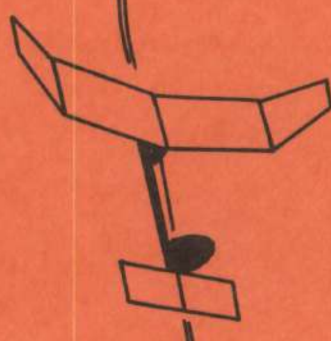
# CIRCULAR AIRFLOW

## AND MODEL AIRCRAFT



by Frank Zaic

# CIRCULAR AIRFLOW
# and
# MODEL AIRCRAFT

by

Frank Zaic

MODEL AERONAUTIC PUBLICATIONS

MODEL AERONAUTIC PUBLICATIONS
Box 135 Northridge California

To the memory
of my friends

C. S. RUSHBROOKE
A. F. HOULBERG
R. J. HOFFMAN

# PREFACE

The miniature aircraft we are flying now are creatures of evolution. We may delude ourselves into thinking that we design them, but an honest appraisal will disclose that our design procedure is similar to nature's way of developing species which will survive in a particular environment.

When we are ready to build a new model, we look over the field and select the one with a performance which we would like to match or improve. To insure a better design, we emphasize the feature we believe gives the prototype model its particular advantage. We do this without finding the real reason why the prototype model performed so well. This is the exact method used by nature in its trial-and-error "designing", and we cannot help but compare some of its dinosaurs with the models we have seen during our time.

If more thought had been given to why a particular and successful model behaved as it did, there would have been no need of over 1,000,000 models biting the dust in bitterness because we had not given them, as we should have, the inherent or built-in ability to fly free once we release them from our hands. Truly, the models we are flying now, are creatures of evolution, and the price for their design was paid by the 1,000,000 models that did not fly.

Many of us may have tried to find the answer to miniature aircraft design problems in large aircraft text books. Sad to say, we were unable to find the information we were seeking. It could have been that we really did not know what we were looking for, but hoped, nevertheless, that we would stumble on the solutions. On the other hand, it is quite possible that such books do not have the answers to our problems, even though they seemingly deal with the same subject — aerodynamics. How else can we account for the fact that so many model builders who studied aeronautical engineering, still have as much trouble as we do to fly and/or control miniature aircraft? We are sure that during their studies, their ears were always attuned to hints that would help clear up the mystery why miniature aircraft behave as unpredictably as they do. When we think of it, we wondered how it feels to be capable to design successfully 2,000 mph Supersonics and then have that little "ole" model exasperate you beyond words.

In truth, though, the large aircraft books can help us find the solutions to our problems, but we will not find them served on a microfilm platter. We will find them by extending the normal designing procedures into areas which have not been investigated. This is a broad statement to make when we consider the vast amount of energy expended in research to make it possible for men to fly in aircraft. Someone in the complex must have gone beyond the accepted safety frontier just to determine the safety limits. Well, someone has, but did not go far enough to do us any good. Think, have you ever seen a large aircraft with the Center of Gravity at 50% chord on the wing? To designers of large aircraft, 50% C.G. is way out in the super critical and unthinkable zone. But to us, 50% C.G. is not even the starting point.

On miniature aircraft, the C.G. location varies from 50% to 100% or on trailing edge. A particular location is determined by the process of evolution. (Even now very few builders know just why a C.G. location is where it is.) All we know is that such a location makes it possible for the miniature aircraft to perform its complete flight cycle, from an extremely steep and high speed climb to a floating glide, without physically changing the relationship between the wing and tail surfaces during the flight. Such an achievement is impossible to duplicate with large aircraft with surfaces fixed and with power to weight ratio of one or more.

The procedure used for large aircraft, and which we can use without reservation, is the calculation of pitching moments of the wing and stabilizer about the C.G. The method is shown in the book. You will note that as we move the C.G. towards the trailing edge, the longitudinal stability is in a razor's edge balance.

Then, there are other aerodynamical phenomena which have a major influence on flight of miniature aircraft, but only of passing note on large aircraft because the pilot automatically adjusts for the changes. In particular, the effect of change of airflow when an aircraft flies in a circular path.

When we stumbled on the effect of Circular Airflow on miniature aircraft (1950) it was a very important discovery for us. Then we were told that it was nothing new, and that it could be found in the text books. We looked, and since we knew what we were looking for, found reference to it in our favorite book, "Airplane Design" by Edward P. Warner, published in 1927. He noted the effect of angular changes on the fixed stabilizer while the aircraft was in a circular path. But the presentation was more in a nature to show that the angular change increased the angle of attack on the fixed stabilizer, and the need to provide the sufficient elevator area and movement so that it (the elevator) would be able to make up or cancel the effect of the positive lift stabilizer. The situation is similar to the one presented by the control models which have fixed stabilizer and movable elevator. Now if this effect of the Circular Airflow is all that an aeronautical engineer would consider applicable to the miniature aircraft, it would be of no help to us. Lack of recorded data seems to indicate that this is the extent to which Circular Airflow is considered in the large aircraft design.

The full impact of the Circular Airflow effect on the miniature aircraft design, can only be appreciated if it is studied in combination with the C.G. location. And we do not mean the super-safe 25% used on the larger aircraft, but, say the 100% location at which the longitudinal balance teeters on razor's edge, and where a $\frac{1}{2}^{\circ}$ plus or minus shift can mean another model biting the dust. But it is this marginal balance in combination with the angular change caused by the Circular Airflow that enables the miniature aircraft to adjust itself to an exceptionally large range of flight attitudes.

The book consists of two sections. The first part (through page 103) was written and set in type in 1951. It was planned to be published after the 1951/52 Year Book, but the financial return from the 1951/52 Year Book made it impossible. The second part was written in the Spring of 1964, as a supplement to the original work to demonstrate the validity of the Circular Airflow and C.G. influence on the current model designs.

The first part should be read and studied with the understanding that it was written while we were investigating the Circular Airflow influence. You might say that it should be read like a technical diary or notebook. Its illustrations, graphs and charts were redrawn from the original notes in a more understandable manner to clarify the 1951 text as much as possible.

It is hoped that this book will help the reader achieve a better visual picture of what occurs during the free flight of his miniature aircraft. With such an understanding, it will be possible to obtain high altitude and floating glide with ease. And the most important point of all, to know the limits to which the aircraft is capable of performing with safety and so keep it in the air where it belongs, instead of making it bite the dust.

MAY, 1964
NORTHRIDGE, CALIF.

FRANK ZAIC

## "WHAT GOES UP MUST COME DOWN"

To become a successful hardware collector in this model game, one has to abide by that old proverb "What goes up fast, must come down slowly." Judging from what we see on the field, we have no trouble with "what goes up fast." It is the "must come down slowly" that is giving us so much trouble, and makes us think that we live by that other flight proverb "the higher they climb, the harder they fall." Whatever the case with you, let us see what can be done about this situation.

Since gas models are the ones which fit the above proverb, it seems best to go right into this phase of model building, rather than lead up to it with general discussion of what has been done in field of low speed aerodynamics and various types of stability since our last book. And we cannot think of a better introduction than by describing a test we made last winter.

Although we have been making gas models since they were first introduced, we did not follow them up as closely as we did with rubber models and gliders. Consequently, our ideas about gas models, until last year, were more or less on the theoretical or "advisory" side. Then we decided to make actual flight tests and see what happened to our ideas. We do not mind saying that the results were quite a surprise, and we did find ourselves in deep water for a while.

## TEST GAS MODEL

Our idea of a perfect gas model is to have it climb at 45° in a gradual turn and then swing into a fairly tight gliding circle when power was out. We planned to obtain this flight by having all forces balanced. Hence, the power plant on our test model was set high over the wing so that the thrust line would be through the wing's center of lift and drag, and also above the C.G. — thus eliminating zooming or looping action and actually have a diving moment above the C.G. To eliminate quickly any upsetting action, we used 20% stabilizer with streamlined section set at zero, in combination with C.G. at 25%. This meant no load on the stabilizer so that any upsetting force would be controlled quickly. With no load on the stabilizer, we had to set the wing at its actual angle of attack to the base line. Experience led us to use 5°.

Do you have a clear picture of this line-up? Thrust line high over C.G. and in line with the streamlined stabilizer; and wing set at 5°; its center of lift almost directly over the C.G. Just what do you think should happen? For fun, write it down and see how close you guess the actual results.

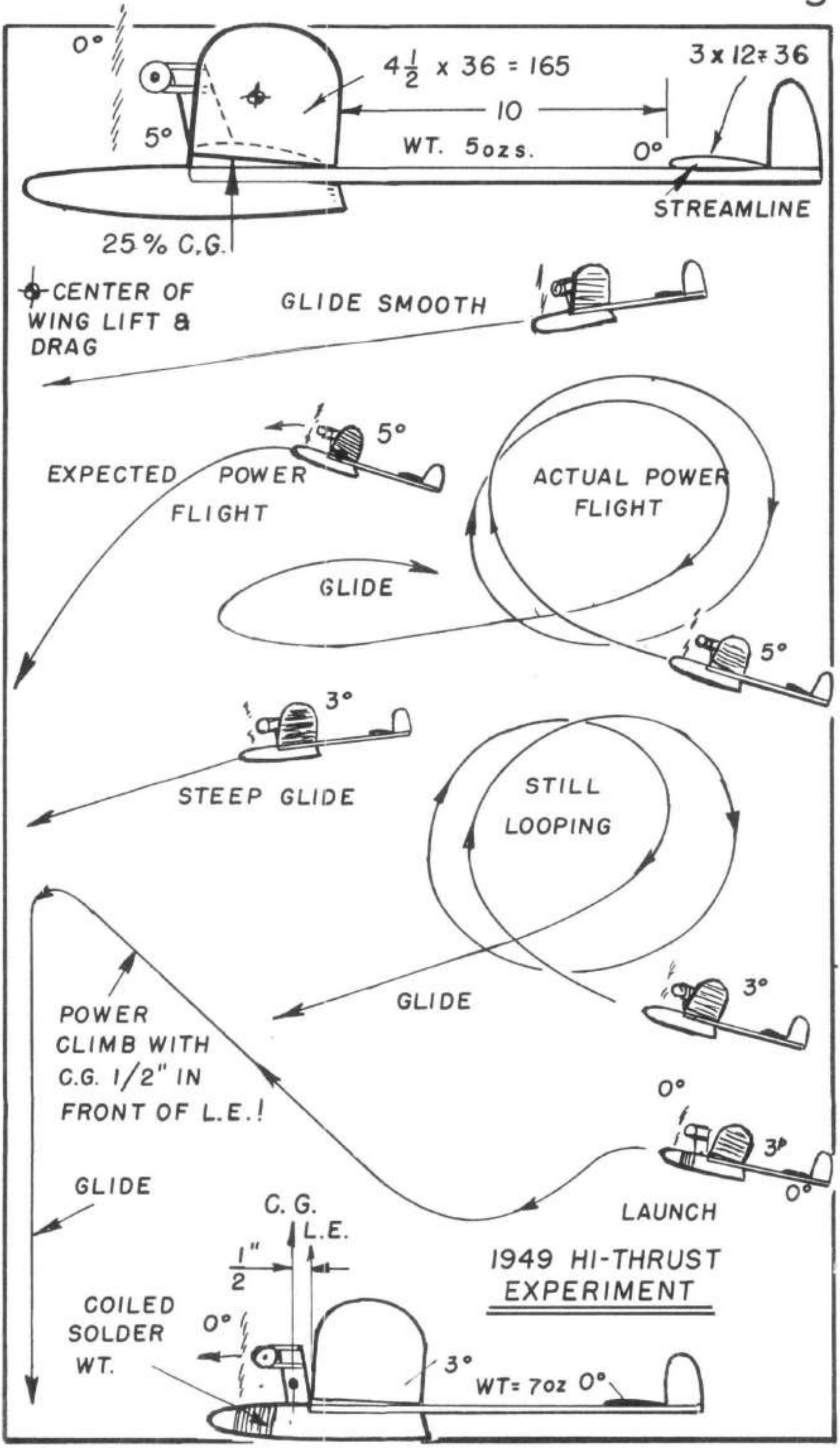
## FLIGHT TESTING

We checked the model for glide and found it smooth. With such a high thrust line we expected to see a nice power dive or at least a long shallow and fast flight across the field. We were, therefore, completely unprepared for what actually did happen. We launched the model and just had enough time to jump out of its way as it looped for our back. Yep, it looped, and kept on making the most symmetrical loops we ever did see until power cut. Then it swung into a smooth right glide. — What now? Where was our 45° climb? For that matter, why a loop in the first place when it was supposed to dive?

Well, maybe we did have too much incidence in the wing. We brought it down to 3°. But this made no difference — it still looped. The glide, however, was of diving variety. (We were happy we used pod and boom design to save the props, otherwise the experiment would have been on the expensive side.) We tried a few more flights with no change in the model's behavior. The motor eventually broke loose.

Overnight, the model was repaired and motor cabane mounted on the pod in front of the wing. We did not bother with glide tests anymore, just wanted to see how it behaved under power. As on the previous day, it looped and looped as usual. We now reached the point where we became determined to stop it from looping at all costs. It was no longer a question of 45° climb, it was a question of who is going to win, the model or us. To that end we brought with us a coil of solder. We wound several coils around the pod to bring the C.G. forward. No change — it still looped. We kept winding on more solder. The model kept looping but a bit on the sluggish side. We began to gloat and wound more solder coils. We finally did it and got our 45° climb. The glide? What do you think? How does a brick glide when you drop it from 100 feet? We might mention that while launching after adding weight, the model would first dive downward and then zoom upward. Eventually, something gave way and we packed up.

At home, we checked the model and we wished we had not been so stubborn about adding weight until we stopped looping, as we were presented with a lulu of a problem. Originally, the model weighed about 5 oz., but with balancing weight it came up to 7 oz. We still had 3° in the wing, zero stab and thrust line. Then we tried to find the C.G. No matter where we placed our fingers under the wing, the nose would point downward. We had to move over to the cabane to find it. And where do you think it was? Fully ½" in front of the Leading Edge! Can you imagine something like this still trying to loop with such a high thrust line. To make matters worse, we had no idea why it kept on trying to loop or, for that matter, why it flew at all.




1949 HI-THRUST EXPERIMENT

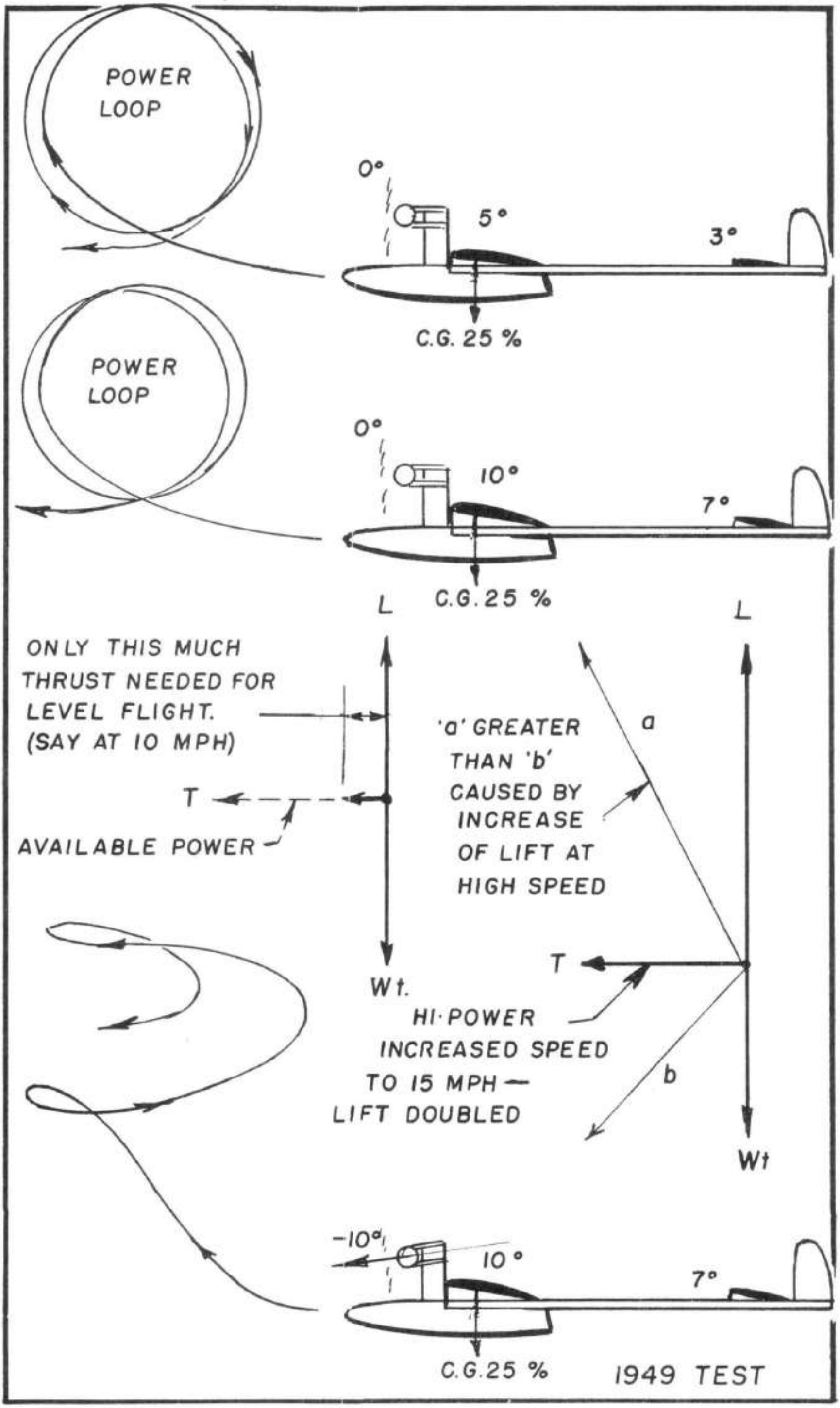
After some thinking, we set up new forces overnight, figuring that since the wing flew at 5° angle of attack and thrust line was only 3° less, it may have an upward component. And so we raised the whole wing back to 5° and stabilizer to 2°, and C.G. back to 25% spot. This should do it, thrust line along the flight path and stab at normal practice angle. The glide was fine. Power flight? Yep, the prettiest loops you ever did see. It made us wonder what happened to the gyroscopic effect.

The next arrangement had 10° wing and 7° stabilizer to make sure that the thrust line would have absolutely no upward force, and to have it down, if anywhere. The glide was still good, but the model looped under power. It would start into a left circle and then swing into looping, with no tendency to spiral dive or climb. After the power was out it would go into right glide. We then cut down rudder area but this made no difference. It simply had a one track mind, to wit: to loop.

## 20° DOWNTHRUST CONTROLS LOOPING

Not having any luck so far in making the model behave with changes listed, we began to doodle with force diagrams. We also wrote to Hewitt Phillips for help. On the diagrams we used similar forces for lift, thrust and weight. The .049 Cub seemed powerful enough to pull the ship straight up, which means thrust equals weight, and lift equals weight when the model is adjusted for glide as ours was. As we made one force diagram after another, nothing positive showed up until IT came to us, that, under power the model has greater speed than while gliding. Greater speed means greater lift. As soon as we used larger lift force, we found the resultant swung upward, in the direction our model insisted on going. Maybe this was it. To counteract this upward resultant we angled the thrust line downward as shown. Since we had nothing to lose, we angled the engine 10° on our test model, which, in combination with 10° already on the wing, would give us 20° difference between wing and thrust line.

The test glide was fine. Launching the model, we had no idea what to expect. So that when it dove into the ground, we were a bit disappointed in seeing the model give up the struggle so easy. Then we noticed that we did not play fair by launching it downwind. — Launching it into the wind, the model seemed sluggish and lacked that eagerness to get out of our hands, but it did climb at about 45° into a left circle without any tendency to loop. With power off, it swung into a shallow right circle. A half dozen more flights, just to enjoy this new experience. Then we tried to make it loop by attempting to make it fly straight. Rudder setting had no effect. Next we tried cutting down the rudder. No change in flight pattern. Eventually, we tore off the entire rudder after which the model barrel-rolled to the right as it should have in following the spiral stability laws.


POWER LOOP
0°
5°
3°
C.G. 25 %
POWER LOOP
0°
10°
7°
C.G. 25 %
L
ONLY THIS MUCH THRUST NEEDED FOR LEVEL FLIGHT. (SAY AT 10 MPH)
T
AVAILABLE POWER
Wt.
L
a
'a' GREATER THAN 'b' CAUSED BY INCREASE OF LIFT AT HIGH SPEED
T
HI-POWER INCREASED SPEED TO 15 MPH — LIFT DOUBLED
b
Wt
-10°
10°
7°
C.G. 25 %
1949 TEST

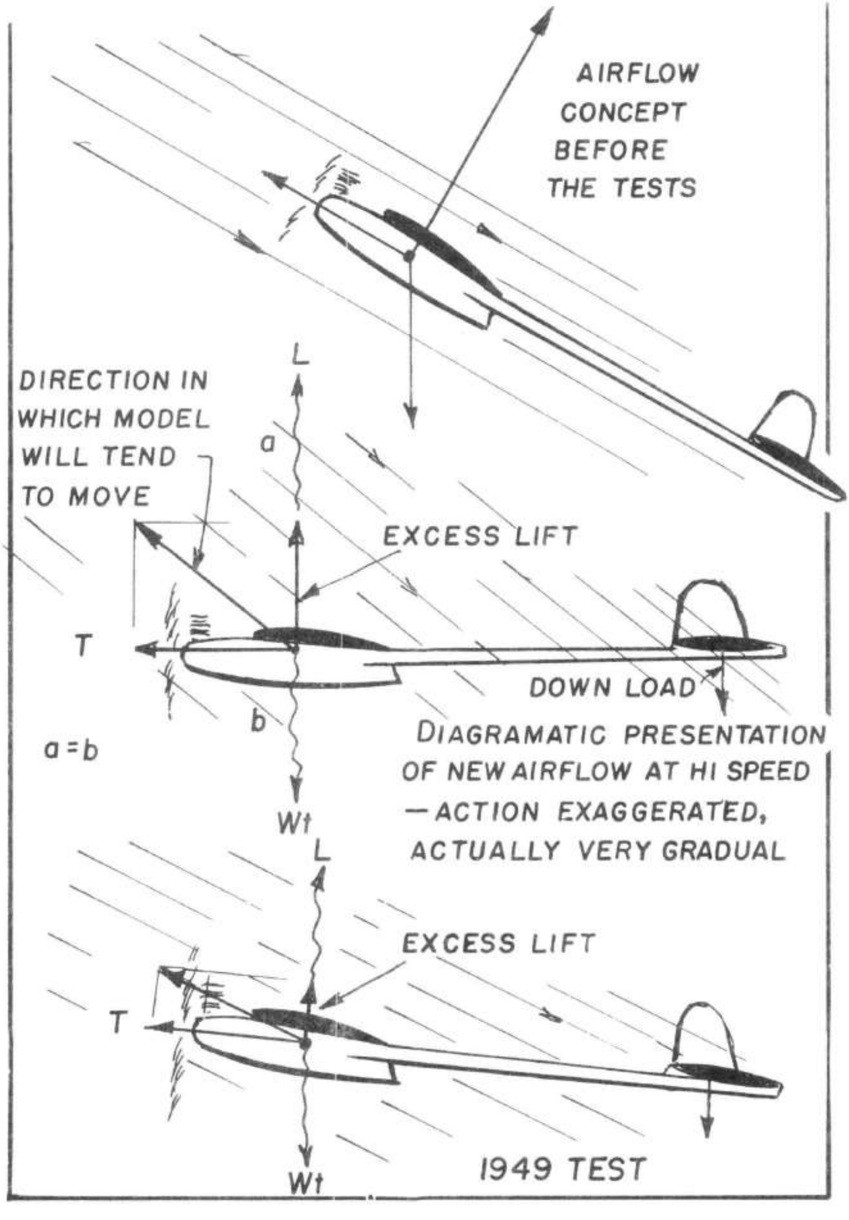
# CONCLUSIONS

While we were testing, several people suggested down thrust. Perhaps you have have been of similar opinion and wondered what took us so long before we came to it. If this had been an ordinary model which we wanted to use for contest, we might have done so at the start. But this was not an ordinary model. According to the ideas we had about model design, it was not supposed to loop with thrust line above C.G. Since we were out to find what makes gas models tick, we had to try as many ways and means of correcting zooming or looping as we could think up, and use down thrust as a last resort. And if we had to use it try to find out why. We believe that we followed our plan to the letter.

Some might wonder why we started with this particular design and not with a present day standard. Well, to our way of thinking at that time, it was supposed to be power-proof; and, frankly, we had no idea where to start improving or explaining the present day design. (It is a result of countless number of try-and-smash tests without anyone knowing for sure what happens.) Since we wanted to know "why", we had to start with our idea of an ideal gas model. That it proved so contrary is the paradox which keeps us interested in model aeronautics. As you will see later on, it led us to investigate the field as a whole.

The test took us ten solid days of flying during the day and repairing in the evening. At first the looping characteristics did not break our "know-it-all" confidence, but as all corrections failed, our minds were getting blank by the hour, and we wondered how we would be able to write another year book without knowing what goes on. Then came the break, and the realization that when speed is increased so is the lift. We knew this a long time ago and until this moment we assumed that it happened to both, wing and stabilizer, at the same time so that there would be no break in their balance. But this new realization of increase of lift during power took on a new significance as we noted the new resultant of forces. To us this new resultant means that under power, the airflow tended to "attack" the model at lower angles than it did when the model was gliding; and somehow we felt that this lower angle of attack tended to give the stabilizer a download which would cause it to force the model into a looping or zooming condition. Just how this came about we did not know at that time. All we knew was that we had a new resultant under power, which would cause looping, and that this resultant could be controlled by downthrust. We had a very vague feeling about the whole business, and the next step was to check up the relationship between wing and the stabilizer very carefully, and see what the boys in the text books had to say about it. In other words, we at last had an idea what we were looking for, and if we saw it we would recognize it. And that, my friends, is the secret of successful experimenting; knowing what to look for and recognizing the slightest indication of your goal.

A few days after we finished the above test, and while we still had vague ideas on what to do next, we received a letter from Hewitt Phillips. It was very timely and it dealt with our problem, perhaps not in detail but enough to give us a start to apply full scale calculations to models just to see what would happen. The results will follow this reprint of his letter.



"I am afraid that your question is rather complicated. It gets into the problem of the effects of power and stability, a subject about which not much is known. You will probably know more about it than most aeronautical engineers after completing your tests. For a look at the theoretical side of the subject, I would recommend the following report:

NACA Tech. Report #774 "Effects of Tilt of the Propeller Axis on the Longitudinal Stability Characteristics of Single Engine Airplanes" by Goeth, H. J. and Delany, N. K.

"I can give you a rough idea of the explanation for effects that you observed, but you must realize that many features of the individual design influence the stability characteristics. Model builders in their theories have a tendency to oversimplify, usually limiting their analysis to such items as thrust axis, position of C.G., etc. Actually, such items as the wing planform, relative location of the wing and slipstream, position of the tail with respect to the wing wake, etc., have been shown to have equally important effects.

"Now to get to your problem. First, it is necessary to keep in mind the conditions for steady flight, which you are no doubt familiar with. These are that the airplane must be *trimmed* and that it must be *stable*. By trim we mean that the airplane is in equilibrium; that is, the resultant force is zero and the resultant moment is zero. An airplane must be trimmed before we can discuss its stability, because stability refers to the tendency to return to trimmed condition following a disturbance. An airplane is stable when an increase in angle of attack causes nose-down moment, and vice-versa. Usually this is expressed by saying "the slope of the pitching moment curve is negative." Typical curves of lift and moment vs. angle of attack are as follows: (For complete airplane.) *diagram A*

Changing the stabilizer setting or the C.G. position have the following effects on the pitching moment curve: See Diagram B.

Now consider your model in glide and in steep climb attitude *diagram C*

Both are in equilibrium; however, the model in climb must have much less lift, because most of the weight is supported by the thrust. Thus the conditions on the lift and moment curves are as follows: *diagram D*

You can see that. if the model is trimmed and stable in the glide, the pitching-moment in the climb will be in the nose-up direction, tending to make the model loop. In order to offset this tendency, it is necessary that there be nose-down moment due to power. You can see that moving the C.G. forward is just going to make the problem more difficult, because it steepens the slope of pitching-moment curve.

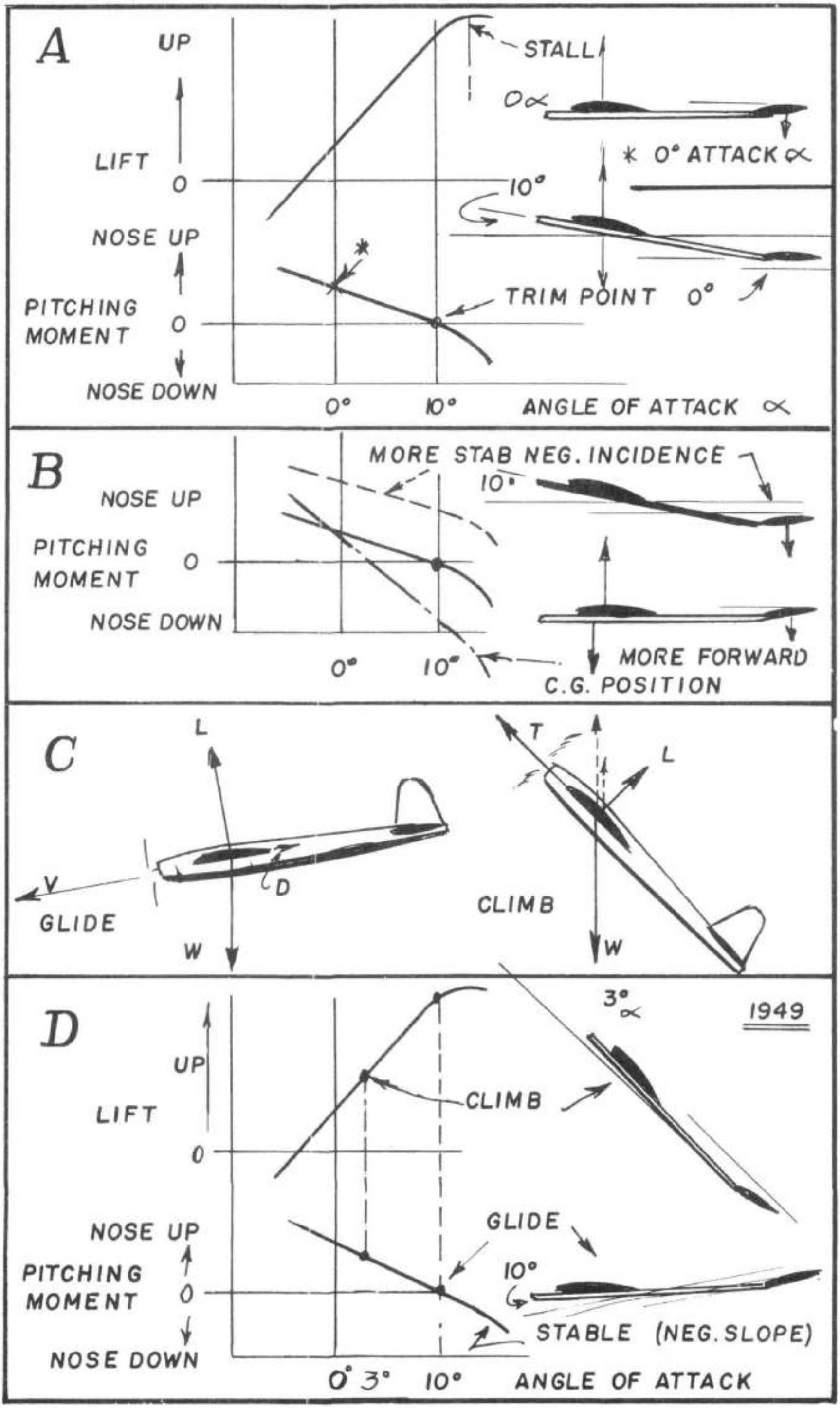

A
UP
LIFT
0
NOSE UP
PITCHING MOMENT
0
NOSE DOWN
STALL
0α
* 0° ATTACK α
10°
*
TRIM POINT 0°
0°
10°
ANGLE OF ATTACK α
B
NOSE UP
PITCHING MOMENT
0
NOSE DOWN
MORE STAB NEG. INCIDENCE
10°
0°
10°
MORE FORWARD
C.G. POSITION
C
L
V
D
GLIDE
W
T
L
CLIMB
W
D
UP
LIFT
0
NOSE UP
PITCHING MOMENT
0
NOSE DOWN
3° α
1949
CLIMB
GLIDE
10°
STABLE (NEG. SLOPE)
0° 3°
10°
ANGLE OF ATTACK

*diagram E*

What we need is the following condition:

*diagram F*

Thus the problem is to obtain a nose-down moment due to power. You probably expected to get this from high thrust line. It is true that the direct thrust moment is nose-down, but this is probably more than offset by the nose-up moment, due to the slipstream acting on the tail.

*diagram G*

The wing tends to curve the slipstream considerably, and a little calculation will show that the resulting moment may be several times as great as the moment of the propeller thrust about the C.G. This is because of the long moment arm of the tail lift. Even considerable down thrust may not be effective, as tests have shown that the wing curves the slipstream very effectively.

*diagram H*

One thing that may be done to achieve the desired results is to locate the wing out of the slipstream, so that it will not tend to deflect the slipstream on the tail. Diagram I.

I have frequently observed pylon-type models, adjusted to fly straight, climb steeply with only small amount of down thrust.

The pylon-type arrangement also has a tendency to give non-linear, pitching-moment curve, with less slope at low angles of attack. Diagram J. Thus it reduces the amount of nose-down moment due to power required to trim at low angles of attack in the climb.

To summarize, then, we may say that to allow your model to climb and glide stably, you need to:

*a*—Trim the model in the glide with most rearward C.G. position that will still give stability.

*b*—Supply the necessary nose-down moment due to power.

I hope that these notes are understandable. I have a little trouble talking in model builder's language nowadays. Also, I hope you don't run out of props before you get a chance to try some of these ideas. The final proof of any theory is in the actual test.

You may be interested in looking up a report that I wrote, based on a set of lecture notes given in one of my courses on stability and control. It has more to do with full-scale airplanes, of course, but it may be more understandable than most discussion of stability. The report is:

NACA Tech. Report #1670—"Appreciation and Prediction of Flying Qualities" by W. H. Phillips.

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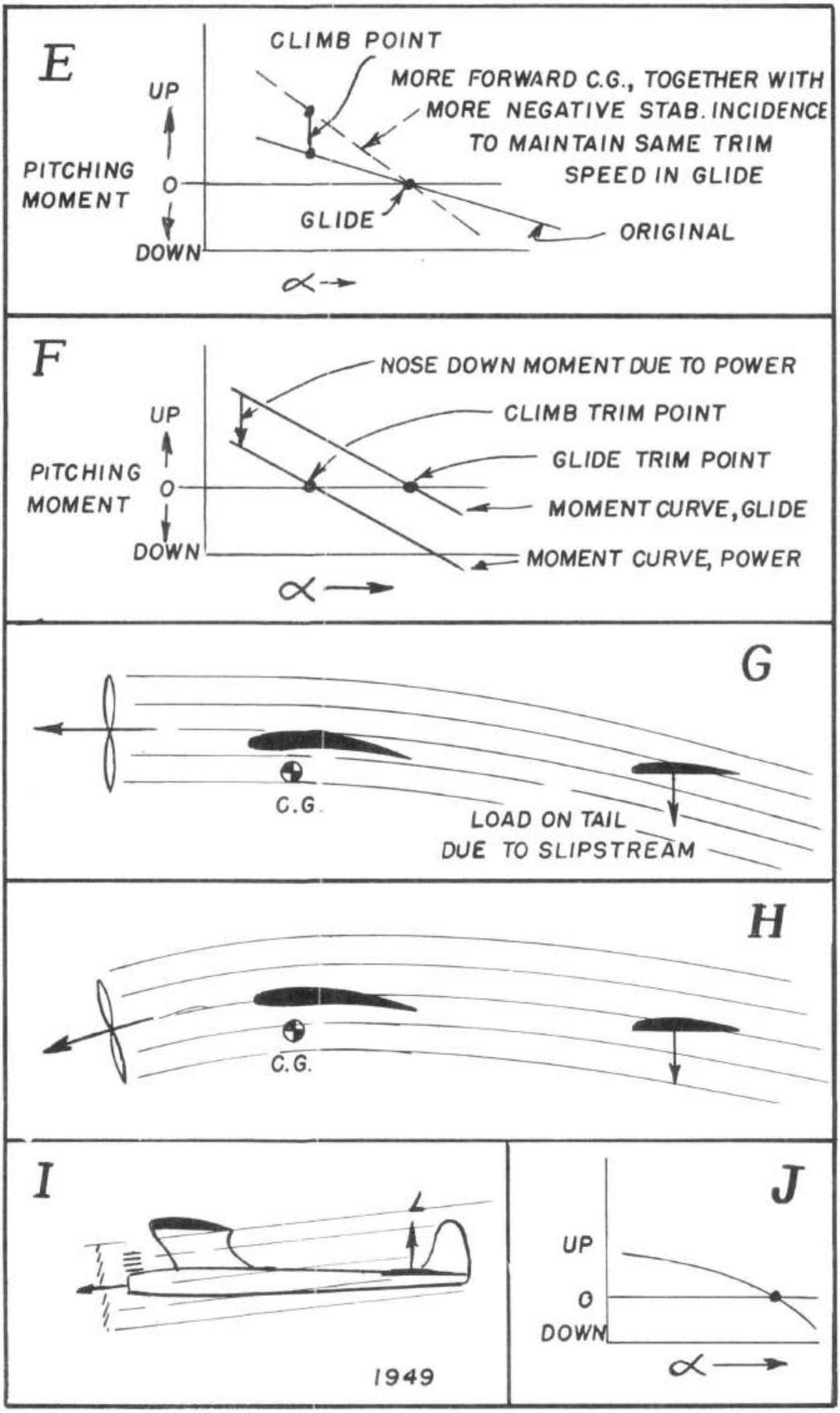
Those of you who had aeronautical engineering will have no trouble in following Hewitt, but those of us who just "fly for fun" may be tempted to skip it with once over lightly. The issue is much too important for that and we should make every effort to understand what is required for longitudinal stability.


E
CLIMB POINT
MORE FORWARD C.G., TOGETHER WITH
MORE NEGATIVE STAB. INCIDENCE
TO MAINTAIN SAME TRIM
SPEED IN GLIDE
UP
PITCHING
MOMENT
O
DOWN
GLIDE
ORIGINAL
$\alpha \rightarrow$
F
NOSE DOWN MOMENT DUE TO POWER
CLIMB TRIM POINT
GLIDE TRIM POINT
MOMENT CURVE, GLIDE
MOMENT CURVE, POWER
UP
PITCHING
MOMENT
O
DOWN
$\alpha \rightarrow$
G
C.G.
LOAD ON TAIL
DUE TO SLIPSTREAM
H
C.G.
I
1949
J
UP
O
DOWN
$\alpha \rightarrow$

Before we can do that, however, we should have an idea how we bring our models into trim or balance, and know at what angles of attack such balance is achieved. If we know the angle we can go ahead with actual calculations.

All free flight models fly at angle of attack close to **6°**. We do not know the exact angle for each type but we will give you our guestimates later.

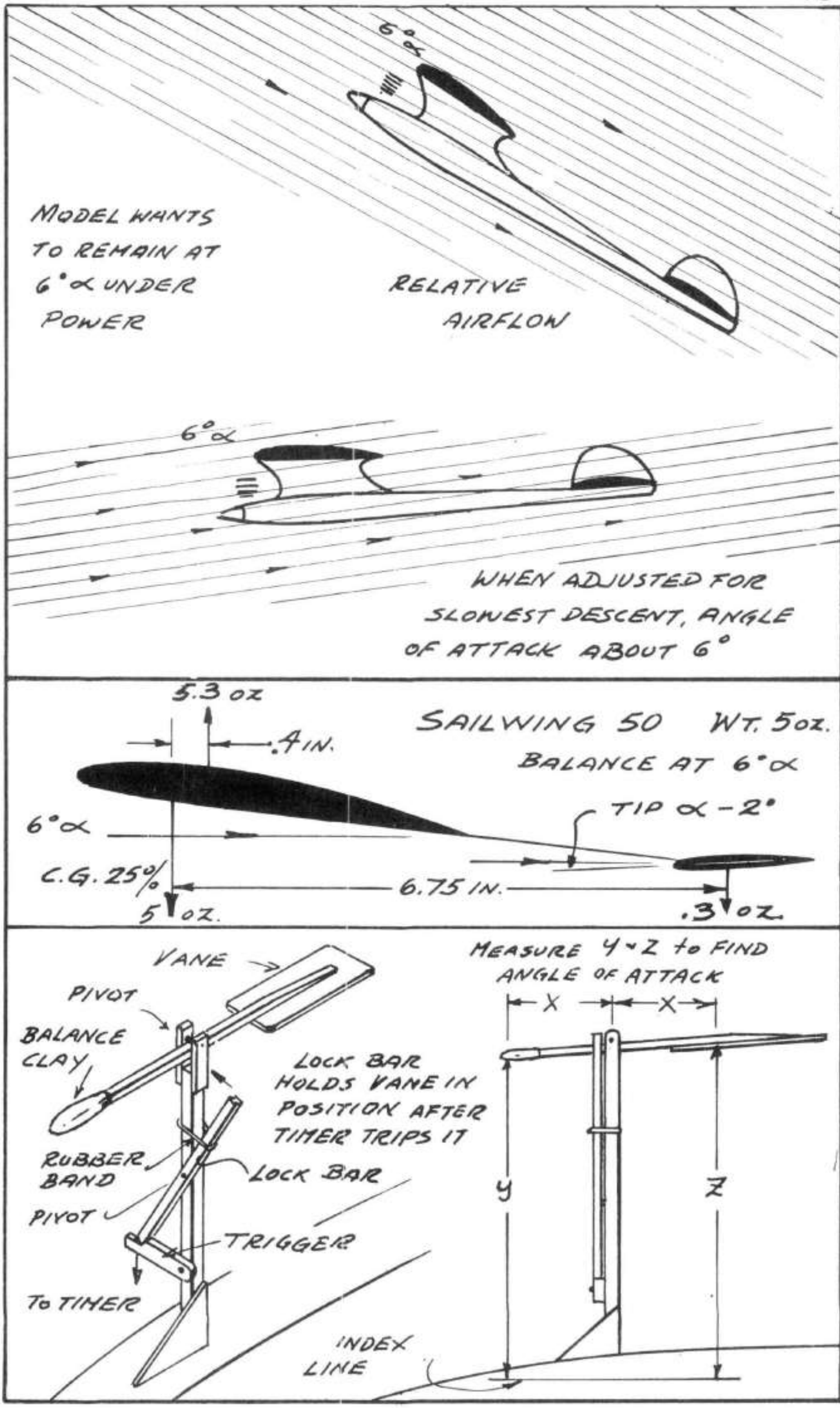
## HIGH ANGLE OF ATTACK BALANCE

We normally adjust a model until we obtained a floating glide. The peculiar fact about such a glide adjustment is that the slightest change to increase its "floatings" results in a stall. To us this means that the model was originally adjusted to glide close to the stall which means high angle of attack in any language. It makes no difference if the wing and stabilizer setting is 0-0, the model is balanced or adjusted so that its wing's angle of attack is high.

For actual proof of the above fact we made an angle of attack indicator shown, which would lock during flight and show at what angle the model flew. Tested on a light "Floater" it showed 5° to 6°. While stationed in Natal, Brazil, we made a flying wing glider, "Sailwing," which also provided a convincing proof. By checking this design elsewhere in this book you will note that the center section has no change in angle, but that the entire tip portion is set at a definite angle of 8° negative to center. The beauty of this design is that we know the exact angular difference between center and tips, and that the tips have streamlined section and are away from the wing's downwash.

We started to test "Sailwing's" longitudinal stability with tips set at 4° negative. By careful weight balancing, we obtained straight flights but any upset would start to oscillate it into an eventual dive. A change to 6° negative definitely improved stability but it would still not recover from oscillation. Then we tried 8° negative and the results were very good. Easy to balance, a floating glide and a sort of a wiggle from upset into a straight and smooth flight. We checked the C.G. and found it at 25% of average chord. This meant that the tips had practically no load, if any, it was down or negative. Since the difference between wing and tip was 8° and tips may have had slight negative we can say that the wing center portion was flying between 6° and 7°.

And so, as long as we are going to adjust models for slowest or floating glide, we will automatically bring such models into high angles of attack. The trouble comes in applying high power to such a set-up. High power and high angles of attack surely raise blood pressure high. Considering everything, we will use 6° angle of attack in our calculations for trim or balance point, which would satisfy the circumstances under glide conditions. Then we will bring in the effect of power on such conditions.


6° α
MODEL WANTS
TO REMAIN AT
6° α UNDER
POWER
RELATIVE
AIRFLOW
6° α
WHEN ADJUSTED FOR
SLOWEST DESCENT, ANGLE
OF ATTACK ABOUT 6°
5.3 OZ
.4 IN.
SAILWING 50 WT. 5 OZ.
BALANCE AT 6° α
TIP α -2°
6° α
C.G. 25%
6.75 IN.
5 OZ.
.3 OZ.
VANE
PIVOT
BALANCE
CLAY
LOCK BAR
HOLDS VANE IN
POSITION AFTER
TIMER TRIPS IT
RUBBER
BAND
LOCK BAR
PIVOT
TRIGGER
TO TIMER
MEASURE Y - Z TO FIND
ANGLE OF ATTACK
X
X
Y
Z
INDEX
LINE

## LONGITUDINAL STABILITY

A model is longitudinally stable when it returns to its trimmed flight position after an upset. It should have inherent ability to return nose downward after a force has pushed it upward, and bring it up when a force may have caused it to dive. The best way to illustrate just how this is accomplished, is to analyze a known model and calculate its pitching moment.

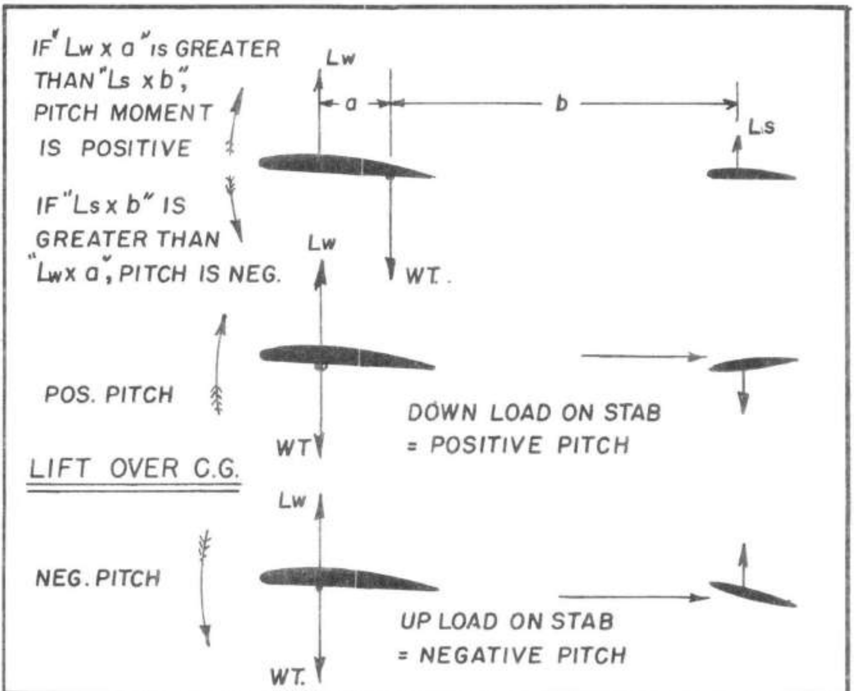
## PITCHING MOMENT

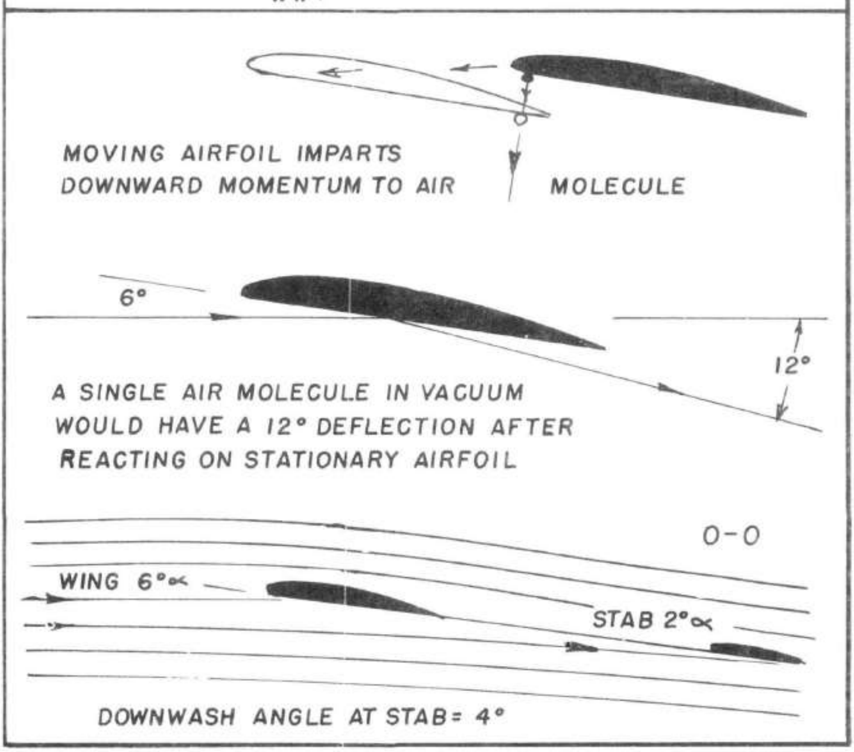
If you have trouble in connecting pitching-moment with models, think of the see-saw plank. (Or anything else which has only one fulcrum point.) As one side goes up, the other side goes down. The motion can be called "pitching". So when we speak of the pitching moment curve, we mean nothing else but what is the direction into which the model wants to swing or "pitch" at a particular angle of attack. It may be up or down. It is determined by calculating the forces of the wing and the stabilizer around the C.G. at different angles of attack. As Hewitt mentioned, many factors contribute to the final answer if accuracy is required, but, for our illustrative purpose, we will just use the wing and stabilizer.

