considerable force to form the well-known "anvil" shape at quite some altitude above. "Lift", of this kind, for full-scale gliders searching in such clouds, may vary between 900ft. per minute which is about the same as the rate of climb for a light aircraft and as much as 2,000ft. per minute—which is about 40ft. per second. In any pilot's log book this is certainly going up! (See Fig. 193). Having said that, and using the following symbols to denote certain factors, let us now study a few simple diagrams which illustrate what goes on but cannot always be seen.

Symbols used in illustrations

Thermal Source = T.S. Thermal Lift = T.L. Ground Level = G.L. Sun = *stylised sun drawing* and Wind an *arrow* in appropriate direction.

Example one

This shows a clear morning sky with a strong summer sun striking a standing cornfield. (More about this thermal source later.) Almost still air. After some time, hot air bubbles will break away, turn into vortex type rings entraining more air and eventually reaching the 500ft. ceiling. Condensation will commence. Droplets will combine and then fall to the outer and lower perimeter of the cloud. They will then break away and fall back towards ground, evaporating as they go. (Fig. 192).

Example two

This shows the same basic conditions but with a general 10 knot wind which will move the bubbles and hot air rings downwind of the source from which they ascend, so that a rather weaker cumulus cloud will eventually form up some considerable distance down-wind from the thermal source, but still about 500ft above ground level (Fig. 190).

Example three

This shows the same basic conditions but with varying wind strata sliding along on top of one another in ascending heights. In this case, the travel-line of the ascending hot air vortex rings will not be a straight diagonal, but more of a gentle parabola.

Whilst conditions such as in Figs. 189 and 190 will perhaps be of assistance to the full-scale soaring pilot, they will not greatly assist the r/c model pilot because of the distances travelled downwind. In the case of the first condition, however, the vertical lift and the down-currents will form in the same fairly close area and may be useful indicators of potential thermal power. (Fig. 189).

Example four

This shows the balancing "horizontal" breezes of a short-lived nature restoring the pressure balance left by a departing hot-air-bubble. (Fig. 191).

Example five

This shows the up-thrust of an arriving hot-air-vortex-ring underneath a cumulus

formation with the release of latent heat, the break-through effect and the formation of the upper "anvil" at much higher altitude where the droplets become frozen into ice crystals when they meet the base of the stratosphere. Such formations and heights are of no practical value to the r/c glider pilot from a flying point of view but they are all very positive indications of what is going on above him and, therefore, what may or may not be going on in his immediate vicinity which may be of direct use to him, or her, as the case may be.

From the first three diagrams, however, it will now be realised that ground contours, obstructions such as buildings and banks of tall trees and large wooded areas, the temperature of the sun's rays when they actually strike the ground and the varying wind speeds both at ground and upper levels; all these things will contribute to quite differing conditions governing the formation, speed, durability and actual "lift strength" of any given thermal. It might now be thought that the ideal condition would be a rapid and continuous generation of near-vertical thermal columns, with little wind at ground or above to disturb the lift. Such a condition may well overtake the decay of the individual cumulus clouds, which will then join together and form into a medium dense layer of stratus formation.

This will not only form a barrier to the sun's rays and thereby eventually reduce the rate of thermal formation but it will also produce an artificial "ceiling" through which it will not be possible for subsequent thermal bubble-vortex-rings to pass. The whole thermal generation process will then slow-down and finally stop. This condition is known as "over-development" (Fig. 193).

So much, then, for the physics and the mechanics and what perhaps might mistakenly be called the "hydraulics" of the business but what, now, about the real nitty-gritty of where to look and under what conditions to find thermals and to go on finding them? This is, perhaps, a more crafty business but it is equally fascinating and rewarding.

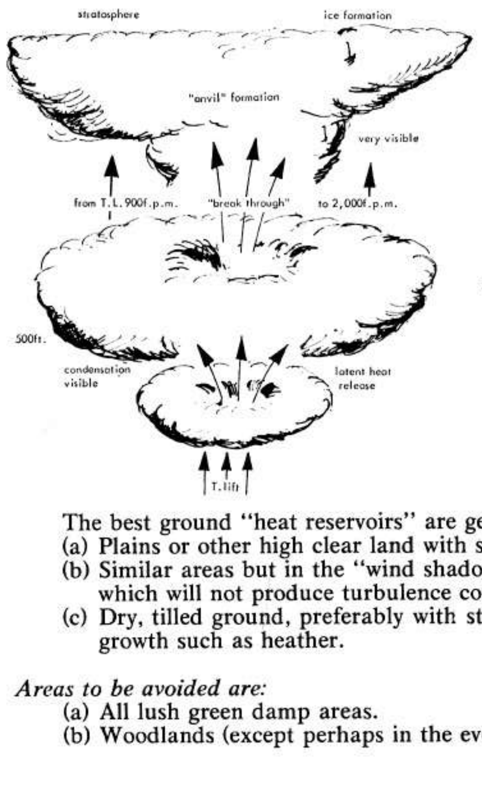


Fig. 193

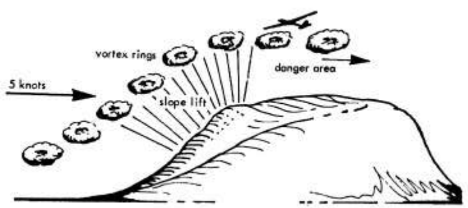


Fig. 194

The best ground "heat reservoirs" are generally thought to be:

(a) Plains or other high clear land with sand or chalk bases.
(b) Similar areas but in the "wind shadow" or lee of much higher sheltering ground which will not produce turbulence conditions.
(c) Dry, tilled ground, preferably with standing crops or other dark and dry surface growth such as heather.