## DOWN WASH

Before we start calculating, we would like to clear up the effect of wing's downwash on the stabilizer. It plays an important part in our calculations. — The wing generates lift by reacting on the air. The final result is that the air behind the wing is in a downward motion. The resultant of the downward moving air and forward speed of the model is to have the actual airflow strike the stabilizer at angles less than that at which the wing meets the air. So that if we have 0-0 setting and the wing is flying at 6° angle of attack, the stabilizer may look as though it is also flying at 6° but the actual angle would be much less. The exact angle can be determined by a formula.

Until we began to work on calculations, we had very little respect for downwash. We never took it into our confidence when working on designs. But after we began to work up mathematical balance between wing and stabilizer, we found that something was missing. Then, by using the downwash factor, balances came about which were too true to facts to disregard them. — We always did wonder, perhaps you have also, why a 50% stab, set at same angle as the wing, would require C.G. at wing's trailing edge. It should, according to our high school physics, obviously be lifting a third of the entire load which would bring the C.G. much further back. As you go along with us, you will find that the downwash factor is a very important point in actual flight calculations.


IF "Lw x a" IS GREATER THAN "Ls x b", PITCH MOMENT IS POSITIVE
IF "Ls x b" IS GREATER THAN "Lw x a", PITCH IS NEG.
Lw
a
b
Ls
WT.
POS. PITCH
DOWN LOAD ON STAB = POSITIVE PITCH
WT
LIFT OVER C.G.
Lw
NEG. PITCH
UP LOAD ON STAB = NEGATIVE PITCH
WT.


MOVING AIRFOIL IMPARTS DOWNWARD MOMENTUM TO AIR
MOLECULE
6°
12°
A SINGLE AIR MOLECULE IN VACUUM WOULD HAVE A 12° DEFLECTION AFTER REACTING ON STATIONARY AIRFOIL
0-0
WING 6°∝
STAB 2°∝
DOWNWASH ANGLE AT STAB = 4°

We checked several books for downwash formula until we found one that we could use in our simple calculations. It is close enough for illustrative purpose, but do not use it for your full scale design. It is applicable when the distance between the wing and stab is between two and four wing chords, and when stabilizer is about ½ chord above or below the wing section directly in front of it.

Downwash Angle in Degrees = $5.25\ C_L + .25$

This means you take the wing's airfoil $C_L$ value at that particular angle, multiply it by 5.25 and add .25. Your answer will be downwash angle in degrees. *Example:* $C_L$ value of Clark Y at 4° is .7.— Downwash will be (.7 x 5.25) + .25, or 3.945°. For our purpose we will assume the downwash factor value to be $5 \times C_L$ or $5\ C_L$. For all we know, it may be more or less. If you feel like doing something for the cause, check us and let us know if we are right or wrong.

## PREPARING COMPARISON TABLES

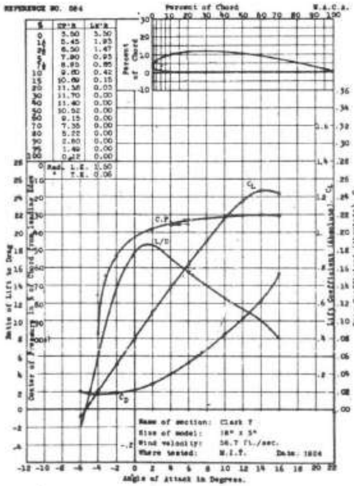
The main work in finding the pitching moment curve is to set up comparison tables of values so that we can match the wing's force about the C.G. against the stabilizer's effort, and so find out where they balance each other, and determine the trim point.

The table for the wing is easy to prepare as we have all of the information on hand. List the various angles of attack from -2° to 8°. Along side, list the appropriate $C_L$ values. *TABLE I*

The going is a bit rougher for the stabilizer — because, to find out the actual angle of attack, we have to consider the downwash. The first step, therefore, is to determine the downwash angle of the wing at different angles of attack. (Just multiply $C_L$ by 5). List it as shown. Since the physical angular setting, between wing and stabilizer, has been established, we list stabilizer setting to correlate with wing.

The second step is to determine the actual angle of attack of the stabilizer. It should be evident that it will be less at a particular wing's angle by the value of downwash. It is found by subtracting downwash angle from the stabilizer's set angle. If set angle is 3° and downwash is 3°, the actual angle of attack will be 0°. The (—) sign may fool you for a while. It should be obvious, however, if the set angle of the stabilizer is 2° and downwash is 3.8°, the actual angle will be below zero.

In fact, it will be —1.8°. A simple trick to find the actual angle of attack is to subtract the lower angle value from the larger. It makes no difference which is downwash angle or stabilizer setting. Use the (—) sign if the downwash value is greater than the set angle. The (—) sign does not have a negative value in calculations. It means that the $C_L$ reading should be taken on left side of the zero angle. The answer will be positive as long as the airfoil produces lift.



| WING Conditions | | | STAB: Actual Angle of Attack (∝) and Lift Coef. for various Wing-Stab Comb. at a particular Wing's Angle of Attack (∝) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 – 0 | | 1° – 0 | | 2° – 0 | | 3° – 0 | | 4° – 0 | | 5° – 0 | |
| ∝ | $C_L$ | DOWN WASH | ∝ | $C_L$ | ∝ | $C_L$ | ∝ | $C_L$ | ∝ | $C_L$ | ∝ | $C_L$ | ∝ | $C_L$ |
| -2° | .25 | 1.2° | -3.2° | .16 | -4.2° | .07 | -5.2° | .02 | -6.2° | -.06 | -7.2° | -.13 | -8.2° | -.2 |
| -1° | .33 | 1.6° | -2.6° | .20 | -3.6° | .12 | -4.6° | -.05 | -5.6° | -.02 | -6.6° | -.1 | -7.6° | -.16 |
| 0 | .4 | 2.0° | -2.0° | .25 | -3.0° | .17 | -4.0° | .10 | -5.0° | .02 | -6.0° | -.05 | -7.0° | -.12 |
| 1° | .47 | 2.3° | -1.3° | .30 | -2.3° | .22 | -3.3° | .15 | -4.3° | .07 | -5.3° | 0 | -6.3° | -.07 |
| 2° | .54 | 2.7° | -.7° | .34 | -1.7° | .26 | -2.7° | .20 | -3.7° | .12 | -4.7° | .05 | -5.7° | -.02 |
| 3° | .62 | 3.1° | -.1° | .39 | -1.1° | .3 | -2.1° | .24 | -3.1° | .16 | -4.1° | .09 | -5.1° | -.02 |
| 4° | .7 | 3.5° | .5° | .43 | -.5° | .35 | -1.5° | .28 | -2.5° | .21 | -3.5° | .14 | -4.5° | .06 |
| 5° | .76 | 3.8° | 1.2° | .47 | .2° | .40 | -.8° | .33 | -1.8° | .26 | -2.8° | .19 | -3.8 | .11 |
| 6° | .82 | 4.1° | 1.9° | .52 | .9° | .45 | -.1° | .38 | -1.1° | .31 | -2.1° | .24 | -3.1° | .16 |
| 7° | .88 | 4.4° | 2.6° | .57 | 1.6° | .50 | .6° | .43 | -.4° | .36 | -1.4° | .29 | -2.4° | .22 |
| 8° | .95 | 4.8° | 3.2° | .62 | 2.2° | .55 | 1.2° | .48 | .2° | .40 | -.8° | .33 | -1.8° | .26 |

TABLE I -- Effect of Downwash on Stab Angle of Attack--For CLARK Y only.

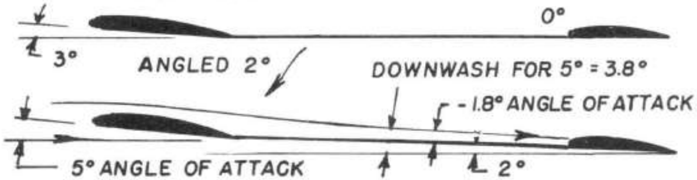



Table tabulated for Clark Y wing and stab. All data obtained from the characteristics chart shown above. Similar Tables can be made for all airfoils whose characteristics are known. Normally, stab airfoil should be thinner as it will be shown for 0-0.

C.P., Center of Pressure, or Center of Lift Position varies with Angle of Attack as shown on the airfoil chart. This changes the moment arm of the wing's lift about the C.G. The shift is appreciable in the model flying range. Should be considered seriously. On a 5" chord a change from 6° to 2° shift is 1/4". This can be meaningful in a delicately balanced 0-0.

To find moment arm of wing's lift, locate C.P. for that particular angle, and then find its distance from C.G.---Ex: At 6° C.P. is at 33% or 1.65" from L.E. The C.G. is at 75% or 3.75" from L.E. Therefore, C.P. has a moment arm of 3.75 - 1.65 or 2.1".

## PLOTTING THE PITCHING MOMENT CURVES

For our first example, we will use "Hurry-Up 210," a well tested Wakefield design, which we developed during the past two years.* We know its flight characteristics to use as check points, and also have its exact dimensions. * 1949-1950

In a manner of speaking, we are going to find the pitching moment curves for models that are trimmed for slowest possible glide. Since we do this to all models, it makes no difference which one, gas, rubber, or glider, we use for our example.

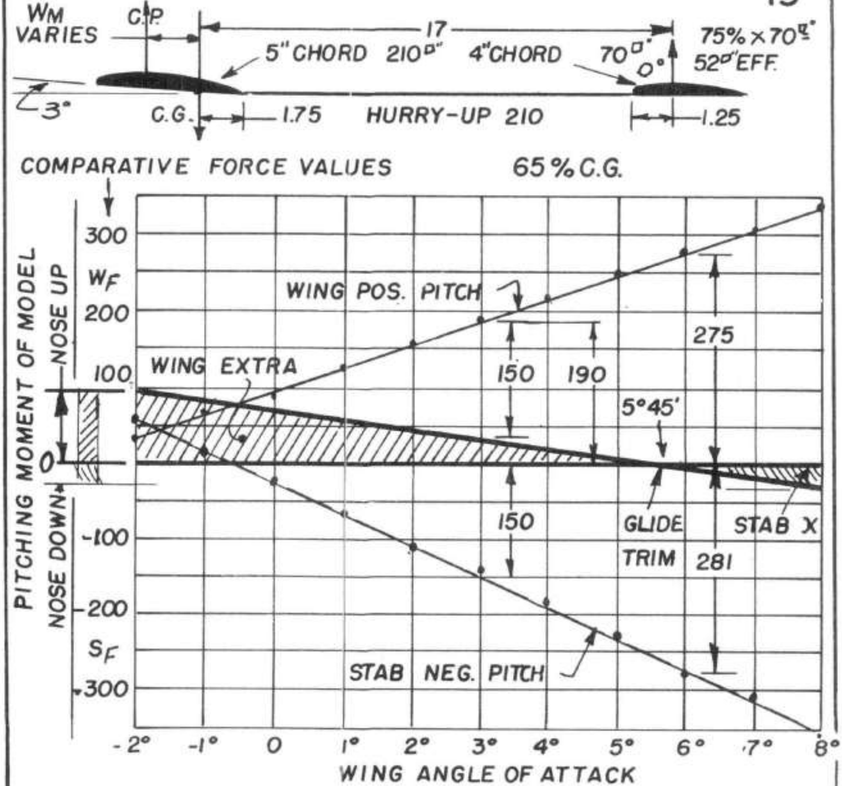
The airfoils used on "210" wing and stabilizer are similar to Clark Y, so that its lift ordinates will be used. The exact specifications for longitudinal stability calculations are given on the diagram. Although the stabilizer area is 70 sq. in., we only used 52 sq. in. as we assumed 75% efficiency due to fuselage interference. (In practice stab thinner - See Notes end of book

To find the pitching moment curve showing the actual force values in ounces about the C.G., calls for more information and time than we have now. However, we can make comparative curves which will show identical slopes and trim points but without exact force values. To make such comparative curves, we disregard air density and speed, and just use areas of wing and stabilizer, their lift coefficients and moment arms.

After the calculations were made, we only used the final answer of each surface at its particular angle to plot our graphs. This can be seen by checking the graph with the values on the table. The lines are not smooth but they do give a fair picture of the situation. Note that the wing has a greater upward force until it reaches 6.0°. At this point, the stabilizer has similar force about the C.G. Beyond 6.0°, the stabilizer has greater power. All this means that if a model is flying at angles below 6.0°, the wing will tend to raise the nose into higher angles until 6.0° is reached. Any tendency for the wing to go beyond this point will be countered by the stabilizer. If for some reason, the model finds itself above 6.0°, the stabilizer will lift up the rear portion into lower or 6.0° angular values.

Since "210" is our baby, you can imagine that we made up its curve with more than usual interest. The results were surprisingly close to actual conditions. The angle of attack might be slightly less than shown when we trim it for a glide, but it is close enough for us.

We never thought that we would one day calculate longitudinal stability curves on models. But you can see what can be done. The value of this type of work will become more apparent as we go along. We will be able to predict many other factors from such graphs. So, let us make a few more calculations for different types of designs so that we can see the difference between them and live accordingly.




| WING (POS. PITCH) | | | | | | STAB (NEG. PITCH) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| W α | C.P. | $C_L$ x $W_M$ x $W_A$ = $W_F$ | | | | Wα | S α | $SC_L$ x $S_M$ $S_A$ = $S_F$ | | |
| -2° | 50% | .25 | .75 | 210 | 39 | -2° | -6.2° | -.06 | -884 | +53 |
| -1° | 45% | .33 | 1 | 210 | 70 | -1° | -5.6° | -.02 | -884 | +17 |
| 0 | 42% | .4 | 1.1 | 210 | 92 | 0 | -5.0° | .02 | -884 | -17 |
| 1° | 40% | .47 | 1.25 | 210 | 125 | 1° | -4.3° | .07 | -884 | -61 |
| 2° | 38% | .54 | 1.35 | 210 | 154 | 2° | -3.8° | .12 | -884 | -105 |
| 3° | 36% | .62 | 1.45 | 210 | 190 | 3° | -3.1° | .16 | -884 | -141 |
| 4° | 35% | .70 | 1.50 | 210 | 220 | 4° | -2.5° | .21 | -884 | -187 |
| 5° | 34% | .76 | 1.55 | 210 | 250 | 5° | -1.8° | .26 | -884 | -230 |
| 6° | 33% | .82 | 1.60 | 210 | 275 | 6° | -1.1 | .32 | -884 | -281 |
| 7° | 32% | .88 | 1.65 | 210 | 302 | 7° | -.4° | .36 | -884 | -309 |
| 8° | 31% | .95 | 1.70 | 210 | 340 | 8° | -.2° | .40 | -884 | -352 |

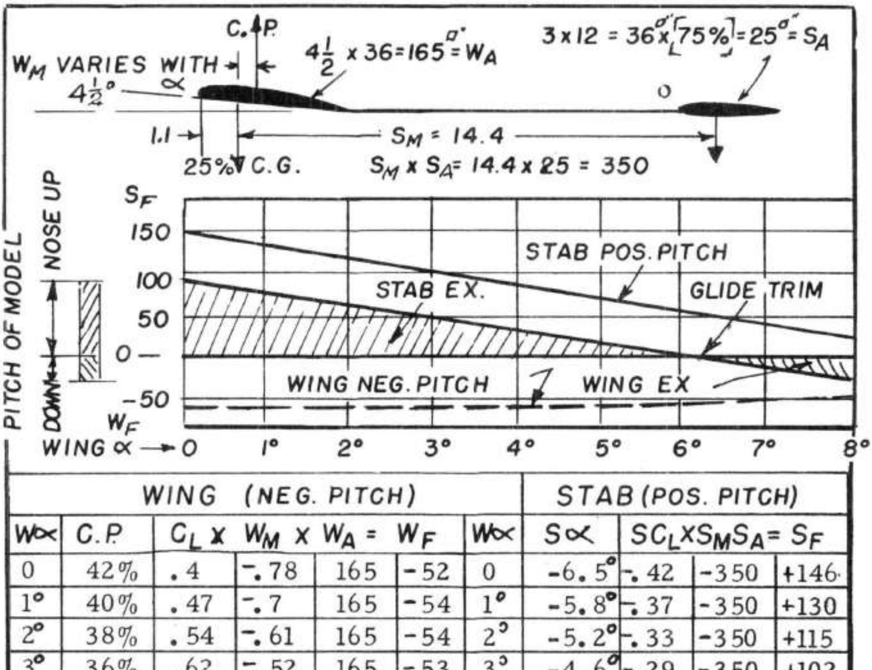
Wα = Wing's Angle of Attack
C.P. = Center of Pressure
$W_M$ = Wing Moment Arm
$C_L$ = Wing's Lift Coef.
$W_A$ = Wing Area 210 sq. in.
$W_F$ = Wing Force about C.G.

Sα = Stab's Angle of Attack
$SC_L$ = Stab's Lift Coeff.
$S_M$ = Stab Moment Arm 17"
$S_A$ = 52 sq. in. Effective area
$S_F$ = Stab Force about C.G.
$S_M$ x $S_A$ = 17 x 52 = 884

## PLOTTING CURVES FOR THE TEST MODEL

In order that we would have something solid on which to explain the behaviour of our original test model, we plotted its pitching moment curves under two C.G. conditions: 25% and ½" in front of the leading edge. Data is given on the diagram and tables. The procedure used is the same as on "210".

The original design had wing at 5°, streamlined stabilizer at zero* and C.G. at 25%. Check the graph and you will find that the trim angle was reached at about 6.3°. Also note that we have an unusual type of arrangement; both surfaces have their forces acting behind the C.G. The effect of the stabilizer is to nose the model upward while the wing tends to make it dive. But they reach the balance point at 6.3°. This, then may have been the true condition under which the model glided satisfactorily but proved so loop-crazy under power.




| WING (NEG. PITCH) | | | | | | | STAB (POS. PITCH) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wα | C.P | $C_L$ x | $W_M$ x | $W_A$ = | $W_F$ | Wα | Sα | $SC_L$ x | $S_M S_A$ = | $S_F$ |
| 0 | 42% | .4 | -.78 | 165 | -52 | 0 | -6.5° | -.42 | -350 | +146 |
| 1° | 40% | .47 | -.7 | 165 | -54 | 1° | -5.8° | -.37 | -350 | +130 |
| 2° | 38% | .54 | -.61 | 165 | -54 | 2° | -5.2° | -.33 | -350 | +115 |
| 3° | 36% | .62 | -.52 | 165 | -53 | 3° | -4.6° | -.29 | -350 | +102 |
| 4° | 35% | .70 | -.47 | 165 | -55 | 4° | -4.0° | -.25 | -350 | +88 |
| 5° | 34% | .76 | -.43 | 165 | -55 | 5° | -3.3° | -.21 | -350 | +73 |
| 6° | 33% | .82 | -.38 | 165 | -54 | 6° | -2.6° | -.16 | -350 | +56 |
| 7° | 32% | .88 | -.34 | 165 | -49 | 7° | -1.9° | -.12 | -350 | +42 |
| 8° | 31% | .95 | -.29 | 165 | -48 | 8° | -1.3° | -.08 | -350 | +28 |

NOTES: To obtain theoretical Glide Trim at 6°, the original incidence had to be changed to 4 1/2°.

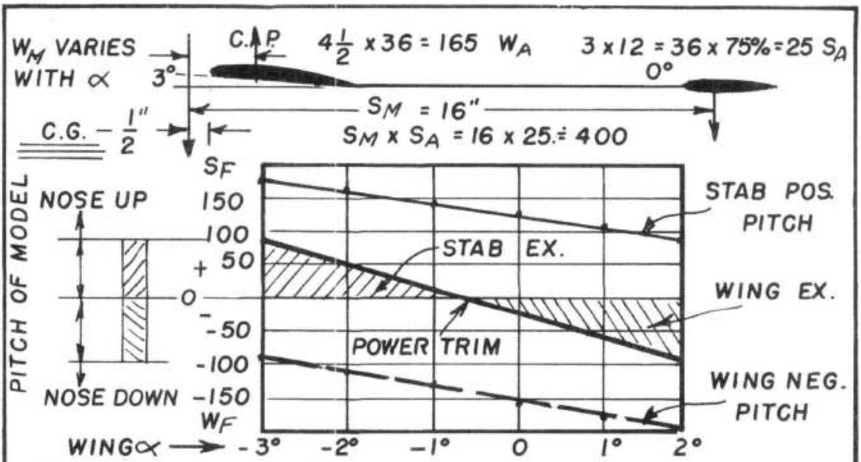
Wing Force has similar values at all angles. This happens because as $C_L$ decreases, the Moment Arm increases.

## FLYING WITH C.G. ½″ IN FRONT OF L.E.

The explanation for having C.G. ½″ in front of the wing and still have a stable power flight can be seen on the graph and table. Calculations show that the trim point for this C.G. position is between 0° and —1°. At this point, the two surfaces will balance each other, providing the wing develops enough lift at zero angle of attack.

Just for fun, we made a hasty lift calculation and found that if the model travelled 20 m.p.h. it could lift 8 oz. at zero angle of attack. See calculations.* Although the formula and calculations may not be exact for model work, the point to remember is that it is possible to make a model fly with C.G. at this ½″ spot providing you are prepared to supply the necessary speed.

Since the above trim only works at this particular speed, we had no chance to observe the glide. Perhaps a drop from several hundred feet would have given it the required speed.




| WING (NEG. PITCH) | | | | | | STAB (POS. PITCH) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $W\alpha$ | C.P. | $C_L$ | x $W_M$ | x $W_A$ | = $W_F$ | $W\alpha$ | $S\alpha$ | $SC_L$ x $S_M$ | $S_A$ | = $S_F$ |
| -3° | 60% | .18 | -3.2 | 165 | -95 | -3° | -6.9° | -.44 | 400 | +175 |
| -2° | 50% | .25 | -2.75 | 165 | -112 | -2° | -6.2° | -.4 | 400 | +160 |
| -1° | 45% | .33 | -2.5 | 165 | -135 | -1° | -5.6° | -.36 | 400 | +144 |
| 0 | 42% | .41 | -2.4 | 165 | -157 | -0 | -5.0° | -.32 | 400 | +128 |
| 1° | 40% | .47 | -2.3 | 165 | -178 | 1° | -4.3° | -.27 | 400 | +109 |
| 2° | 38% | .54 | -2.2 | 165 | -194 | 2° | -3.7° | -.23 | 400 | +92 |

The effect of Thrust Line over C.G. not used in calculations. Had it been, Power Trim Angle would be much lower because stab needs more positive pitch than 144 units to balance both, wing and High Thrust Line.

* LIFT $= C_L \times \rho/2 \times$ Area, sq. ft. $\times V^2$ ft. sec. $C_L$ at $0 = .41$

Lift $= .8$ oz. $= .5$ lb. $\rho/2 = .0012$ Area $= 165$ sq. in. $= 1.2$ sq.'

$.5 = .41 \times .0012 \times 1.2 \times V^2$ $V^2 = 900$ V = 30 ft. sec = 20mph

## SPECIFICATIONS OF EXAMPLE MODELS

In the examples which will follow we will use a 200 sq. in. wing which has a Clark Y airfoil. The size of the Stabilizer will vary as will the location of the C.G. Moment Arms, wing and stab, will vary with the C.G. location.

The wing force values were found by using wing area, lift coefficient at the particular angle of attack, and distance between the wing's "Center of Lift" and C.G. position.

The stabilizer's force values were found by using its area (minus its loss in efficiency), lift coffiecient corrected for "downwash" and the distance between the stab's "Center of Lift" and C.G. position.

The force values on the graphs are to be used only for comparison. To obtain actual forces in ounces, it is necessary to use the complete Lift Formula, which includes air speed and air density factor.

## C.G. LOCATIONS

If the areas of the wing and the stabilizer, and the distance between them are fixed, the location of the C.G. will be determined by the angular setting of the two surfaces. We can also say that if the area and angle of the wing, and the C.G. location are fixed, the area of the stabilizer will depend on its distance from the C.G. and the angle at which it is set. In the following examples we will vary the location of the C.G., and make corrections with the stabilizer area and angular placement to bring about Longitudinal Balance which is supposed to give the model Longitudinal Stability.

## C.G. AT 33% CHORD

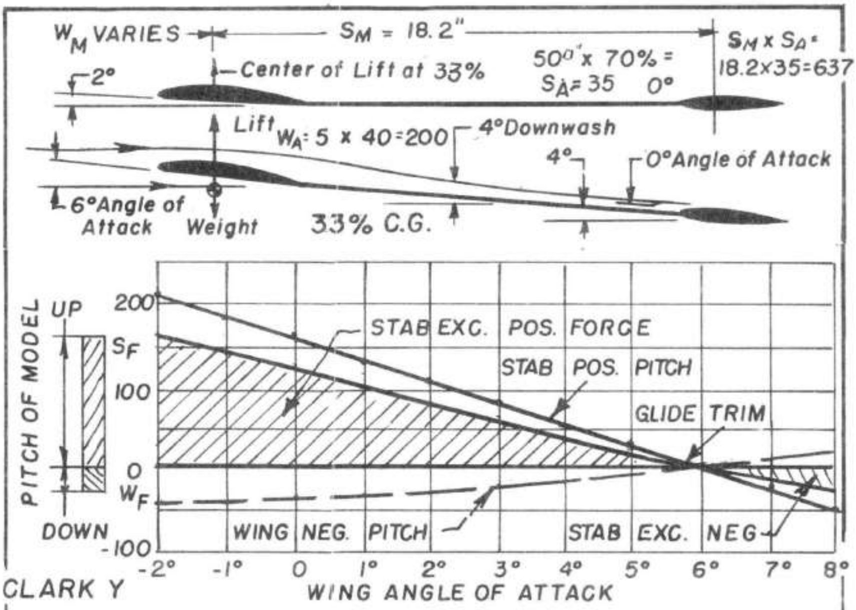
If we fix the C.G. at 33%, and then make adjustments to bring about the 6% angle of attack for the best "duration glide," we will find that the stabilizer must have no force, up or down in this situation. This can be explained by noting that when Clark Y is at 6°, its Center of Pressure or Lift is at the 33% spot. This means that the wing's lift is directly over the C.G. and that it has no force about the C.G. To keep it at this setting, the stabilizer must also not have any force about the C.G. But to take care of possible upsets, some sort of a stabilizer is needed to bring the wing back to the "trimmed" 6° angle of attack.

For our example we assumed a 50 sq. in. stabilizer with a streamlined airfoil. So that it will not develop lift when the wing is at 6°, we set it at 0° while the wing has 2° incidence. That 4° downwash will give the stab 0° angle of attack while the wing has 6°. In our calculations we assumed the stab to be 70% efficient.

---

As you can see, when the wing is at 6°, the stabilizer has no load, up or down. But if the wing should be upset to 4°, the stabilizer has a force value of 37 units downward with which to bring the wing back to 6°. And if the wing is forced to 8°, the stab has an upward force of 32 units to bring it back home.

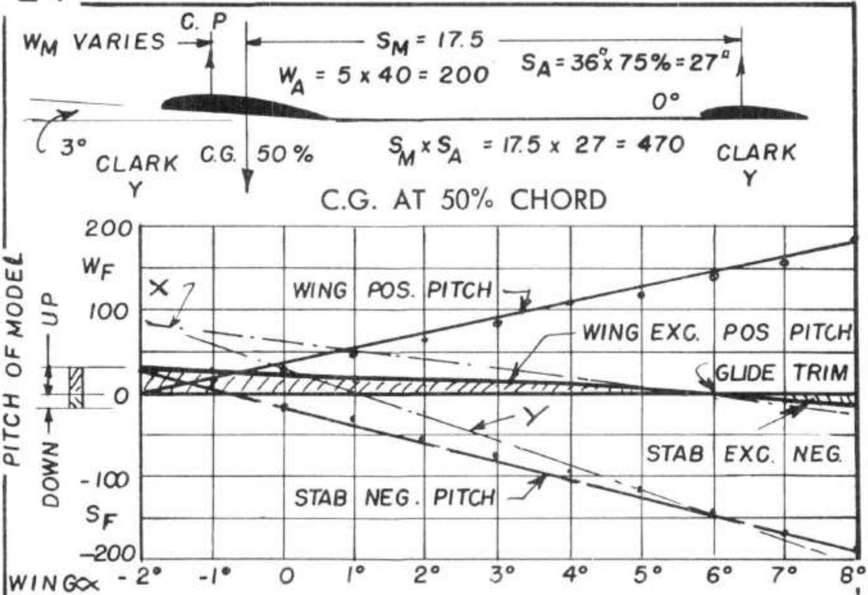
It should be evident that when the C.G. is located at 33% point, the Longitudinal Stability is exceptionally good. And it is so. Just a slight upset change in the wing will be promptly corrected by the ever watchful stab with its abundance of corrective force. Why don't we use this C.G. location on our models? That is an interesting question!




| WING (NEUTRAL PITCH) | | | | | | STAB (POS. PITCH) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| W∝ | C.P. | $C_L$ x | $W_M$ x | $W_A$ = | $W_F$ | W∝ | S∝ | $SC_L$ x | $S_M S_A$ = | $S_F$ |
| -2° | 50% | .26 | -.85 | 200 | -43 | -2° | -5.2° | -.33 | -637 | +210 |
| -1° | 45% | .33 | -.60 | 200 | -40 | -1° | -4.6° | -.29 | -637 | +185 |
| 0° | 42% | .40 | -.45 | 200 | -36 | 0 | -4.0° | -.25 | -637 | +160 |
| 1° | 40% | .47 | -.35 | 200 | -35 | 1° | -3.3° | -.21 | -637 | +134 |
| 2° | 38% | .54 | -.30 | 200 | -32 | 2° | -2.7° | -.17 | -637 | +109 |
| 3° | 36% | .62 | -.15 | 200 | -19 | 3° | -2.1° | -.13 | -637 | +83 |
| 4° | 35% | .70 | -.10 | 200 | -14 | 4° | -1.2° | -.08 | -637 | +51 |
| 5° | 34% | .76 | -.05 | 200 | -8 | 5° | -.8° | -.05 | -637 | +32 |
| 6° | 33% | .82 | 0 | 200 | 0 | 6° | -.1° | 0 | -637 | 0 |
| 7° | 32% | .88 | +.05 | 200 | +9 | 7° | .6° | .03 | -637 | -19 |
| 8° | 31% | .95 | +.10 | 200 | +19 | 8° | 1.2° | .08 | -637 | -51 |

Basically, the Longitundinal Stability depends on the balance between the wing and the stabilizer about the C.G. pivot. Also, the basic difference between model designs is almost entirely based on their difference in the C.G. locations.—Without telling us nothing else but the C.G. location we could give you a fair approximation as to how your model behaves in flight, or how it should behave.

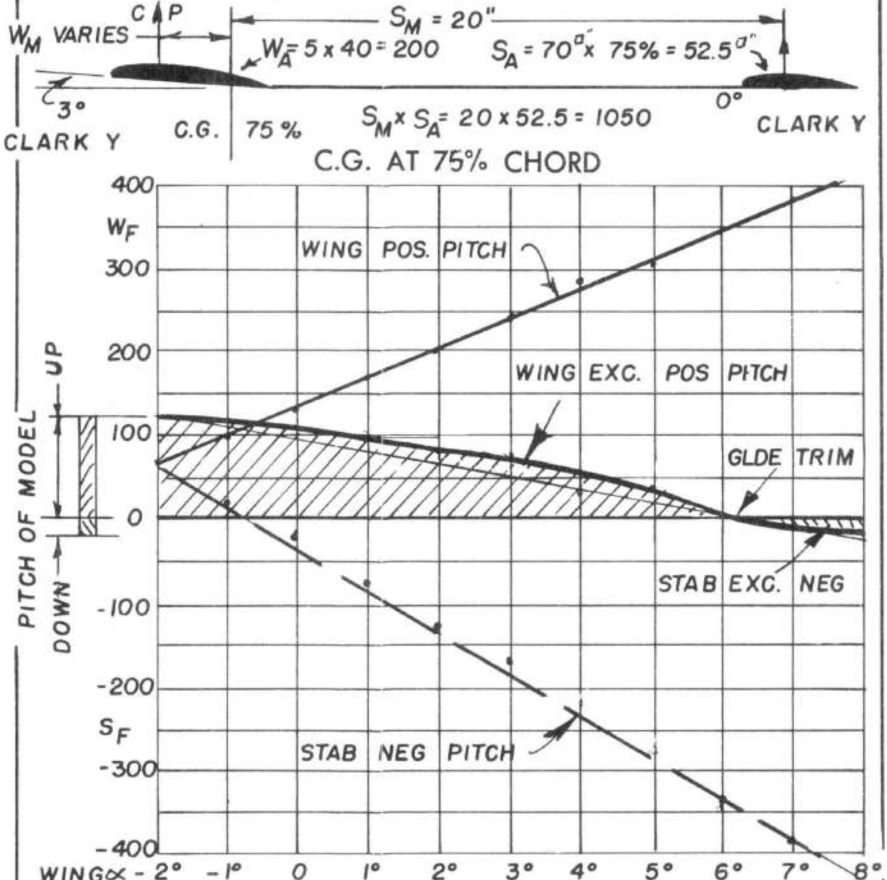
We would also like to point out that one reason why we have so little data on model design is that the full size aircraft designers stop with C.G. at 35% of the Chord, while we just begin at this point. To full size designers, the 35% point is on verge of being unsafe. While we have to go on into the region where a change of angles by thickness of a hair could mean disaster.—Why do we go beyond the 35% point? That is a very interesting question. We will give you the answer in due time, but you may not be able to comprehend it at first. So, if you do not find the answer at first reading, do not blame us but look into the mirror, and try again.



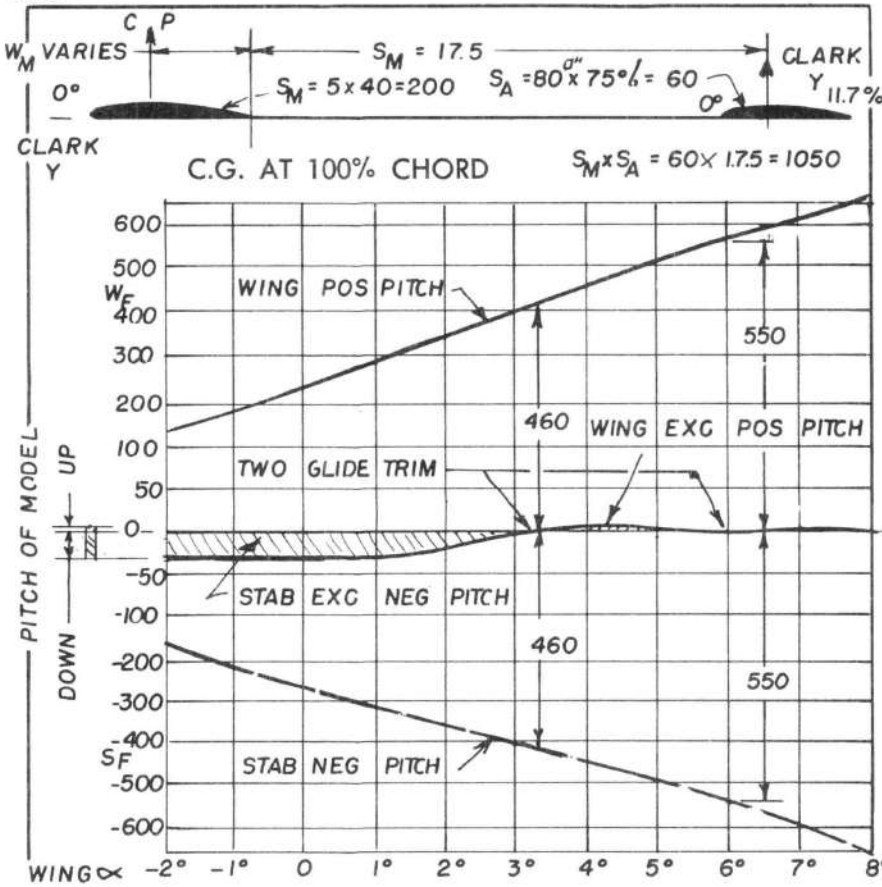

| WING (POS. PITCH) | | | | | | | STAB (NEG. PITCH) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wα | C.P. | $C_L$ × | $W_M$ × | $W_A$ = | $W_F$ | Wα | Sα | $SC_L$ × | $S_M S_A$ = | $S_F$ |
| -2° | 50% | .26 | 0 | 200 | 0 | -2° | -6.2° | -.06 | -470 | +28 |
| -1° | 45% | .33 | .25 | 200 | 16 | -1° | -5.6° | -.02 | -470 | +9.4 |
| 0 | 42% | .40 | .40 | 200 | 32 | 0 | -5.0° | .02 | -470 | -9.4 |
| 1° | 40% | .47 | .5 | 200 | 47 | 1° | -4.3° | .07 | -470 | -33 |
| 2° | 38% | .54 | .6 | 200 | 65 | 2° | -3.7° | .12 | -470 | -57 |
| 3° | 36% | .62 | .7 | 200 | 87 | 3° | -3.1° | .16 | -470 | -75 |
| 4° | 35% | .70 | .75 | 200 | 105 | 4° | -2.5° | .2 | -470 | -94 |
| 5° | 34% | .76 | .8 | 200 | 121 | 5° | -1.8° | .25 | -470 | -117 |
| 6° | 33% | .82 | .85 | 200 | 140 | 6° | -1.1° | .32 | -470 | -150 |
| 7° | 32% | .88 | .9 | 200 | 158 | 7° | -.4° | .36 | -470 | -170 |
| 8° | 31% | .95 | .95 | 200 | 180 | 8° | .2° | .4 | -470 | -188 |

The above presentation of the Pitching Moment for 50% C.G. is not typical. It illustrates what can happen if the angular difference between wing and stab is kept at the popular 3°. 50% C.G. is used for gliders to give quick response to airflow changes. The above Ex. Wing Force is too shallow for this. Better arrangement would be to increase wing incidence to 4° and M.A. to 20". This would change Stab Neg. Slope to "Y" and give wing more power around C.G. as shown by "X".

Moving the C.G. further back to the 75% spot we find that we had to use Clark Y on stab and increase its area to 70 sq. in. We also set the wing at 3° and stab at 0° incidence setting. The layout seems to be close to what we are using on some power models.

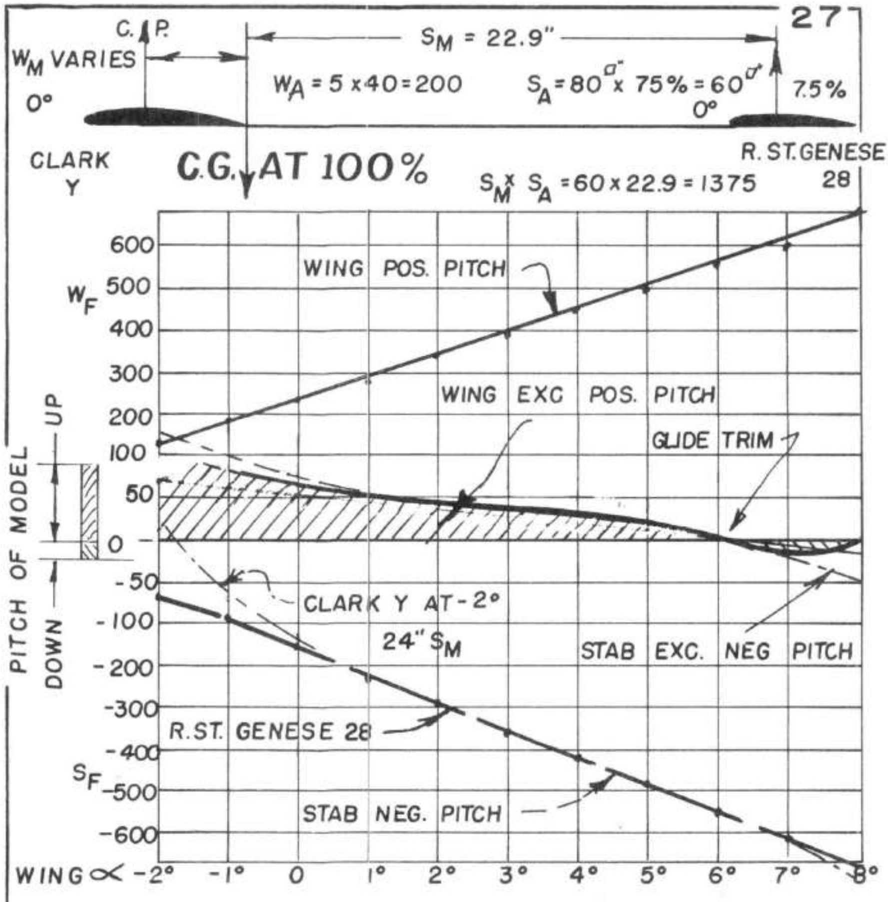



| WING (POS. PITCH) | | | | | | STAB (NEG PITCH) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wα | C.P. | $C_L$ x | $W_M$ x | $W_A$ = | $W_F$ | Wα | Sα | $SC_L$ x | $S_M$ $S_A$ = | $S_F$ |
| -2° | 50% | .26 | 1.25 | 200 | 65 | -2° | -6.2° | -.06 | -1050 | 63 |
| -1° | 45% | .33 | 1.50 | 200 | 99 | -1° | -5.6° | -.02 | -1050 | 21 |
| 0 | 42% | .40 | 1.65 | 200 | 132 | 0 | -5.0° | .02 | -1050 | -21 |
| 1° | 40% | .47 | 1.75 | 200 | 170 | 1° | -4.3° | .07 | -1050 | -73 |
| 2° | 38% | .54 | 1.85 | 200 | 200 | 2° | -3.7° | .12 | -1050 | -125 |
| 3° | 36% | .62 | 1.95 | 200 | 240 | 3° | -3.1° | .16 | -1050 | -168 |
| 4° | 35% | .70 | 2.0 | 200 | 280 | 4° | -2.5° | .21 | -1050 | -220 |
| 5° | 34% | .76 | 2.05 | 200 | 310 | 5° | -1.8° | .26 | -1050 | -273 |
| 6° | 33% | .82 | 2.1 | 200 | 340 | 6° | -1.1° | .32 | -1050 | -340 |
| 7° | 32% | .88 | 2.15 | 200 | 380 | 7° | -.4° | .36 | -1050 | -380 |
| 8° | 31% | .95 | 2.2 | 200 | 417 | 8° | .2° | .4 | -1050 | -420 |




| WING (POS. PITCH) | | | | | | | STAB (NEG. PITCH) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| W | C.P. | $C_L$ | x $W_M$ | x $W_A$ = | $W_F$ | W∝ | S∝ | $SC_L$ | x $S_M S_A$ = | $S_F$ |
| -2° | 50% | .26 | 2.5 | 200 | 130 | -2° | -3.2° | .15 | -1050 | -157 |
| -1° | 45% | .33 | 2.75 | 200 | 181 | -1° | -2.6° | .2 | -1050 | -210 |
| 0 | 42% | .40 | 2.9 | 200 | 231 | 0° | -2.0° | .25 | -1050 | -262 |
| 1° | 40% | .47 | 3.0 | 200 | 282 | 1° | -1.3° | .3 | -1050 | -315 |
| 2° | 38% | .54 | 3.1 | 200 | 335 | 2° | -.7° | .34 | -1050 | -355 |
| 3° | 36% | .62 | 3.2 | 200 | 395 | 3° | -.1° | .39 | -1050 | -410 |
| 4° | 35% | .70 | 3.25 | 200 | 455 | 4° | .5° | .43 | -1050 | -450 |
| 5° | 34% | .76 | 3.3 | 200 | 500 | 5° | 1.2° | .47 | -1050 | -495 |
| 6° | 33% | .82 | 3.35 | 200 | 550 | 6° | 1.9° | .52 | -1050 | -550 |
| 7° | 32% | .88 | 3.4 | 200 | 600 | 7° | 2.6° | .57 | -1050 | -595 |
| 8° | 31% | .95 | 3.45 | 200 | 655 | 8° | 3.2° | .62 | -1050 | -655 |

This 0-0 has diving pitch below 3° and two Glide Trims. Impossible to fly. Reason? Clark Y Stab has too high lift at low angles. Cure: Thinner stab with lower lift. See next page.




| WING | | STAB (NEG. PITCH) | | | |
|---|---|---|---|---|---|
| $W_F$ | $W\alpha$ | $S\alpha$ | $SC_L \times S_M$ | $S_A =$ | $S_F$ |
| 130 | -2° | -3.2° | .05 | -1375 | -68 |
| 181 | -1° | -2.6° | .09 | -1375 | -95 |
| 231 | 0 | -2.0° | .12 | -1375 | -165 |
| 282 | 1° | -1.3° | .17 | -1375 | -230 |
| 335 | 2° | -.7° | .22 | -1375 | -290 |
| 395 | 3° | -.1° | .26 | -1375 | -358 |
| 455 | 4° | .5° | .3 | -1375 | -412 |
| 500 | 5° | 1.2° | .35 | -1375 | -480 |
| 550 | 6° | 1.9° | .40 | -1375 | -550 |
| 600 | 7° | 2.6° | .45 | -1375 | -620 |
| 655 | 8° | 3.2° | .50 | -1375 | -655 |

Stab change from 11.7% Clark Y to 7.5% R.St.G.28 changed pitching moment to normal. Thinner St.G.28 has less lift than Clark Y when compared angle for angle. Hence its lower lift at lower angles enables the wing to have positive pitch up to 6°. We made calculations which showed that if Clark Y had been set at -2° to wing, on a 24" M.A. it would produce almost identical pitch values as the R.St.G.28. —— These examples illustrate the sensitivity of the 0-0 design to the thickness of the Stab airfoil and its angular setting.

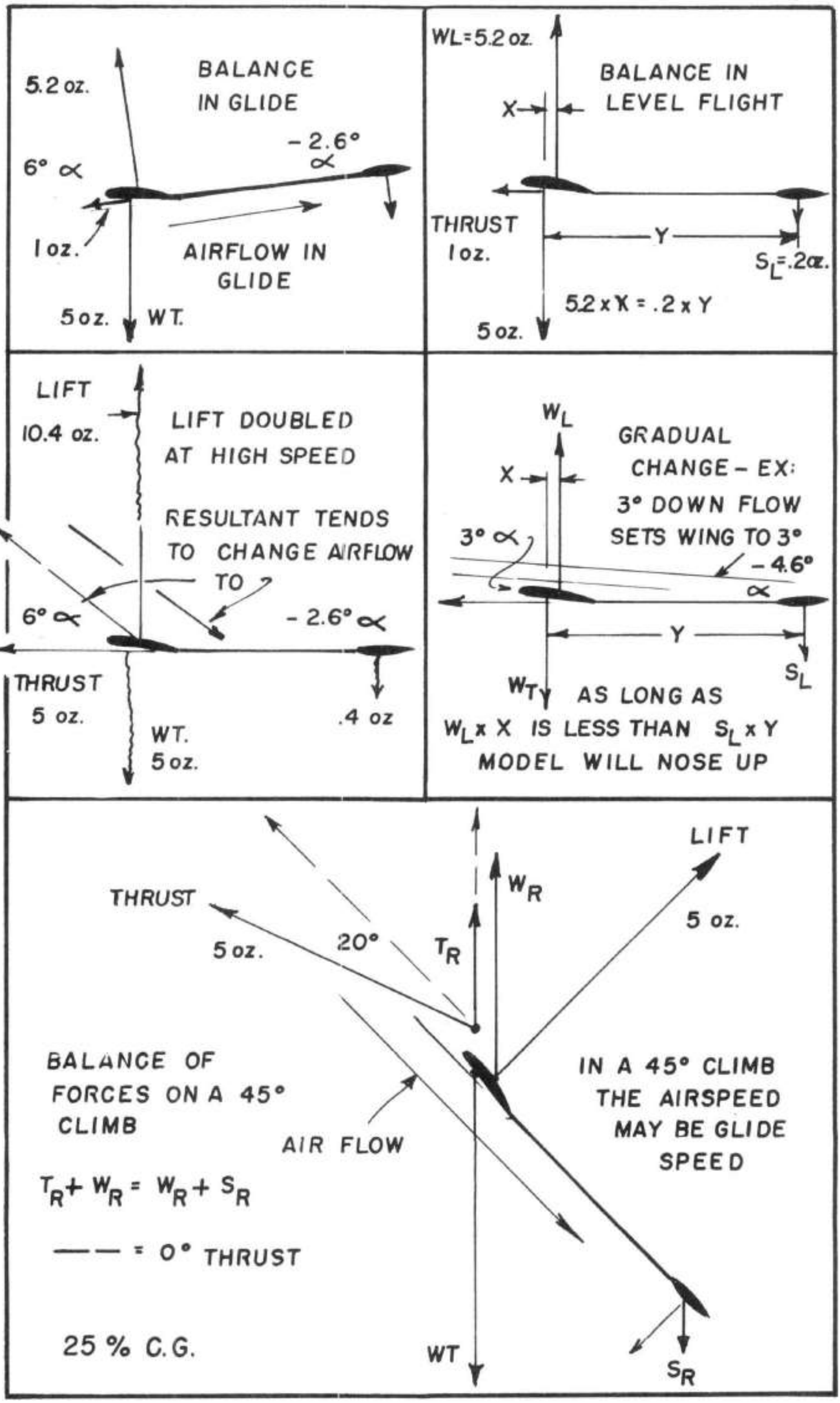
## CAUSE OF LOOPING —25% C.G.

If the wing and stab, trimmed at 6.3°, and the thrust line was over the C.G., why did it loop? This can be best explained by reviewing the force diagram of the model at various stages. In the glide, the wing and stab were in balance, and lift almost equalled the weight. When we applied power, it increased speed. With increase in speed, we automatically increased the lift as the model was trimmed for high angles of attack. There was nothing present to make it go into lower trimmed or balanced angles except the high thrust line. Evidently, this did not work as expected. But let us see what happens if we place higher lift force into the diagram. We find a new resultant whose direction is upward.

The natural tendency of this resultant is to "pull" the model along its new direction. This means that the airflow has changed from angle shown in dotted line to one parallel to the resultant. Follow this new airflow and you will find a decrease in the angle of attack for the entire model. We have no way of knowing at this time what it was, but let us say that the change was 3°. Check the graph at 3.0° and note the low force value of the wing and high value of the stabilizer. What do you think will happen? The stabilizer would naturally swing the nose upward. Since we have overabundance of power, the model will follow through and loop. Now that we know, we can say that this design, C.G. at 25%, is made to order for looping: Needs very little encouragement. It may be compared to stunt line control models. So, as long as the speed under power is greater than that required for a glide or level power flight, the model will keep on developing that lift resultant and keep it under the 6.3° trim or balance with looping as the result.

As Hewitt mentioned, the prop wash passing through the wing may also have been deflected downward, and so increase downwash angles below the trim point. — Frankly, at the moment, we are not sure of what happened, but signs point to a reduction of stablizer's angle of attack under power. Our theory of change of angle of attack, due to development of upward resultant, is the closest thing we have at this time. Be this as it may, the fact remains that models tend to loop under power, and excessive lift is the basic reason. Reduce lift and your looping troubles will be over and you can climb on the prop pull.

Evidently, the counter-loop power of thrust line 1″ above the C.G. is comparatively small in relation to the force developed by the stabilizer. Let us see what happens when we use large amount of downthrust. Note how we bring the results closer to the glide speed at which the wing and stabilizer are balanced. Of course, excessive downthrust is wasteful and later on we will show our version of new design.



BALANCE IN GLIDE
5.2 oz.
6° ∝
- 2.6° ∝
1 oz.
AIRFLOW IN GLIDE
5 oz.
WT.
WL=5.2 oz.
BALANCE IN LEVEL FLIGHT
X
THRUST 1 oz.
Y
SL=.2 oz.
5.2 x X = .2 x Y
5 oz.
LIFT 10.4 oz.
LIFT DOUBLED AT HIGH SPEED
RESULTANT TENDS TO CHANGE AIRFLOW TO
6° ∝
- 2.6° ∝
THRUST 5 oz.
WT. 5 oz.
.4 oz
WL
GRADUAL CHANGE - EX:
3° DOWN FLOW SETS WING TO 3°
X
3° ∝
- 4.6° ∝
Y
WT
SL
AS LONG AS WL x X IS LESS THAN SL x Y MODEL WILL NOSE UP
THRUST
5 oz.
20°
TR
WR
LIFT
5 oz.
BALANCE OF FORCES ON A 45° CLIMB
AIR FLOW
IN A 45° CLIMB THE AIRSPEED MAY BE GLIDE SPEED
TR + WR = WR + SR
—— = 0° THRUST
25 % C.G.
WT
SR

## EFFECT OF PITCHING MOMENT IN GLIDE

The above conditions exist in a smooth glide. If the model is disturbed and forced to move away from its trim point, the balance of power comes into play and brings the model back to trim angle. The difference between the three C.G. conditions is the degree of time in which they act to bring about corrective measures.

The snappiest in response is, of course, the 33% C.G. layout. If the upset causes a 1° change in airflow, the stabilizer has a force of 75% $S_F$ to bring it back to 6°, if the upsetting force tends to make it dive; and a force of 52% $S_F$ if it tends to make it stall. Such layouts can actually be seen to wiggle the model into smooth flying as they strike gusts and the like. Such powerful stabilizer control keeps the model pretty close to its trim position at all times.

When 1° disturbance hits the 75% design, the wing has a force of 15 $W_F$ to bring it back up to 6°. While the stabilizer has small $S_F$ to bring it out of stalling region. The reaction is definitely much milder than on the 33% design, but it is still practical.

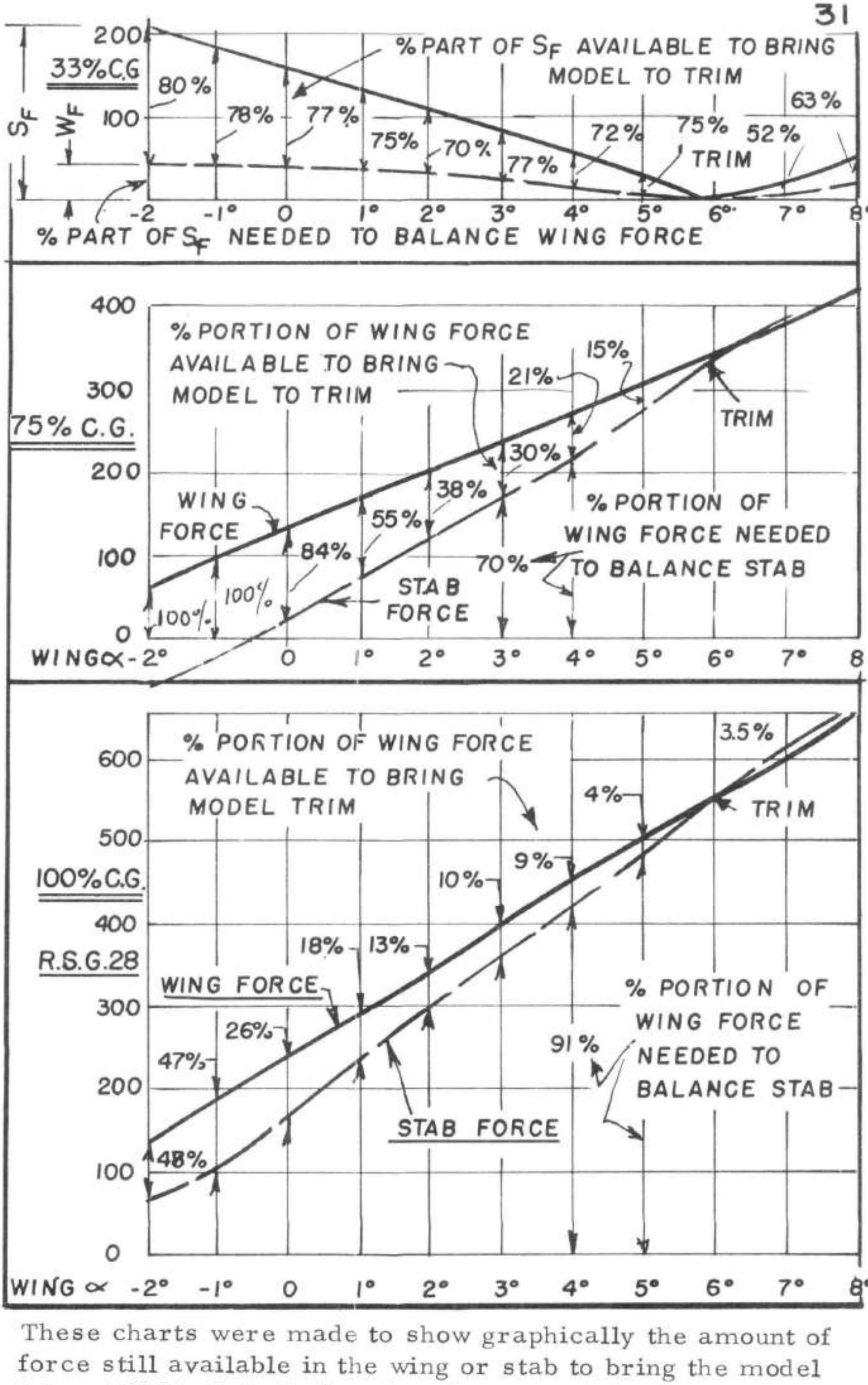
The 100% C.G. is definitely in the slow side. The wing has only 4% $W_F$ to correct diving upsets, while the stabilizer has only 3.5% $S_F$ to prevent it from stalling. So that if the upsetting force happens to be greater than these force units, the model will keep on diving or go into a stall without having a chance to recover.

Some might say, you still have some balancing control on 100% according to the graph. We do have, but we must not forget what is known as inertia. Once the model starts to move into a new direction it wants to go on. If the correction is applied fast, like on 33%, the model will be checked before it has a chance to pick up inertia. But on 100%, it will move quite a distance before the surfaces even know that there has been a change in the direction. Hence, those long zooms from a stall or no recovery from a dive.

The slope of the moment curve is a good indication of the design's ability to stay trimmed or stable. If the slope is steep, as for 33%, the recovery will take place with small change in angle of attack. But a slope, like 100%, will need a great change before it can develop sufficient counter-action.

You should also observe that as the C.G. moves towards the trailing edge, the recovery takes longer; and how the moment curve comes close to the zero line so that only slight upset or misalignment in flight would cause it to break out of trim. Notice that 33% C.G. hardly needs any stabilizer, while 100% position requires close to 50% of wing area to provide trim. Also, how the load on the stabilizer is increased as noted by angular settings.

It is a pity that the best glide setting, 33% C.G., is not suitable for high power as we have found out.




These charts were made to show graphically the amount of force still available in the wing or stab to bring the model into a "Glide Trim" after the wing or stab has been balanced. See Page 33 for calculations for actual values.

## EFFECT OF PITCHING MOMENT UNDER POWER

The very factors which cause poor recovery when a model is upset in a glide make it possible to obtain high power flights without looping.

As we have mentioned before, when we apply power, the increase of speed increases lift which decreases the overall angle of attack. What is the value in degrees of this overall decrease of angle of attack we do not know. But for the sake of carrying through with our explanation, let us say 3°. This means that the angle of attack of our wing is now 3° instead of 6°. Let us check the various graphs at the 3° mark and see what happens.

On the 33% C.G. design the stabilizer definitely wants to point the nose upward into a loop when the wing is flying at 3°. As long as we have excessive power, there is nothing to check this action of the stabilizer. This action has already been covered in explaining the looping tendencies of our test model. So, any overpowered model using this type of balance, will have looping tendency, and it will require considerable amount of downthrust to make it behave. But for low-powered models, where just slow cruise is desired, it will prove to be very stable and easy to fly.

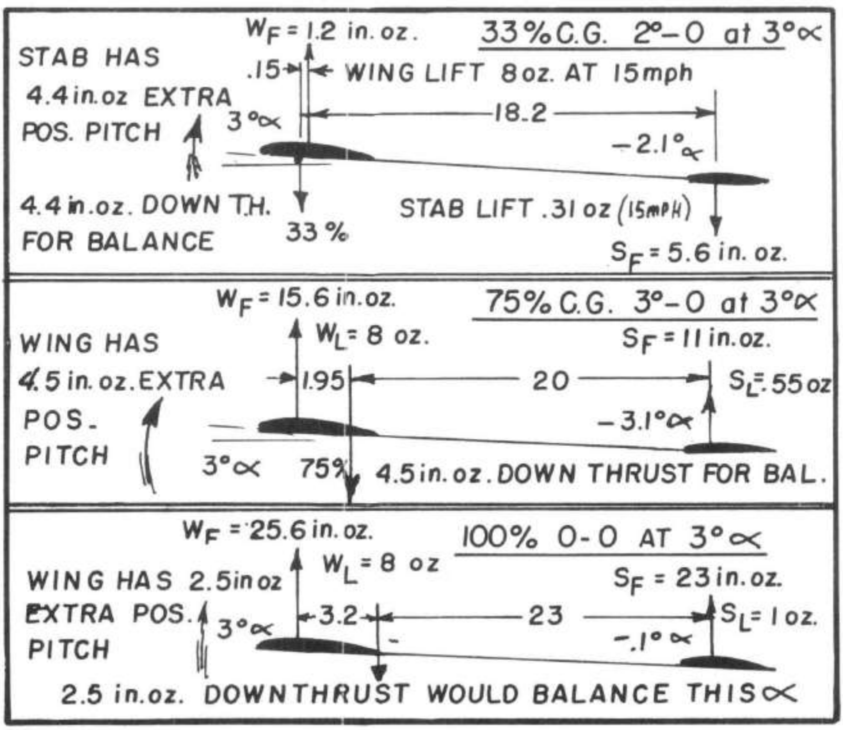
On 75% layout a change of 3° gives the wing a certain amount of power to nose the model into a loop. Our experience with this set-up on the Wakefield design is mixed. When fully wound, we have trouble in directing our model's high power into high climb. A straight-away flight almost always leads into looping or power stall. But as the power dies down the model assumes a stable climbing attitude which gradually levels into a cruise. It does not take much reasoning to see that, at the beginning, high-power increases speed and lift and brings the model into lower angles than glide setting, and so cause looping. And as power drops, the speed decreases and with it extra lift, so that the model shifts back to its basic glide balance. Downthrust is definitely needed for rubber models to prevent power stalls. On gas models a straight power flight will very likely end up in a large loop. Of course, normal flight adjustments and use of pylon tends to make the model assume a helical climb.

100% C.G., in combination with 0-0 setting, is made to order for high power. Reason for this is that there is such a slight difference in the correcting forces of the wing and stabilizer, through a large range of angles. Take a look at the graphs showing their force lines. If there is a reduction of the overall angle of attack to 3°, the wing has a very slight edge over the stabilizer and we should not expect fast looping response from it. And this difference remains at similar values through a large range of angles.

This small difference of balance force between wing and stabilizer should also explain why 100% C.G. and 0-0 design do not require downthrust. The stabilizer force keeps close to the wing's throughout large range of angles so that it needs no help from thrust line. Of course, if the two forces, for some reason, do not run so close on your 100% 0-0 design, downthrust may be needed.

The small extra force of the wing may cause a loop. Such a loop, however, would be of a very large diameter in comparison to 33% kind, and it will require a very high power-weight ratio because of the small force that the wing can apply towards looping. It is this large loop, characteristic of the normal high power 100% C.G. design, that is its salvation under high power flying. You can see that by the time the model reaches a vertical position, it has travelled a long distance and taken a certain amount of time, in contrast to 33% snappy reaction due to high force or lift value of the stabilizer under 6°. It is not too far fetched to reason that, as the model climbs upwards, the propeller became gradually loaded with the weight of the model, plus its drag. This extra load would definitely slow up the forward or upward speed. As the speed is reduced, the lift resultant comes closer to the glide path line where the wing and stabilizer balance, and so removing the slight looping tendency. The model can then proceed on its way up without trouble.

Before you go overboard for 100% C.G. 0-0 read on and see why it can only be handled by the experienced flyers, and why you should keep it away from the beginners.



## ADJUSTING FOR LONGITUDINAL STABILITY

The difference of the various C.G. positions, which, after all, is the basis for difference in designs, can be further distinguished by noting what happens when we make slight changes in angles.

Would you like to know why those 0-0 settings on 100% C.G. are so touchy to adjust? Well. let's take our 100% C.G. as an example. While testing, we find that it has a slight stall in the glide. We decide to correct it by placing 1/16″ strip under the stabilizer's leading edge. The result is a fast drop dive out of our hands. We keep on fiddling around until we cure the stall, and find that the adjustment required less than 1/32″ wedge. Now, let us examine the pitching moment calculations and see what actually happened.

1/16″ means almost 1° on 4½″ chord. This increases stabilizer's incidence by 1° over the wing. So we shift the stabilizer calculations by 1° as shown. We know this did not work. As you can see, there is no point within -2° to 8° range at which the wing force is greater than the stabilizer's to bring about a trim. The stabilizer naturally takes over, but definitely, and you get a fast drop dive. We decrease the angle by 1/32 or ½°. The result is still a fast dive, but not so violent. Table for this condition shows that the model could reach the trim point between 2° and 3°. Then we use 1/64″ or ¼° blocking. This works and the calculation table has the trim point between 5° and 6°. Just think, only 1/32 or ½° increase of the stabilizer's incidence was required to bring the model from a slight stall into a fast dive. Take note that this type of model is practically a standard design

If we had used the wing for corrections, the results would have been similar as it is the angular change between the two surfaces that gives the results mentioned.

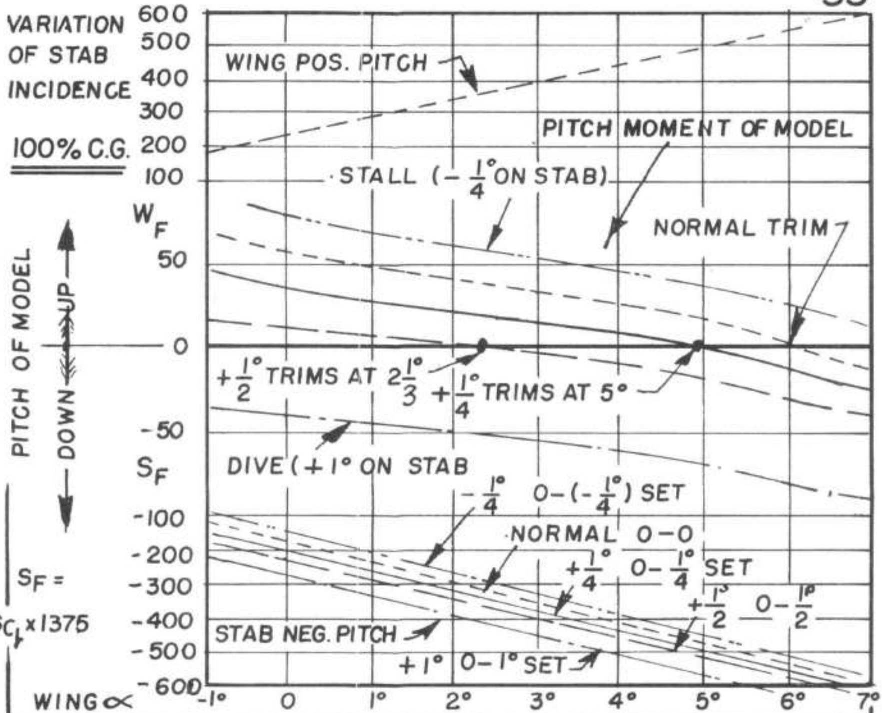
The same procedure or reasoning applies when we try to bring the model to a smooth glide from a diving tendency. —

————————— The adjustments are just as touchy but with the difference that the model insists on complete and positive stalls, if we use ¼° too much incidence in the wing.

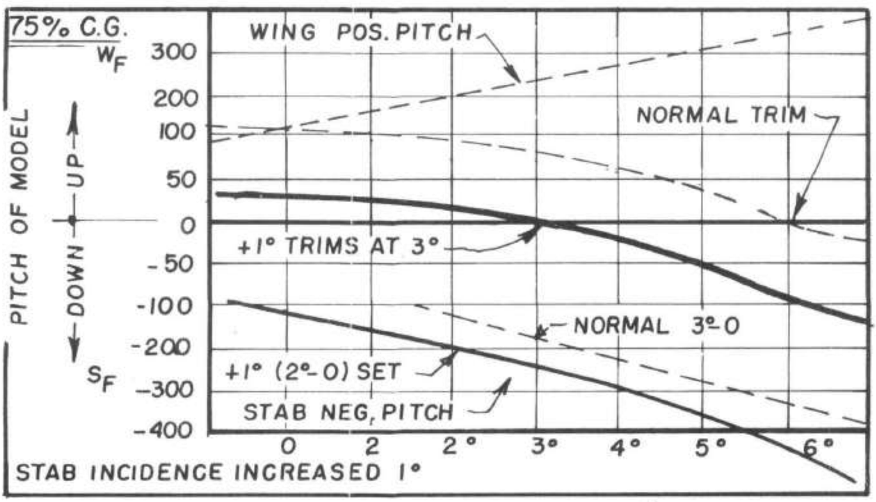
This slightest change of angular setting can be just as deadly under power. The touchy adjustment is with you at all times. If, for some reason, (we could list them by the dozen, such as loose and sloppy mounting) the stabilizer should increase its incidence by 1° during power flight, the result would be a power dive that would hold its beholders spellbound. Sounds familiar, doesn't it? In fact, a change of ¼° would be disastrous.

The 75% C.G. is comparatively easy to adjust. Increasing the stabilizer's angle by 1°, to correct stalling tendency, would bring the trim or balance point to 3°.

While on the 33% C.G., 1° stabilizer change would mean a change of only 1° for the wing's angle of attack. This means you can make course adjustments without getting into trouble.




| WING | | STAB $-\frac{1}{4}$° | | | STAB $+\frac{1}{4}$ | | | STAB $+\frac{1}{2}$° | | | STAB +1° | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wα | $W_F$ | Sα | $S_{C_L}$ | $S_F$ | Sα | $S_{C_L}$ | $S_F$ | Sα | $S_{C_L}$ | $S_F$ | Sα | $S_{C_L}$ | $S_F$ |
| 0° | 231 | -2.25° | .11 | 150 | -1.75° | 14 | 193 | -1.5° | .16 | 220 | -1° | .2 | 275 |
| 3° | 395 | -.35° | .24 | 330 | .15° | .27 | 371 | .4° | .29 | 400 | .9° | .32 | 440 |
| 6° | 550 | 1.75° | .37 | 510 | 2.15° | .41 | 565 | 2.4° | .42 | 580 | 2.9° | .46 | 630 |




SCALE OF CHART VARIES "PITCH OF MODEL" EXPANDED

## DESIGNING FOR LOW LIFT AT HIGH SPEED

You can be sure that our experience with the high thrust counter-looping design surely flattened our ego. However, we were still determined to make a·ship that would climb at 45° straight-away. And so we read and re-read Hewitt's letter, trying to tie up his information with what we found in our test. The main facor which gradually emerged from our poor brain was that somehow we will have to keep lift low during power portion of the flight.

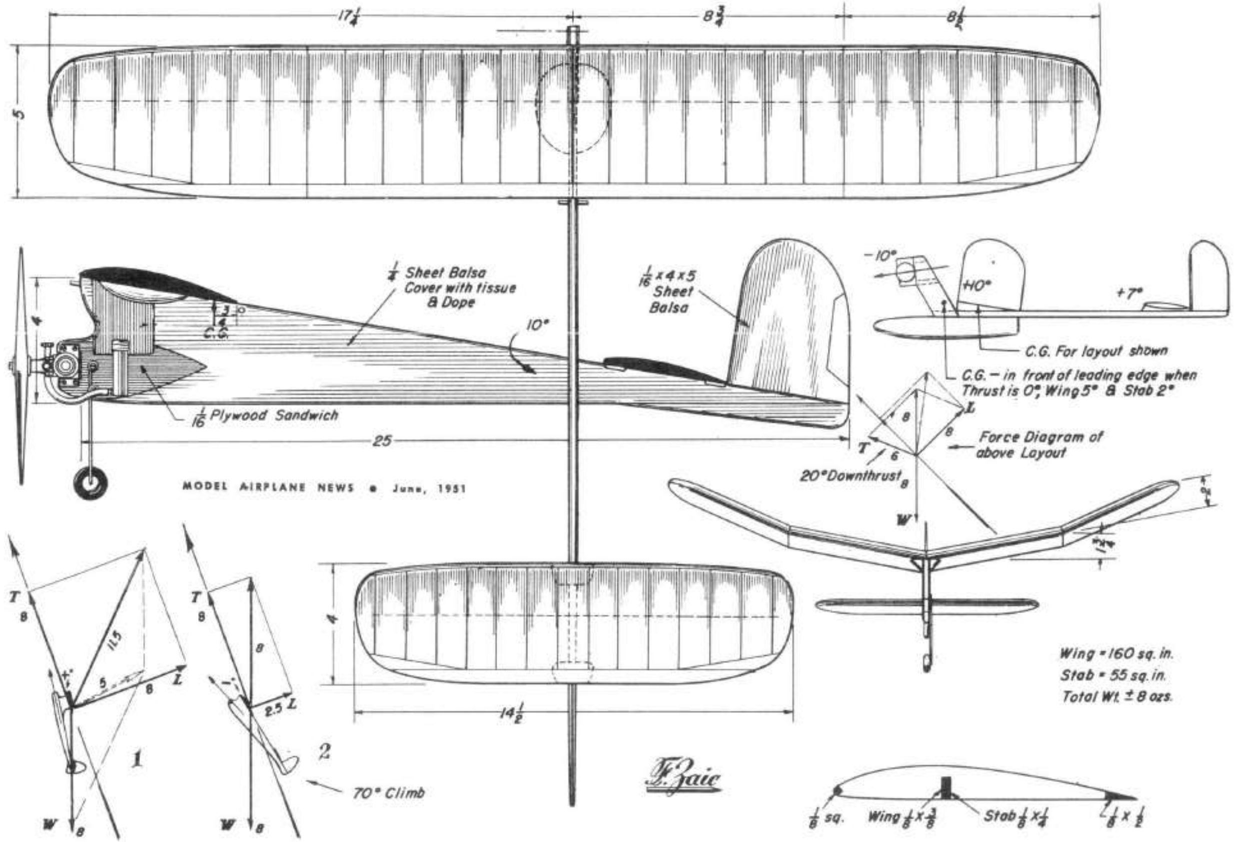
We had no idea just how to reduce lift during power, nor did we know the exact reason why we should. Remember, all this happened before we began to delve deeper into this problem,— before we made the pitching moment calculations.

And so the question of how to keep lift low during power without excessive downthrust kept us stumbling into blondes for days. Hewitt suggested using pylon design to prevent stronger downwash due to prop blast. But since practically every model now in use is a pylon and still loops or zooms under power, we had to look further. We thought of using the cut -off timer to operate the stabilizer during power run. We also designed a device which would adjust stabilizer's angle only while the prop was rotating. Our main objective was to increase the stabilizer's positive angle so that it would tend to keep the model from looping under power, and then come back to normal glide adjustment.

A second, or was it the tenth, look at Hewitt's pylon sketch made us think that it could be used for something else besides having the prop blast clear the wing. We could utilize the prop blast by having it directed on the stabilizer. This would be especially effective if we set the stabilizer at large positive angle to the blast and thereby making it create greater lift during power than in the glide. And this would only happen while the power is on. With this new idea in mind, we designed the model shown.

Knowing that we must have high angular difference between the stabilizer and the prop blast, that wing should be out of prop wash and some downthrust was desirable, the design followed natural inclination. Since we wanted to use 2° difference between wing and stabilizer, and have stabilizer at a large angle to the prop blast line, we decided to have 10° difference between wing and thrust line. This might be on the high side but the actual downthrust below the flight path may be 5° and loss of forward thrust due to this angulation is low. The important point was that we had a blast angle of 8° on our stabilizer.

The model itself was made very simply: 1/4" balsa sheet used for fuselage with engine mounted on side; wing, stabilizer and general outline are shown. We had planned to use .049 Cub but it refused to operate on test day. The .09 was substituted, which may be high for this size of model, but it would definitely show if we were on the right track in obtaining low lift at high speed, or controlling the looping tendencies.



17 1/4
8 3/4
8 1/2
5
1/4 Sheet Balsa
Cover with tissue
& Dope
1/16 x 4 x 5
Sheet
Balsa
10°
C.G.
1/16 Plywood Sandwich
25
4
-10°
+10°
+7°
C.G. For layout shown
C.G. – in front of leading edge when
Thrust is 0°, Wing 5° & Stab 2°
Force Diagram of
above Layout
20° Downthrust
14 1/2
70° Climb
Wing = 160 sq. in.
Stab = 55 sq. in.
Total Wt. ± 8 ozs.
1/8 sq.
Wing 1/8 x 3/8
Stab 1/8 x 1/4
1/8 x 1/2
F. Zaic

We glide-tested the model and it was fine. The power flight? Man, now you are talking! Practically straight up without a side quiver. As it got overhead, we could swear that it was actually "lifting" horizontally. You know, vertical climb but low lift pulling it to one side without looping tendency; just pure power pull. Nice fly-into recovery. Glide was wide open without any definite direction. It looked like we finally got our ideal design.

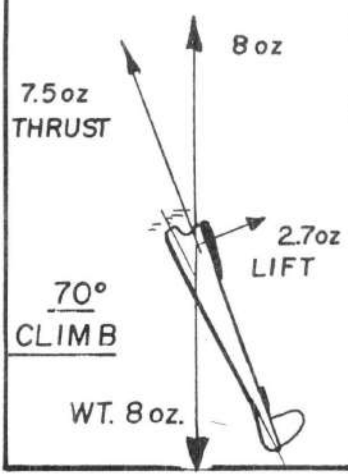
Then we tried to make it have a definite glide circle, a tight one preferably. No dice. A slight right rudder adjustment would make it dive to right. Then it came to us that in a vertical flight a right circle setting would produce a sort of a vertical circle, or a wing-over loop. Evidently, we just had too much power for any adjustments, but our basic problem, how to control looping was solved. It was just a matter of time and "loafing money" to work out the rest.

## CONTROLLING POWER FLIGHT WITH PROP SLIPSTREAM

The explanation why our new test model had no looping troubles can be best explained by checking its pitching moment curve. For normal glide, its trim point was as shown. When we applied power, the prop slipstream was directed on the angled stabilizer which increased its angle of attack, and thereby moving the trim point to lower angles of attack for the entire model at which the wing developed less lift, or just enough of it to preserve the balance.

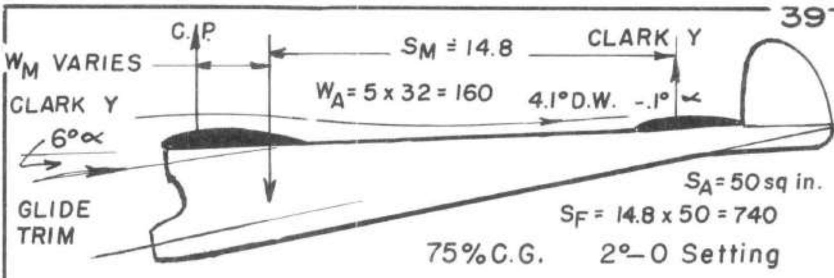
Just by how many degrees did the slipstream increase stabilizer's angle of attack, we do not know. We could calculate if we knew the speed of the model and slipstream. See examples.

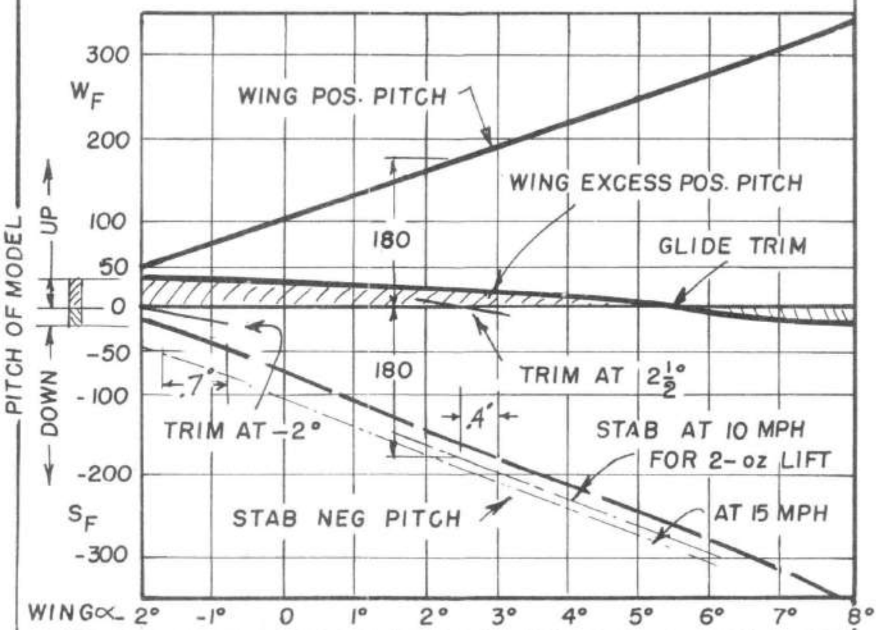
The force diagrams showing conditions in glide and power at various angles should help in clearing up the effect of slipstream on angled stabilizer without wing interference.




AT 10 MPH WING WILL LIFT 2.7 oz AT 2½° ∝. TO BRING WING TO 2½° ∝, STAB ∝ MUST BE INCREASED BY .4° BY PROP BLAST (TO -2°)

AT 15 MPH 2.7 oz. WING AT -2° ∝ PROP BLAST MUST INCREASE STAB ∝ BY .7° (TO -4.5°)
NOTE GLIDE CHART, WHERE WING IS AT -2°, STAB IS AT -5.2°




| WING (POS. PITCH) | | | | | | STAB (NEG. PITCH) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| W∝ | C.P. | $C_L$ x | $W_M$ x | $W_A$ = | $W_F$ | W∝ | S∝ | $S_{C_L}$ x | $S_M$ $S_A$ = | $S_F$ |
| -2° | 50% | .26 | 1.25 | 160 | 50 | -2° | -5.2° | .02 | 740 | 15 |
| -1° | 45% | .33 | 1.50 | 160 | 78 | -1° | -4.6° | .-5 | 740 | 37 |
| 0° | 42% | .40 | 1.65 | 160 | 105 | 0° | -4.0° | .1 | 740 | 74 |
| 1° | 40% | .47 | 1.75 | 160 | 131 | 1° | -3.3° | .15 | 740 | 110 |
| 2° | 38% | .54 | 1.85 | 160 | 160 | 2° | -2.7° | .20 | 740 | 148 |
| 3° | 36% | .62 | 1.95 | 160 | 195 | 3° | -2.1° | .24 | 740 | 177 |
| 4° | 35% | .70 | 2.0 | 160 | 222 | 4° | -1.5° | .28 | 740 | 207 |
| 5° | 34% | .76 | 2.05 | 160 | 250 | 5° | -.8° | .33 | 740 | 242 |
| 6° | 33% | .82 | 2.10 | 160 | 275 | 6° | -.1° | .38 | 740 | 280 |
| 7° | 32% | .88 | 2.15 | 160 | 300 | 7° | .6° | .43 | 740 | 318 |
| 8° | 31% | .95 | 2.25 | 160 | 340 | 8° | 1.2° | .48 | 740 | 355 |

NOTE: Slipstream covers only portion of stab. Effect of Down Thrust not considered.

## EFFECT OF THIN AIRFOIL STABILIZER

Most of us use thinner airfoils on the stabilizer than we do on the wing. The nearest section that would fit our purpose is Rhode St. Genese 28. We used it to calculate the stabilizer force on 100% C.G. problem. Page 27. — The effect of thinner airfoil is similar, if we increased the angular difference between the wing and stabilizer with the regular Clark Y. On 100% C.G. and 0-0 design, the use of thinner section definitely eased up the tight or touchy adjustments. ———— So, if you like large stabilizers, 0-0 line-ups and easier adjustments, by all means, use thin airfoils on your stabilizer — but remember to use larger areas or you will have to use larger angles on the stabilizer than on the wing — which is bad.

## EFFECT OF MOMENT ARM ON PITCHING MOMENT

We are about ready to stop making graphs, but new situations are always arising. For instance, what happens when moment arm is changed? Wing force same. Longer M.A. smaller stab area. etc.

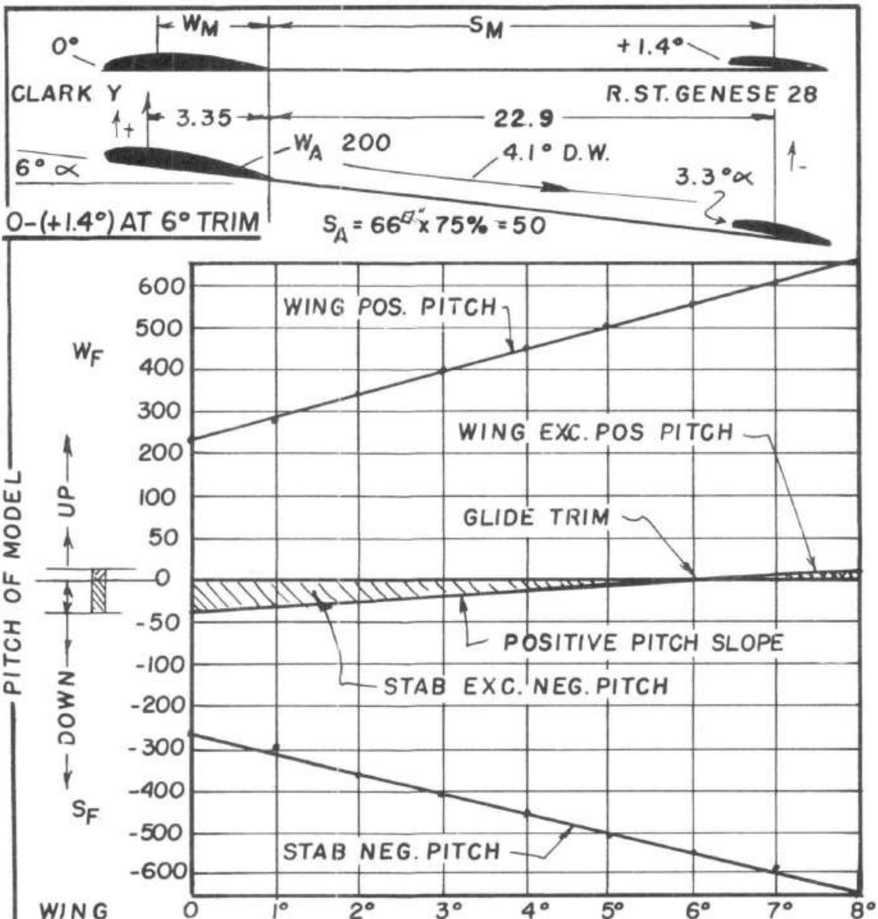
If you compare graphs with the original M.A. conditions, you will find no difference. This only means you can use stabilizer area or its moment arm for control force. Perhaps, other factors, such as more or less downwash, would change the situation. At long M.A. lengths, it is quite possible that downwash angle is lower, in which case you can use less stabilizer area to achieve the same balance. 0-0 setting is just as mean at short moment arm as it is on longer. see CIRCULAL AIRFLOW.

## 100% C.G. AND SMALL STABILIZER

Have you ever found yourself in trouble adjusting a new model, whose basic urge was to stall, no matter what you did? And when you finally got the stall under control, it would dive at the slightest provocation?

See tables and diagram. Note that we had to increase stabilizer incidence 1.4° above the wing's to obtain balance at 100% C.G. and at 6° angle of attack. — The force curves are most interesting. ———— No wing force to prevent it from going into a dive. — No stabilizer force to prevent it from going into a stall. The slightest correction means a dive or a stall. This definitely shows that stabilizer area should be increased as the C.G. moves towards the trailing edge of the wing.

This type of layout just cannot take any kind of adjustment. Just a touch on the stabilizer will make it go up or down. In glide or power, it makes no difference. It is a perfect example of positive pitching moment slope. A model of this type can be best described as an arrow; it will go wherever you may point, under power or glide. But Lord help you if something should disturb its delicate balance and make it point your way. Can you recognize some of the models you have seen lately?

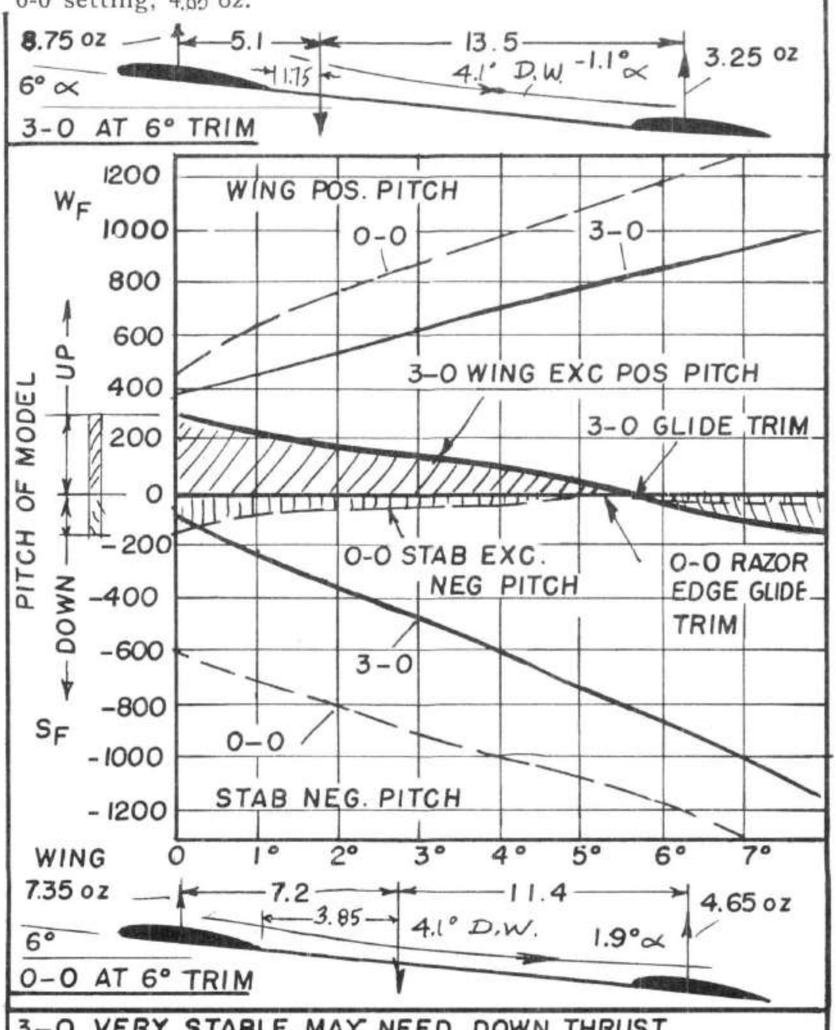



| WING (POS. PITCH) | | | | | STAB (NEG. PITCH) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| W∝ | $C_L$ x | $W_M$ x | $W_A$ = | $W_F$ | W∝ | S∝ | $S_{CL}$ x | $S_M$ x | $S_A$ = | $S_F$ |
| 0 | .40 | 2.9 | 200 | 231 | 0 | -.6° | .22 | -23.5 | 50 | -270 |
| 1° | .47 | 3.0 | 200 | 282 | 1° | .1° | .25 | -23.4 | 50 | -292 |
| 2° | .54 | 3.1 | 200 | 335 | 2° | .7° | .31 | -23.3 | 50 | -362 |
| 3° | .62 | 3.2 | 200 | 395 | 3° | 1.3° | .35 | -23.2 | 50 | -405 |
| 4° | .70 | 3.25 | 200 | 455 | 4° | 1.9° | .39 | -23.1 | 50 | -455 |
| 5° | .76 | 3.3 | 200 | 500 | 5° | 2.6° | .44 | -23.0 | 50 | -505 |
| 6° | .82 | 3.35 | 200 | 550 | 6° | 3.3° | .48 | -22.9 | 50 | -550 |
| 7° | .88 | 3.4 | 200 | 600 | 7° | 4.0° | .53 | -22.8 | 50 | -585 |
| 8° | .95 | 3.45 | 200 | 655 | 8° | 4.6° | .57 | -22.8 | 50 | -650 |

In the above calculations the only change from balance shown on Page27is reduction of Stab area from 88 sq. in. to 66 sq. in. & Stab incidence increase to $1.4^{\circ}$. Only razor edge glide trim is possible. No power trim. Reducing $1.4^{\circ}$ to $1^{\circ}$ means stall.

## PITCHING MOMENT OF TANDEM DESIGNS

Quite a number of us may be thinking about using tandem, or something close to it, to get by the wing loading rules. Let us use our 200 sq. in. Clark Y wings on both surface and have 14″ distance between them, and calculate on using them at 3° difference and 0-0. Since we are dealing with large stabilizer, we will not use an efficiency factor on it. As you will note, on the 3°, the trim point is 1.75 behind the front wing, and on 0-0 setting, it is 3.85. The force lines show familiar signs of what happens when we use angular differences. We did a bit of calculating and assumed our load to be 12 oz. On 3°, the "stabilizer" carries 3.25 oz. and on 0-0 setting, 4.65 oz.



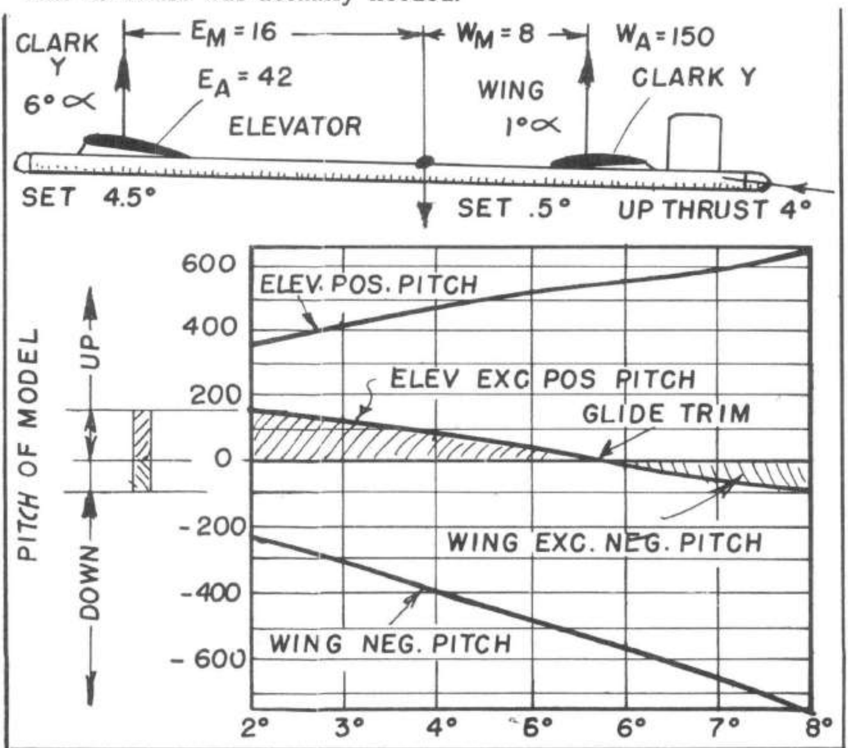

3-0 VERY STABLE, MAY NEED DOWN THRUST
0-0 IMPOSSIBLE TO TRIM. REAR TOO POWERFUL

# PITCHING MOMENTS FOR PUSHERS

The common belief, shared by the writer until now in a vague sort of way, is that the pusher derives its stability by having its elevator stall first; thus, causing the front to drop back to level flight. Following this logic, one would think that the elevator must be in a constant stalling state if stalling is required for balanced flight. More out of curiosity than with expectations that it could be aerodynamically balanced, we made the calculations shown. For our example, we used Torey Capo 1935 single pusher shown elsewhere. We were not sure of its C.G. position and assumed it to be about 6" in front of the wing.

The 5° difference provided the force lines shown, and balance occurs at about 6°.

Note the divergence of the two force lines which would indicate fairly stable condition and also looping tendency. So, we are very happy to see that Torey took care of this with an upthrust in the rear, which is the same as downthrust in front. Now that you have a chance to see a pusher as it actually is, you can see that, somehow, Torey hit upon a good arrangement and that upthrust was actually needed.




CALCULATIONS: SAME AS FOR OTHERS, NO DOWN WASH

EX: ELEV. AT 5° $E_{C_L}$ = .76 WING AT 0° $W_{C_L}$ = .4

ELEV. FORCE = .76 x 42 x 16 = 510 WING FORCE = .4 x 150 x 8 = 480

## MAKING GRAPHS FOR EXISTING MODELS

To bring this work closer to home, we checked and graphed Paul Gillian's "Civy Boy 74," which is more or less considered as the extreme in long arm and large stabilizer area. Although he seems to have used his own style of airfoils, we tried to duplicate their value by using NACA 6409 for wing and thin Clark Y or Rhode St. Genese 30 for the stabilizer. The diagram and calculation results are shown.