Areas to be avoided are:

(a) All lush green damp areas.
(b) Woodlands (except perhaps in the evening).

(c) Snow and ice covered ground of any kind.
(d) Rivers and lakes or areas crossed by streams.

Woods which have had the strong sun on them all day may release their accumulated heat towards evening time but, in general, all water surfaces and the tops of high banks of trees are possibly the most difficult and damaging areas from which to attempt retrieval of groundward bound sailplanes. Preferably, keep well away at all times.

Thermal "up-lift" may also be found, on occasions, joining company with natural slope lift, particularly if a steady gentle breeze is releasing thermal bubbles from such a source as standing crops well up-wind and well out from the slope base. Thermal bubbles, rather like thistle-down, may then sometimes be detected riding up on the back of the slope lift. (See Fig. 194.) To keep in such a windward travelling thermal for too long, however, may find the sailplane much too far downwind and considerable discretion needs to be used in deciding just when to quit and dive back into the wind and the greater safety of the more constant slope lift.

The following factors must be "permed" with the locales given above in determining the probability of thermal existence.

(a) Angle of incidence of the sun's rays to the ground. Season will affect this.
(b) General clarity of the sky or cloud filter effect between the sun and the flying site.
(c) The heat "absorbability" of different substances and materials. More technically, latent heat.

If some ice in a calorimeter is gently warmed and stirred, and the temperature is noted throughout, the thermometer will remain steady at 0°C. until all the ice has been melted to water. As further heat is supplied, thermometer readings will rise so that the temperature of the water will now be found to rise. The heat absorbed before the temperature rises has been called the hidden or latent heat.

The specific latent heat of fusion of a substance is defined as the "quantity of heat required to change a unit mass from a solid to a liquid at the melting-point". Therefore the sun's rays in the winter striking snow-covered high ground will probably never produce any thermal bubble because all the heat will be absorbed in melting the ice. Put simply, ice and snow will absorb about three-quarters of the sun's radiant heat. Green grass will absorb about one-quarter but tilled ground only about one-eighth and standing crops about one-seventh, leaving a good six-sevenths for thermal bubble formation.

Wind strength has an increasing heat dispersal effect proportional to speed and temperature, as with a car radiator. The angle of thermal bubble climb, as indicated in Figs. 189, 190 and 192, shows that the further downwind a thermal bubble has travelled from source, the more heat it may have lost on the way and therefore the less "lift" it may provide at cumulus cloud height.

Fairly even-surfaced dry grass or heathland over which a gentle breeze is travelling is more likely to produce better thermal effect than broken ground which will provide greater ground turbulence. Correspondingly, a good wide corn or wheat field, in the lee of a large wood or a line of high poplar trees, may not produce such useful thermals as a smaller field or crops in a sheltered valley at the foot of a gentle slope, because of the relative amounts of turbulence produced.

It will now be realised that the permutations of conditions are very many and these have to be constantly watched, for good conditions in the morning may well deteriorate by "over development", or an increase in wind speed or shift in its direction may completely change the type and strength of thermal production. Not to lose heart, however, for herein is the real challenge! The positive and outward signs of thermal lift are quite real. They are:

(a) Largish cumulus cloud formation at about 500ft. altitude. Thermal sources will be some distance upwind depending on wind strength.
(b) Short-lived spurts of cool and then warmer breezes at ground level on a relatively still summer day.
(c) On very hot days "dust-devils" or mini-tornados may be observed. Leaves, small pieces of paper and dust are drawn into the vacuum caused by rapidly ascending thermals, and they themselves are carried upwards in a spiral type of thermal column to quite considerable heights and with great force.

(d) Gulls and swallows are very efficient thermal-seekers and gulls, in particular, may be seen "circling" with motionless outstretched wings riding, it would seem, with enjoyment on the otherwise invisible thermal lift.

When wing movement starts again, the gull has run out of the lift or encountered sink in a nearby down-current. It will then employ the tight-circling thermal seeking technique until more lift is found, when the wings will again become quite still.

(e) Gulls of many sorts may also be seen "ridge-riding" above a line of cliffs on the slope lift generated by an off-sea breeze supplemented by some thermal activity from the hot sands or a bank of heated dunes below. Such r/c soaring is really only for the gulls and the real experts, for the lift here, although sometimes very strong, is strictly limited, both seaward and inland, and it is best enjoyed by watching the ease with which the gulls slide effortlessly to and fro, calling out to one another from time to time in gullish exhilaration.
(f) Strong sink, unless generated by turbulence, should indicate associated lift which some tight circling should find in reasonable time!

Finding and keeping thermals is an art quite apart from slope soaring itself, but one thing is fairly certain. Thermals alone will not last as long as slope lift, and decisions must be made in good time as to when to leave and look for more. One of the many skills in staying aloft is in not being too content, but in "searching" whilst the going is still good and satisfactorily high.

The memorable Sherlock Holmes said of all detection, "It's elementary my dear Watson". The elements, or basic principles of thermal detection are outlined in the foregoing. The art of slope and thermal soaring is, indeed, not elementary—but it is most certainly elemental! The application of the basic principles in using the power of the elements and the development of such skills may best be learned by listening to other very experienced pilots and, as with the gulls, in watching what they do and where they go!