It was not exactly an easy job as slight change here and there would give us an unstable condition, but we believe that we came pretty close to the actual condition, with the force lines as shown. The divergency of force lines would indicate that it might have slight looping tendency, which Paul countered with 6° downthrust. ——————————————— He should not have much trouble in adjusting for glide as it is not sensitive in this respect.

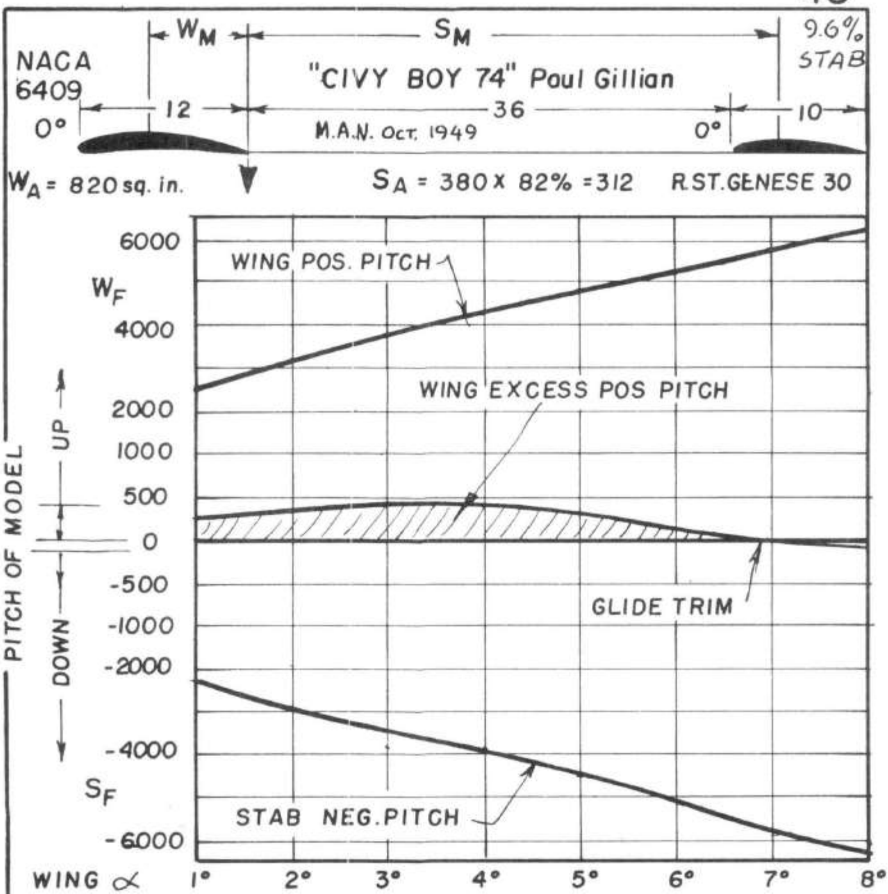
Although he uses 0-0 setting and large stabilizer and C.G. at 100%, he still has fairly good stability factor. This can be attributed to the long moment arm, high lift wing airfoil and low lift stabilizer, which is equivalent to angular setting.

## PITCHING MOMENT SUMMARY

Now that we have all of this information on pitching moment, what are we going to do with it? Well, a great deal depends on how much of it you understand. If you have been flying for a long time, you might recognize symptoms you found on your models, and understand the actual cause of the trouble. Knowing the exact reason for instability, you can now go ahead and make corrections.

If you build from kits or plans, and you recognize the behavior of your model as one of those which was "cased", you can check and compare their layouts and see what you have in technical design. If you have trouble with your model and recognize the symptoms from the description we have given, you should be able to work out a cure from the information given. You might as well reconcile yourself to the fact that kit designs are not 100% perfect, and that some are not as good as others, to put it kindly.

It might be timely to point out, at this time, how important it is to have good workmanship and construction. Wing and stabilizer should have substantial mounts and be well fixed. Did you notice how the slightest change in angles or C.G. would throw the model into a dive or stall? A sloppy fixing might change all your flight settings after you release the model. We do not care how the model looks in appearance, but it should have or be in good aerodynamical condition. You should expect sloppy flights from sloppy models. We should not expect some miracle to make the model fly if it is not fit for flying, through lack of proper layout, poor workmanship and complete disregard for knowledge of what makes them tick. Sloppy models, in hands of inexperienced flyers, are a menace to mankind.




| WING (POS.PITCH) | | | | | | STAB (NEG. PITCH) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wα | $C_L$ x | $W_M$ x | $W_A$ = | $W_F$ | Wα | Sα | $S_{C_L}$ x | $S_M$ x | $S_A$ = | $S_F$ |
| 1° | .54 | 5.8 | 828 | 2600 | 1° | -1.7° | .18 | -41.6 | 312 | -2350 |
| 2° | .62 | 6.3 | 828 | 3250 | 2° | -1.1° | .23 | -41 | 312 | -2950 |
| 3° | .7 | 6.7 | 828 | 3850 | 3° | -.5° | .27 | -40.8 | 312 | -3440 |
| 4° | .76 | 6.9 | 828 | 4350 | 4° | .2° | .31 | -40.5 | 312 | -3920 |
| 5° | .82 | 7.1 | 828 | 4820 | 5° | .9° | .36 | -40.1 | 312 | -4500 |
| 6° | .86 | 7.2 | 828 | 5120 | 6° | 1.6° | .41 | -39.9 | 312 | -5100 |
| 7° | .95 | 7.3 | 828 | 5850 | 7° | 2.3° | .47 | -39.8 | 312 | -5850 |
| 8° | 1.02 | 7.4 | 828 | 6250 | 8° | 2.9° | .51 | -39.6 | 312 | -6300 |

## EFFECT OF UNDER CAMBER WING AND THIN STABILIZER

If we had used 7.5% Stab, at 0-0 and 100% C.G. we would need 420 sq.in. area (82% Eff.). With same area (380 sq.in.) and set 0-0, the C.G. would be at 97%. With same area (380 sq.in.) and C.G. (100%) the thinner (7.5%) stab would be set at higher angle (-.7°). Wing 0, Stab -.7°. This is razor edge trim.

## SPIRAL STABILITY

Sometimes, we wonder if we would have as much fun with models if we had studied to become an honest-to-goodness aeronautical engineer. It is quite possible that we would have an idea that we knew all there was to know about aerodynamics and, would not bother to hunt down minute details, peculiar to model flying and building. But, when we think of it, our aeronautical friends seem to have just as much trouble controlling models as we do. Perhaps, when all is said and done, it is for the best that we kept away from the deep water of full scale and kept to our muddy little pond. In that way, we can kid ourselves into believing that we are pioneering into the unknown phase of aerodynamics; namely, the super-automatic stability under extreme range of conditions. If you look at the situation in this light, it could be fun.

Back in 1935, we really thought we had discovered something new when we found the tie-up between dihedral, rudder area and prop torque. This may not have been new, but until that time, no one had tied it up for model use, but from that time on, "Spiral Stability" was our special baby and we do not miss a chance to talk about it.

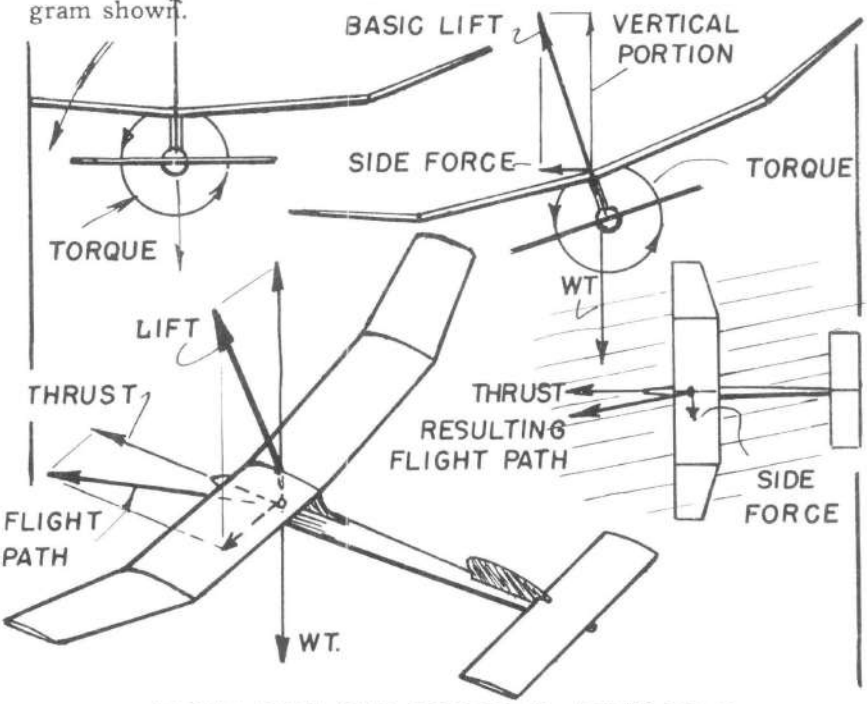
Spiral Stability is a very important portion of the overall stability problem as it explains many peculiar behaviors of the models. It also makes you realize that a model is in a constant state of "shimmy" to adjust itself to ever changing conditions. Unless the various parts of the model are in harmonious combination, we may expect expensive trouble. In the following test, we will endeavor to illustrate Spiral Stability from all angles and describe dangerous situations and their cures, so that you will be able to recognize them and make proper corrections while you are building or flying your model.

## TORQUE, SIDESLIP AND DIHEDRAL

Perhaps, the best way of introducing you to Spiral Stability is to show how the dihedral controls the torque. Working with known forces gets you out of that hazy and nebulous "technical talk" feeling that you believe should be taken to heart by the other fellow.

Torque problems are still with us, although they may not be so evident as they used to be in 1935. At that time, many models had very little dihedral and you could see torque take over and swing the ships into left spiral dives. As you will see, torque is the "force" which sets in motion the flight pattern your particular model will make once it is released. It does not determine this pattern, mind you; it is the force that carries through to a conclusion whatever the aerodynamical design dictates. Do not blame the torque for your troubles. You know it is there and you are supposed to know how to make it help you. It can be done, if you know how.

Looking from the rear of a model, we find that the torque force will try to swing the model into direction shown. As the model swings into this direction, the lift force also swings with the model. Once the basic lift force swings beyond the vertical position, it tends to pull the model to one side. So, here we have a condition in which the propeller is pulling the model forward and the wing. besides holding it up, also wants to pull it to one side. Breaking up this basic lift force, which is now angled, into its lifting and side pulling components, we have the force diagram shown.




## HOW SIDE SLIP FORCE IS DEVELOPED

The perspective of the forces involved is shown. Note that lift and weight balance each other, but that there is no balance for the side pulling portion of the lift force. Since the thrust or forward moving force is so much greater, we should not expect a side force to perform some sort of a side step which we could see. Its actual effect on the model can be determined by making a force diagram of the thrust line and the side force. The resultant is the direction into which the model will try to move. You can see that it is a compromise between thrust and side force. The main thing to remember, though, is that the fuselage will remain on the thrust line axis and that it will not move "head on" into the new direction, but will move in a "skidding" fashion. This is the most important phase of our work. Once you can see that it is possible for the model to move in a "skidding" fashion, the rest is easy.

Just how does this new motion look to the air molecules? For this view, we should look at the model from the front along the resultant line. The view is shown. It is a compressed side view. — It is from this view that we can predict exactly what the model will do as far as spiral stability is concerned. But you will have to know what to look for. To help you in this, we have worked up a visual demonstration with gliders.

## SPIRAL STABILITY DEMONSTRATION

The following demonstration shows reaction to torque" of different side area distributions and dihedrals. It saves us so much trouble in trying to put arm motion into words and sketches. Besides, you can always check up on us by making the models shown and going through the test yourself. We are sure that, after you see them behave as they do, you will want to know why they seem to be so contrary to normal expectations.

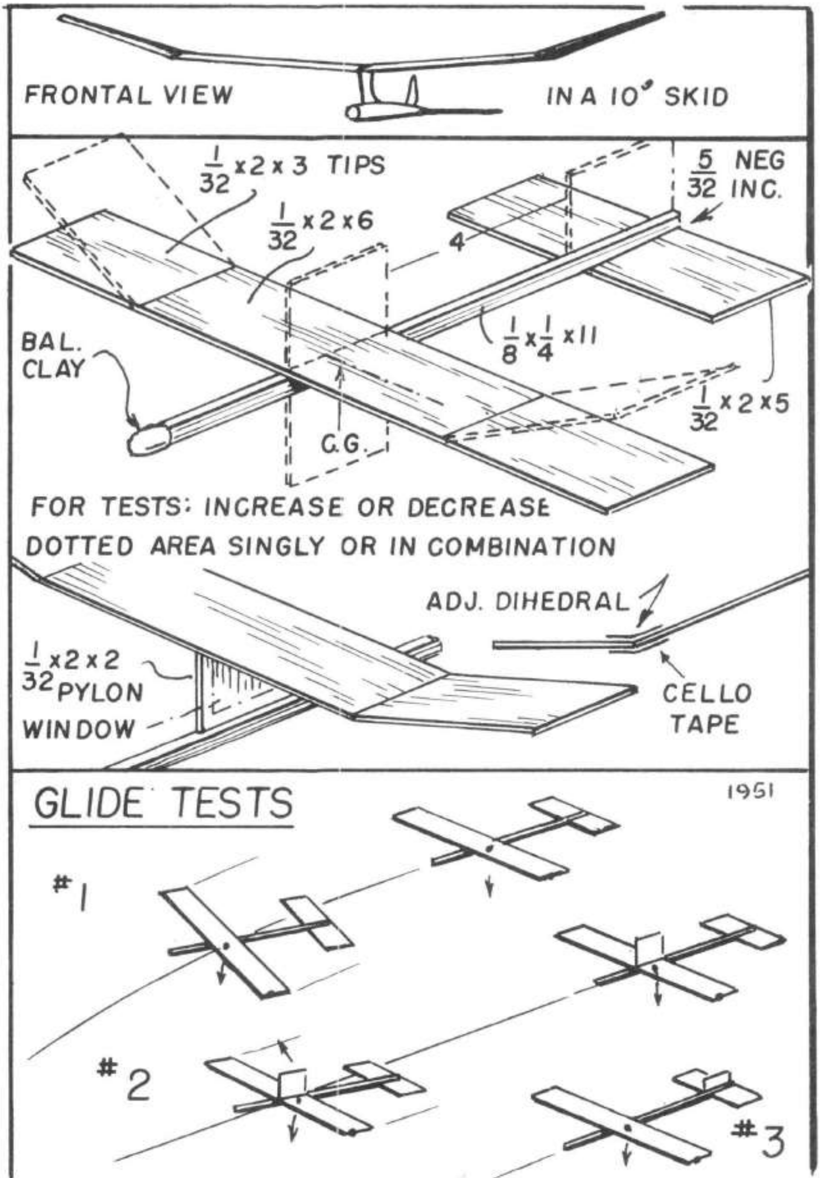
## TEST GLIDERS

Test gliders are very easy to make. We made two, one with the wing on the fuselage, and the other on 2 x 2 pylon. We changed the dihedral angle by creasing the balsa and using cellophane tape to keep the desired angle. If you like, you can make a model for every dihedral angle you wish to investigate. This is a good idea if you would like to have a demonstration before a club group. Rudders can be cemented and taken off easily enough, especially, if you use "Testor A" cement. Be sure to use only flat "C" grain 1/32 balsa sheets, so that you will not have warps to counteract what you are trying to do.

While we were developing this particular demonstration during 1938, we wondered how we could stimulate torque without using motor and prop. Then came the idea of using weights on tips. Weight on tip shifts C.G. position from center line outwards, requiring more lift on that side to preserve a level attitude. Torque may not shift C.G., but it does tend to force one wing down. To make this wing come up, it must have greater force than the other. As far as the wing is concerned, the actions of tip weight and torque are similar. The result of torque and/or tip weight is to introduce side skid conditions. Just what happens is shown by the following tests:

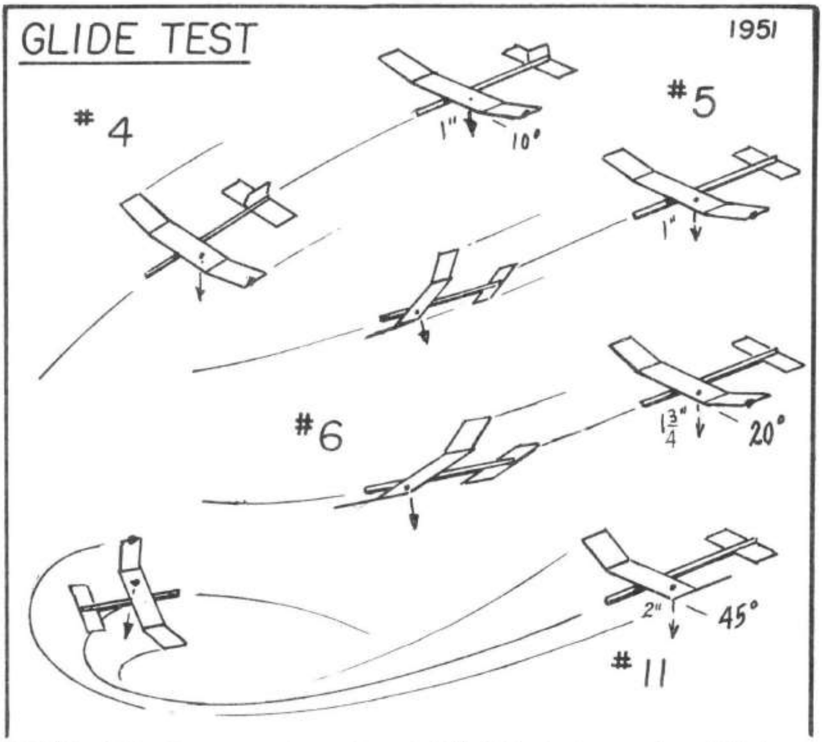
## TESTING WING ON FUSELAGE GLIDER

*TEST #1: No rudder is used. After balancing for straight flight, add clay to left wing tip to bring C.G. about ¼" from center line. Model will make a sort of a left skidding turn. You will see that airflow is not along its fuselage line. It is fairly well balanced for side area with possibly slight edge for rear because of longer fuselage length.*




*TEST #2: Add 2 x 2 fin to top of wing so that you will definitely be sure that model is skidding. The fin, being above C.G., will try to bring model level, but it does not have enough power to counteract the weight at the tip. Its frontal area may have stronger effect.*

*TEST #3: Here we add 2 x ¾ rudder and remove fin over wing. We now find that the model has a smooth left banked turn, indicating that rudder is keeping model in a much smaller skid than in #1. Note C.G. is ¼″ from center line.*




*TEST #4: Here we introduced 10° dihedral on tips. Without tip weight, model flew straight, as it should. Added enough tip weight to bring C.G. 1" from Center Line. Resulted in a smooth left circle.*

*TEST #5: To find out what happens, we ripped off the 2 x ¾ rudder and found that model tended to skid to right. Quite a contrast, just by removing this small rudder, we changed flight direction from left to right. Why? We will explain later.*

*TEST #6: Same set-up as #5 but dihedral changed to 20°. No change until C.G. shifted to 1¾". Then the model developed a definite tendency towards right with outside skid very apparent.*

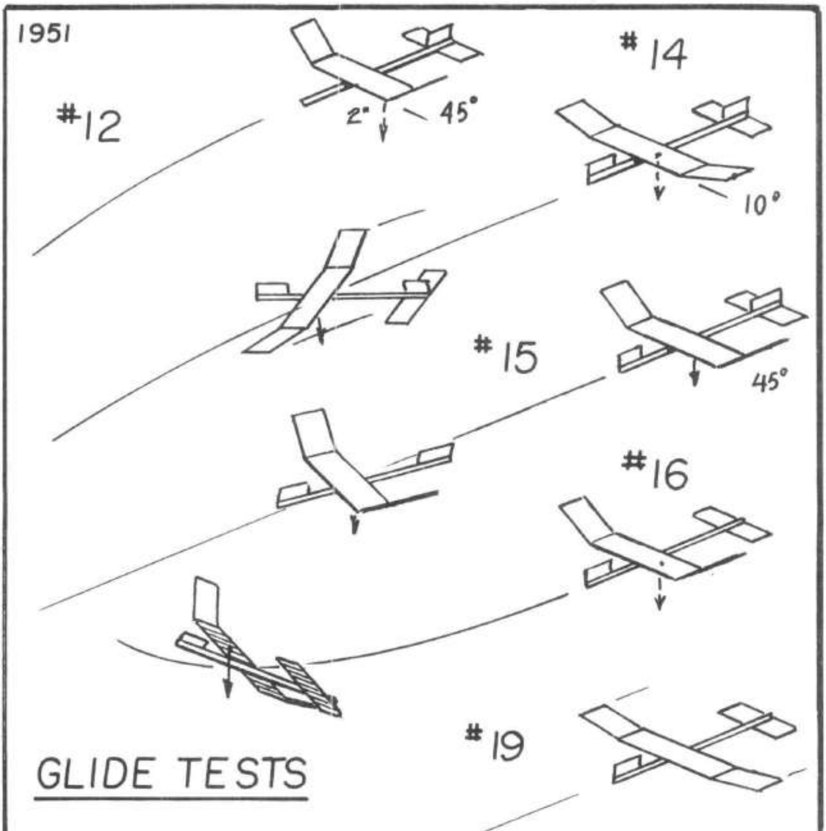
*TEST #7: To #6 we added 2 x 1 rudder, with C.G. still at 1¾". Model now behaved as #4, a smooth left circle showing that rudder is trying to keep model facing the side skid airflow.*

*TEST #8: Cut rudder to about 3/16 before it would fly straight ahead from the left — #7 condition. The straight flight had a skid.*

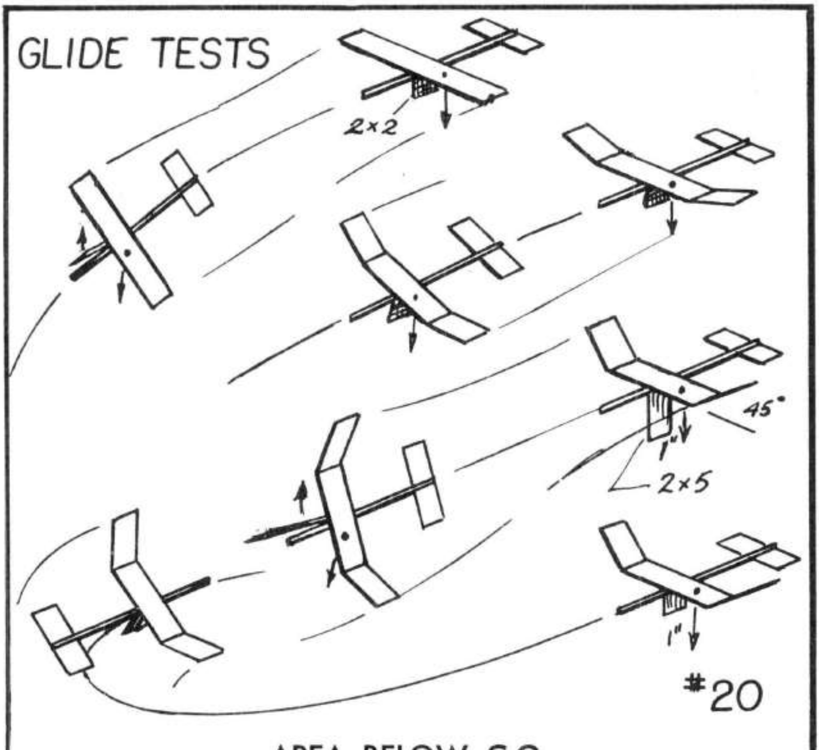
*TEST #9: Increased dihedral to 30°. ¾ C.G. shift tended to make model turn to right with wings level.* 3/16 Rudder

*TEST #10: Increase of C.G. to 2" made only slight difference to #9.* No Rudder.

*TEST #11: Increased dihedral to 45°. With C.G. at 2", the model made a definite swing into steep right turn with diving tendency.* No Rudder.




*TEST #12: Added 2 x ¾ rudder to 45° dihedral and 2" C.G. position. Model made a smooth left turn.*
*TEST #13: Cut rudder to 2 x ⅜ with result that model made a straight flight with slight skid.*
*TEST #14: Added 2 x ¾ rudders in front and back. On 10° dihedral, the model, with slight C.G. shift, would tend to left circle with exaggerated skid.*
*TEST #15: Front and rear rudders on 45° would tend towards straight flight with slight skidding action.*
*TEST #16: Removing rear rudder would develop into a fast skidding swing to right with flying speed killed, regardless of the dihedral used.*
*TEST #17: Removed the tip weight but model would still swing to right due to large frontal area.*
*TEST #18: Cut front rudder to 2 x 3/16. Exaggerated skid still present on 10° dihedral and complete instability with 45°. Slightest tip weight would show in the following action towards right.*
*TEST #19: Decreased dihedral towards zero and watched the effect of 2 x 3/16 frontal area. Model became less sensitive to frontal area as dihedral decreased.*



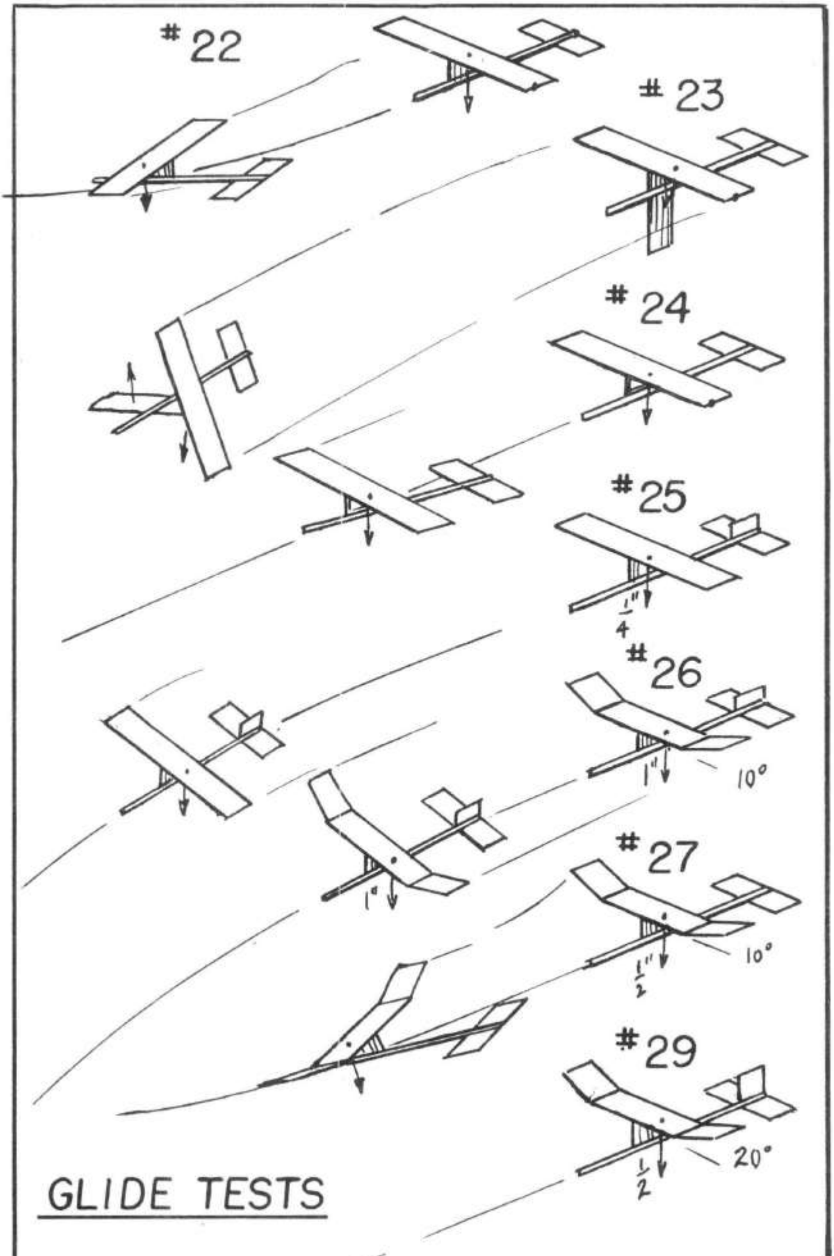

## AREA BELOW C.G.

*TEST #20: 2 x 2 plate under flat wing would definitely develop into a left spiral dive if weight is on left tip. Adding dihedral would level the wing into less acute angle or spiral. A 2 x 5 plate under 45° wing and 1" C.G. shift would produce almost a vertical wing skid but in straight line, showing the presence of side skid airflow. When this large plate was cut to 2 x 2 on 45° wing, the model would level out and develop into a right turn, showing the greater effectiveness of dihedral over side area.*

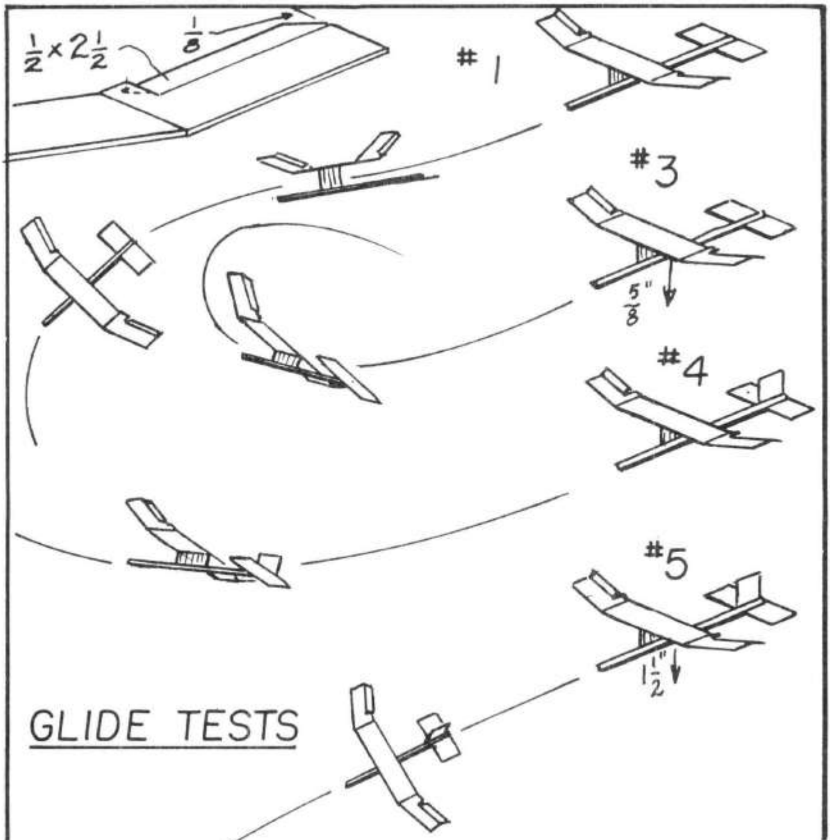
## PYLON WING GLIDER TESTS

*TEST #21: Balance pylon for level flight, no rear rudder used.*
*TEST #22: Added weight to left tip resulted in a skidding right turn.*
*TEST #23: Added 2 x 5 plate under C.G. which developed into a left spiral dive.*
*TEST #24: Cut "Window" in pylon to remove its frontal area effect. Result: A straight skidding flight, showing that in #22, it was frontal area that caused right turn. (Full pylon means "window" closed.)*

*TEST #25: Replaced "Window", added 2 x ¾ rudder and shifted C.G. ¼" and obtained a smooth and banked left turn, with or without open pylon.*
*TEST #26: Using 2 x ¾ rudder, added 10° dihedral and shifted C.G. 1". Smooth left banked turn for both pylon conditions.*




*TEST #27: 10° Dihedral and C.G. ½". Removing rudder would result in skid to right, more pronounced with full pylon.*
*TEST #28: Increased dihedral to 20°. With C.G. at ½" a straight skidding flight.*
*TEST #29: Addition of 2 x 1¾ rudder definitely swung model to left.*




## AILERONS' CONTROL

As long as we are at it, we might as well make a thorough job of all items that we use for torque control. Since warping the wing is similar to operating ailerons, we will see what happens. Pylon model used with 25° dihedral and $\frac{1}{2}$ x 2$\frac{1}{2}$ ailerons and set $\frac{1}{8}$" up and down as shown on the drawing.

*TEST #1: Without rudder, the model would swing from level flight slightly into right bank, then swing to left and ever steeping circle. This seems contrary to ailerons setting. Removing "Window" to remove frontal area made model fly straight.*

*TEST #2: Moving C.G. $\frac{1}{4}$" would cause straight flight with full pylon.*

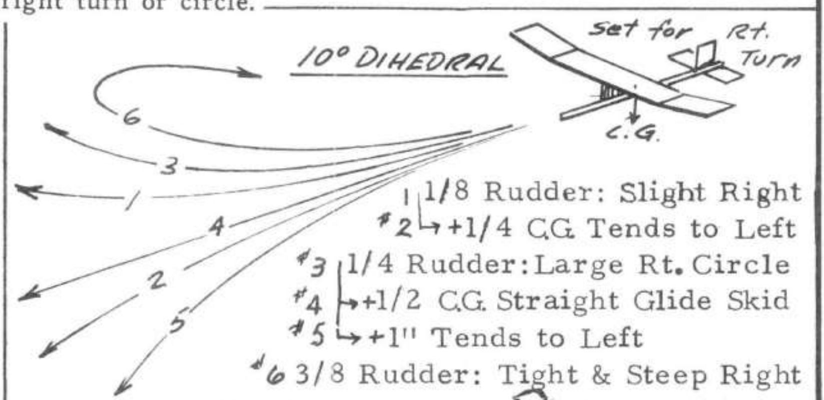
*TEST #3: C.G. to $\frac{5}{8}$" would develop right circle ending in a spiral dive.*

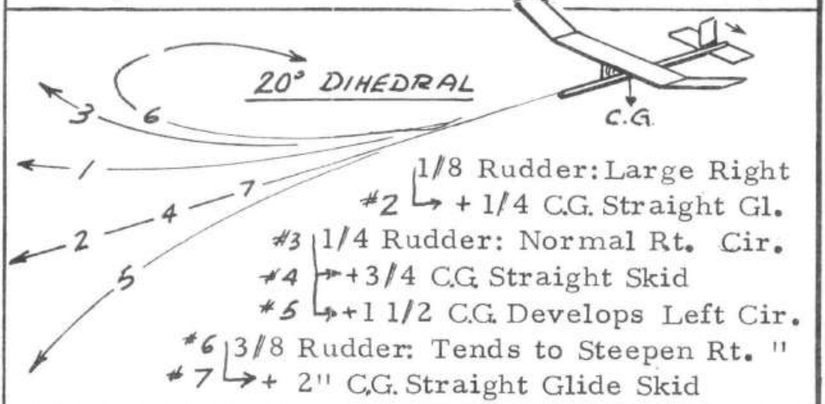
*TEST #4: Addition of 2 x 2" rudder without C.G. shift would make model turn right according to aileron setting.*

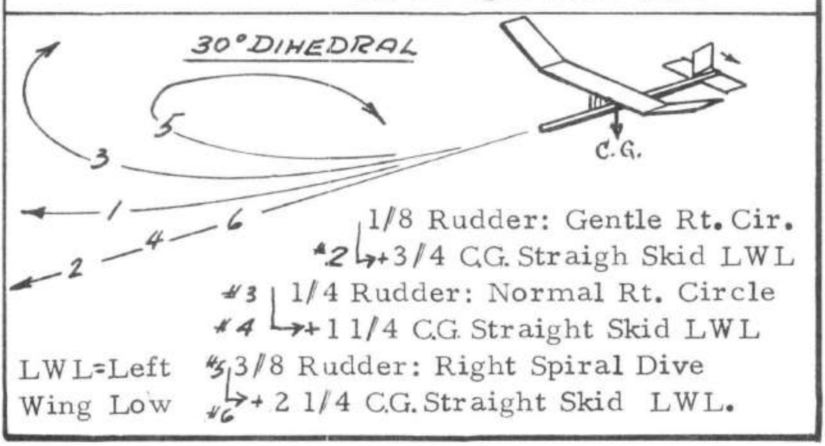
*TEST #5: Gradually shifting C.G. weight would bring model out of right circle to straight line, even though rudder was in place. A 1$\frac{1}{2}$" C.G. would develop a definite left turn, just opposite to aileron setting.*

## USING RUDDER FOR CIRCLING

Our most common "adjuster" is the rudder. So, since we were testing the effect of dihedral and side area we felt that we should also investigate the effect of the rudder settings. Perhaps, we would find out something while testing. Perhaps, get an idea of the actual skid angles. We used 2 x 1½ rudder on the pylon model. The entire rudder was set at angles indicated to produce right turn or circle.



## ANALYZING THE SPIRAL TEST RESULTS

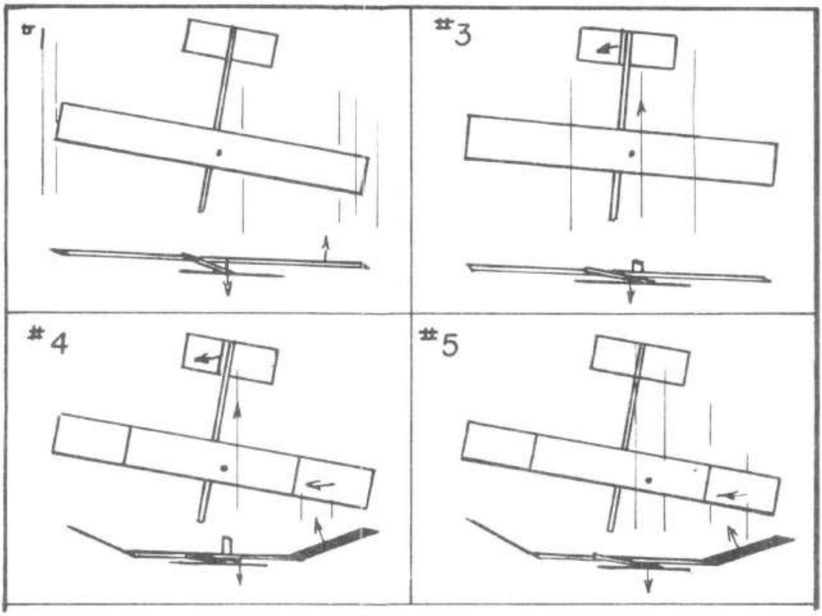
All of the actions which you saw were brought about by one force, the side airflow developed by torque or tip weight. The variation on the theme was caused by different arrangements and conditions about the C.G. Going back to the explanation of our side slip development, we pointed out that the model no longer flies with fuselage in flight path, once the torque force is applied, and that the new airflow is at an angle to it. (Later on, we will see just what this angle could be.) Looking along this flight path, we see the model's side as a sort of a compressed side view, while the wing is almost normal front view. The exact view, naturally, depends on the model. Let us take a look along this airflow line at our models at various conditions.

*TEST #1:* Note that side areas on both sides of the C.G. line are almost equal so that the model can reach a position where the tip or torque force is balanced without interference from side area distribution. The fact that the model did not spin or drop is caused by the wing developing enough counter lift on the lower or left wing. Although we do not have dihedral, this is brought about by having the airflow across the left tip into the wing proper, while on the right wing it flows out of it. This means that left side does not have tip losses while the right has, and is thereby able to carry that 1/4" C.G. shift.

*TEST #2:* The 2 x 2 skid on top of the wing tends to rotate the model into a level position but it is not strong enough.

*TEST #3:* Actual molecular view is shown of the model. It is difficult to see much. The plan view illustrates the point much better. It shows how side flow acts on the rudder, tending to force it into the airflow. As it moves into the airflow, the rest of model follows it. So that the action of the rudder is to prevent any movement of the model into side slip airflow. This means that as the wing develops side force to obtain side airflow for torque control, the rudder will tend to keep it from such developments by forcing the model to stay in the original airflow. The trick is to bring about a side force stronger than the rudder's but not too strong to overpower rudder completely when it is forced into some skid angle. — Or we can use conditions where the change to side flow need not be large.

*TEST #4:* By using dihedral, we need but have slight deviation from the center to obtain all the counter-torque force we need. By increasing or decreasing dihedral angle, we can control the actual side skid angle. In the front view, note how the left wing tip has greater angle of attack than the right one. This means greater lift development with which to counteract the torque force. To review, the tip weight or torque brings about side skid airflow in which dihedral works. As the airflow changes from "alongside or parallel to the fuselage" to crosswise, the rudder will try to bring the fuselage directly into the new airflow, removing the side flow needed by the dihedral. If the rudder is small, it will be forced to come into the angled airflow, but if it




is too big, it will hold the model in the original airflow and never allow the dihedral to develop counter torque force. In such cases, the model will spiral dive to the left. Just use an extra large rudder on any test model and it will spiral dive if enough tip weight is used.

*TEST #5:* By removing the rudder, we gave the wing unlimited scope in selecting its skid angle. So that with C.G. 1" from center, the wing is able to keep itself almost level due to increase of angle of attack on left side. Why it changed direction from left to right as we removed the rudder is a question which answer needs more space.

The other tests followed the above basic pattern. We used greater dihedral angles and C.G. shifts. By close inspection, you should see that as we increase the dihedral, we can increase the torque value or shift C.G. further from center line. If we load low dihedral with high torque, the loaded wing will drop downward and tend to skid as shown in Test #1. Increasing the dihedral, the tendency of the model will be to change direction, and the left wing will carry almost the entire weight of the model. Take Test #11 for an example.

## PYLON TEST MODEL

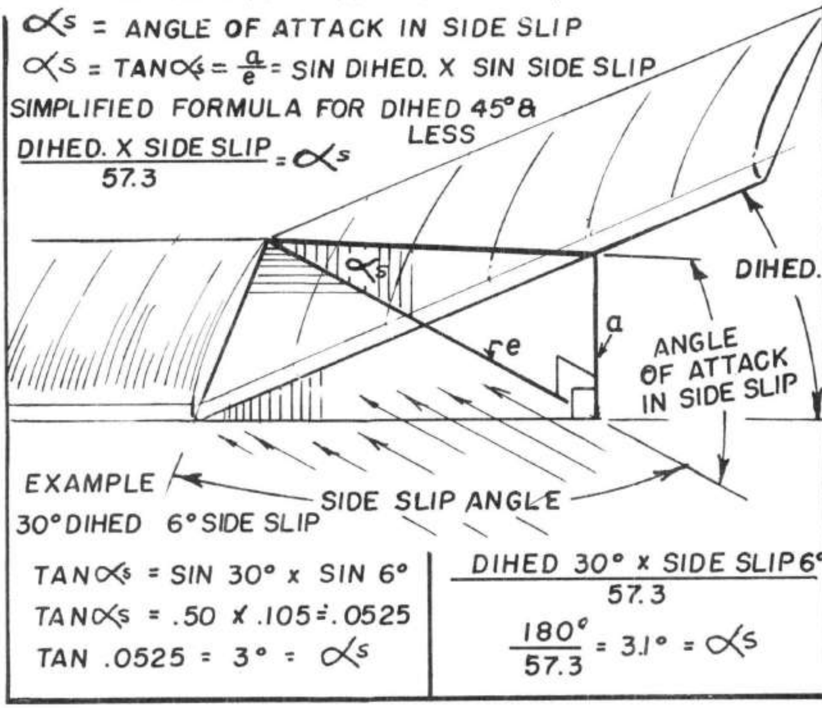
Results of tests while using pylon wing followed closely those observed for ordinary wing position. However, the pylon did have effect of frontal area and so tended to swing the model into a right turn much more readily. This point should be kept in mind whenever comparing the two models for advantages of one over the other. Pylon design may be preferred over ordinary wing position but be sure you know why.

## COMPARING TESTS WITH THEORY

We surely made a lot of tests. We walked back and forth in our office all day long and climbed upon a radio cabinet to get more altitude. Next day we had that feeling we used to have when in Switzerland. Just to complete the illusion, we were listening to short wave radio broadcast from Switzerland. But back to serious work.

The purpose of making all these tests was to give visual presentation of what goes on, and show that we can duplicate flights that occur on the field. Of course, in our case, were able to pick up the model and go on, which is more than you can say most of the times. The tests, however, did not give us any exact pictures. We saw skidding, but had no idea just at what angle. We loaded the left wing tip with clay — almost half of the model's weight — and saw the model actually lift the left wing up and swing into a right turn, with no idea just what was the exact angle of attack of the two tips to bring about this unusual weight lifting performance. Then we placed a small rudder on the model and saw it reverse the model's direction. Things like this just cry for mathematical clearance and we spent over two days just for calculating side drift angles and their effect on different dihedral angles.

MEASURING ANGLE OF ATTACK IN SIDESLIP



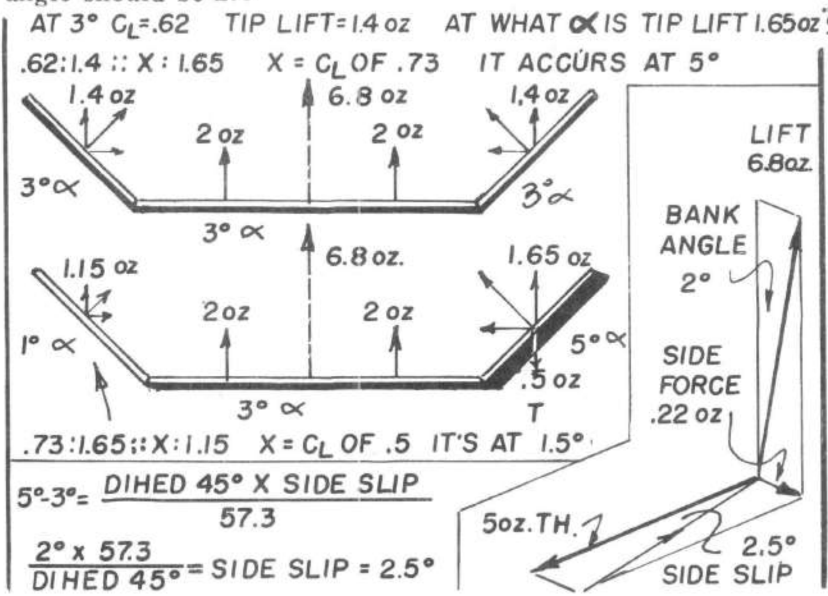
## HOW MUCH DRIFT ANGLE FOR PARTICULAR DIHEDRAL

The problem we have right now is how to find value of drift angle for a particular flying condition. We found that by working "backward", we would arrive at a reasonable figure.

Let us assume torque value to be .5 oz. at point "T". This means that, when the model is flying, the left wing must lift .5oz more than the right wing. This is accomplished by having different angle of attacks on tips, more for left and less for right. Consulting our airfoil characteristic graphs, we find that, if the model is flying at 3°, a change of plus 2° for left and minus 2° for right would give us 4° difference between the two tips. Or 5° for left and 1° for right. And it just so happens that lift coefficient at 5° is .76 that of 1° is .47. CLARK Y

Rearranging our wing layout to accommodate the .5 oz. of Torque, we have the condition shown. The total upward lift is still 6.8 oz.

The next problem is to find out what slip angle is required to bring 45° wing into a 2° increase of angle of attack for left wing and 2° less for right. According to our formula, the slip angle should be 2.5°




$$5°-3° = \frac{\text{DIHED } 45° \times \text{SIDE SLIP}}{57.3}$$

$$\frac{2° \times 57.3}{\text{DIHED } 45°} = \text{SIDE SLIP} = 2.5°$$

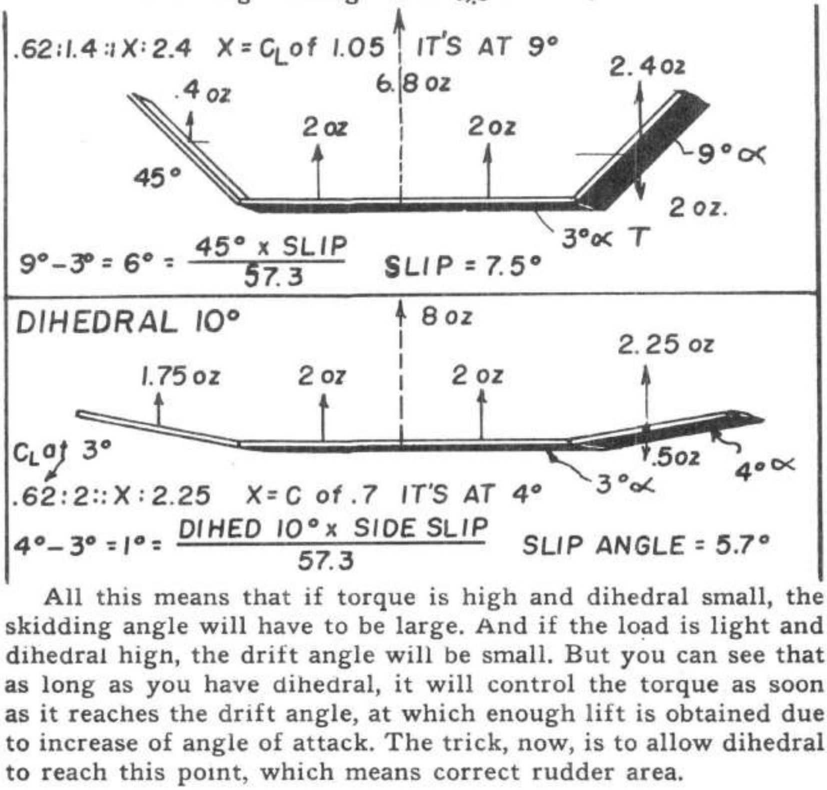
Now that we have the actual drift angle, at which the dihedral will give the left wing tip .5oz. more lift than the right, how much did the wing angle to obtain this drift angle?

We now use the Thrust 5oz. and the Lift 6.8oz as shown. If the angle of drift of 2.5° is used as a resultant of Thrust and Wing's side force, then the side force can be used to measure the wing's inclination. The answer is 2°. Rather a let down, but it shows what 45° dihedral can do.

## DIHEDRAL'S AUTOMATIC CONTROL OF TORQUE

As the torque or tip load swings the left wing low, the total lift tends to develop a side skidding airflow, in which dihedral angle becomes effective. Just where the wing will stop its swing from level depends on torque and dihedral angle. If torque is small, the counter-torque force developed by the wing, need not be great.

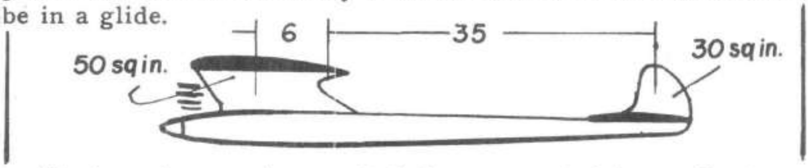
An increase of tip load from .5 oz. to 2 ozs. on the 45° called for drift angle change from 2.5° to 7.5°.




All this means that if torque is high and dihedral small, the skidding angle will have to be large. And if the load is light and dihedral high, the drift angle will be small. But you can see that as long as you have dihedral, it will control the torque as soon as it reaches the drift angle, at which enough lift is obtained due to increase of angle of attack. The trick, now, is to allow dihedral to reach this point, which means correct rudder area.

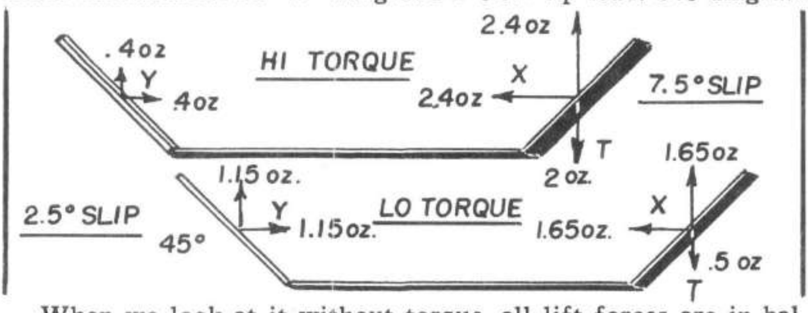
## SPIRAL DIVES WITH HIGH POWER AND LARGE DIHEDRAL

Present day high power, large dihedral and small rudder models seem to be natural for right spiral dives. Why? Some of you may look at the small rudder, if you have followed the tests, and say "That is it." We were inclined to be of similar opinion, until we checked side areas of such models and found that center of side area was comfortably behind the C.G. Check for yourself. Take a 600 sq. in. model. 5% rudder would mean 30 sq. in. on 25" moment arm or 750 Units. The major frontal area is the 6 x 9 pylon on a 6" arm which would give 324 Units. The rear portion of the fuselage would definitely balance out the front. Yet, such models have right spiral dive tendencies and require very fine adjustments. We do not say that larger rudder would not cure the trouble, and bring other griefs, but it is not the small rudder that brings about the spiral dive conditions under high power. Just recall how directionally stable such small rudder models can be in a glide.



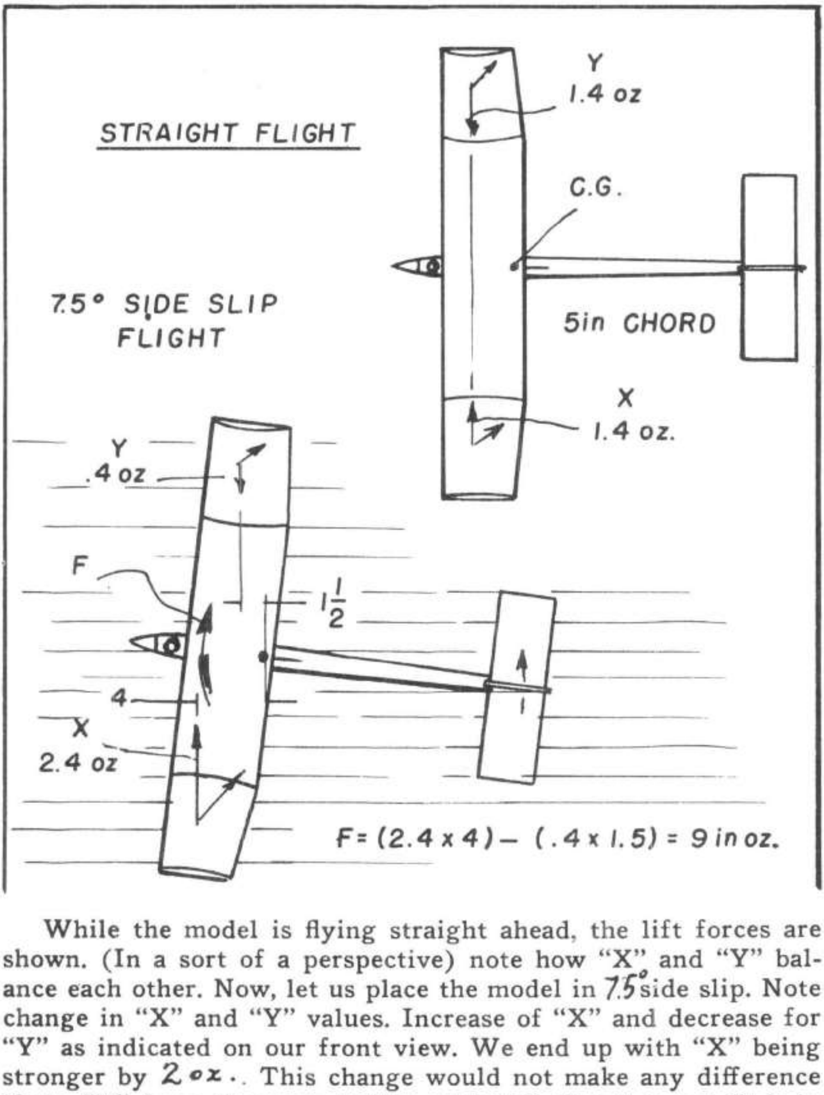

We have been trying to find the cause of this trouble for a long time, at least 15 years. We thought we had it, but the coming of more powerful engines broke our theory. Watching the models swinging over to the right, knowing the heavy load the left wing had to carry, we wondered how it could do it. We had ideas of excessive side drift. Yet such excessive side drift would cause stalling and make the left wing drop. We know that large dihedral, with high torque, would tend to develop right spiral dives, but we could not point at the exact trouble spot. The light finally came while we were working on side drift calculations.

According to our present feeling, it is the high torque and large dihedral condition or combination which brings about spiral downfall. Let us examine lift forces on such a wing. We already made calculations for 45° wing and 2 oz. tip load. See diagram.




When we look at it without torque, all lift forces are in balance. But when we introduce the tip load or torque, there is a definite change. The two tips, right and left, may be in balance, (tip load taking care of left wing's lift) but we still have to account for side components "X" and "Y". You may not believe it, but we have an idea that our trouble will be found in these components.

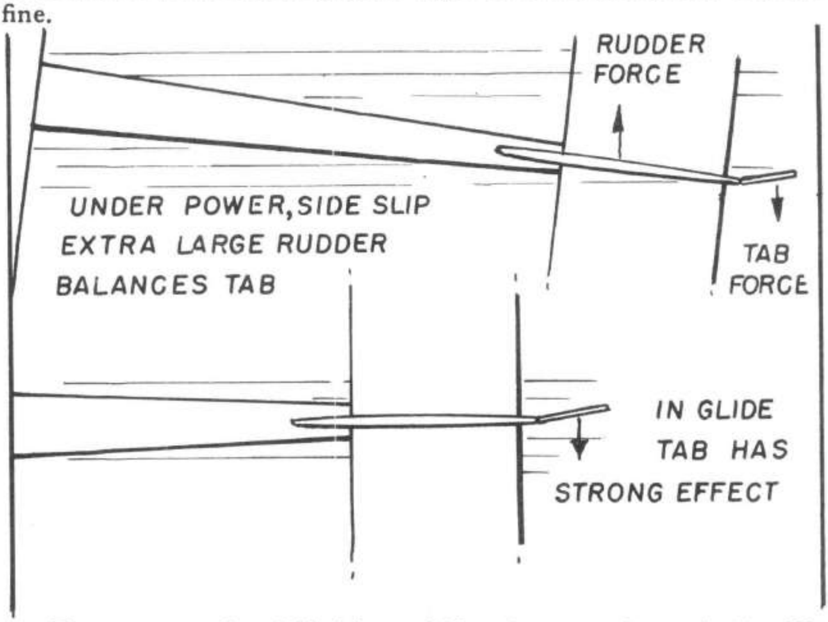
On the 2 oz. example, the conditions are extreme and "X" has no opposition from "Y". On the .5 oz. and 45° example, the values are different, but "X" is still greater. You may say "What about it?" What good is a force that is directed across the wing?" If anything, it would tend to counteract the inclination of the wing and bring the wing level. This is cleared by realizing that this greater "X" value is developed only when we do have side drift. We must look elsewhere to find out the effect "X" has on the model. Let's take a look at the situation from topside.




While the model is flying straight ahead, the lift forces are shown. (In a sort of a perspective) note how "X" and "Y" balance each other. Now, let us place the model in 7.5° side slip. Note change in "X" and "Y" values. Increase of "X" and decrease for "Y" as indicated on our front view. We end up with "X" being stronger by 2 oz.. This change would not make any difference if the "X" force line were in line with C.G. But it is not. It is in front of C.G. And that is the SECRET OF RIGHT SPIRAL DIVE. This force in front of the C.G. tends to swing the model to the right and around the C.G. point. If we have a rudder of correct size, it will, or should, resist any movement of the "X" force after 7.5° drift has been reached. But if the rudder is not strong enough, "X" force will keep on forcing the model into a higher drift angle. It becomes a self-feeding condition. The greater the drift angle, the greater will be the "X" force with which to force the model into still greater drift. You just can't win if your rudder is not correct or if nothing else is done to control this "X" force.

## USING RUDDER AREA AND DRIFT ANGLE FOR CONTROL

While developing "Hurry Up 210", we wanted to have tight glide turns and open power circles. This means picking up every bit of thermal activity in the glide, and making power adjustments easier. On the first model, we had the motor operate the rudder. Tight motor would bring it in for straight flight, and loose motor would let it open for tight circles. The system worked fine.




Then we wondered if this could be done aerodynamically. We knew about the effect of small and large rudders. Small rudders would tend to develop right turns or spins, while large rudder would tend to develop left. So we used (found by experiment) an exceptionally large rudder, 15% of wing. We adjusted for tight glide with rudder tab. Normally, such adjustment on small rudder would mean a fast right power dive, but a large rudder would offset such glide setting as soon as power was applied and side airflow developed. This worked in practice. The model would make large right power circles and then swing into tight right glide turns. You can see how this works by consulting our test series. Such a model would be safe to hand to beginners as it will automatically control its power.

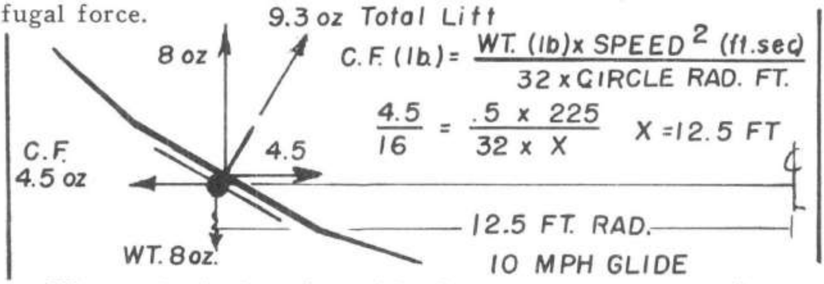
The model itself is not perfect. It will behave as mentioned as long as power is not to maximum. Under full power, it has a tendency to power stall. But this should not be blamed on rudder, but on longitudinal stability. Once we begin to correct this longitudinal instability by trying to obtain tighter helical climb, we get back to touchy adjustment field. However, we have definitely proven that it is possible to control circling of the model, under power, by use of rudder area.

## HOW CIRCLING IS DEVELOPED

Merely setting the rudder does not mean a plane will automatically start circling. Other factors must be present.

To obtain a circling flight, we must also have a side force pulling the model towards the center. And the only available force is lift developed by wing and stabilizer. The idea is to divert a part of this lift into side pulling force. This is done by anglng or banking the wing as shown. We now have the needed side pulling action. The greater this side force, the smaller will be the circle. Some might ask, why doesn't this force sort of fly the model to center in a spiral? Or what determines that a particular circle is of that diameter and uniform throughout the flight?

As the plane begins to circle, it comes into influence of centrifugal force which tends to pull rotating objects away from the center. Its value depends on speed of the object and diameter of the circle. This centrifugal force increases with the increase of speed and the decrease in diameter. And so, a plane will reach a "stable" or uniform circle when its side force equals the centrifugal force.




$$C.F.\,(lb.) = \frac{WT.\,(lb) \times SPEED^2\,(ft.sec)}{32 \times CIRCLE\ RAD.\ FT.}$$

$$\frac{4.5}{16} = \frac{.5 \times 225}{32 \times X} \qquad X = 12.5\ FT$$

We can bank the wing with ailerons, or rudder and dihedral combination. The operation of ailerons is obvious. As a matter of interest, it is possible to make a plane circle only by the use of ailerons, if the rudder area is large enough.

As the wing banks, it is allowed to develop a slight inside skid. The reaction of side skid on the rudder will be to turn the plane into the new airflow, which happens to come from the direction into which we want to go.

The operation of the rudder-dihedral-combination is known. To obtain a left turn, we set the rudder left. This makes the model skid outward, so that the right wing will develop more lift and so bank the model into a left turn. Thus, the required side force is obtained.

It should be obvious that the wing will have to develop more lift while circling to provide enough vertical lift and, at the same time, the required side force. This means higher speer or higher angle of attacks. If this is not done, *the model will make a gradual spiral descent.* We have a special reason for underlining these words, as we have another theory, known as "Circular Airflow" to clear up later.

## CIRCULAR AIRFLOW THEORY

The "Circular Airflow Theory" was developed soon after we became civilian again. And for a while we used it to explain practically every unknown trouble. But after going through the Longitudinal Stability and Spiral Stability, it more or less clicked into its proper place. So that now we can present a much clearer picture of (the) model stability. Sometimes, an action will happen that you would swear was caused by high dihedral, but the actual trouble may have been brought about by the Circular Airflow. Only by knowing the exact nature of the background of "Circular Airflow Theory" can one separate or distinguish one action from the other. Hence, the following background history:

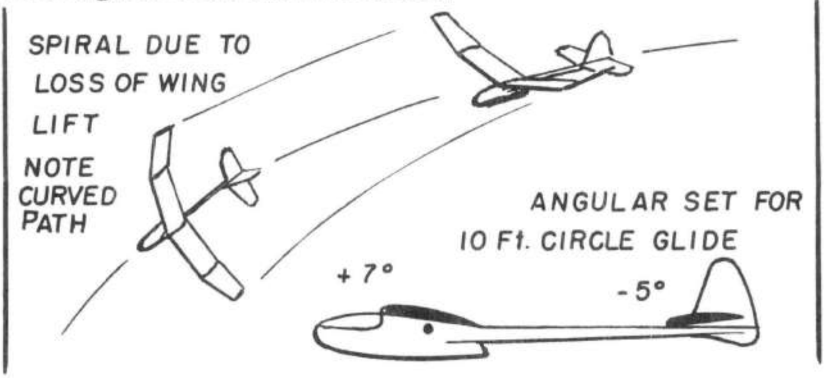
Having begun to specialize in glider design, we found that tight circle flights were best to keep gliders out of trouble. They would pick up slightest bits of thermal activity and stay up despite tight or banked turns. On windy days their tight turns would keep them from being upset by gusts or forced into straight flights which often lead to stalling dips. Luckily, many of these designs found themselves in the commercial kits so that our idea was tried by many and found good.

Our basic turn adjustment was to remove weight from the nose, as we tightened the circle with the rudder. If we used rudder alone, the glider would tend to spiral dive. At that time, we had no special reason for using this particular system; just found it by process of testing and elimination. We had an idea that the wing, when banked, lost some of its lift due to triangulation of its main lift force, and that by taking weight out we would balance this loss. We never stopped to think that a removal of only 1/10 oz. on an 8 oz. model would bring it from a spiral dive into a floating glide; or that the banked position was the same for the wing and the stabilizer, so that their balance should have been preserved. It took a broken leg, and a stubborn model to make us think why our particular adjustment worked so well.

Early in 1946 we were testing a new pod and boom glider with its full contest load. It just so happened that we cracked a small leg bone and twisted the ankle while skiing a few weeks before, and we had to use crutches for main support. This relieved us from running with the towline, and we were, therefore, able to observe the glider throughout its flight.

Well, this particular model just would not take our usual "weight-out rudder-in" adjustments. If we tried to tighten it beyond a certain point it would develop a spiral dive. Correcting this by removing balance weight would result in a sort of a clumsy stalling action. It is rather difficult to recall the exact action now, four years later, but the report is close to fact. We tried cutting rudder area down, thinking that it migh be forcing the glider into a spiral dive along the lines shown in the Spiral Stability section. It did not help.

While watching a development of one such spiral dive, "it came to us" that the wing simply was not developing enough lift for level flight or floating glide. Since removal of balance weight from the nose would not bring about the desired result, we decided to try increasing wing's lift by increasing it's incidence. (We already had the normal glider angular difference of 5° between wing and stabilizer. Hence, any further increase of incidence was a marked improvement, and we were able to obtain much tighter circle than heretofore.

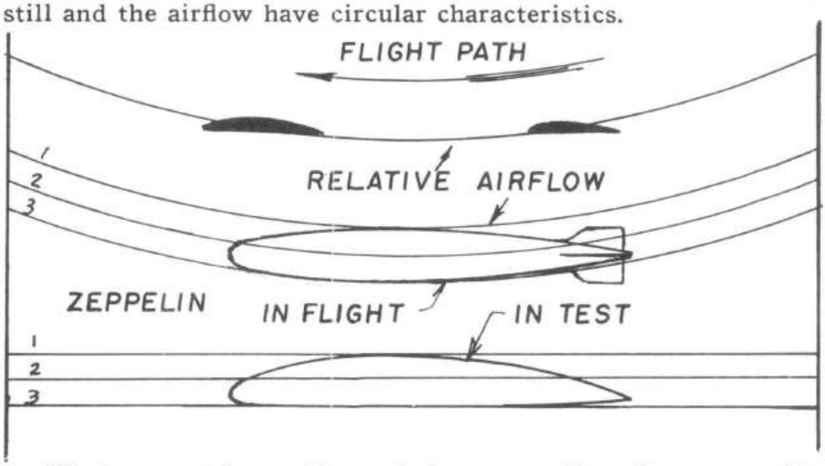



We decided to follow up this "increasing of wing's incidence" business, and see where it would lead us in developing safe and tight circling flights. We would build—in certain amount of incidence on the test model. After getting its tightest possible circle, we would add more incidence. By such gradually process, we eventually obtained almost wing-tip circles. Can you imagine a 50″ span glider having it's outer wing inscribing a 120″ diameter circle? The glider may have had at times 45° bank, but it did not develop into a spiral dive.

Would you like to know the angular difference we used to obtain such small circles? Well, we had 7° positive in the wing and 5° negative in the stab; a total of 12° difference between wing and stabilizer. Of course, any attempt to fly this model in a straight line was awkward, to say the least. It would only work well in tight circles, and then superlatively well. Why should such large angular difference between wing and stabilizer produce such stable tight turns?

We had the usual "quite a time with ourselves and it gradually came to us" that when a model flies in a circle, the relative airflow is no longer a straight line, but circular. By placing our model in this circular airflow we find that a change in angle of attack occurs. This angle decreases for the wing, and increases for the stabilizer, and in relation the wing loses lift and stabilizer gains it. What else can a model do under such circumstances but go into a spiral dive. When we saw our glider act as though the wing had no lift, that was exactly what was the matter. Before we go into specific details, let us clear the "circular airflow."

Perhaps the easiest way to describe the "circular airflow" is to see exactly what happens. For sake of simplicity, let us say that a model is circling in a vertical bank. Its reaction on the air molecules will be such, that the molecules will hit the wing on its upper surface, and the stabilizer on its lower surface. See diagram. The result would be the same if the model was standing still and the airflow have circular characteristics.




We have not been able to find any specific reference to this type of airflow in regular textbooks from which we could quote. Perhaps, we did not look under proper headings. The nearest similé which we could give is a talk we had with J. P. Glass a long time ago, (could be 1934). He mentioned how a test lab made a zepellin model to look like a cucumber, so that they could test it in a straight airflow windtunnel, to obtain action which occurs when the zepellin is flying in a tight circle in relation to its length. See diagram. Straighten out the airflow and make the zepellin to fit similar conditions, and, since this circular airflow has been accepted by others, there is no reason why we cannot do likewise.

The zepellin is a good illustration for our side because of its relative large size in relation to the circle it can make. Full size planes make relatively large diameter circles. We have an idea that soaring boys could profit from this knowledge. In case of models we definitely have to include circular airflow in our design consideration. Not only do models make small circles, but their areodynamic layout makes them very sensitive to circular airflow, as you will presently see.

Going back to our diagram, we note how the angle of attack decreases for the wing and increases for the stabilizer. Not only does the wing lose lift through its "natural" decrease in angle of attack, but it is forced into still lower angles because the stabilizer now has a greater force about the C.G. It is no wonder that a model develops such a fast spiral dive. And its characteristics are so similar to the spiral dive that we discussed under Spiral Stability that you can be easily fooled.

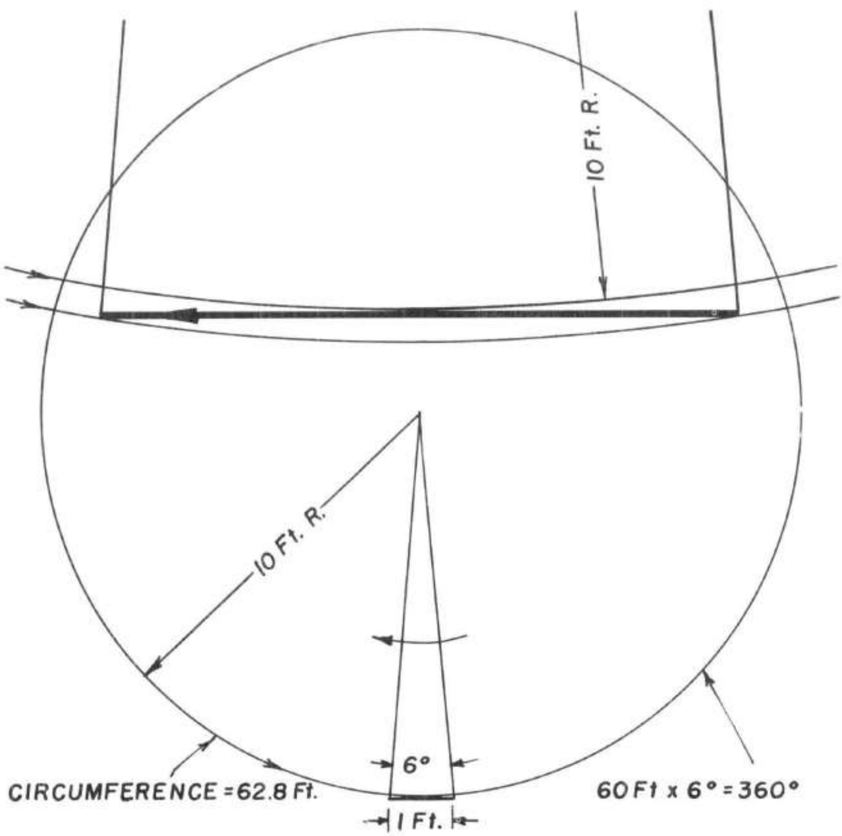
## CIRCULAR AIRFLOW

So far we have assumed that the flight or glide path is straight ahead. In this type of flight it is easy to imagine how the Longitudinal Stability works. However, a straight path in model flying is rare. Circling of some sort is the rule. And so we reach the "Circular Airflow" part of the model's flight.

Frankly, if your ideas about the Longitudinal Stability or Balance are vague, it would be best to go back to the beginning of the book and start all over again, and study the subject until you know what we are trying to show. It is simply impossible to understand the part that "Circular Airflow" plays in flight unless one has a clear picture of Longitudinal Stability.

While a model is circling, the angles on the wing and tail change so that the initial "trim" angle is no longer in power. Without you doing a thing, the stabilizer may acquire few degrees of greater angle of attack while the model is flying in a circular path. By knowing just what happens, it is possible to take advantage of this situation. But if you are in dark———.

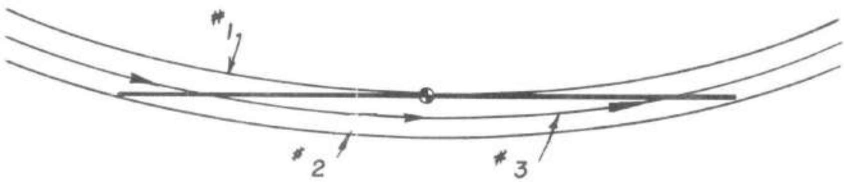
We are at loss how to explain the development of the "Circular Airflow." So, suppose we assume that we have a one foot long piece of iron rod. To the rod ends we attach 10 ft. strings. We grasp the end of the strings together and begin to whirl the rod around in a 20 ft. diameter circle. Diagramatically the situation will be as shown.—The center of the rod will follow the 20 dia. circle, while the rod ends will extend beyond the 20 ft. circle, and form a larger diameter circle.

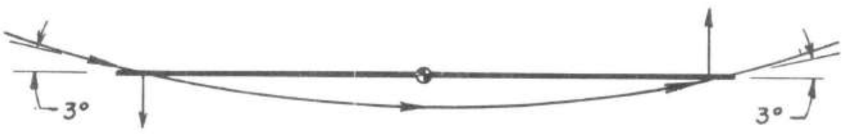


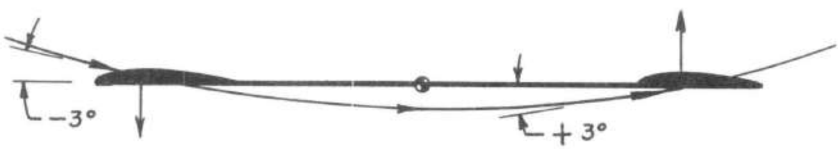
The next step is to imagine two air molecules, one on the 20 ft. diameter orbit and the other on the larger orbit. As the rod is swung around it is easy to imagine that the center of the rod and the tips just skim by the two molecules. And nothing happens.

Now, let us place a third molecule between the two circles. What happens now? As the rod reaches the #3 molecule the point of impact will be on the "upper" surface of the rod. As the rod continues around, the #3 molecule will again inpinge on the rod, but this time on the "lower" surface.

Forgetting about the restraining forces of the two end strings, which way do you think that the rod would rotate if the two "impacts" were powerful enough to make the rod pivot about the C.G.? To us it looks like counter clockwise.




By doing a bit of calculation we can also determine at what angle the #3 molecule "attacked" the rod. To simplify the situation let us assume that the attack occurred at the tip of the rod so that we will have an even one foot value. Well, it just so happens that one foot in a 20 ft. diameter circle takes up 6° of the circumference's 360°. This would resolve into 3° for each side of the rod.

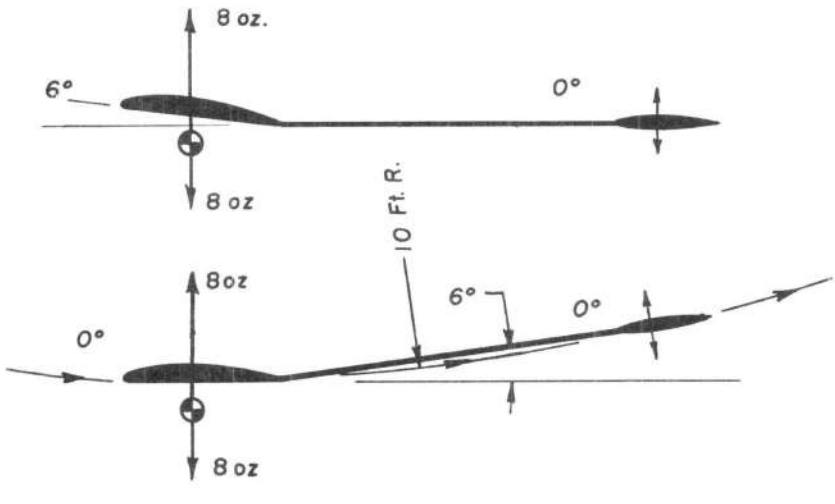
To bring the problem closer to home, let us suppose that we had a wing on each end of the rod, set at 0° to the rod and each other. It can also be seen that, if we forget about the downwash from the front wing and C.P. locations, the two would be in balance. Then we begin to whirl this combination around so that the wings are vertical. A look from the top is shown on the diagram.—Is it asking too much to make you believe that the front wing now has a 3° negative angle of attack while the rear one has a 3° positive angle of attack?

If we were to remove the strings from the ends of the rod and tie them to the center or C.G. of the rod, which way would the combination rotate? To us it looks like counter clockwise.

## CIRCULAR AIRFLOW AND LOOPING

Let us now change the whirl, from horizontal to vertical, to represent looping. This gives us a more familiar condition in which the Longitudinal Stability plays a part. In a straight flight our tandem arrangement may be in a balanced condition, but in a loop it is obviously no longer in balance. The angle of attack has decreased in front and increased in the rear. The angular difference between the two wings has increased by 6°. If you followed the logic so far, we can move to practical problems.

The C.G. location which will show the effect of the "circular airflow" most clearly is the 35%.—Here the C.G. is at the wing's C.P. so that whatever angular changes will come about due to looping will be shown directly on the stabilizer. Say that the model is in a 20 ft. dia. loop, and that the distance from the wing's C.P. and stabilizer's C.P. is one foot, and that the stabilizer is placed outside of the downwash. In a straight glide the wing would be at 6° angle of attack and stab at 0°. But if we place this lay-out in a 20 ft. dia. loop, the 6° "angular change in one foot" will act on the stabilizer so that it will bring the wing to 0° angle of attack.

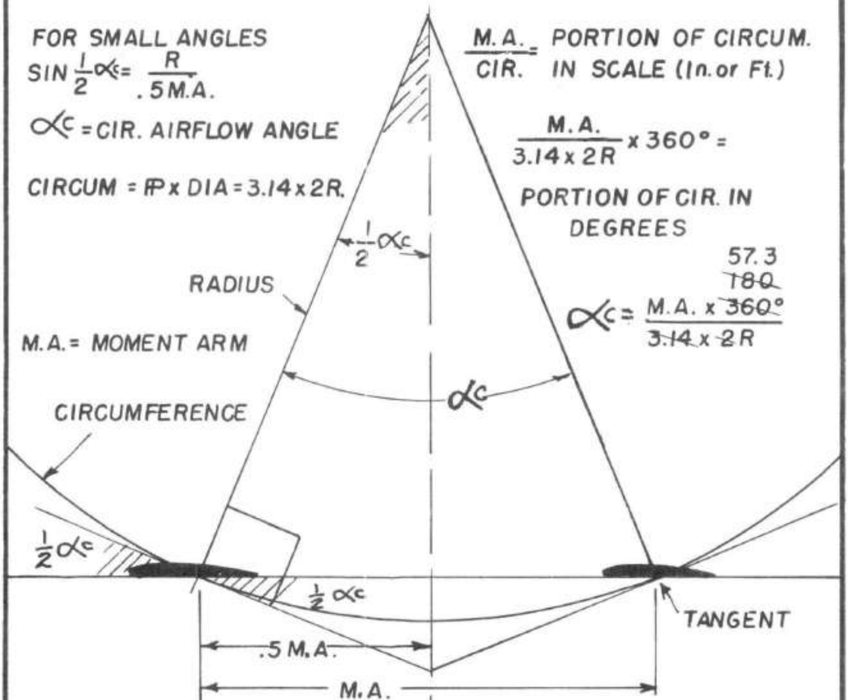



So, by actually making no physical changes, except to make the model fly fast enough to generate enough lift to cause a 20 ft. loop, we brought the angle of attack from 6° to 0°. We now get into ever widening area of explanation as to what happens as the angle of attack is decreased, and with it, a decrease of lift which originally started or caused the 20 ft. loop.—Well, the outcome depends on the power, if it is great enough to make the wing develop 8 oz. at 0° angle of attack, the loop will be balanced at 20 ft. Dia.—

Actually, this is no place to worry about minutae. The basic purpose for all this talk is to make as many of you see the action of "Circular Airflow" so that it will be easier to understand what goes on. At present we are trying to show how the curved flight path can change the "Longitudinal Balance." This condition can be very handy in providing an automatic system for changing the balance for glide and power. If you grasp the basic idea you will sit back and say, "What do you know?" And you will also realize that models have been flying despite all we did or do to keep them from flying.

## ANGULAR VALUE OF CIRCULAR AIRFLOW

We had the usual fun devising a formula for finding the exact Circular Airflow for a particular condition. It was relatively easy to work out a formula when the model is in a vertical bank. But it was a different story for banked conditions between vertical and horizontal positions. Here they are:

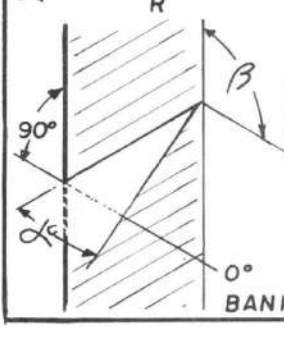


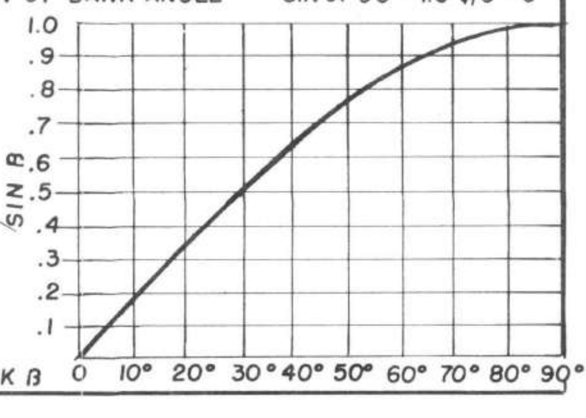

CIRCULAR AIRFLOW ANGLE $\alpha_c$ FOR 90° BANK = $\frac{M.A. \times 57.3}{R}$

CIRCULAR AIRFLOW $\alpha_c$ FORMULA FOR BANK ANGLES FROM 90° 0

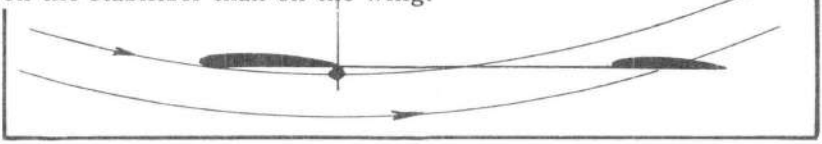
$\alpha_c = \frac{M.A. \times 57.3}{R} \times$ SIN OF BANK ANGLE  SIN of 90° = 1.0 of 0° = 0

$\alpha_c = \frac{M.A. \times 57.3 \times \sin \beta}{R}$



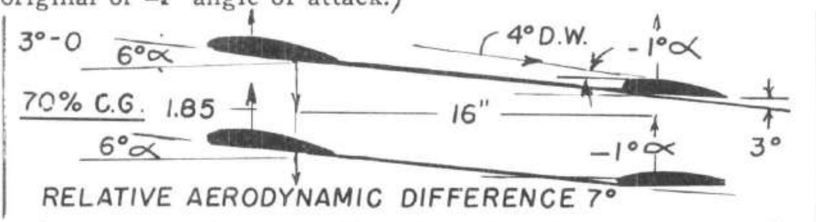
The above formulas will give us the increase of angular difference between the stabilizer and the wing, but it will not give us the exact angular change for individual units, wing and stabilizer. We just cannot divide and give half to each side. The position of the C.G. governs the exact change. This can be best seen by checking the diagram. We must assume that the C.G. will be on the circumference, and the fuselage perpendicular to the radius line as shown. It is evident that the change will be greater on the stabilizer than on the wing.



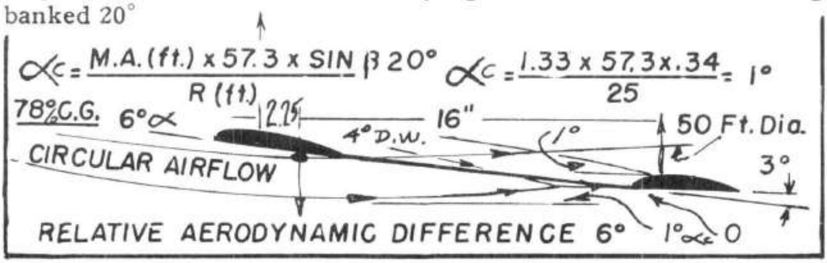
## EXAMPLES OF CIRCULAR AIRFLOW

Now that we know that there is such a thing as Circular Airflow, and that we can calculate it's relationship to the model, we can show it's effect on the model during the circular flight. We can also explain our glide adjustments, and the reason for using 12° angular difference in our original "spark plug of it all" glider.

The (usual) glider has a 3° setting for the wing, 0° for the stabilizer and C.G. at 75% spot. We have already shown in the Longitudinal Stability section that we can assume a 6° angle of attack for most models. Under such conditions the angle of attack on the stabilizer would be about $-1°$ when we include downwash angle. Such situation, which occurs on a straight flight, is shown on the diagram. (To make it easier to show the effect of circular airflow on the model, we made another diagram on which we straightened out the downwash but set the stabilizer to fit the original or $-1°$ angle of attack.)

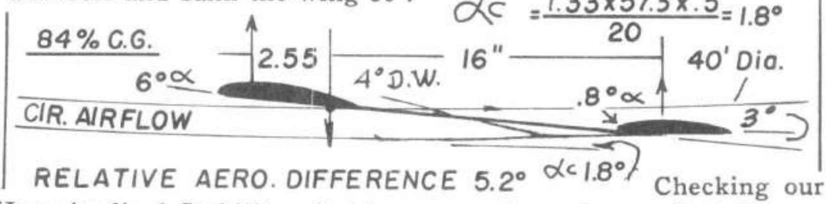



As soon as we begin to adjust the rudder for circling, the effect of the circular airflow becomes apparent. Let us take for an example a 16" moment arm model flying in a 50 ft. circle and being banked 20°



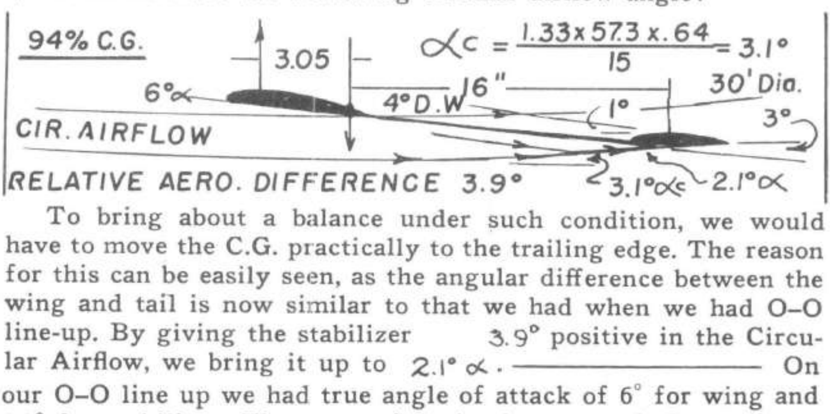
This 1° may not seem much, but since the major portion of it is used up by the stabilizer, we can see that the model will tend to nose down, perhaps slightly, but down, nevertheless. To correct for this downward tendency, we remove weight from the nose. This, in effect, provides the wing with a longer moment arm with which to balance the increase of stabilizer power. Mind you, the wing's angle of attack is slightly less than on straight flight but we gave it greater force about the C.G. by increasing its moment arm.

Let us see what happens when we tighten the circle to 40 ft. diameter and bank the wing 30°.




Checking our Longitudinal Stability pitching moment graphs, we find that we would have to shift the C.G. to 84% to obtain balance under such conditions.

When we tighten the circle to obtain a 30 ft. dia. turn and a 40° bank we have the following circular airflow angle:



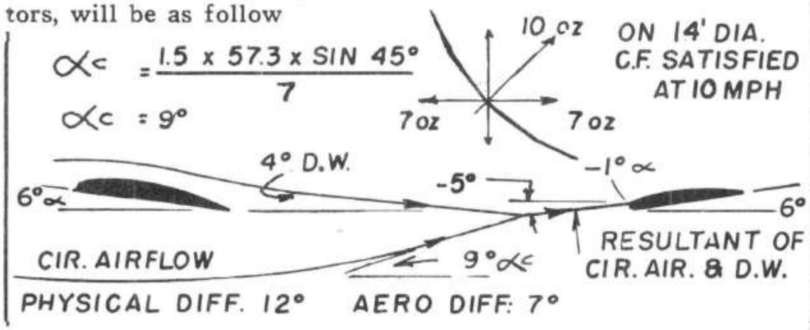

To bring about a balance under such condition, we would have to move the C.G. practically to the trailing edge. The reason for this can be easily seen, as the angular difference between the wing and tail is now similar to that we had when we had O–O line-up. By giving the stabilizer 3.9° positive in the Circular Airflow, we bring it up to 2.1° α. On our O–O line up we had true angle of attack of 6° for wing and 1.9° for stabilizer. The comparison is close enough for our purpose. And this purpose is to remind you, how touchy the O–O set-up can be for adjusting.

STAB EFF. AREA = 57□"

| WING | PITCH BALANCE | | | | | | | | STAB | |
|---|---|---|---|---|---|---|---|---|---|---|
| C.G. | $C_L$ | x AREA | x M.A. | = WF | Wα | Sα | $SC_L$ | x M.A. | x AREA | = SF |
| 70% | .82 | 200 | 1.85 | 299 | 6° | -1° | .33 | 16 | 57 | 300 |
| 78% | .82 | 200 | 2.25 | 370 | 6° | 0 | .4 | 16 | 57 | 365 |
| 84% | .82 | 200 | 2.55 | 418 | 6° | .8° | .46 | 16 | 57 | 420 |
| 94% | .82 | 200 | 3.05 | 490 | 6° | 2.1° | .55 | 16 | 57 | 501 |

The above example shows that we have reached the maximum point in our turn adjustment. To be on the safe side, we should open up the turn now. It also showed why we had to remove weight as we tighten the turn; the stabilizer's force became stronger and we had to counter it by giving the wing greater moment arm. Also, it showed why we were not able to have tighter turns on our original test glider: we reached the O–O conditions. Honestly, it is unbelievable how the flights we made over four years ago, can be so closely duplicated with an abstract example we just made. Why, then, were we able to obtain tighter circles when we used 12° built-in angular difference?

We are not sure of the exact proportion of our original glider but we can safely assume a 18" moment arm, 70% C.G., 14 ft. dia. circle and a banking angle of 45°. The formula, having these factors, will be as follow



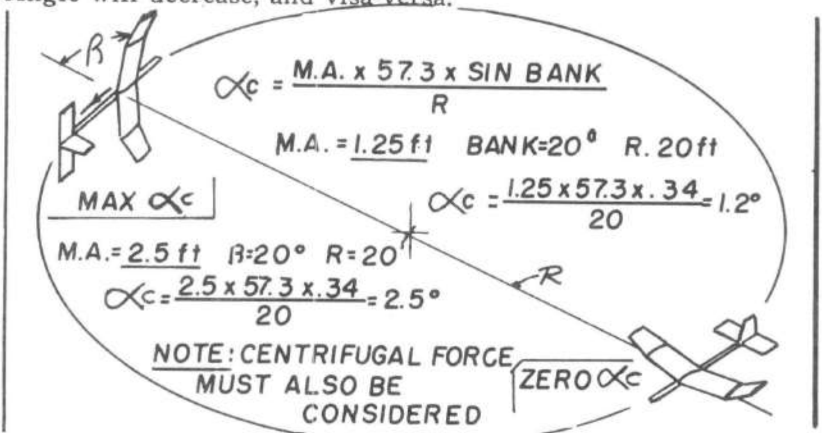

You will have to follow closely the reasoning we will now use to explain the action of our 12° model. We draw a line to represent the 5° Resultant Airflow. We place the stabilizer –1° in relation to it. The reason we are doing this, is to duplicate a condition which we had in Longitudinal Stability pitching moment example when we used 70% C.G., and when the wing had 3° incidence and stabilizer 0°. In this set-up, if you remember, the actual angle of attack, at trim point, was 6° for the wing, and –1° for the stabilizer. It, therefore, follows that the wing should be 6° positive and stabilizer –1° to the Circular Airflow. The aerodynamic condition now existing is that the wing has 6° angle of attack and the stabilizer –1°. A duplicate of our example and a perfectly respectable and stable situation as you should know. So you can see why our model was able to make such tight turns and still be in safe adjusting zone; it was normal. But if we were to check for physical angles, we find that there is a difference of 12° between wing and the stabilizer. This makes no difference to the air molecules. It's the 6° and –1° that bothers them.

It should be evident that such a large divergence of angles would not work well in straight flight, so that for practical purpose 12° may be too much. Still, the lesson was well taught. If you want tighter turns, be prepared to increase incidence setting. Just removing weight, and setting the rudder has a definite limit. A good sign of this limit is touchy adjustment.

## WHAT DETERMINES CIRCULAR AIRFLOW ANGLE

An inspection of the Circular Airflow formula will give the best answer to what factors determine the angle.

Increasing the "Moment Arm" and/or "Bank Angle," and you will increase the airflow angle. Decrease them, and you will decrease the angle. Increase the "Dia. of Circle" and the Airflow Angle will decrease, and visa-versa.




Try a couple of examples, check the diagrams. Note what a difference it makes if the moment arm is doubled in a similar circle. To explain the banking factor is a bit awkward, as we do not have a ten word sentence to explain it. If we tried, we could do it, but it might require a great deal of trig work which only one or two of you may bother to check or follow. (Problem is similar to change of angle of attack as we side skid with a dihedral angle.) Just assume that when the model is flying level but in a circle, the circular airflow angle has no influence on the wing and stabilizer. But as the model is gradually banked from horizontal towards the vertical the angle becomes more and more aggressive, and a factor to keep in mind.

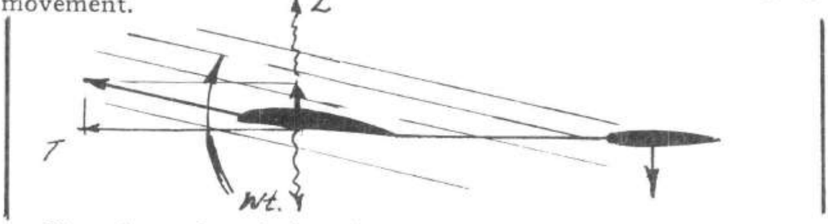
## CIRCULAR AIRFLOW AND LONGITUDINAL STABILITY

We have covered a portion of this inter-relation of Circular Airflow and Longitudinal Stability for gliders and/or models during their "glider" period. We have showed how we automatically shifted our angular differences from safe 3°–0° to touchy 0–0 without making any actual changes in our original incidence settings. We did it by tightening the circle with rudder, and shifting C.G. from 75% to 100%. Also, that the standard 3°–0° can have a minimum circling diameter which may not be the smallest we may want. And that extremely tight circles can be safely obtained by changing angular settings to fit the Circular Airflow conditions found in small circles. All this was well and good for gliders and gliding models, but it is another story for models under power.

# LOOP CALCULATIONS

It may seem far fetched to be using a loop to illustrate action of Circular Airflow and Longitudinal Stability under power, but follow us and see what happens.

A loop is developed when the model has excessive power by which the wing can produce greater lift than required for level flight. Because of that, balance about the C.G. favors a nosing up movement.



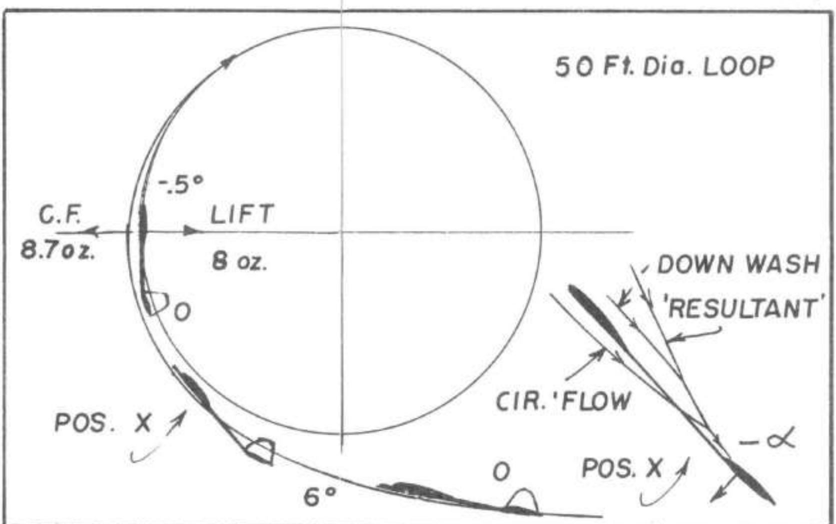

The above description fits our condition as set forth in the Longitudinal Stability section. If you remember, we pointed out how the high power brings about high lift, which, in turn, develops a "resultant" that tends to lower the over all angle of attack. The result of this action is, that the wing has a greater force about the C.G. The natural tendency of the model will be to loop. On the 33% C.G. position design, however, the "resultant" tends to produce loop by "down loading" the stabilizer which in turn produces the nosing up movement. 33% used below.

The sequence of action is as follows: As we release the model, the "resultant" will "down" load the stablizer which will nose the model upward into a loop. As the loop develops, the airflow assumes circular characteristics, and it tends to produce airflow in direction opposite of that produce by the "Resultant." Somewhere along the line, ——— the loop will reach a "uniform" diameter when the lift of the wing equals Centrifugal Force. In our case, the model will tend to narrow the loop as long as it produces "resultant" which forces the model into looping. At the same time, of course, it must generate enough lift to balance the Centrifugal Force. All this while, the Circular Airflow is killing the lift of the wing by reducing its angle of attack. Quite a bit of excitement going on, isn't there? See Pos. X.

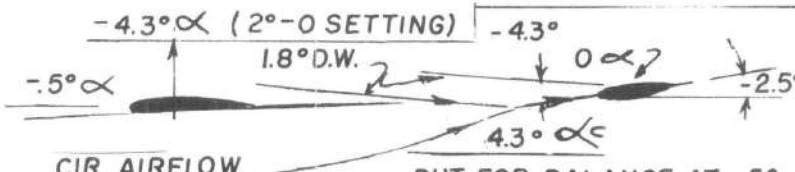
When lift of the wing equals Centrifugal Force, "Resultant" ≐ 0

We played with calculation and examples a bit, and found that if we placed the wing almost on the Circular Airflow path we would have balanced conditions.

| 33% C.G. MODEL |
|---|
| MODEL: 188 sq.in. (1.3 sq.ft.) 23" M.A. (1.9 ft.) LIFT (Wt.) = 8 oz. (.5 lb.) at 20 MPH (30 ft/sec) |
| WHAT $\alpha$ FOR 6 oz LIFT? .5 lb. = $C_L$ x .0012 x 1.3 x 900 $C_L$ = .35 IT IS AT -.5° |




WHEN WING IS AT -.5° STAB WOULD NORMALLY HAVE




BUT FOR BALANCE AT -.5°
STAB SHOULD BE 0°. THEREFORE IT NEEDS $4.3°\alpha_c$

$$4.3°\alpha_c = \frac{1.9 \times 57.3 \times 1\,(\sin 90°)}{R} \qquad R = 25 \text{ Ft. LOOP DIA.} = 50 \text{ Ft.}$$

WILL 8oz. LIFT BALANCE C.F. AT 20 MPH IN 50 Ft. LOOP?

$$C.F. = \frac{.5 \times 900}{32 \times 25} \qquad C.F. = .55 \text{ Lb} = 8.7 \text{ oz.} \qquad \text{ALMOST!}$$

NOTE: C.P. AT 43% WHEN WING AT -.5° WE USED 33%

We doubt that our loop calculations would stand up against regular aeronautical practice. We assumed constant speed. Actually, speed varies, slow going up, fast going down. On top of the loop, weight of the model helps lift against C.F. Still, it was interesting to see what happened.

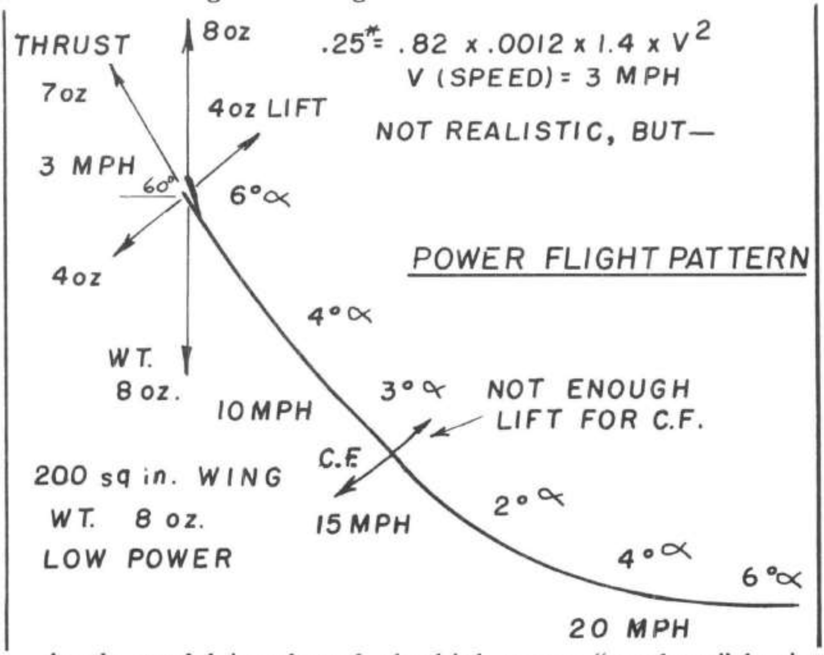
Although no one may bother to make such calculations, we had to do it to give substance to the Circular Airflow theory, and its effect during flight. You can see how it reduced the angle of attack to 0° on a model which was set to fly at 6°. And that this was done without physical change. It happened because the model was in acircular motion. It may be this change of angle of attack which may account for automatic balancing and reducing of looping tendencies of high powered models which we mentioned before.

## CIRCULAR AIRFLOW UNDER POWER

If you recall, we discussed in the Pitching Moment section that what we need, when super power is used, is a change of angle of attack from 6°, set for glide, to some smaller value. We proved it by making a model which used prop blast to bring about lower angles during power.

After we had studied the problem, we realized that Circular Airflow, like high angle of attack, has been with us as long as we have been flying models. It is one of those built-in, automatic actions that just happen to be there. Of course, Circular Airflow effect will operate for good or bad, depending on the conditions. If we knew more about it, we might be able to help it give us good service.

We have an idea that the flight path of balanced power model would be a beginning of a loop, and then a gradual "tear-away" until almost a straight angular flight is achieved. See drawing. We might not see this exact duplicate on the field as the model may be turning at the same time. But logic and knowledge of Circular Airflow seem to dictate this type of power flight. We use the following "reasoning:"

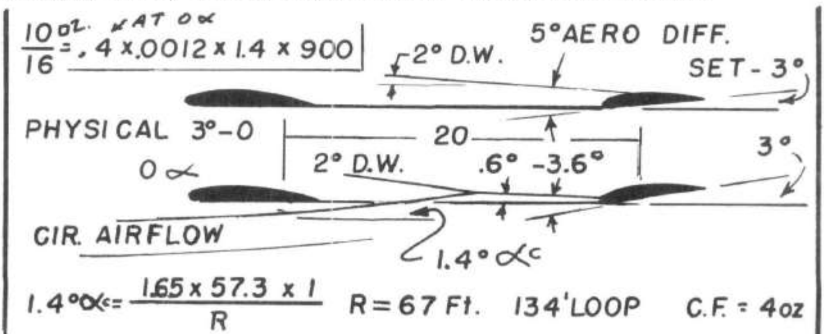



As the model is released, the high power "resultant" begins to produce looping tendencies. As the loop builds up, the Circular Airflow automatically decreases the angle of attack. A decrease in angle of attack means a decrease in lift. The model may now not have enough extra lift to counteract the Centrifugal Force, and the loop will automatically open up. If during this time the model has not reached the peak of the loop, it will most likely not be able to do so at all, because a portion of the model's weight may now be loaded on the prop. This will slow down the model. Slower speed means that the "resultant" might disappear, and model assume closer setting to original 6°. The situation may now be such that the speed may be actually below its normal glide speed. But since the prop is pulling it up, we don't mind. See our graphic presentation.

While on graphs, we might explain the force diagram shown on top. We are assuming a 60° climb; 7 oz. prop pull and 8 oz. weight. The resultant of these two forces has a value of 4 ozs. To counteract this force, the wing should develop at least this value. We made some rough calculations and found that if the model was moving at 3 m.p.h. and the wing was set at 6°, the lift produced would be about 4 ozs. It is close enough for our example. ( 3 m.p.h. is **260 ft.** per minute.) Later on we will show a different type of force diagram during high power climb.

## CIRCULAR AIRFLOW FOR 75% AND 100% C.G.

We were curious to find out what sort of a Circular Airflow angle would be required to stabilize the 75% model, when the wing was flying at 0° angle of attack and 20 m.p.h., to produce 10 ozs. We checked and found that the stabilizer should have –3.6° angle of attack to obtain a balanced condition. Accounting for the wing's 2° downwash, the stabilizer should have -5° to the "base" line. Since our normal incidence setting difference is 3°, we will need a 1.4° Circular Airflow. To find out what sort of a loop it would make, if sufficient power was used, under such conditions, we used the Circular Airflow Formula as follows:




Using 134 ft. dia. loop in our Centrifugal Force formula we find that its force would be about 4 ozs. This means that the natural loop is probably a "bit" smaller than our calculated 134'.

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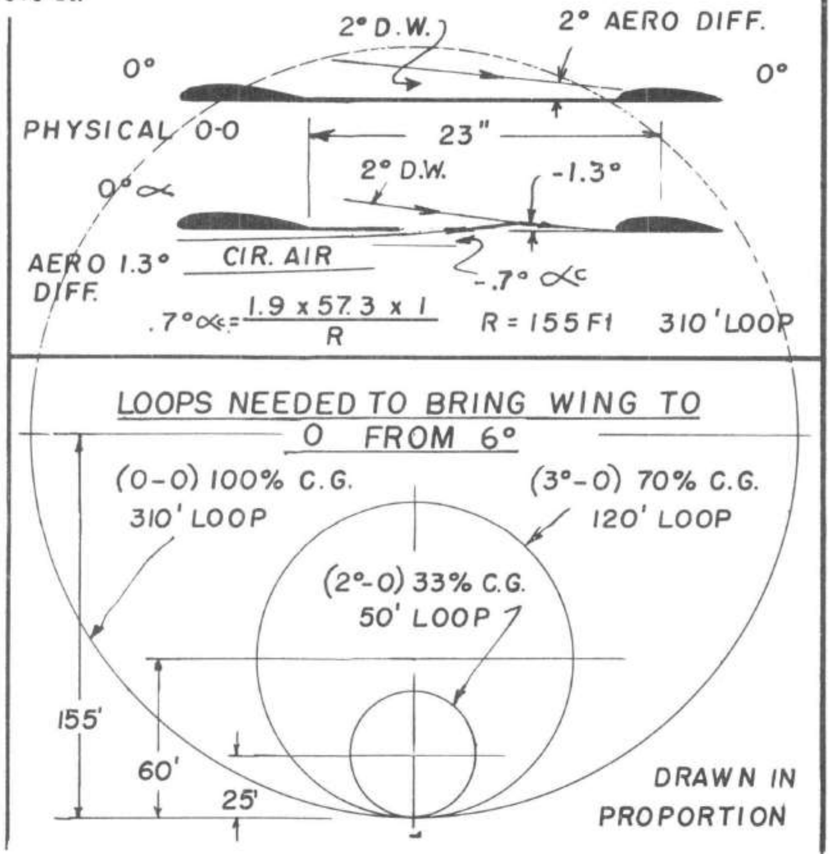
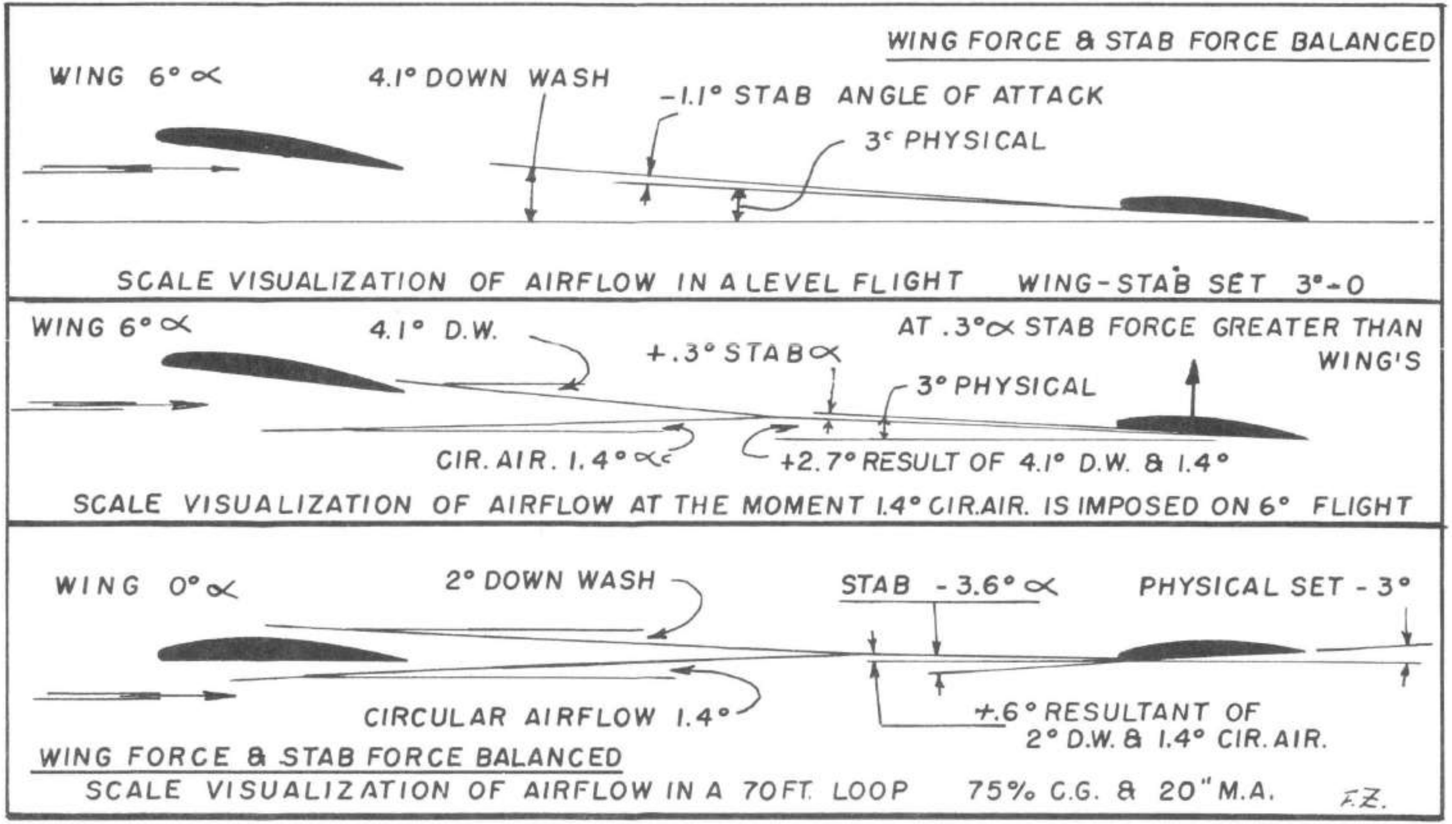
The 100% design is very interesting. With wing at 0° angle of attack, we find that the stabilizer needs -1.3° angle of attack to balance the wing about the C.G. — there is need for .7° Circular Airflow to bring the two surfaces into a balance. The force lines on the Pitching Moment graph are very close, and only slight difference in angles is required for one or the other to become stronger. In fact, we found that a ½° change would bring almost drastic results. What sort of a loop would bring about .7° change? Using the formula; we find the loop diameter to be 310 ft.




We stated before that this design has large diameter looping tendencies. This model has to reach 155 ft. before it can begin to go towards the top of the loop. It is bound to hang on the prop by then, and slow down to a point where looping "result out" disappear. This shows how our guess can be pretty close.

## ACADEMIC STUDY

The above discussion should be taken more or less in an academic vein as we used calculations which may not have correct factors. Also, it was given for clarity sake so that you can have a better idea of every move that a model makes, and just how different designs have different characteristics. Just changing C.G. from 33% to 100% meant that the natural loop diameter increased from 50 ft. to 310 ft.


WING FORCE & STAB FORCE BALANCED
WING 6° ∝
4.1° DOWN WASH
-1.1° STAB ANGLE OF ATTACK
3° PHYSICAL
SCALE VISUALIZATION OF AIRFLOW IN A LEVEL FLIGHT WING-STAB SET 3°-0
WING 6° ∝
4.1° D.W.
AT .3°∝ STAB FORCE GREATER THAN WING'S
+.3° STAB∝
3° PHYSICAL
CIR. AIR. 1.4° ∝c
+2.7° RESULT OF 4.1° D.W. & 1.4°
SCALE VISUALIZATION OF AIRFLOW AT THE MOMENT 1.4° CIR.AIR. IS IMPOSED ON 6° FLIGHT
WING 0° ∝
2° DOWN WASH
STAB -3.6° ∝
PHYSICAL SET -3°
CIRCULAR AIRFLOW 1.4°
+.6° RESULTANT OF 2° D.W. & 1.4° CIR. AIR.
WING FORCE & STAB FORCE BALANCED
SCALE VISUALIZATION OF AIRFLOW IN A 70FT. LOOP 75% C.G. & 20" M.A.
F.Z.

## CIRCULAR AIRFLOW AND POWER CIRCLING

We saw how the Circular Airflow introduced a balanced condition by decreasing the angle of attack as the model tended to fly in a zoom or loop. Similar reasoning can be applied to a model while it is circling or turning. The problem here is complicated, as the Circular Airflow has no effect on the wing and stabilizer as long as they fly level, regardless of the circle's diameter. But as soon as the wing banks, the Circular Airflow comes into the picture. Some of this action has already been covered when we described the action of gliders under different conditions.

## SIZE OF CIRCLE

The size of a circle is determined by the force which pulls the model towards the center of the circle, and the Centrifugal Force which tends to pull it out. We obtain circling force by banking the model so that part of the wing's lift is used for countering Centrifugal Force. As soon as we bank the model in a circle, it comes under Circular Airflow influence. The question; What effect does the Circular Airflow have on the model? The answer, of course, depends on the design.

To simplify this problem, we have prepared the following Circular Airflow Chart. (Sometimes we wonder from where do all these things come.) It shows the Circular Airflow angles for a particular bank angle in combination with a particular size of a circle. We used 12″, or 1 ft. moment arm in our calculations. This makes the table usable for any moment arm. WING BANK

| DIA. | 5° | 10° | 15° | 20° | 25° | 30° | 35° | 40° | 45° | 50° | 60° | 70° | 80° | 90° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 1° | 2° | 3° | 3.9 | 4.8 | 5.7 | 6.6 | 7.4 | 8.1 | 8.8 | 9.9 | 10.7 | 11.3 | 11.4 |
| 15 | .67 | 1.3 | 2° | 2.6 | 3.2 | 3.8 | 4.4 | 4.9 | 5.4 | 5.9 | 6.6 | 7.2 | 7.5 | 7.6 |
| 20 | .5 | 1.0 | 1.5 | 2° | 2.4 | 2.9 | 3.3 | 3.7 | 4.1 | 4.4 | 4.9 | 5.4 | 5.6 | 5.7 |
| 25 | .4 | .8 | 1.2 | 1.6 | 1.9 | 2.3 | 2.6 | 2.9 | 3.2 | 3.5 | 4° | 4.3 | 4.5 | 4.6 |
| 30 | .33 | .67 | 1° | 1.3 | 1.6 | 1.9 | 2.2 | 2.5 | 2.7 | 2.9 | 3.3 | 3.6 | 3.8 | 3.8 |
| 35 | .28 | .57 | .86 | 1.1 | 1.4 | 1.6 | 1.9 | 2.1 | 2.3 | 2.5 | 2.8 | 3.1 | 3.2 | 3.2 |
| 40 | .25 | .5 | .75 | .98 | 1.2 | 1.4 | 1.6 | 1.8 | 2° | 2.2 | 2.5 | 2.7 | 2.8 | 2.8 |
| 45 | .22 | .45 | .67 | .8 | 1.1 | 1.3 | 1.4 | 1.6 | 1.8 | 1.9 | 2.2 | 2.4 | 2.5 | 2.5 |
| 50 | .2 | .4 | .6 | .78 | .96 | 1.1 | 1.3 | 1.4 | 1.6 | 1.7 | 2° | 2.2 | 2.2 | 2.3 |
| 60 | .16 | .33 | .5 | .65 | .8 | .95 | 1.1 | 1.2 | 1.3 | 1.4 | 1.7 | 1.8 | 1.9 | 1.9 |
| 80 | .12 | .25 | .37 | .49 | .6 | .72 | .82 | .92 | 1° | 1.1 | 1.2 | 1.3 | 1.4 | 1.4 |
| 100 | .1 | .2 | .3 | .39 | .48 | .56 | .65 | .74 | .81 | .88 | 1° | 1.1 | 1.1 | 1.1 |
| 120 | .08 | .16 | .25 | .32 | .4 | .48 | .55 | .62 | .67 | .73 | .83 | .9 | .94 | .95 |
| 140 | .07 | .14 | .21 | .28 | .34 | .41 | .47 | .53 | .58 | .63 | .71 | .77 | .81 | .82 |
| 160 | .06 | .12 | .18 | .24 | .30 | .36 | .41 | .46 | .5 | .55 | .62 | .67 | .70 | .72 |

FT. FOR SMALL FINAL CIR. AIR. ANGLES, 6° or LESS.

CONVERSION PROCEDURE: To find Circular Airflow angle of your model, multiply the angle shown on the table which fits your condition by the moment arm of your model; (be sure to convert it to feet). Example: At 30° bank and 40 ft. circle the Circular Airflow angle is 2.5° If your model has 1.5 ft. moment arm. Its Circular Airflow will be 3.75°.

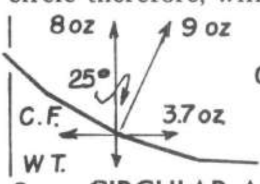
If you have the moment arm, and Circular Airflow angle of your model, divide the angle by the moment arm to find the corresponding angle in the table. Example: 1.5° ÷ 1.5 ft. = 1°. Its place on the Chart will depend on your requirements.

## CHART

This chart may give you the Circular Airflow angles you may be seeking, but it does not mean that your model will be able to make every combination shown. As we will show, it may be able to do only one combination out of possible 100. Remember, to obtain a uniform and level circle, we must have two matched forces; side force of the lift (produced in a banked position), must match the Centrifugal Force developed at that particular moment. For example:

We have a wing developing 9 ozs. lift at 20 m.p.h. We want to use the wing in a 25° bank. What is the smallest circle it can make?—The lift will be resolved as shown; 8.0 ozs. vertically to hold up the model, and 3.7 ozs. to counter the effect of the Centrifugal Force. Knowing that the Centrifugal Force should equal the side force of the lift, or 3.7 ozs., we can use the Centrifugal Force formula to find the diameter of the circle.

Solving for radius, we find it to be 60 ft. The diameter of the circle therefore, will be 120 ft.




$$C.F. = 3.7\,oz = .23\,lb = \frac{.5 \times 900}{32 \times R} \quad R = 60\ Ft.$$

CIRCLE = 120 Ft.

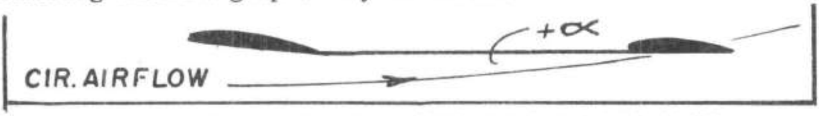
## CIRCULAR AIRFLOW AND 100% C.G. MODEL

Checking our Chart at 120 ft. dia., and 25° bank, we find the Circular Airflow of .4°. Converting for 1.9' moment arm, the angle is .76°. Upon checking our familiar designs, we find that it fits the 100% C.G. design. If you recall, during the Pitching Moment discussion, we mentioned that for the 100% C.G. model, a change of only .7° was needed to bring the trim angle from 6° to 0° angle of attack. We have that change now. And in the Loop Chapter we made a lift calculation which showed that at 20 m.p.h., the 200 sq. in. wing will produce 10 ozs. of lift when angle of attack is 0°.

The above example shows that the 100% C.G. has to make a 120 ft. diameter circle, and bank 25°, to obtain .76° Circular Airflow required to stabilize the model in a level circular flight when flying at 20 m.p.h.

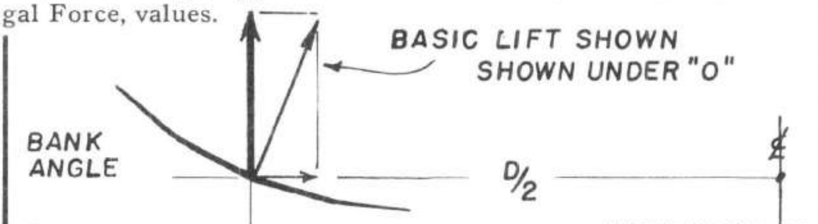
## CIRCULAR AIRFLOW AND STABILIZER

It is a good idea to consider Circular Airflow angle as an increase to stabilizer's angle of attack. For example: If a model banks 30°, in a 40 ft. circle, the stabilizer has an increase of 1.4° in its angle of attack (assuming 12" moment arm). To find out the effect of this increase of stabilizer's angle of attack, consult the Pitching Moment graphs of your model.




## CHARTS OF LIFT FORCES IN A BANK AND CENTRIFUGAL FORCE

One shows the effect a banked wing has on its basic lift force. As you can see, we resolved the basic lift into its vertical and side components. We used a 200 sq. in., Clark Y, wing, flying at 20 m.p.h., to obtain the lift values shown for various angles of attack. Heavy type indicates the vertical portion of the angled lift, and the light type shows the horizontal, or the anti-Centrifugal Force, values.




WING : 200 sq. in. CLARK Y 20 MPH WING BANK

| ∝ | $C_L$ | 0 | 10° | 20° | 30° | 40° | 45° | 50° | 60° | 70° | 80° | 90° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6° | .82 | **19** | **18.7** | **17.9** | **16.4** | **14.5** | **13.3** | **12.3** | **9.5** | **6.5** | **3.3** | **0** |
| | | 0 | 3.3 | 6.5 | 9.5 | 12.3 | 13.3 | 14.5 | 16.4 | 17.9 | 18.7 | 19 |
| 5° | .76 | **18.2** | **17.9** | **17.1** | **15.6** | **13.8** | **12.7** | **11.7** | **9.2** | **6.2** | **3.2** | **0** |
| | | 0 | 3.2 | 6.2 | 9.2 | 11.7 | 12.7 | 13.8 | 15.6 | 17.1 | 17.9 | 18.2 |
| 4° | .7 | **16.8** | **16.6** | **15.8** | **14.5** | **12.8** | **11.7** | **10.8** | **8.4** | **5.7** | **2.9** | **0** |
| | | 0 | 2.9 | 5.7 | 8.4 | 10.8 | 11.7 | 12.8 | 14.5 | 15.8 | 16.6 | 16.8 |
| 3° | .62 | **14.5** | **14.3** | **13.6** | **12.5** | **11.0** | **10.1** | **9.3** | **7.2** | **4.9** | **2.5** | **0** |
| | | 0 | 2.5 | 4.9 | 7.2 | 9.3 | 10.1 | 11.0 | 12.5 | 13.6 | 14.3 | 14.5 |
| 2° | .54 | **13** | **12.8** | **12.2** | **11.1** | **10.0** | **9.1** | **8.3** | **6.5** | **4.5** | **2.3** | **0** |
| | | 0 | 2.3 | 4.5 | 6.5 | 8.3 | 9.1 | 10.0 | 11.1 | 12.2 | 12.8 | 13 |
| 1° | .47 | **11.3** | **11.1** | **10.6** | **9.7** | **8.6** | **7.9** | **7.2** | **5.7** | **3.9** | **2.0** | **0** |
| | | 0 | 2.0 | 3.9 | 5.7 | 7.2 | 7.9 | 9.7 | 10.6 | 11.1 | 11.1 | 11.3 |
| 0 | .4 | **9.6** | **9.5** | **9.0** | **8.3** | **7.3** | **6.7** | **6.2** | **4.8** | **3.3** | **1.67** | **0** |
| | | 0 | 1.67 | 3.3 | 4.3 | 4.8 | 6.7 | 7.3 | 8.3 | 9.0 | 9.5 | 9.6 |

The other chart shows the value of the Centrifugal Force at different speeds and diameters. An 8 ozs. model was used in calculations, and the values listed are in ounces.

| SPD | DIAMETER OF CIRCLE (Ft) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MPH | 10' | 15' | 20' | 30' | 40' | 50' | 60' | 70' | 80' | 100' | 120' | 150' |
| 10 | 11 oz | 7.2 | 5.5 | 3.7 | 2.7 | 2.2 | 1.8 | 1.6 | 1.3 | 1.1 | .96 | .8 oz |
| 15 | 24 | 16 | 12 | 8.0 | 6.1 | 4.8 | 4 | 3.5 | 3.0 | 2.4 | 2.1 | 1.6 |
| 20 | 43 | 29 | 22 | 15 | 11 | 8.7 | 7.2 | 6.1 | 5.5 | 4.3 | 3.7 | 2.9 |
| 25 | 67 | 45 | 34 | 22 | 17 | 14 | 11 oz | 9.6 | 8.5 | 6.9 | 5.6 | 4.5 |

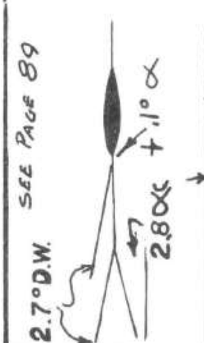
## FINDING SIZE OF CIRCLE FOR 33% C.G. MODEL

The first step in finding the circle for the 33% C.G. model is to match the horizontal component of the lift against the Centrifugal Force values. It is obvious that we can obtain a great many combinations from the Charts, if we use just these two factors. To make it more specific, we should match them only when the vertical lift component is around 8 ozs. This will indicate that the model is flying in a level circle. A collection of such combinations is shown on the chart. We also included other points of information.

## COMBINATION CHART

The next question is: Which combination will fit our 33% C.G. model? The answer depends on the Circular Airflow angle shown in the combination. If this angle happens to be such, that it will allow the wing to operate at the angle of attack listed in the combination, we can assume that our 33% C.G. model will make a circular flight as described in the combination, at 20 MPH

The 33% C.G. model has 2° incidence difference between wing and the streamlined stabilizer, and in a trimmed flight, the stabilizer's angle of attack must be 0°. These facts indicate that the combination found under the 50° bank will fit this model. In this combination, the wing's angle of attack is 2° and the Circular Airflow is 2.8° Consulting our Pitching Moment graph, we find that in the 2° line, the stabilizer's angle of attack is -2.7°.

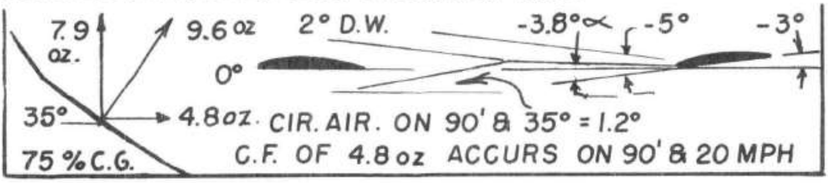



| WING | | LIFT oz. | C.F. Dia. | CHART | ACTUAL |
|---|---|---|---|---|---|
| α | BANK | UP SIDE | TO FIT | αc x M.A. | αc |
| 0 | 30° | 8 - 4 | 110' | .52° x 1.5 | .8° |
| 1° | 45° | 8 - 8 | 55' | 1.45° x 1.5 | 2.1° |
| 2° | 50° | 8 - 10 | 44' | 1.9° x 1.5 | 2.8° |
| 3° | 55° | 8 - 11 | 40' | 2.3° x 1.5 | 3.5° |
| 4° | 60° | 8 - 14 | 30' | 3.3° x 1.5 | 5.0° |
| 5° | 65° | 8 - 16 | 29' | 3.4° x 1.5 | 5.1° |
| 6° | 65° | 8 - 17 | 27' | 4.1° x 1.5 | 6.2° |

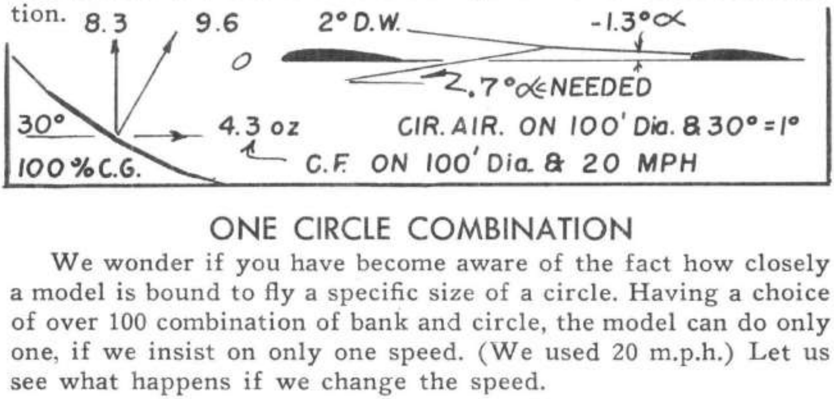
## CIRCLE COMBINATIONS FOR 75% C. G. AND 100% C. G. MODELS

We have found that the 75% C.G. model will fit the 35° bank combination. At 0° angle of attack, our Pitching Moment chart shows 2.0° downwash. Since we already have a 3° difference in incidence, the stabilizer will have an angle of attack of −5°.

In this 35° bank combination, the Circular Airflow is 1.2° ∴ $-5° + 1.2° = -3.8° \alpha$. Referring again to the Pitching Moment chart, we see that at −3.6° the stabilizer has same force about the C.G. as the wing has at 0°. And so, the trim point is achieved when the model flies in a 90 ft. circle and at a 35° bank.




For the 100% C.G. model we have already gone through the calculations and found that it belongs in the 30° bank combination.




## ONE CIRCLE COMBINATION

We wonder if you have become aware of the fact how closely a model is bound to fly a specific size of a circle. Having a choice of over 100 combination of bank and circle, the model can do only one, if we insist on only one speed. (We used 20 m.p.h.) Let us see what happens if we change the speed.

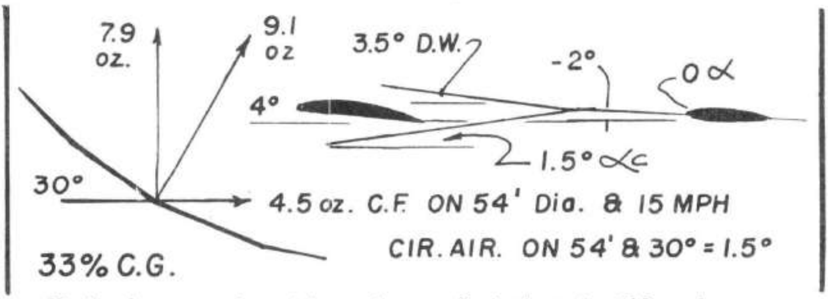
## CIRCULAR AIRFLOW AND SPIRAL STABILITY

Now that we have began to introduce variable factors, we are entering the Spiral Stability domain. After all, if a model is circling, and if for some reason or other, it spirals up or down, we are definitely concerned with its Spiral Stability. . . . We are going to be very nice and assume that our rudder area and dihedral combination is just right. So that whatever trouble we have for the next few paragraphs, we can trace them right back to improper use of Circular Airflow.

## CHANGING AIR SPEED

To help us along, we made up a table showing lift values at 15 MPH & used in finding the new bank and circle combination for the 33% C.G. model as it flies at 15 m.p.h.

| WING 200 sq in CLARK Y 15 MPH | | BANK ANGLE | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| α | $C_L$ | 0 | 10° | 20° | 30° | 40° | 45° | 50° | 60° | 70° | 80° | 90° |
| 0 | .4 | 5.2 | 5.1 | 4.9 | 4.5 | 4.0 | 3.7 | 3.3 | 2.6 | 1.8 | .9 | 0 |
| | | 0 | .9 | 1.8 | 2.6 | 3.3 | 3.7 | 4.0 | 4.5 | 4.9 | 5.1 | 5.2 |
| 1° | .47 | 6.1 | 6 | 5.8 | 5.3 | 4.6 | 4,3 | 3.9 | 3.0 | 2.2 | 1.0 | 0 |
| | | 0 | 1.0 | 2.2 | 3.0 | 3.9 | 4.3 | 4.6 | 5.3 | 5.8 | 6 | 6.1 |
| 2° | .54 | 7.0 | 6.9 | 6.6 | 6.1 | 5.3 | 4.9 | 4.5 | 3.5 | 2.4 | 1.2 | 0 |
| | | 0 | 1.2 | 2,4 | 3.5 | 4.5 | 4.9 | 5.3 | 6.1 | 6.6 | 6.9 | 7.0 |
| 3° | .62 | 8.0 | 7.9 | 7.5 | 6.9 | 6.1 | 5.6 | 5.1 | 4.0 | 2.8 | 1.4 | 0 |
| | | 0 | 1.4 | 2.8 | 4.0 | 5.1 | 5.6 | 6.1 | 6.9 | 7.5 | 7.9 | 8.0 |
| 4° | .7 | 9.1 | 9 | 8.6 | 7.9 | 6.9 | 6.4 | 5.8 | 4.5 | 3.1 | 1.6 | 0 |
| | | 0 | 1.6 | 3.1 | 4.5 | 5.8 | 6.4 | 6.9 | 7.9 | 8.6 | 9 | 9.1 |
| 5° | .76 | 9.9 | 9.8 | 9.3 | 8.6 | 7.5 | 7.0 | 6.4 | 5.0 | 3.4 | 1.72 | 0 |
| | | 0 | 1.72 | 3.4 | 5.0 | 6.4 | 7.0 | 7.5 | 8.6 | 9.3 | 9.8 | 9.9 |
| 6° | .82 | 10.7 | 10.5 | 10 | 9.3 | 8.0 | 7.5 | 6.8 | 5.5 | 3.6 | 1.85 | 0 |
| | | 0 | 1.85 | 3.6 | 5.5 | 6.8 | 7.5 | 8.0 | 9.3 | 10 | 10.5 | 10.7 |




Reducing speed to 15 m.p.h., we find that the lift value we can use occurs at 4°, to wit: 9.1 ozs. At 30° bank, this value breaks up into 7.9 oz. vertical value and 4.5 ozs. for side. This side force of 4.5 ozs. will balance Centrifugal Force of similar value produced in a 54′ dia. circle at 15 m.p.h. In a 54 ft. circle and 30° bank, the Circulatory Airflow angle is about 1.5° ( 1° on chart x 18″ M.A.) Referring to Pitching Moment chart, we find that at 4° incidence difference, the stabilizer seemingly has -1.2° angle of attack. But, we bring the 1.5° Circular Airflow into the picture and so bring about the required 0° angle of attack on the stabilizer for a balanced condition.

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In the examples presented, we are assuming that the speed in the particular division was held constant, despite change in angle of attack. Also, that correct rudder adjustments were used to bring about the circles and banks listed. If incorrect rudder is used, you will get spirals, up or down. More about this in the following paragraphs.

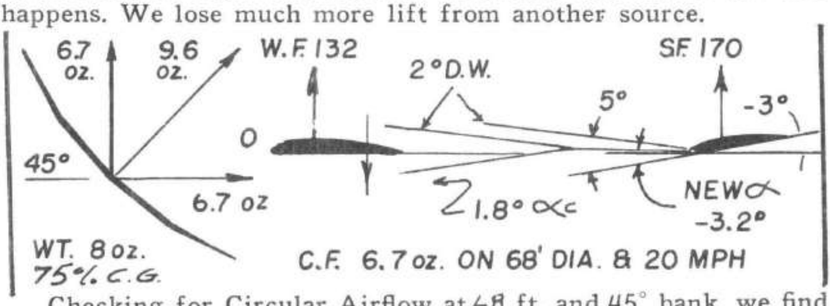
## CIRCULAR AIRFLOW AND SPIRAL INSTABILITY

Have you wondered why we spent so much time and effort in finding conditions in which our models would fly in a level circling flight? We had to do this, so that you would know what we did to obtain such stable flights. Then, if a model is not stable, we can deduct from its action what could be wrong. To make this point clearer, let us make a model spirally unstable.

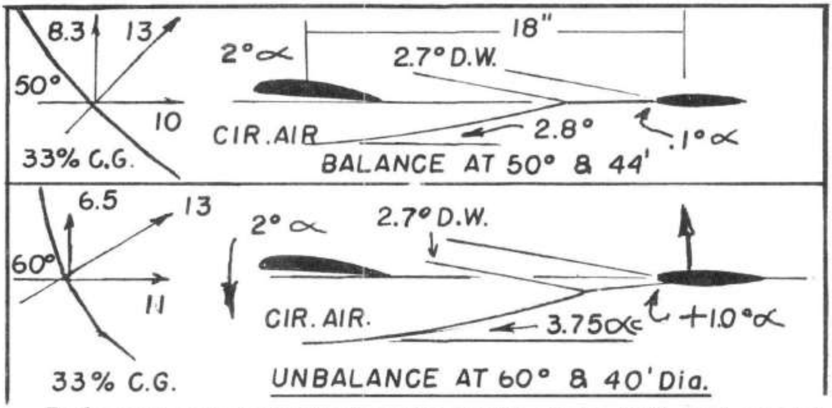
How are we going to make a model unstable? What a foolish question to ask, when such action is the rule, rather than the exception out in the field. Seriously, we mean "scientifically." Taking a page from practice: we have a model circling in a certain size diameter, and want to tighten up its turn; we set the rudder accordingly. The next flight develops into a spiral dive. What did we do wrong?

We will use the 75% C.G. model in our scientific instability test. Using the 20 m.p.h. situation, we find that its trimmed circle calls for a 35° bank and 90 ft. circle. Under such condition, the angle of attack is 0°. Then we decide to tighten this turn to 68 ft. When we do that, we find that the model tends to spiral dive. Why?

In a 68 ft. circle, the Centrifugal Force is 6.8ozs. To balance this force, we set the rudder so that the wing banks 45°. Checking along the 45° column, on the 0° line, we find that we now have 6.7 ozs. of vertical lift and 6.7 ozs. of side force to counter the Centrifugal Force. Although the Centrifugal Force may be balanced, we lack 1.3 ozs. to hold the model level. From this we should expect a gradual descent. However, this is not all that happens. We lose much more lift from another source.




Checking for Circular Airflow at 68 ft. and 45° bank, we find it to be 1.8°. (1.20 on chart). In a 35° bank and 90 ft. circle we had 1.2°. This means an increase of .6° to the stabilizer's angle of attack. This may not mean much but it is enough to make the difference in the trimming. Since the model at 0° is trimmed or balanced when the stabilizer is at –3.8°, the new condition will bring the stabilizer to –3.2°. The stabilizer now has a greater force about the C.G. and is able to force the wing into lower angles of attack. We do not know just how far. Wing 0 α WF = 132 STAB -3.2° SF = 170 The model has no choice but spiral dive down. It simply does not have enough lift to stay up.—So, you better change your setting back to 35° and 90 ft. circle.




Before you start tightening the circle of the 33% C.G. model, check the Centrifugal Force at the circle you wish to obtain. Say it is 30 ft. instead o fthe 44 ft. now in use. At 30 ft. you will need 15 ozs. of side force, and at 2.8 the wing only develops 13 ozs. Perhaps, you should be satisfied with a 40 ft. circle that calls for 11 ozs. of side force. If you force the model into a 60° bank, you will obtain 11 ozs. of side force, but only 6.5 ozs. of upward lift. Obviously the model is on its way down. Besides, as soon as you begin to increase the bank, you automatically increase the Circular Airflow angle. At 60° bank and 40 ft. circle, it is 3.75°. And do you know what 3.75° Circular Airflow would do? Reduce the wing to -1° angle of attack! And how much lift do we get there? So, my friend, be happy with 50° and 44 ft. circle. (4 oz ↑ up)

---

On 100% C.G. model, the slightest adjustment to tighten the turn will bring about an increase in Circular Airflow. We are already playing mighty close in accepting .7° Circular Airflow in our stabilizing calculations as shown on the table. A change to 70 ft. diameter and 40° bank to balance the Centrifugal Force would give us a Circular Airflow of 2°. Such a change would bring about such a fast spiral dive that you would not have enough time to get out of the way. Our advice is to increase the original 100 ft. to at least 120 ft.

## SUMMARY OF CIRCULAR AIRFLOW INFLUENCE ON SPIRAL INSTABILITY

The above, in a manner of speaking, is again academic. We never want our models to circle level while under power. We want them to go up, but fast! However, we should realize from the examples given, that every design has a limit in its circling ability. No matter how you cut it, the closer the C.G. comes to the trailing edge, so much larger will the circle have to be. So, when adjusting for circling under power, if you find that the model tends to spiral dive, the only solution you have is to open up the circle. If you need turn adjustment for subsequent glide, make such adjustment come about only after the power is out. For example, if you have right rudder for right glide turn, be sure to have left thrust to balance it during power period.

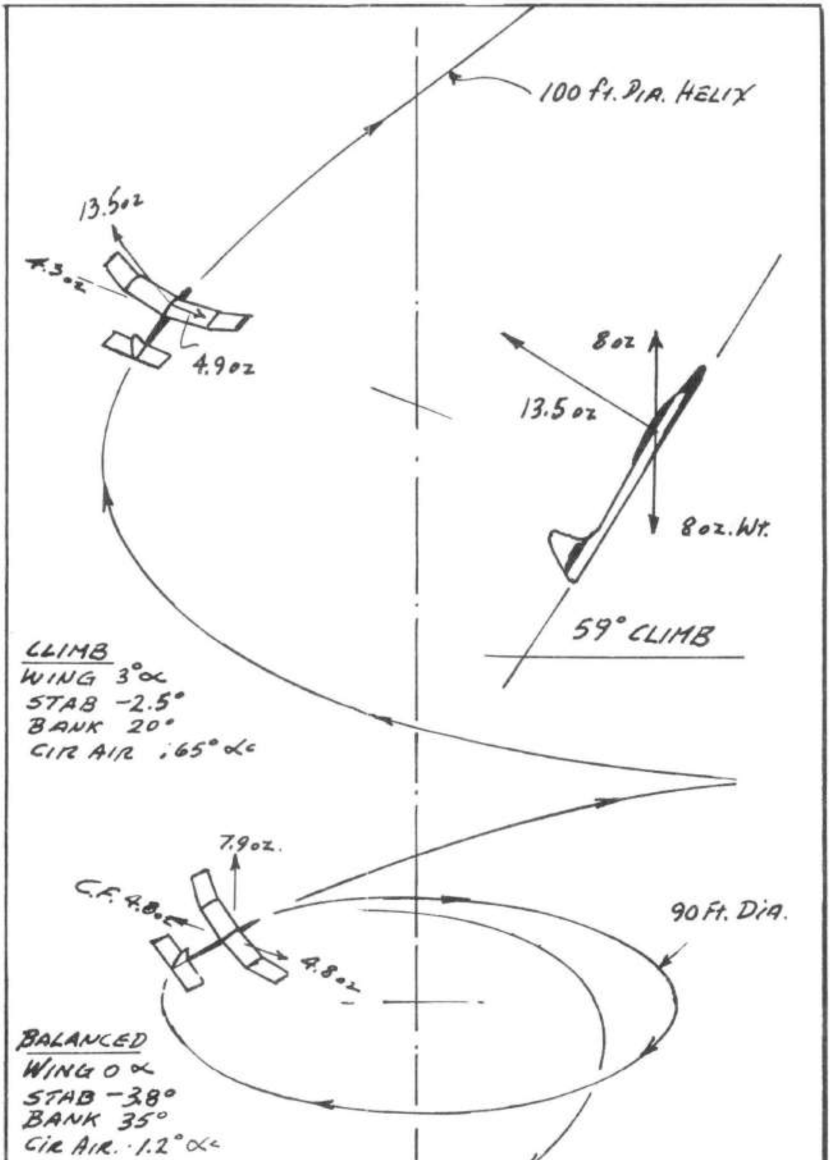
We believe that we have given you enough specific information on the effect of Circular Airflow on Spiral Instability. You should now be able to judge for yourself when you are forcing a model into a circling condition for which it was not designed. — Also, note how it is possible to obtain nasty spiral dives without any help from rudder and dihedral combination. So, do not be hasty to blame the rudder or dihedral for all your spiral instability troubles ,even though we put up a strong case against them. We hope that you have somehow realized how sensitive 100% C.G. model is to the Circular Airflow. Therefore, be sure not to have touchy rudder and dihedral combination which may bring your model into unsafe tight turns.

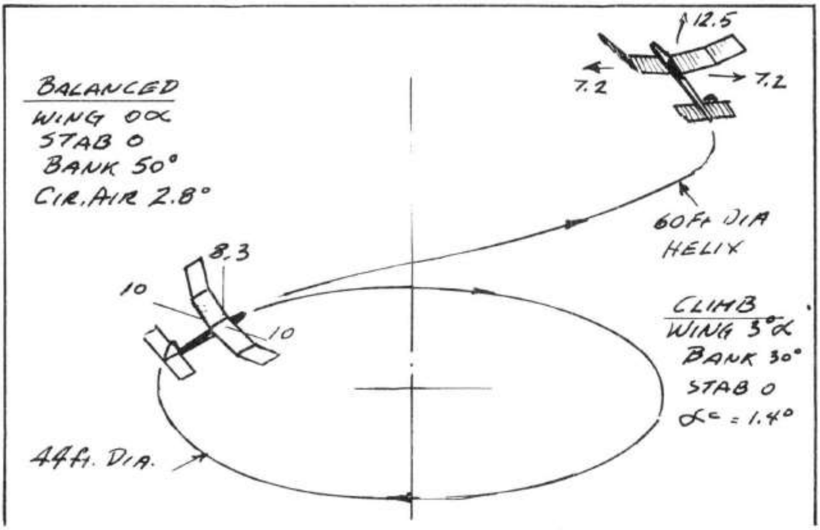
## CIRCULAR AIRFLOW AND POWER CLIMB

Believe it or not, we have been working towards this portion of the book for a long time. We will, finally, open up our critical and level circles, and let the models 'rip up'.

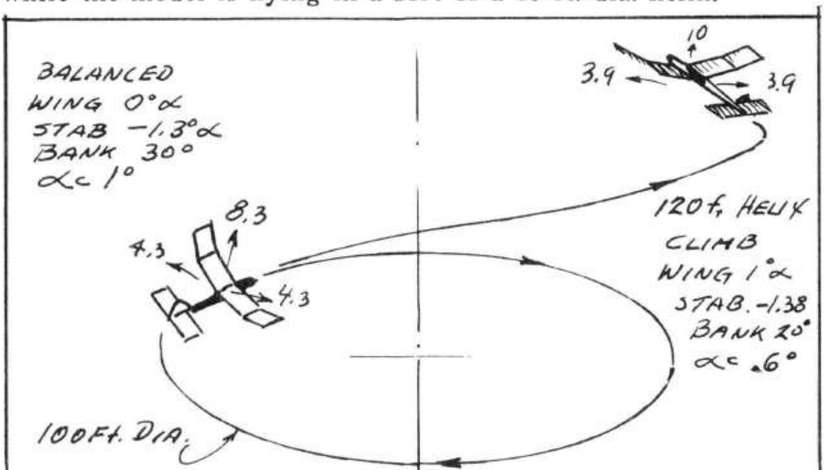
When we open up our high speed, level flight circle, we set off a regular chain reaction. You will be surprised at the number of actions that happen as soon as you reduce the rudder adjustment. The first action is that the bank of the wing is reduced. When this happens, the basic lift of the wing is tilted towards the vertical, so that more of it is used for upward lift and less for side force. Reduction of side force means that the Centrifugal Force will match lower side force of the model.

Let us assume that we opened up the original 90 ft. circle of the 75% C.G. model to 100 ft. by reducing its bank from 35° to 20°. As the model moves out to larger circle, the Circular Airflow angle is reduced from 1.2° to .65° (Remember? At 6° angle of attack rim, the stabilizer is at —1°. Increasing stabilizer's angle of attack, by Circular Airflow angles forces the wing into lower angle. So, decreasing the Circular Airflow angle means that the stabilizer will allow wing to operate at higher angles.) This will make itself evident by increasing the wing's angle of attack from 0° to about 3°, at which the lift is 14.5 ozs. Checking our chart we find this 14.5 ozs. lift resolved into 13.6 ozs. vertical lift and 4.9 ozs. horizontal, or anti-Centrifugal force. It may be a bit more than we need for 100 ft., but you should get the idea. — We are getting a bit tired looking for the exact situations. — By opening up our original circle of 90 ft. to 100 ft., we now have available 13.5 ozs. of upward lift with which to carry our 8 ozs. model. It should be obvious that the result will be a climb. Roughly, its climbing angle now is 59°* while in a 100 ft. diameter helix.


100 ft. DIA. HELIX
13.5 oz
7.3 oz
4.9 oz
8 oz
13.5 oz
8 oz. Wt.
59° CLIMB
CLIMB
WING 3° α
STAB -2.5°
BANK 20°
CIR AIR .65° αc
7.9 oz.
C.F. 4.8 oz
4.8 oz
90 Ft. DIA.
BALANCED
WING 0 α
STAB -3.8°
BANK 35°
CIR AIR. 1.2° αc
6.7 oz
6.7 oz
6.7 oz C.F.
SPIRAL DIVE
WING 0 α
STAB -3.2
BANK 45°
CIR. AIR 1.8° αc
68 Ft. DIA




By changing the 33° C.G. model from 50° bank and 44 ft. dia. circle, to 30° bank and 60 ft. circle, we decrease the Circular Airflow angle from 2.8° to 1.4°. This change allows the wing to operate at 3°. At 3° angle of attack, the basic lift of 14.5 ozs. is broken up into 12.5 ozs. vertical lift and 7.2 ozs. of sideforce. This 7.2 ozs. side force will be able to mtach the Centrifugal Force in a 60 ft. dia. circle. Our estimate of the climb now is 50°, while the model is flying in a sort of a 60 ft. dia. helix.




If we change the 100% C.G. model to 20° bank and 120 ft. circle, we would have a Circular Airflow of about .3°. This would shift the wing into a 1° angle of attack. The resulting 11.3 ozs. lift would be resolved into a 10 ozs. vertical lift, and 3.9 ozs. side force, which would match the Centrifugal Force in a 100 ft. circle. 10 ozs. vertical lift would result in a climbing angle between 45° and 50°.

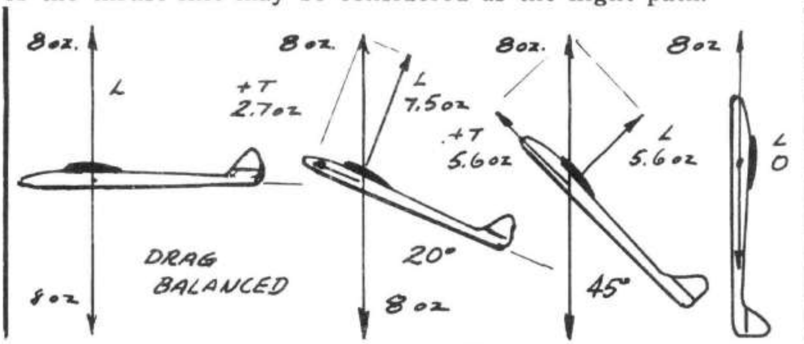
## FINDING CLIMBING ANGLE

We found the "climbing angle" by using the Cosine Formula. We know the "wing" lift" and the weight of the model. The weight of the model now becomes the "vertical lift." See diagrams.

## COMPLEXITY OF POWER CLIMB CALCULATIONS

The climb calculations made so far were pure and simple. We just assumed that only the wing contributed the required 8 ozs. of vertical lift as shown. We must now consider other factors. During power flight, the thrust also contributes a portion of its force into upward direction.

We made several diagrams of relationship between thrust and weight of the model at various climbing attitudes. The direction of the thrust line may be considered as the flight path.

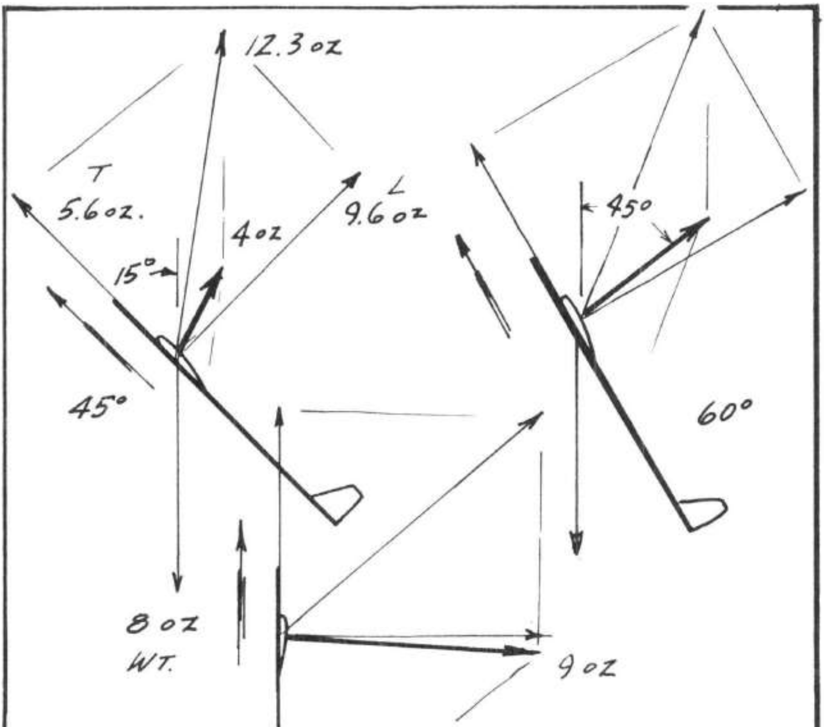



It is evident that in a horizontal flight, the wing will have to supply the required 8 ozs. of lift. In a 20° climb, the wing needs to supply only 5 ozs., as the thrust supplies 3 ozs. And in a 45° climb, the thrust is now carrying the major share of the load with its 5.6 ozs. While in a vertical climb, we have no need for the wing. Such, then, are conditions for a balanced power flight in various climbing angles.

## WING LIFT AND THRUST FORCES

What we will write in the next few paragraphs should not be taken for granted. We are not sure just what does happen, and we would like to have qualified opinions. The problem is: What do you do when you have a "wild force" A force for which we have no counter force, nor are we sure what it does. Such a question is now presented.

What would happen if we use our 6.7 ozs. of wing's vertical lift, produced in a 45° climb, in the same force diagram with 8 ozs. of thrust along the 45° flight path? The force diagram is shown. (Note that we are using the original 9.6 ozs. of wing lift to simplify the diagram). We now have a total upward force of 12.3 ozs., 6.7 ozs. from the wing and 5.6 ozs. from thrust. Justifying all the forces we see, we end up with a force value of 4 ozs. 15° from the vertical, and pointing towards the point of departure.




Judging from the experience we had with high powered models, we would say that this force would tend to swing the model into still higher angle of climb, say to 60°. If this were to happen, the results are shown on the second series of diagrams. Our "wild force" has been increased to 6 ozs. and its angle to 45°. If this is the cause of looping, we can see that once it starts, it has self-regeneration powers to continue its motion into a loop.

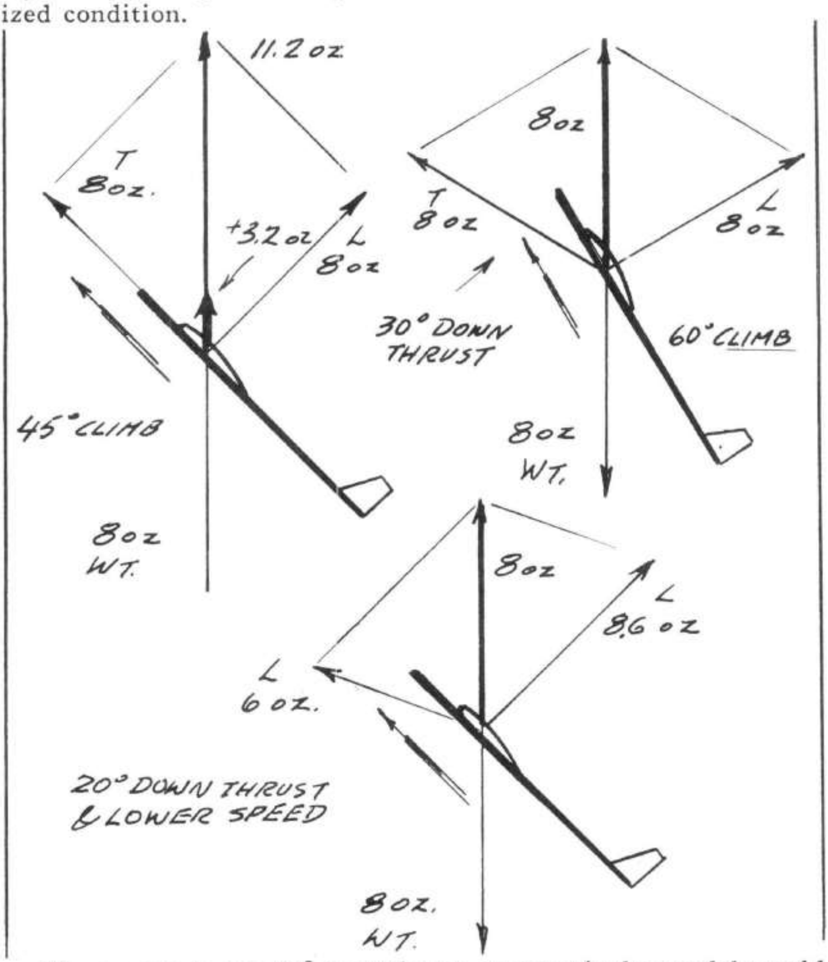
Carrying on with the tendency of the model to move into higher angle of climb, we reach the vertical position. The forces here are all straightforward. The lift force is now acting to counteract the Centrifugal Force. We should expect the model to continue the usual loop procedure.

Coming back to our 75% C.G. model, to which all this has been happening, we could imagine that the loop tendency, in combination with a spiral climb, could produce a "cork screw" climb. We do not feel up to it at present, to wor kout exactly the position of the model in the "cork screw".

We again come back to our original theory, that as long as we have excessive lift, the relative airflow tends to decrease the over all angle of attack, and give the wing predominance around the C.G. Perhaps our "wild force", in combination with forward motion, does just that. However, we are reluctant to offer this force diagram as we have no idea where our forward force comes from. Remember, we used up the thrust in balancing it with the lift force.

## BALANCING WING AND THRUST FORCES

We also wonder what would happen if the wing's life were reduced to 8 ozs. so that the resultant would be straight up and in line with the weight force. We will still have a surplus of 3.2 ozs. Will this "wild force" behave the same as other two? We are inclined to think so, and we should expect the model to try for high angles or loops. Somehow, we must obtain a stabilized condition.




If we were to use 30° downthrust, our particular model would be stabilized at 60°. The diagram shows the resultant is now 8 ozs.

## REDUCING POWER TO BALANCE A CLIMB

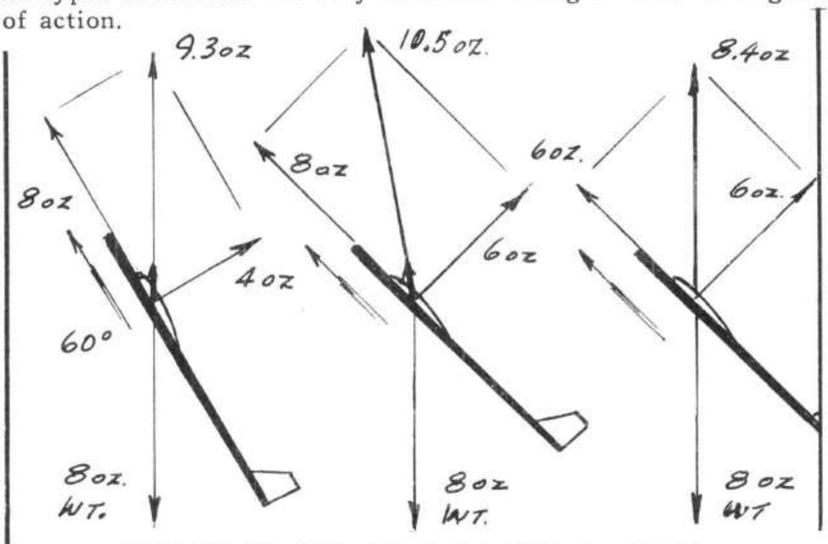
We reduced speed to 17.5 m.p.h. and we found the following results: Wing force 8.6 ozs., and the thrust force 6 ozs. If we use 20° downthrust we will have a balanced condition for a 45° climb. If 6 oz. thrust had been used along 45° line, we would still have our "wild force".

## HIGH POWER AND LOW LIFT

We can lessen the "wild force" to some extent when we use "thrust equal weight" engine, by reducing the lift to about 4 ozs., and increase climb to 60°. Such condition will give us only 1 oz. of "wild force." We have an idea that this may have been the condition under which our test model, which had prop blast directed against the stabilizer, was able to obtain such a steep, but safe, angle of climb.

Excessive power will also automatically reduce the lift force to lower values, where a stabilized condition may be achieved. This is done by developing high Circular Airflow angles which, as we know, will reduce lift. Such conditions may be found in a tight cork-screw climb.

Conditions mentioned for the 70% C.G. model, will apply to all types of models. The only difference being a matter of degree of action.




## REDUCING LIFT TO BALANCE A CLIMB

By reducing lift to 6 ozs., and leaving thrust at 8 ozs. we now have our "wild force" pointing to where the model is going. Using our reasoning, it would seem that the model would come below 45° climb angle. — Reducing thrust to 6 ozs., we obtain balanced condition without down thrust, and without any "wild force" left over to bother us. It would seem, therefore, if you want a 45° climb, in a 30° bank and 80 ft. circle, use a motor that will not pull the model straight up.

Frankly, we just do not know how you can keep a model, that has greater thrust than the weight of the model, under control. It is obvious, that the only safe launch is sraight up, and so prevents building up high speed. Also, such a model should definitely have 0–0 setting and C.G. at 100%. How to obtain proper glide, is a matter for gadgets.

## SUPER POWER IN A CLIMB

What may actually save many of our models, is the fact that as soon as the model points upward, the prop becomes loaded with a portion of the model's weight. The steeper the climb, so much greater is the load on the prop. This means that it will have to work at higher angle of attack. This will slow it up, and with it, the speed of the model will slacken. With slackening of speed, the lift is reduced. And with its reduction ,we move out of the critical range described above. However, if you have a super-Super-motor, consult us at our usual rate of ten dollars per hour.

## CIRCULAR AIRFLOW AND SPIRAL STABILITY SUMMARY

It is quite possible that we may have left many facts still unanswered. However, we believe that we have given you a glimpse of what goes on in a model's mind. —

Returning to the beginning of this discussion, we demonstrated how Circular Airflow is developed while a model circles in a banked position. Then we combined the facts we learned in the Longitudinal Stability, with the Circular Airflow theory, and showed how it is possible to control high power looping tendencies by reducing the angle of attack on the wing through the medium of Circular Airflow angles. The tighter the circle, the greater the Circular Airflow angle. The greater the Circular Airflow, greater is the angle of attack on the stabilizer. An increase in stabilizer's angle of attack brings the wing to lower angles of attack where just enough vertical lift is produced for the flight.

Having stabilized our high powered models in level circles, we opened up the circles, and the models climbed. This happened because, the Circular Airflow angles were reduced. This fact, in turn, reduced stabilizer's angle of attack. And the stabilizers allowed the wings to produce more lift, required for fast climb.

Then we showed how it is almost impossible to bring about a stable condition of climb, if we use super power and high lift, that is, just by the use of aerodynamic arrangements. It should be evident that some sort of control, such as blasting on the stabilizer with the prop air slip, or by gadgets, is essential for safe flight.

The final word in this summary is to call your attention to the fact that every design has its own particular or "natural" circle characteristics. The closer the C.G. is to the trailing edge, so much larger should the circles be. Any attempt to tighten up circles beyond the "natural" circle of the model, will result in spiral dives. If you must have glide turn adjustments, apply them so that they will not be effective during power flight. — We will now cover the effect of Circular Airflow and Spiral Stability in a glide.

## CIRCULAR AIRFLOW AND SPIRAL STABILITY IN GLIDE

We all try to obtain the minimum size of gliding circle to take advantage of thermals. But, here again, the C.G. position on the model will determine the safe minimum diameter that a model can use. From the information shown so far, we know that a model with C.G. at 33% will be able to make tighter circles than the 100% type. The large change in Circular Airflow angles will not have as much effect on the lift production of the 33% model as they will on the 100%. This point will be shown later on.

At the moment we are in a peculiar position. Earlier in the book we mentioned that the normal glide adjustment is such that the angle of attack on the wing is 6°. To this end, we set our stabilizer so that the model will be trimmed or balanced at 6° angle of attack. Now we have to show that, to obtain turns or circles, we have to shift away from this ideal gliding angle of attack.

The reason that we have to shift away from the maximum lift angle of attack is that we have to make the model circle. To make the model circle, we must bank the wing to obtain counter force for the Centrifugal Force. In doing so, we introduce Circular Airflow which brings about lower angles of attack.

On gliders, we can make adjustments so that the wing will be at 6° angle of attack while it is in its required circle. But on powered models, we cannot do so, in full sense of the word, when we depend on aerodynamic adjustments. This is especially true for models that have power circle differ from gliding circle. If we have the same circle for power as for glide, we have a better chance of having glide adjustments which would be especially suited for its gliding circle. — Those points will be clearer, we hope, as we go along.

## POWER TURN OPPOSITE GLIDE TURN

We will first work on models that make power turns opposite to glide turns. This means that in a change over period, from power to glide circle, the model will be flying a straight course for a moment. For this moment in the flight, we had to make sure that its angle of attack was not greater than 6°. If you recall, our models were adjused so that they would be in a trimmed or balanced condition at 6° angle of attack, so that, no matter what sort of fancy glide adjustment you may have on your model, it will never have greater angle of attack than 6° when it changes the direction of the circle.

It should, also, be obvious that the model will not develop more than 8 ozs. of lift in a glide. Knowing our angle of attack, we found that we will obtain 8 ozs. of lift when the model is moving at 13.0 m.p.h. (Using 200 sq. in. wing and Clark Y section.)

We now have three factors, 6° angle of attack, 8 ozs. maximum lift, and 13.0 m.p.h. Using this information, we are able to prepare the following tables; lift, triangulation of lift, and Centrifugal Force. Now comes the matching game to find where our factors will match for a particular circle.

LIFT COMP. CHART

| WING 200 sq in (1.4 sq. ft) CLARK Y 13 MPH | | | | | | | | BANK | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| α | $C_L$ | 0 | 5° | 10° | 15° | 20° | 25° | 30° | 35° | 40° | 45° | 50° |
| 4° | .7 | 6.7 | 6.65 | 6.6 | 6.5 | 6.3 | 6.1 | 5.8 | 5.5 | 5.15 | 4.75 | 4.3 |
| | | 0 | .58 | 1.15 | 1.5 | 2.3 | 2.8 | 3.4 | 3.8 | 4.3 | 4.75 | 5.15 |
| 5° | .76 | 7.4 | 7.35 | 7.3 | 7.2 | 6.95 | 6.7 | 6.4 | 6.05 | 5.65 | 5.25 | 4.75 |
| | | 0 | .65 | 1.3 | 1.7 | 2.5 | 3.1 | 3.7 | 4.3 | 4.75 | 5.25 | 5.65 |
| 6° | .82 | 8.0 | 7.95 | 7.9 | 7.7 | 7.5 | 7.25 | 6.9 | 6.55 | 6.15 | 5.65 | 5.5 |
| | | 0 | .7 | 1.4 | 1.8 | 2.7 | 3.4 | 4.0 | 4.6 | 5.5 | 5.65 | 6.15 |
| 7° | .88 | 8.5 | 8.45 | 8.4 | 8.2 | 8.0 | 7.7 | 7.35 | 7 | 6.5 | 6 | 6.5 |
| | | 0 | .72 | 1.5 | 1.9 | 2.9 | 3.6 | 4.3 | 4.9 | 5.5 | 6 | 6.5 |

CENTRIFUGAL FORCES OF 8oz. AT 13 MPH CIR. DIA.

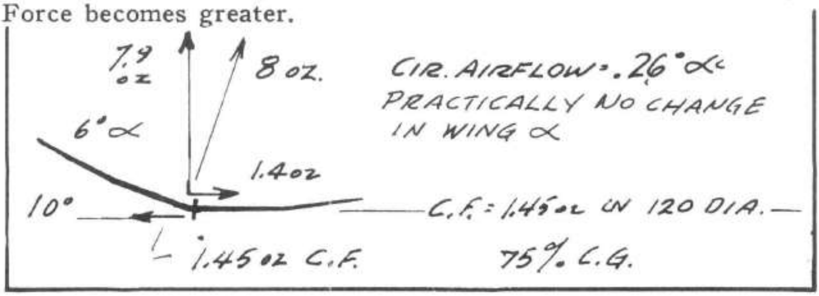
| 10' | 20' | 30' | 40' | 50' | 60' | 70' | 80' | 90' | 100' | 120' | 150' | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 8.9 | 6oz | 4.5 | 3.5 | 3oz | 2.5 | 2.2 | 2oz | 1.8 | 1.45 | 1.2 | .9 |

## TYPE OF TURN DESIRED

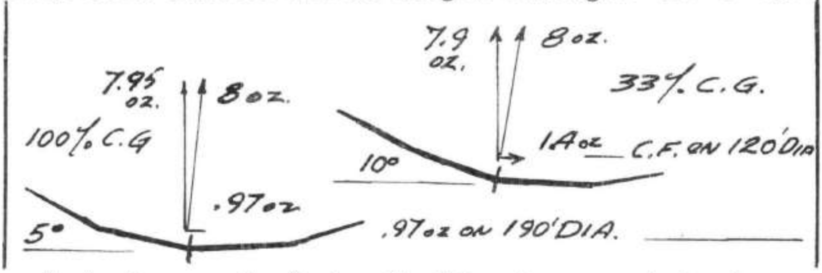
In deciding what sort of a circle we want, we have to consider two facts: to obtain maximum duration or lowest descent requires the wing be as level as possible, or a large circle. But to obtain maximum advantage from thermals, a tight circle is required.

## MAXIMUM DURATION

It is easy to determine the minimum descent circle. We try to keep wing level, yet still produce enough side force to develop the circle. We find such condition in a 10° bank. The vertical lift is 7.9 ozs. and side force is 1.4 ozs. To match this side force, the model may make 120 ft. circle before the Centrifugal Force becomes greater.



In a 120 ft. circle and 10° bank, the Circular Airflow is .25° for the 33% C.G. model, .26° for the 75% and .3° for 100% C.G. models. The effect of .25° on the 33% C.G. model is practically null. While on the 75% C.G. design, the .25° angle will have a tendency to reduce its angle of attack to about 5.3° So, relatively speaking, we may consider 120 ft. and 10° bank satisfactory for this model. But on the 100° C.G. model, a .3° change in the Circular Airflow would mean a shift to 4° angle of attack. At 6° angle of attack, we find a stabilized condition when the circle is 190 ft. in diameter and the wing is banking at 5°. $\alpha$c=.12°

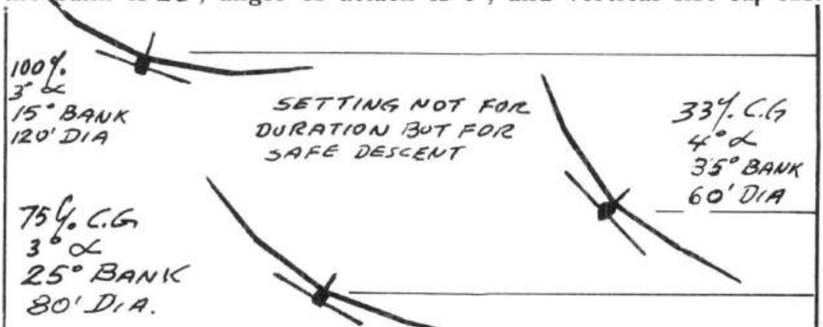



Such, then are the "natural" gliding turns or circles for our three different types of models when maximum duration is desired, and also, when the turn changes in the course of the flight. Note how the C.G. position determined the size of the circle.

## MINIMUM TURN

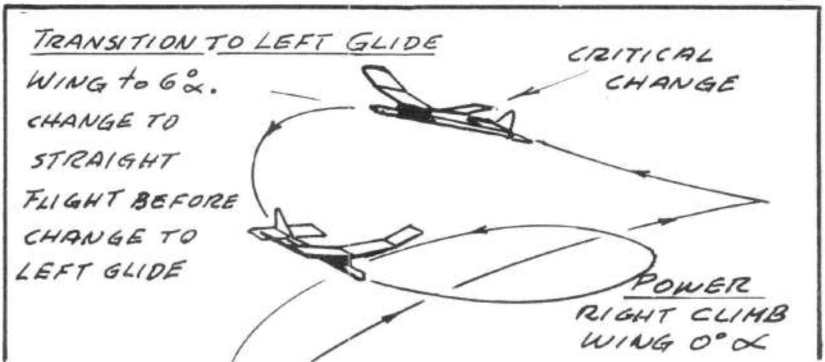
Using the same calculation procedure, we found that the tightest turn that the 33% C.G. model can make, within reason, is about 60 ft. in diameter, and when the bank angle is 35°, angle of attack is 4°, and vertical lift is 5.5 ozs.

The tightest turn for 75% C.G. model would be 80 ft., when the bank is 25°, angle of attack is 3°, and vertical lift 5.4 ozs.




On the 100% C.G. design, the minimum safe turn would be 120 ft. with the wing banked at 15°, angle of attack is about 3°, and vertical lift 5.6 ozs.

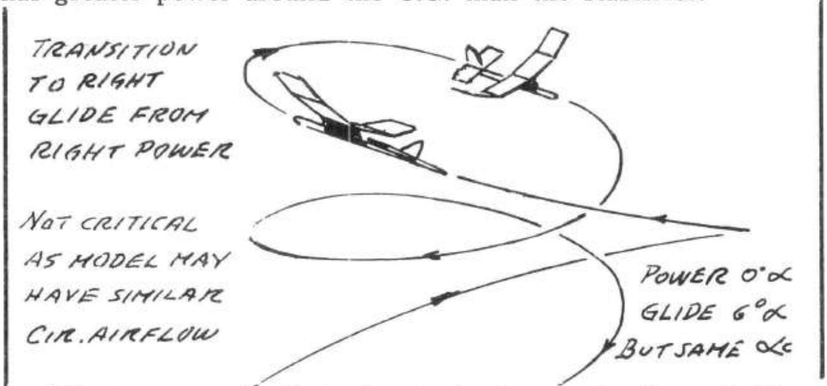
Any effort to increase such turns would mean a rapid descent, which not even strong thermal would balance. Also, especially on the 75% and 100% designs, there is always the danger of introducing spiral drives due to Circular Airflow angles.




There is not much one can do to tighten circles on models that have to change circling direction in flight. The model must go through the transition period without stalling. And this means the 6° trim. So, consider the situation and realize that there is a definite limit to the size of the circle that can be made under such circumstances.

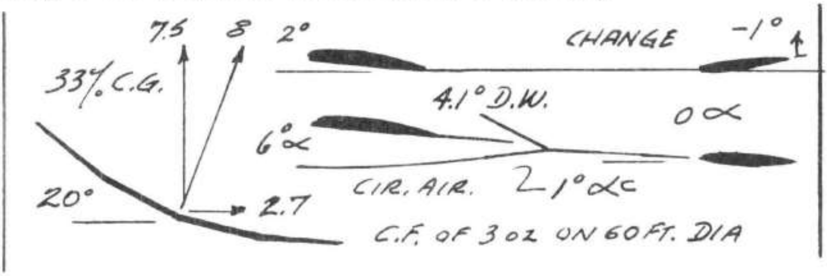
## SIMILAR TURN FOR POWER AND GLIDE

When a model is made to circle in the same direction during glide as it does under power, we can obtain tighter glide circles. The reason that we can do this, is that that the model does not have to go through the transition period, or the change-over, from one circle into another .This means that we do not have to adjust the exact 6° angle of attack. We can play with incidences a bit so that the model will actually have stalling tendencies in a straight flight; and a stalling tendency means that the wing has greater power around the C.G. than the stabilizer.

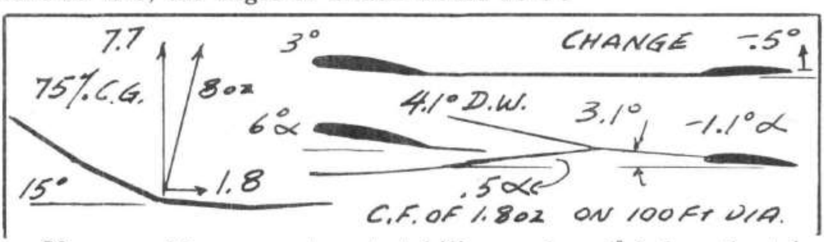



What we are actually trying to do, is to make the model have full 6° angle of attack while it is banking and turning in the smallest possible circle. If this 6° angle of attack could be retained while banking 45°, our model could circle in 35 ft. diameter, and still have 5.6 ozs. of vertical lift. On gliders, as we have shown, it is possible to obtain such conditions, but on power ships it is practically impossible.

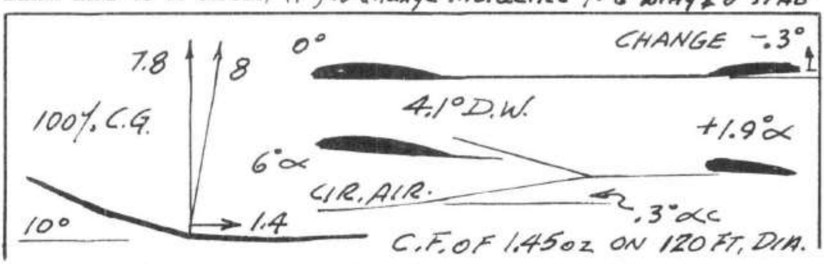
Let us say, then, that we were able to make our 33% C.G. model fly under power after we adjusted the stabilizer to be 1° less than that required for 6° trim. The straight away glide would be of stalling variety, but let us see what happens when we place this new incidence layout in the airflow. (New Setting 3° for wing 0° for stabilizer in contrast to 2° and 0°.)




Let's start flying the model in 20° bank and 60 ft. circle, and still have 6° angle of attack for the wing. In a 20° bank and 60 ft. circle the Circular Airflow is 1°. This 1° now brings the stabilizer's force back to its original value with which to balance the wing at 6°. The vertical force now is 7.5 ozs. And it would be no problem to circle in 40′ dia. in 40° bank while developing 5.2 of vertical lift; the angle of attack would be 4°.




If we could manage to set stabilizer only –.5° below the trim point on the 75% C.G. model, we would obtain a "natural" turn of 100 ft. diameter at 15° while the wing was acting at 6° angle of attack and providing 7.7 vertical lift. Or you can tighten it to 30° bank and 45 f. circle, *if you change incidence to 6° wing & 0° STAB*

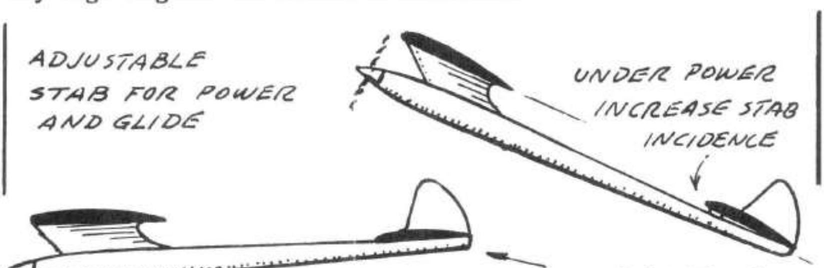



On 100% C.G., if we could safely reduce stabilizer's incidence by only .3° we would get a natural turning circle of 120 ft. in a 10° bank. This set safe circle could be reduced from 120 ft. at 10° to *20° & 70′ by changing incidence to 1.2° Wing 0 stab.*

## HOW TO OBTAIN TIGHT TURNS

Just how we could have the above stabilizer adjustment in the model while it is under power, we do not know, their natural reaction would be looping under power. But it may be possible to have an adjustable stabilizer. While under power, we could set the stabilizer at higher angle for high lift. And so keeping the wing under low lift condition. As the power runs out, the stabilizer should bring the wing back to high lift, or 6° angle of attack, condition. Although we may not have the "gadget" answer, we do know the problem. And should not have too much trouble in finding the gadget design. Down thrust is one answer, as it be shown later. Also note how the prop blast on the stabilizer seems to do the right thing. It synthetically loads the sabilizer under power, sothat it develops more lift than required to counteract the wing. The result is; low wing angles under power, and high angle of attack under glide, the conditions that we need.

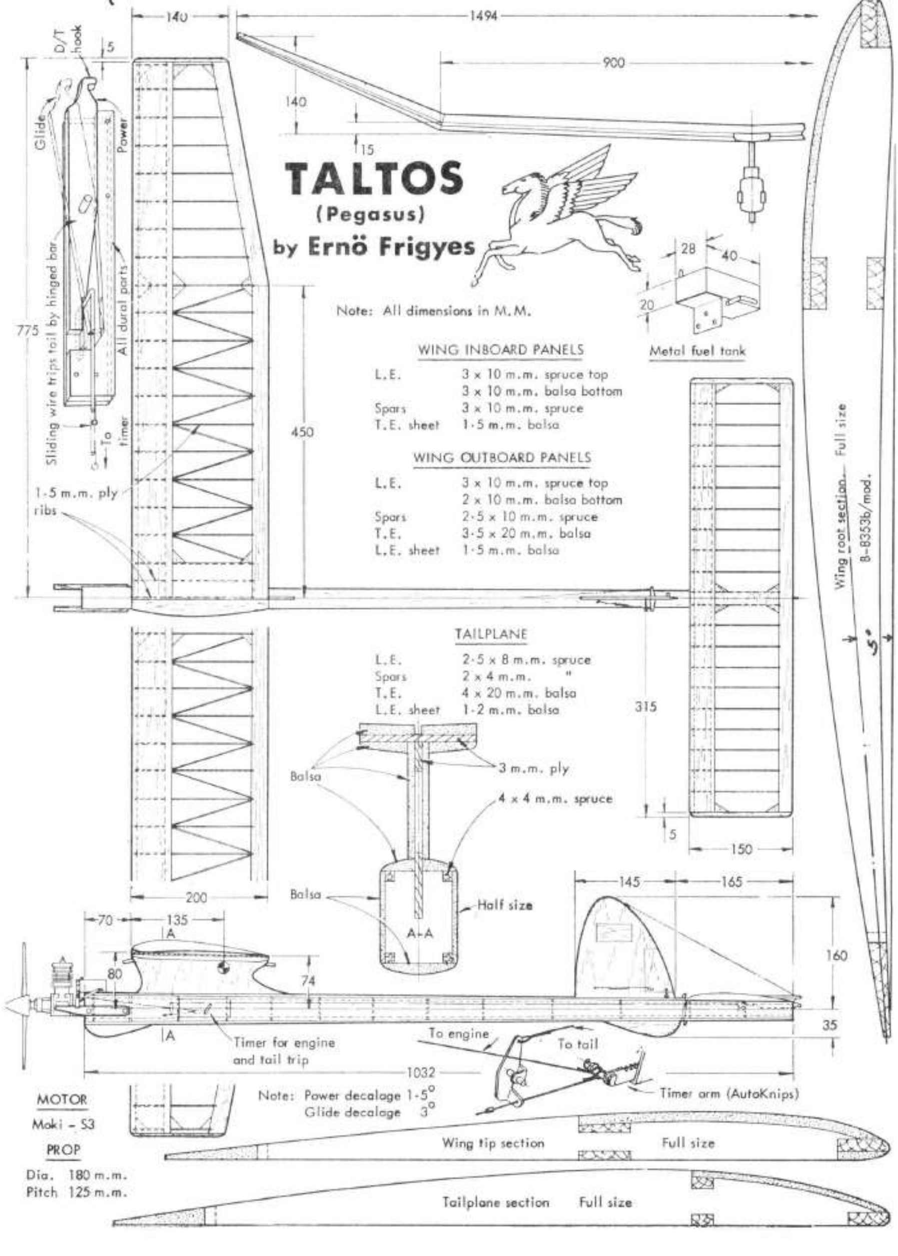
We will show how it is possible to obtain still tighter turns when we discuss glider design. While on this subject, you can also refresh your memory by referring to the beginning of the CIRCULAR AIRFLOW theory section. There we showed how we were able to obtain extremely tight turns by having exceptionally high angular difference in incidence.




### SUMMARY OF CIRCULAR AIRFLOW AND TURNING

When a model is designed, or adjusted, to fly under power in a definite circle, and to glide in opposite direction, do not try to tighten the glide turn too much. As soon as you see it steepen, back off and be satisfied. Circling in same direction during power and glide allows tighter turn adjustments with less loss of vertical lift, by having higher incidence values between wing and stabilizer.

END OF MATERIAL
PREPARED IN 1951


TALTOS
(Pegasus)
by Ernö Frigyes
Note: All dimensions in M.M.
WING INBOARD PANELS
L.E. 3 x 10 m.m. spruce top
3 x 10 m.m. balsa bottom
Spars 3 x 10 m.m. spruce
T.E. sheet 1·5 m.m. balsa
WING OUTBOARD PANELS
L.E. 3 x 10 m.m. spruce top
2 x 10 m.m. balsa bottom
Spars 2·5 x 10 m.m. spruce
T.E. 3·5 x 20 m.m. balsa
L.E. sheet 1·5 m.m. balsa
TAILPLANE
L.E. 2·5 x 8 m.m. spruce
Spars 2 x 4 m.m. "
T.E. 4 x 20 m.m. balsa
L.E. sheet 1·2 m.m. balsa
Metal fuel tank
28
40
20
140
1494
900
140
15
5
775
450
315
150
200
145
165
160
35
70
135
80
74
1032
D/T hook
Glide
Power
Sliding wire trips tail by hinged bar
All dural parts
To timer
1·5 m.m. ply ribs
Balsa
3 m.m. ply
4 x 4 m.m. spruce
Half size
A-A
A
Timer for engine and tail trip
To engine
To tail
Timer arm (AutoKnips)
Note: Power decalage 1·5°
Glide decalage 3°
MOTOR
Moki – S3
PROP
Dia. 180 m.m.
Pitch 125 m.m.
Wing tip section Full size
Tailplane section Full size
Wing root section Full size
B-8353b/mod.
5°




AERO MODELLER January, 1964

# Model on the Cover!

## Story of the World's No. 1* power modeller Erno Frigyes of Hungary and his latest design

* WORLD CHAMPIONSHIPS PERFORMANCE
1958 1st: 1959 No contest: 1960 Equal 1st (technical 8th in fly-off). 1961 2nd: 1962. No contest: 1963. 1st (after three fly-off rounds).

IT WILL BE A SURPRISE to many that Erno Frigyes designed FM-70 Taltos II early in 1963 and completed construction only two weeks before the World Championships. He certainly made good use of experience with his Championship winning FM-58, together with the original *Taltos* (FM-67).

It is well known to all those who deal with free flight models that a satisfactory solution of the two aspects of power flight is not an easy task. In the interests of obtaining a fast climb it seems advisable to use slightly cambered airfoils which are set at small angles of incidence. The disadvantage of this is the faster descent. Better gliding calls for a higher curved section and higher incidence angle. But in such conditions the climbing speed deteriorates, consequently one has to be content with a moderate altitude of climb.

In earlier contests when a power time of 15 secs. was permitted, the use of such compromise sections seemed satisfactory. Erno succeeded in improving the capability of his models to over four minutes average. In January 1961 the power run of the engine was reduced to 10 secs. and it had an immediate result of diminishing of the possible average efficiency. The official flight time of 3 min. was only possible for those models which had sections of highest efficiency, trimmed with great care, and using high power engines.

Analysing power and gliding flight of free flight models with a view to further improvements of efficiency it seemed best to Erno to establish separate optimum conditions. That is to say, to make power flight with a small incidence angle so that drag is less and the model can reach a higher speed; and in the glide a larger incidence angle is applied which results in a better descent. On this basis Erno made long tests and succeeded in producing a simple mechanism which made possible any difference of incidence angle between the wing and the tailplane at any time. (Based on V. Hajek's Czech system).

At the 1961 World Championship in Leutkirch each Hungarian competitor's model was furnished with the angle setting mechanism. In this contest—beside helping to win the Team Championship for the 3rd time Erno won second place with *Taltos* FM-67, using a Moki S-1 glow-plug engine.

In the Autumn of 1962 he had the possibility of making accurate measurements of altitude with Taltos FM-67. The measurement was made in good atmospheric circumstances at sunset by sportplane with a sensitive altimeter. In three launches the average altitude reached was 460 ft. with 9.5 secs. power run.

The gliding measurements took place early next morning, weather was fine this time, too and six launches were made. Power flight time discounted, the duration was 245-250 secs. Supposing the altitude obtained was the same as the previous day, the descending speed of the model about 1.9 feet/sec.

In earlier models Erno used the original B-8353b section. This gives good effect under conventional conditions. Its only sensitive point is the tapering depth of the rear portion, where—especially in case of a balsa rib, the frame of the wing can easily crack and deform near the trailing edge. Because of this and for theoretical reasons the upper part of the section was modified. The highest camber point was moved backwards and this made possible the use of a thicker tailing edge.

Gliding properties of the experimental wing having the modified section improved slightly. One could not notice any deterioration. The wing of the new *Taltos II* was built with this modified section, at the same time its surface was increased with area taken from the tail.

Test flying took place a week before the Championship in Austria. Trim was established during four days in changing weather conditions over nearly sixty flights using the new powerful glow plug Moki S-3 engine. On flights made early in the morning, times of 270-280 secs. were made. Two days before departure, the team held a test contest for training. This time Erno succeeded in reaching 900 secs. in five successive flights, repeated of course in the Champs.

### Technical description

The model was produced mainly out of balsa, only the strongly stressed parts are of spruce or plywood. The right wing has slight wash-in. Covering is Japanese tissue. The wings weigh just under 8 oz., the tailplane 1⅜ oz., and the fuselage, with engine, 17¼ oz.

The incidence angle mechanism is built in the end of the fuselage. This mechanism—together with the rudder and motorstop—is operated by an Autoknips. During power flight the angular difference of the wing and tailplane is 1.5 deg. this increases to 3 deg. for the glide. At the extreme tail there is a 'sandwich' of dural. The centre plate is hinged and incorporates the lower (or fuselage) tail retaining hook. A sliding wire which comes from the timer to a slot in the outer halves of the 'sandwich,' will hold the centre plate in its 'neutral' position. When pulled forward, the centre plate is free to drop at the front, and it does because of the rubber band tension on the rear hooks and the d/t band at the front of the tail. Thus the tail is controlled to give two positions by timer action.

Assembly of the engine to the fuselage is resolved in an almost superficial manner by dural side plates. A gravity feed tank serves the carburrettor without pressure. Propeller diameter is 7⅞ in. and pitch 5 in. The fuel formula is nitro methane 45 per cent, Methyl alchohol 25 per cent, Castor oil 20 per cent, nitro benzine 10 per cent.

## 1964 DESIGNS AND CIRCULAR AIRFLOW

We are now ready to face the facts of life by analyzing high performance models and fitting them into our theoretical pattern developed in the 1951 book. If this can be accomplished satisfactorily within reasonable approximation, we have a fair chance to design model aircraft and predict their flight patterns. Our first example will be Erno Frigyes' TALOS II power model which won the 1963 World Championship.

All our calculations are based on the information found in an article published in the January 1964 issue of AERO MODELLER. With the publisher's kind permission, we are reprinting it in its entirety. Erno's recording of 460 ft. maximum altitude obtained in 9.5 sec., is the key in the computation structure. His use of adjustable stabilizer to obtain 1.5° decalage during power and 3° during glide, fits into our prediction that such a control is one way of obtaining low lift in high-speed power flight.

Our first attempt will be to calculate the "Glide Trim" Pitching Moment. Although the article provides us with the exact C.G. location (67%), wing and stab areas, moment arm and decalage (3°), we lack the airfoil characteristics charts. Without them it is not possible to make computations. We will, therefore, use other airfoils of similar shape and thickness, and for which we have the characteristics.

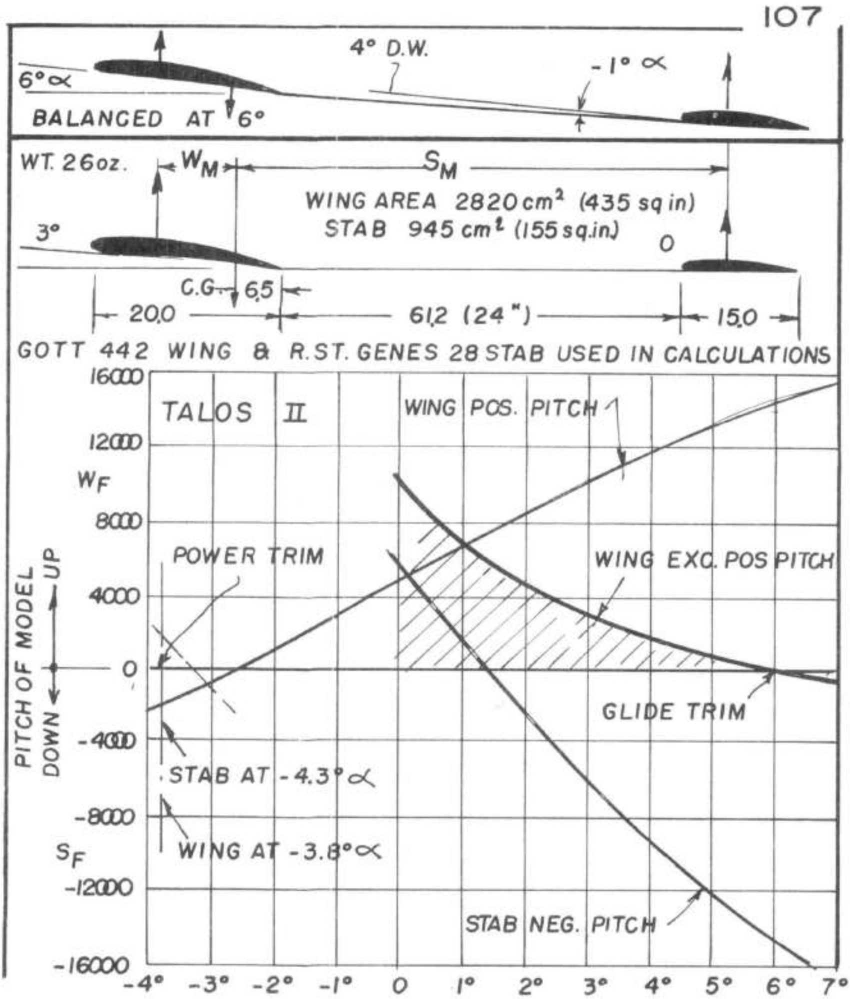
## SUBSTITUTING AIRFOILS

The basic criterion for duplication is to have similar Zero Lift Angles. (Zero Lift Angle is the angle which is determined when a line is drawn from the T.E. to the center of the airfoil at 50%)* Drawing such a Zero Lift Angle on the full size airfoil template of the B-8353b/Mod. showed the Zero Lift Angle to be about 5°. A quick look at the Clark Y showed almost a similar Zero Lift Angle. However, after making a complete set of calculations for the "Glide Trim", TALOS II would not balance at a 6° angle of attack. The stab area proved to be too small to balance the wing. Obviously, we must have given the wing too much lift. A closer look into details called for calculated Zero Lift Angles. The airfoil ordinates for B-8353b, disclosed a Zero Lift Angle of 4.5° and 5.7° for Clark Y. The difference is like giving the B-8353b an extra degree of incidence. A careful search through our old airfoil books showed that Gott 442 was very similar to B-8353b. In fact, the test wing had an almost identical chord as TALOS II. Gott 442 has a 5.16° Zero Lift Angle, but knowing that Erno thickened the original B-8353b slightly, we feel that Gott 442 can be used as shown.

For the stabilizer airfoil, we substituted R. St. Genes 28. Its thickness of 7.5% and Zero Lift Angle compares favorably with the stab airfoil used on TALOS II. *See Page 158

## GLIDE TRIM CALCULATIONS

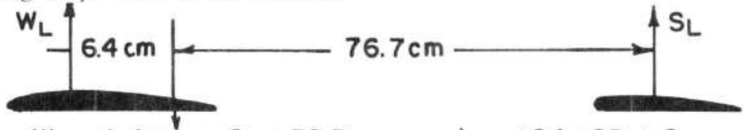
Now we have the necessary information to "slide rule" the 6° angle of attack Glide Trim Pitching Moment. Note that full stabilizer area was used without using the "efficiency factor" to "justify" certain conditions as we did in the 1951 book.




| WING (POS. PITCH) | | | | | | | STAB | STAB (NEG. PITCH) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wα | D.W. | C.P. | $C_L$ × | $W_M$ × | $W_A$ = | $W_F$ | SET. | Sα | $SC_L$ × | $S_M$ × | $S_A$ = | $S_F$ |
| -4° | .5 | | .1 | - | 2820 | | -7° | | | | | |
| -3.8° | .6 | 100 | -.11 | -6.5 | 2820 | -2016 | -6.8° | | | | | |
| -3° | .9 | 77% | .18 | -2 | 2820 | -1230 | -6° | | | | | |
| -2° | 1.3 | 60% | .25 | 1.5 | 2820 | 1270 | -5° | | | | | |
| -1° | 1.6 | 51% | .32 | 3.5 | 2820 | 3500 | -4° | | | | | |
| 0° | 2.0 | 46% | .39 | 4.3 | 2820 | 4700 | -3° | -5.0° | -.08 | 84 | 945 | +6400 |
| 1° | 2.3 | 43% | .46 | 4.9 | 2820 | 6350 | -2° | -4.3° | -.025 | 83 | 945 | +1960 |
| 2° | 2.6 | 40% | .53 | 5.5 | 2820 | 8200 | -1° | -3.6° | .03 | 83 | 945 | -2340 |
| 3° | 2.9 | 38% | .59 | 5.9 | 2820 | 9850 | 0° | -2.9° | .08 | 82 | 945 | -6200 |
| 4° | 3.3 | 37% | .66 | 6.1 | 2820 | 11200 | 1° | -2.3° | .12 | 80 | 945 | -9100 |
| 5° | 3.6 | 36.5 | .73 | 6.2 | 2820 | 12700 | 2° | -1.6° | .17 | 78 | 945 | -12500 |
| 6° | 4.0 | 35.5 | .8 | 6.4 | 2820 | 14400 | 3° | -1.0° | .2 | 77 | 945 | -14500 |
| 7° | 4.3 | 35% | .865 | 6.5 | 2820 | 15850 | 4° | -.7° | .225 | 76.2 | 945 | -16150 |

Note similar Force Units for Wing at -3.8° and Stab at -4.3°

From the Glide Trim, we can determine the glide speed by using the Lift Formula in which the Velocity or Speed is unknown. But before we can do that, we must know the exact lift value contributed by the wing only. Here is the method:




| | |
|---|---|
| $W_L \times 6.4\,cm = S_L \times 76.7\,cm$ | $164 = 83.1\ S_L$ |
| $W_L + S_L = 26\,oz \quad W_L = 26 - S_L$ | $S_L = 2\,oz$ |
| $(26 - S_L) \times 6.4 = 76.7\,S_L$ | $W_L + 2 = 26\,oz$ |
| $164 - 6.4\,S_L = 76.7\,S_L$ | $W_L = 24\,oz$ |

The lift of the wing is 24 ozs. or 1.5 lbs. By placing this value in the Lift Formula, we obtain 16 mph glide speed. Sounds reasonable.

LIFT at 6° ($C_L = .8$) $1.5^{\#} = .8 \times .0012 \times 3\,sq.ft. \times V^2$

$1.5\,lb. = .00288\,V^2 \qquad V^2 = 540 \qquad V = 23.3\,ft.\,sec.$

## POWER TRIM CALCULATIONS

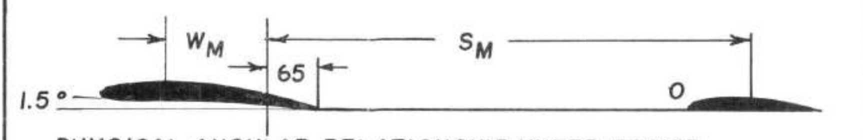
At this point, we are ready to attempt our major and most important phase of constructing a mathematical framework: The Pitching Moment for the aircraft while it is under high power and in a steep climb. As you know, while TALOS II is under power, the relationship between wing and stab is changed to 1.5° from the normal 3° Using this 1.5° difference in our calculations to make up the Power Trim Point, we find that the model trims with the wing at about 1° angle of attack.

Normally, most of us would assume that this new lower angle of attack is the angle at which the aircraft will fly while under power. After all, a change from 6° to 1° is quite a bit. (Note how a stab change of only 1.5° was needed to shift the wing from 6° to 1°.) But to be on the safe side, let us check the wing's lift while it is flying at 1° angle of attack. (This brings us up to the fact that before we can go on, we should know the model's air speed during climb).

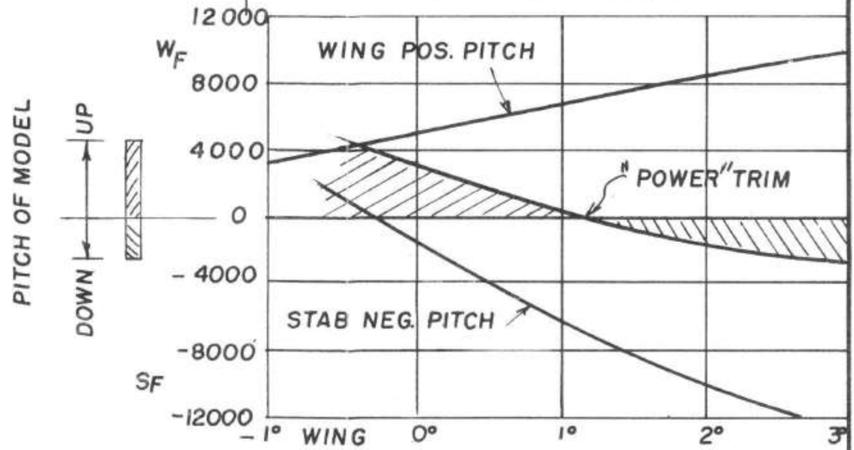
## SPEED AND LIFT IN CLIMB

Erno furnished us with a very basic data when he checked, by aerial observation, that his model reached 460 feet in 9.5 sec. (A vertical speed of 33 mph or 48.5 ft. sec.) Since the flight was not vertical but at high angles, the actual speed must be higher. Assuming a 60° climb, to reach 460 feet in 9.5 seconds, the model traveled 535 feet. Converting, we have a speed of 38 mph or 56 ft. sec., which we can use in the Lift Formula.

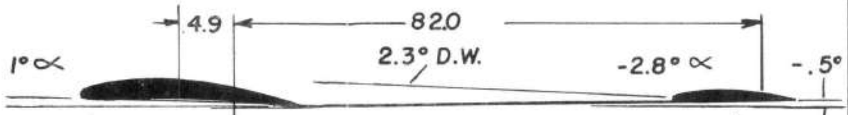
The answer to our question of how much the wing lifts at 1° and 38 mph, is striking enough to make anyone stop and wonder. A wing lift of 82 ozs., which is three times the weight of the model, just cannot exist on this model while it is climbing.




PHYSICAL ANGULAR RELATIONSHIP UNDER POWER




| WING (POS. PITCH) | | | | STAB (NEG. PITCH) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $W\alpha$ | D.W. | C.P. | $W_F$ | SET ∠ | $S\alpha$ | $SC_L$ x | $S_M$ x | $S_A$ = | $S_F$ |
| -1° | 1.6 | 51% | 3500 | -2.5° | -4.1° | 0 | — | — | — |
| 0 | 2.0 | 46% | 4700 | -1.5° | -3.45° | .02 | 83 | 945 | -1565 |
| 1° | 2.3 | 43% | 6300 | -.5° | -2.8° | .08 | 82 | 945 | -6200 |
| 2° | 2.6 | 40% | 8200 | .5° | -2.1° | .13 | 80 | 945 | -9850 |
| 3° | 2.9 | 38% | 9850 | 1.5° | -1.4° | .17 | 78 | 945 | -12500 |



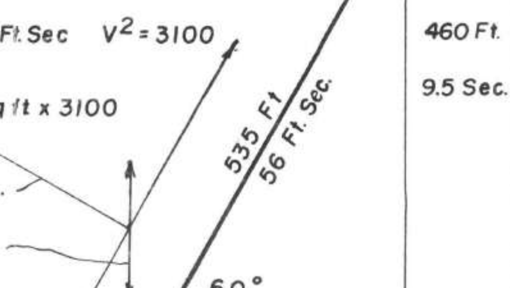

BALANCED WITH WING AT 1°

$C_L$ AT 1° = .46   V = 56 Ft. Sec   $V^2$ = 3100

LIFT = .46 x .0012 x 3 sq ft x 3100

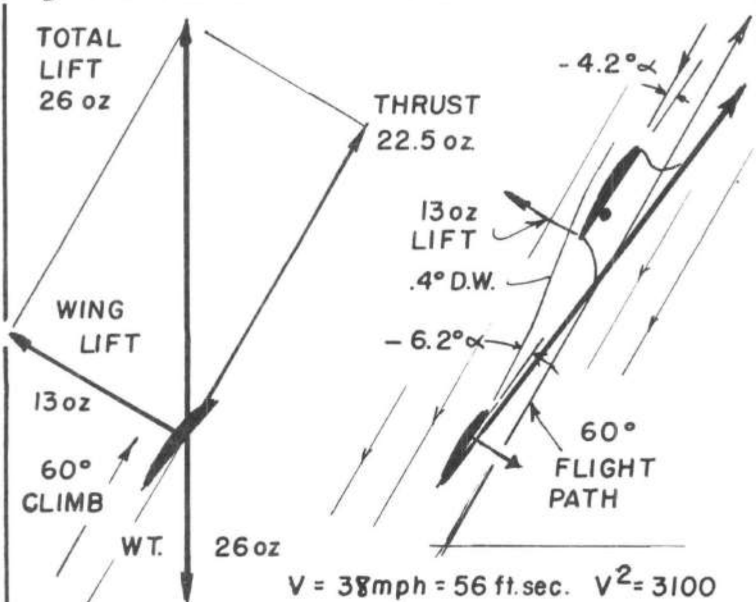
LIFT = 5.15 Lbs. = 83 oz.

WT. OF MODEL 26 oz.



Where do we go from here? The variable stabilizer by itself, obviously cannot bring about the overall reduction of lift needed by a model hurling upward at 60° and 38 mph. Honestly, we are as much disappointed as you may be in not seeing the adjustable stabilizer place the model ever so nicely into a position in which the normal lift would be something the model could live with. Let us now take a long look at the overall picture and determine what we may have left out of our calculations.

To begin, just how much lift is needed during climb? Placing the aircraft in a 60° climb attitude, the 26 ozs. weight of the model is balanced by the thrust and wing lift. Using the parallelogram system, the wing contributes only 13 ozs. of normal lift. Fine! At what angle of attack does the wing generate 13 ozs. when it is flying at 37 mph? Using the Lift Formula with C1 unknown:




ASSUMING TOTAL LIFT FROM WING, NO STAB HELP

$$\text{LIFT} = \frac{13\,\text{oz}}{16} = C_L \times .0012 \times 3\,\text{sq.ft} \times 3100 \qquad .81\ \text{lb.} = 11.0\ C_L$$

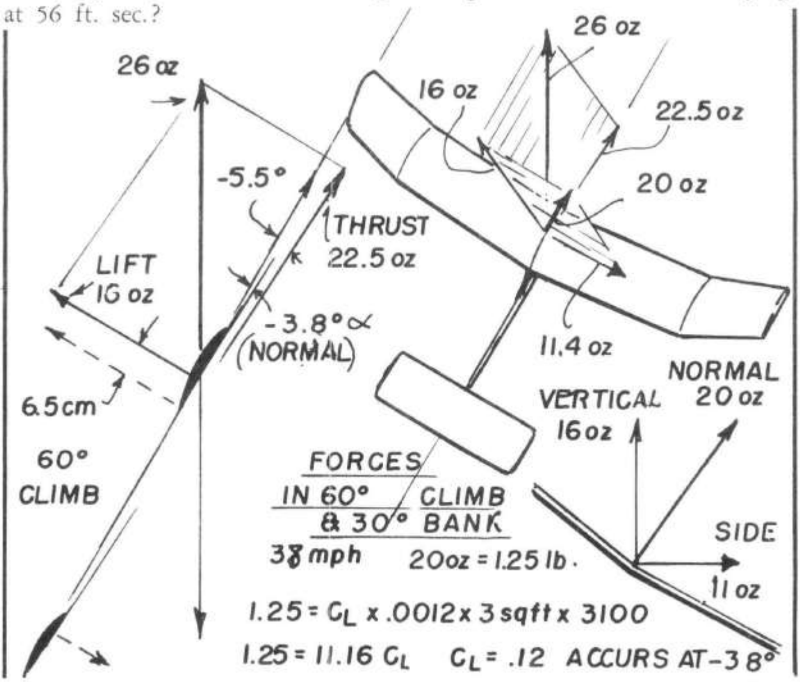
$C_L = .075$     $C_L$ OF .075 FOR GOTT 442 AT -4.2°

We find, to our horror, that a $C_L$ of .075 occurs at −4.2° angle of attack. Why the horror? Well, when the wing is at −4.2° the stab is at −6.2°, and at this angle the stab has a negative lift which tends to nose the model upward into higher angles. In fact, this situation calls for a complete check-up as we are now beginning to move into an area where the Center of Lift moves away from the airfoil into space behind the T.E. But before we do that, let us correct our space diagram to fit conditions which seem to be coming up.

## SPACE ATTITUDE OF MODEL

As you may have noted, so far we have neglected to consider the wing as being in a banked position. (We are assuming that the model did have a right spiral climb.) Another factor about which we are now sure is that the wing will be operating in a negative divergence in relation to the flight path. By making these assumptions, we now find that the vertical lift should be 16 ozs. Also by assuming a 35° bank, the normal lift is 20 ozs.

With the wing in a 35° bank and lifting 20 ozs. or 1.25 lbs., at what angle of attack will the wing develop 20 ozs. of lift while flying at 56 ft. sec.?




The formula shows that the model is now zooming upward at 38 mph, with wing at −3.8° and fuselage in a 5.5° negative angle in relation to the flight path. It may seem unexpected, but we should have been prepared to accept this attitude, as way back in the 1951 book, we emphasized the fact that the wing will develop less lift during the power phase of the flight than it does during the glide.

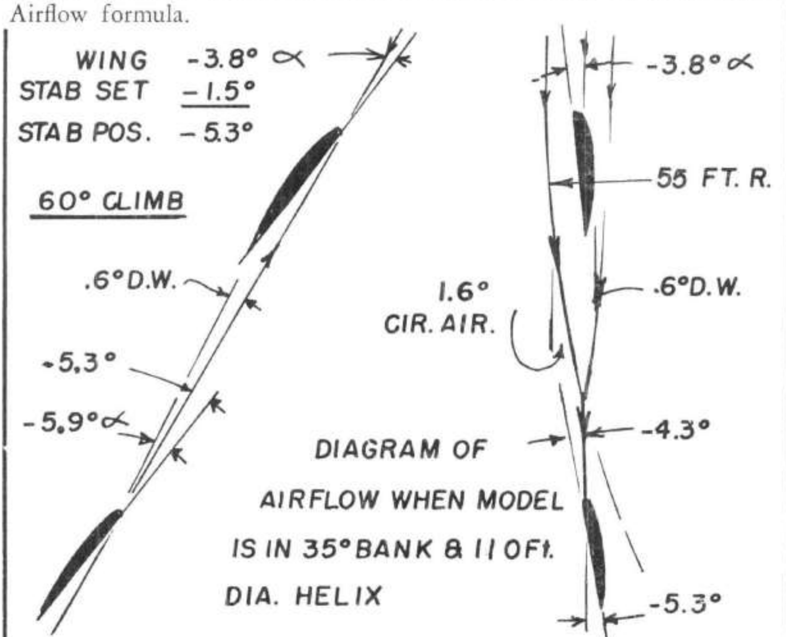
## NEED FOR CIRCULAR AIRFLOW

To determine the Moment Arms of each surface, it is necessary to know where on the airfoil we will find the Center of Lift or C.P. At −3.8° the C.P. of the wing is at its Trailing Edge. With the wing's C.P. behind the C.G., the wing has a negative pitching moment which tends to dive the model. With a $C_L$ of .11 on a 6.5 cm Moment Arm the wing force value is −1520 units.

To balance the wing at its −3.8° and its force of −2016 units., the stabilizer needs a positive Pitching Moment or a down load which will tend to stall the model. Aerodynamically, it means an extra large negative angle of attack so that its "lift" will be "down". To find this negative angle of attack we go through our usual balance computation in which we find that the stab should have $-4.3°$ angle of attack.

**SEE PAGE 107 AT $-3.8°$ WING FORCE $=-2016$ UNITS**
**STAB WILL BALANCE AT $-4.3°$ WHERE $C_L$ IS .025**
**STAB FORCE AT $-4.3° = .025\,(C_L) \times 83\text{cm} \times 945\text{cm}^2 = 1960$**

If we position the model in the 60° climb airflow with the wing at $-3.8°$ to the flight path, the stabilizer will be physically $-5.3°$ to the airflow. The .6° downwash would increase the $-5.3°$ to aerodynamical angle of attack of $-5.9°$. But as we have determined, the actual aerodynamical angle of attack should be $-4.3°$. We must now bring about an angular change so that $-5.8°$ will become $-4.3°$ without physical action. The change must be made aerodynamically, namely by applying Circular Airflow. The needed reduction is 1.6°. Since the model is in a helix climb, we can determine the helix diameter by the usual Circular Airflow formula.




**MOMENT ARM = 83cm = 32in = 2.7 Ft. SIN 35° = .574**

$$\text{CR.AIR. CHANGE} = 1.6° = \frac{2.7 \times 57.3 \times .574}{R} \qquad 1.6R = 88 \quad R = 55'$$

This 55 ft. radius, in which Circular Airflow change is 1.6°, implies that the climbing helix has a diameter of 110 ft. It seems tight, but we can doublecheck if it is satisfactory by finding out what sort of Centrifugal Force is developed in this circle.

## CHECK WITH CENTRIFUGAL FORCE

If you recall, when we determined the normal lift of the wing to be 20 ozs., we also found that the side resultant would be 11.4 ozs. Now, if the Centrifugal Force of the model, while it is in a 110 ft. diameter helix, is near this value, we must be very close to the actual flight pattern. To find the diameter at which the C.F. will be 11.4 ozs. or .72 lbs., we must know the speed of the model before we can use the C.F. formula. The reason we are bringing up the need to know the speed of the model for C.F. calculations is that we do not know this speed now. Although the obvious speed may seem to be 38 mph, some calculating brings out the fact that at such speed, a diameter of 440 feet would be needed to satisfy the equation for 11.4 ozs. of side force. Besides looking immense, it is a far cry from the 110 ft. diameter needed for the 1.6° Circular Airflow.

**TO FIND R. ON WHICH .72 lb. C.F. WILL BE SATISFIED AT 38 mph**

$$.72 = \frac{1.63 \text{ lb} \times 3100}{32\ R} \quad 23R = 5050 \quad R = 220 \text{ Ft.}$$

On second thought, the speed for C.F. calculation has nothing to do with the actual aircraft speed, in a manner of speaking, when such a craft is in a circular flight pattern. The C.F. is only concerned with the relative speed in the circular path. To obtain this relative circular speed, we only need to know the "shadow" distance of the climb during the 9.5 sec. flight. This shadow distance in a 60° climb, is 267 ft. Converting, it comes to 28 ft. sec. or 19.5 mph. Quite a difference.

Using this new speed in the C.F. formula with .72 lbs., as the required C.F. value, we find that a radius of 55 ft. would satisfy the condition. And the need for the 1.6° Circular Airflow is 55 ft. radius! If we had deliberately planned for this approximation, we could not have come closer.

## MATHEMATICAL FRAMEWORK SUMMARY

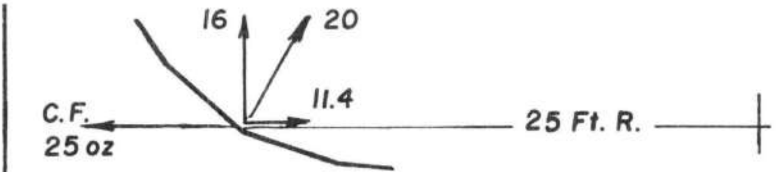
After this mental gymnastic, we should take a break and relax. But just think, we now have the model bracketed in every phase of its flight, from power to glide with numbers that seem real! Also, note that its power turn is about ¾ of a circle.

It is quite possible that the actual flight pattern may have varied from the mathematical one we reconstructed. Perhaps someone will translate this effort to Erno, and he will be able to check it for us. At the moment, however, we do not have the time for such correspondence, as this is being prepared in a very fine financial squeeze.

We believe that the method employed in determining the mathematical flight path sounds good. We brought in as many variable factors and forces we know (except torque), and some which we did not know when we began this work. As you may have noted, finding the Glide Trim Pitching Moment was easy. The major problem is the power flight. Here is where every bit of information that could be gathered from the actual flight is like gold in the bank. Note how we broke up the normal wing lift into vertical and side components to partly sustain the weight of the model and counteract the Centrifugal Force. Also, that the adjustable stab by itself was not able to bring the model into the extra low lift requirements. We had to resort to Circular Airflow to provide the final angular change.

## FLIGHT WITH DECALAGE CHANGE

As a matter of interest, let us consider what sort of a power flight would result if the model had the 3° decalage fixed for glide and power. Without getting involved in details, assuming 38 mph, 35° bank and −3.8° as wing's angle of attack, the model will need a Circular Airflow angular change of 3.1°. To obtain this angular change, we will need a 50 ft. diameter circle. A double check for Centrifugal Force values shows that C.F. would be 25 ozs. And since we only have 11.4 ozs. of side force, we can see that this combination is not practical. We could go on and show how and where it could be stabilized, but the model would not be as safe and efficient as it is when the adjustable stab is used for this particular C.G. location of 67%. (A 45° bank and 120 ft. circle would provide the 3.1° angular change.)




$$C.F. = \frac{1.6 \times 780}{32 \times 25} = \frac{1270}{800} = 1.51 = 25\,oz.$$

WING LIFT = 24 oz. = 1.5 lb  $C_L$ AT 1° = .46  30 Fs = 21 mph

$$1.5 = .46 \times .0012 \times 3 \times V^2 \quad 1.5 = .00165\,V^2 \quad V^2 = 900 \quad V = 30\,Ft.s.$$

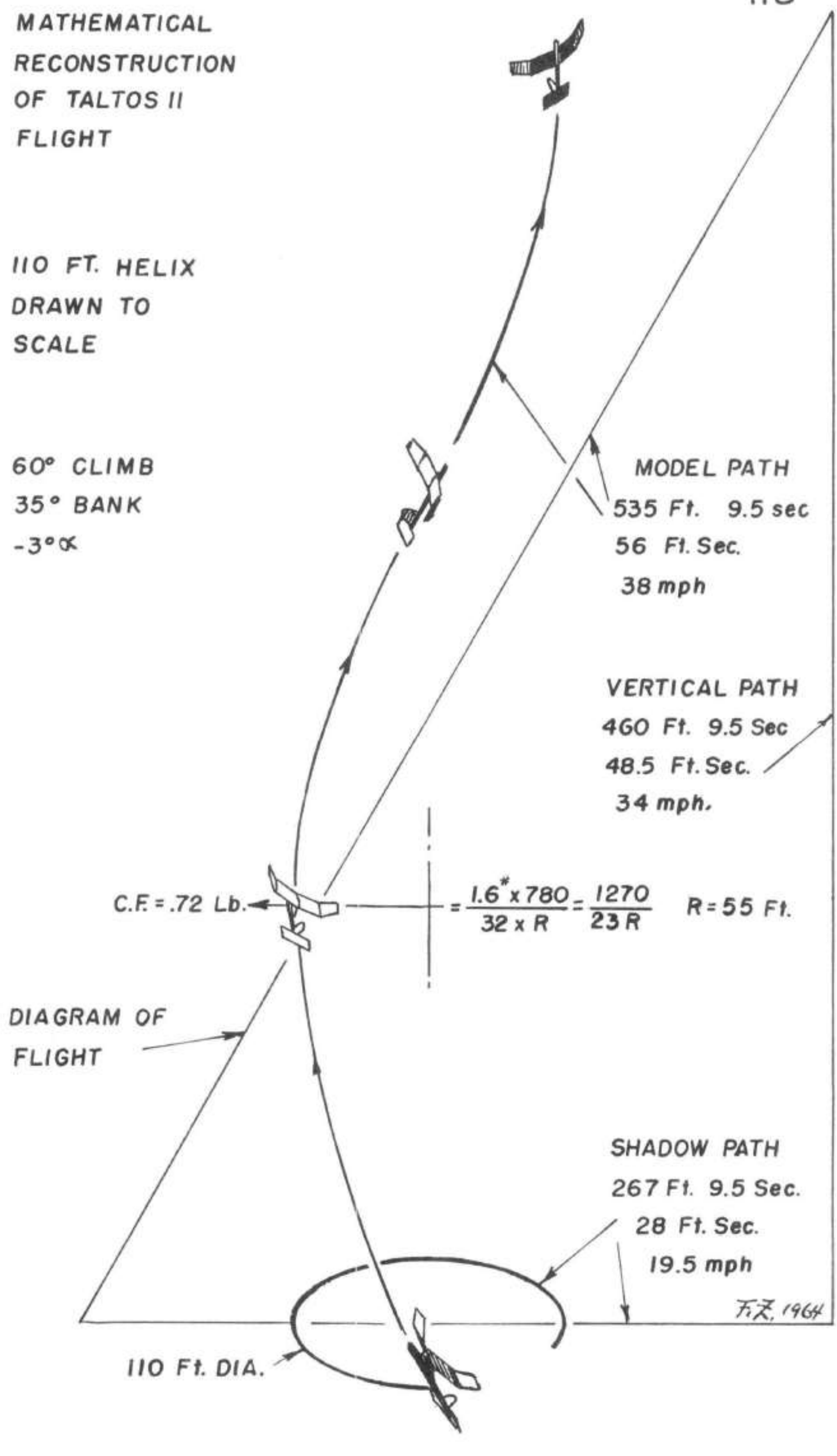
## ENGINE CUT-OFF TOO SOON

Talking about safety with adjustable stabilizer leads us to the question: What would happen if the engine cuts off before the alloted time? What sort of a glide would result? We know that when the stabilizer is set to provide 1.5° decalage, the wing is balanced at 1° angle of attack. Again, turning to the Lift Formula, with speed unknown, we find the gliding speed to be 21 mph when the wing is at 1°. Not too bad, if the model had a chance to make a good transition from 60° climb to high speed glide.

---

As you may have noted, we used a climbing right turn in our calculations. We assumed that such flight pattern was used on the original model. It is common enough with most high powered models now flying. What makes us wonder is how such a pattern is developed, because Erno showed no adjustments on plans nor mentioned any in his text how to obtain this pattern. In fact, the adjustment on the right wing calls for WASHIN. This would normally aid the torque in throwing the model into a left turn. Why, then, did the model turn right? Is there a built-in tendency to develop a right turn on such powerful models? A right thrust or rudder adjustment would answer the question, but without such a setting we wonder how it is done.

See Torque Control and Rotating Models at the end of the book.


MATHEMATICAL RECONSTRUCTION OF TALTOS II FLIGHT
110 FT. HELIX DRAWN TO SCALE
60° CLIMB
35° BANK
-3° α
MODEL PATH
535 Ft. 9.5 sec
56 Ft. Sec.
38 mph
VERTICAL PATH
460 Ft. 9.5 Sec
48.5 Ft. Sec.
34 mph.
C.F. = .72 Lb.
$= \frac{1.6^{\#} \times 780}{32 \times R} = \frac{1270}{23 R}$
R = 55 Ft.
DIAGRAM OF FLIGHT
SHADOW PATH
267 Ft. 9.5 Sec.
28 Ft. Sec.
19.5 mph
F.Z. 1964
110 Ft. DIA.

## GETZLAFF's "AMEN"

By a happy coincidence, just as we finished the calculations on the TALOS II, we received an example of the vertical climb design. It is Norman Getzlaff's "AMEN", appearing in the May/June 1964 issue of "American Modeler". With their permission, we are presenting a side view with information essential for computation.

A quick check on its design characteristics shows that it meets the basic requirements for vertical flight: Mainly, its 16° downthrust and "low" wing position. It is not necessary to go through the Glide and Power Trim Pitching Moment calculations. They are almost identical to those of TALOS II in this respect. Wing and stab areas, moment arms and 3° glide decalage are very similar. The airfoils may vary somewhat, as indicated by the slight difference in the C.G. locations.

The main feature is the 16° downthrust, and it is this feature we will discuss. First, we know from experience gained with TALOS II, that the wing will have to fly at a negative angle of attack. After some trials, we found that an angle of attack of −3° will give us a fair approximation. Using this information to locate forces, we place the thrust line at −22° to flight path. The physical position of the stab to flight path is −6°. We add to the flight path .9° downwash, which gives the stab a total angle of attack of −6.9°.

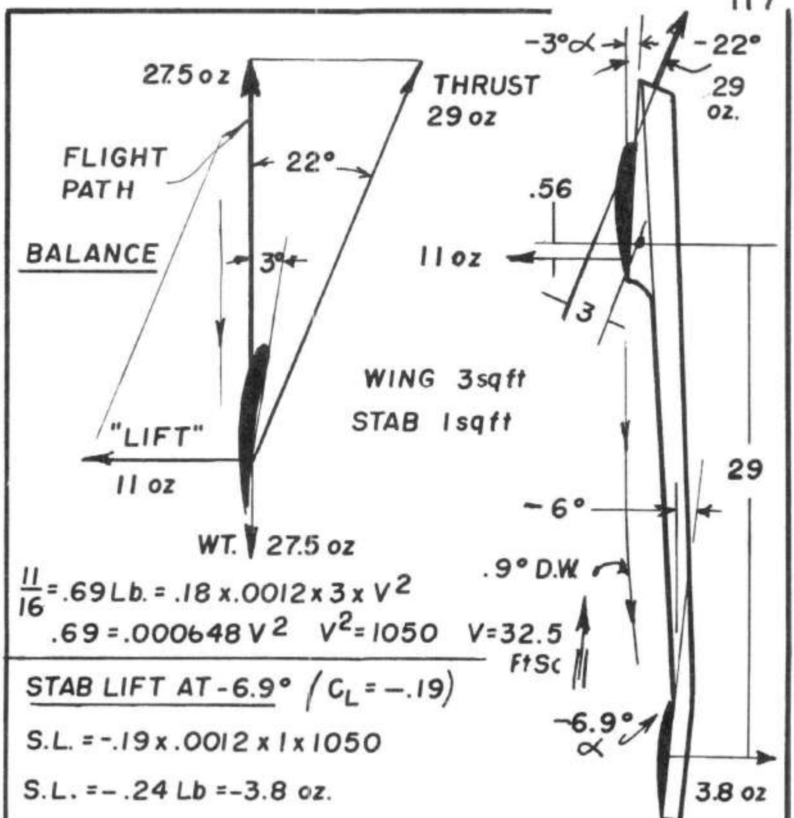
Using 27.5 ozs. for needed vertical lift, we find that thrust contributes 29 ozs., and the normal wing lift, 11 ozs.

Using this 11 ozs. lift of the wing at −3° in our Lift Formula, we find that the model climbs at 32.5 ft. sec. (22.5 mph or a climb to 325 ft. in 10 seconds). This sounds reasonable, if you can count on settling atop the "Thermal" Norman finds with his "Windicator". We are of course, assuming that wing and stab are in balance at this attitude so that the model can keep its vertical position.

To double check: At −3° the Center of Lift is at about 77%. With the C.G. being at 75%, we have a .56 inch moment arm for 11 oz. Note that this moment is negative or tending to dive the model. We are also assuming that the 16° downthrust line passes about 3 inches above the C.G. (Here is where that mention about "low" wing shows up. A wing on a pylon will definitely raise the C.G. to a position which will not cooperate fully with the downthrust.) In this type of design, we need all of the negative pitch we can find to balance the positive pitch of the stabilizer. Remember, there is no Circular Airflow in this type of flight pattern to help out with angular changes.

The stabilizer operates at −6.9°, at which the $C_L$ is −.19. Using this −.19 value in the Lift Formula, we find that the stab develops .24 lbs. or 3.8 ozs. of negative lift. Placing this value on a 29 in. moment arm, we obtain a positive pitch of 110 in. oz. Now, we add up how much negative pitch thrust line and wing we have and see if it balances the stab.

We have 29 ozs. thrust on a 3 inch arm giving us 87 in. oz. and about 6 in. oz. from the wing, or a total of 93 in. oz. with which to




balance the 110 in. oz. of the stab. As far as we are concerned, this approximation is close enough. Especially since our main purpose for going through this calculation was to show that it is possible to reach such balances mathematically, and so more or less substantiate the facts of actual flight. What we have just done, is to prove that it is possible to obtain vertical flights if certain design criteria are followed, and if you have power to spare. Thanks to Norman Getzlaff, the mathematical predictions have been proven in practice with dependable maximum flight regularity.

Notice that Norman used a very slight right thrust for torque control. Although it is quite possible that his main counter torque came from the warpage of the stabilizer; 1/16 in washin on the left and 1/8 in washout on the right side.

(NOTE: We arrived at the 325 ft. altitude for the climb height in ten seconds by using the Lift Formula. We can make a fair check on this value using pitch and diameter of prop, and the engine's rpm. Assuming 18,000 rpm, or 3000 revolutions in ten seconds, and 50% prop efficiency or 1.5 in advance for every revolution, we obtain a height of 4500 inches or 375 feet in ten seconds. Close! (50% efficiency implies that the prop airfoil's angle of attack was 3.5° at the tips.)

## GLIDERS AND CIRCULAR AIRFLOW

A complete coverage of the glider design would need a book. Therefore, we will limit the discussion to the Nordic A/2 and use it to demonstrate the important part the Circular Airflow angular change plays in its performance.

Rather than using an existing Nordic as an example, we averaged a design as shown. We used airfoils found in the Airfoil Report Books, which are close to those used in practice.

Fortunately, our need for a verified glide speed data was satisfied in a letter from Jim Horton, in which he mentions the methods he uses to record air speed during full flight time of the glider. He found 10 mph to be a good figure. We also have a record of Hacklinger making indoor Nordic glide tests by which he determined the gliding speed to be 13 mph.

After running through sample calculations, we found that 11.4 mph glide speed would best satisfy the Lift Formula when 14.5 ozs. of lift is needed. Since 11.4 mph is the average of the above two values, we feel we are close to the actual flight conditions. Airfoils used, Gott 499 wing and Gott 377 stab, will be found in the back of this book.

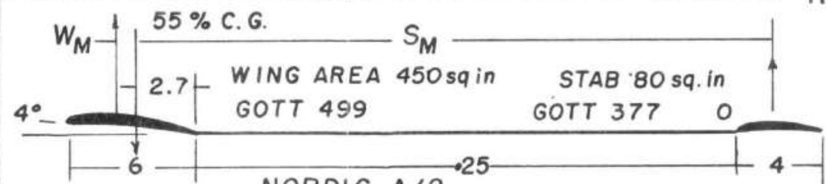
**WING $C_L$ AT 6° = .9   WT. = .91 Lb = 14.5 oz   AREA = 3.1 sq.ft.**

**$.91 = .9 \times .0012 \times 3.1 \times V^2$   $V^2 = 270$   $V = 16.5$ Ft.Sc = 11.4 mph**

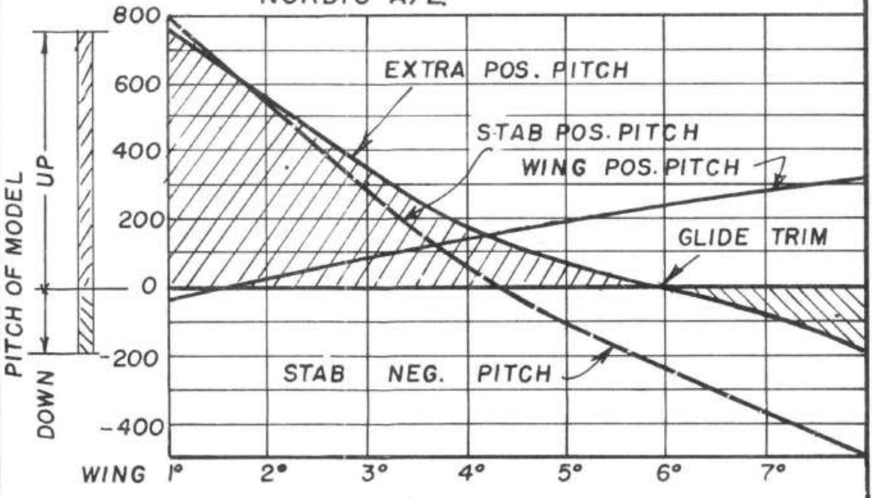
We made the usual Glide Trim Pitching Moment calculations and charts, using 6° as the angle of attack. Inspecting the Nordic graph, you will note that it is most unusual. Of particular interest is the extremely powerful control the stab has over the wing to keep it at 6°. This feature may seem desirable, for a Nordic in which the main design effort is to have the wing contribute maximum possible lift with other desirable characteristics placed in second choice.

## NORDIC SENSITIVE TO CHANGES

By being sensitive to the slightest change in angular airflow, its fast reaction makes it very important that its dynamic stability (determined by weight distribution). does not interfere with the static stability (determined by the stab, in this case). For example, if the glider is suddenly forced to nose down into a thermal, its weight distribution will determine how quickly it can come back to normal flight after the sudden updraft fades. If the weight distribution is such that the model's momentum will tend to keep the model "rotating" in the direction it began after the updraft fades, the stabilizer may have difficulty bringing the model back to normal glide path. This fact can be better appreciated if one realizes that on our example model the stab lift contribution is only .25 oz. or 1.7% of the total 14:5 oz. Also, this .25 oz. on a 31 in. moment arm equals 7.8 in. oz. force about the C.G. So that if the rotational momentum of the model happens to reach 7.8 in. oz. value, the stab has no recovery surplus left.

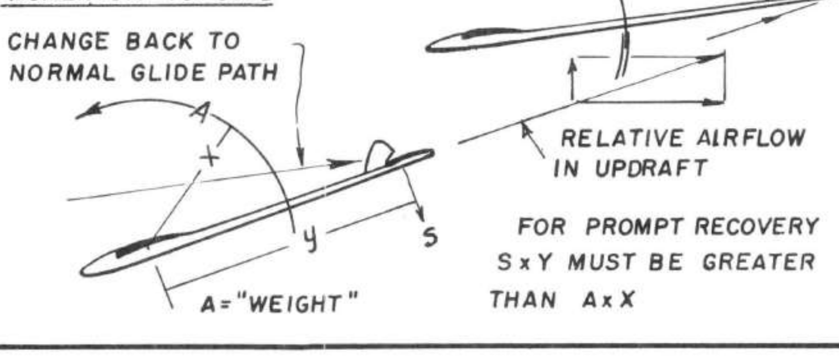



NORDIC A/2.

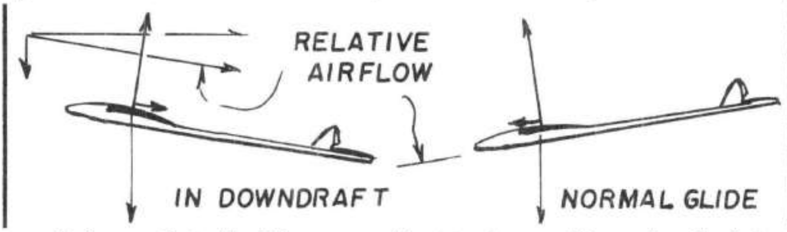



| WING (POS. PITCH) | | | | | | | STAB (NEG. PITCH) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wα | D.W. | C.P. | $C_L$ × | $W_M$ × | $W_A$ = | $W_F$ | S% | Sα | $SC_L$ × | $S_A$ × | $S_M$ = | $S_F$ |
| 1° | 2.8 | 57% | .57 | -.1 | 450 | -25 | -3° | -5.8° | -.32 | 81 | 31 | 800 |
| 2° | 3.2 | 54% | .64 | .08 | 450 | 23 | -2° | -5.2° | -.22 | 80 | 31 | 550 |
| 3° | 3.5 | 52% | .70 | .18 | 450 | 56 | -1° | -4.5° | -.12 | 80 | 31 | 300 |
| 4° | 3.8 | 50% | .77 | .33 | 450 | 113 | 0° | -3.8° | -.025 | 80 | 31 | 66 |
| 5° | 4.2 | 48% | .83 | .44 | 450 | 165 | 1° | -3.1° | .045 | 80 | 31 | -110 |
| 6° | 4.5 | 46% | .90 | .55 | 450 | 228 | 2° | -2.5° | .092 | 80 | 31 | -226 |
| 7° | 4.8 | 45% | .97 | .60 | 450 | 260 | 3° | -1.8° | .160 | 80 | 31 | -350 |
| 8° | 5.1 | 44% | 1.02 | .69 | 450 | 315 | 4° | -1.1° | .21 | 80 | 31 | -500 |

MOMENTUM VS. STAB

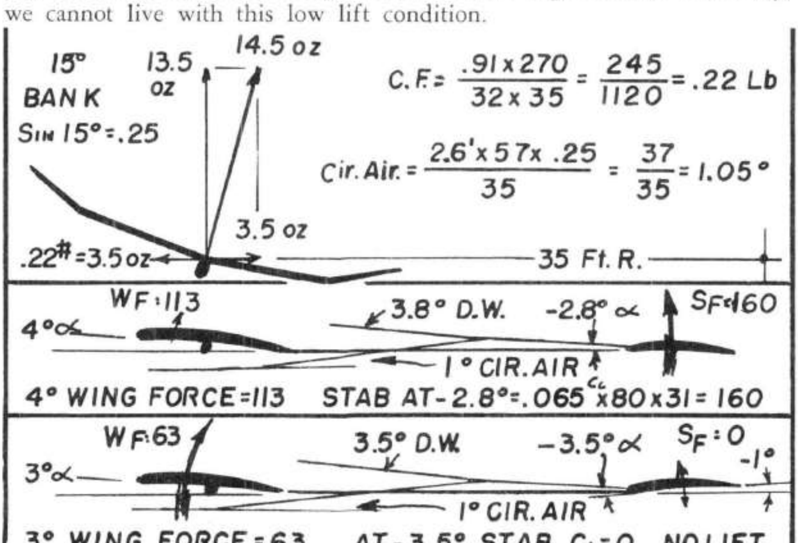


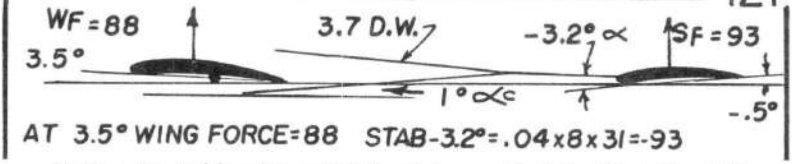
In a downdraft, we do not have to worry about rotational momentum as much as we should about the model coming to a stand still. To keep the gliding speed, the glider's flight path must be negative to the horizontal line so that lift and gravity will provide forward component with which to balance the drag. Now, if the glider is forced to "face" upward, the forward "thrust" component is lost and speed reduced.



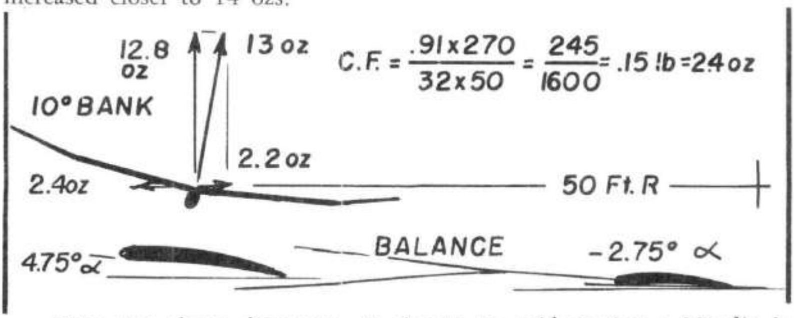

It is true that all gliders are subject to the conditions described, but the Nordic glider is especially vulnerable because of its evolutionary development, in which maximum lift from the wing is the objective.

Another characteristic peculiar to Nordic gliders, is their inability to fly in tight circles. Let us see what happens in a 70 ft. circle. The C.F. requires a 3.5 oz. counter force. To obtain 3.5 ozs. from a basic lift of 14.5 ozs. the wing must be banked 15°. This is not asking too much. In this circle and bank, the Circular Airflow angular change will be 1°. What will this additional 1° of positive airflow do to the balance between wing and stab? We checked for balance, a degree at a time, as shown by the diagrams, until we reached the new balance, which we found to be when the wing's angle of attack is 3.5°. This means that when we set the rudder on the Nordic to have a 70 ft. circle with the wing banked 15°, the wing was automatically forced to drop to 3.5° angle of attack by the resulting Circular Airflow angular flow. Obviously, we cannot live with this low lift condition.






Easing the rudder for a 100 ft. circle, we find the Centrifugal Force needs 2.45 ozs. counter force. This can be satisfied in a 10° bank. In this 10°, the Circular Airflow angular change is .5°. With this positive angular airflow change, we found that the balance between wing and stab will be reached with the wing at 4.75° angle of attack. Not too bad here. The basic lift has been reduced to 13 ozs. and C.F. almost satisfied. It is quite possible that the Nordic will speed up a bit as the wing now has less drag due to lower angle of attack and basic lift increased closer to 14 ozs.




From the above discussion, it should be evident that a Nordic is not inherently capable of making tight turns. It is basically a drifter. Any attempts to obtain turns which require a degree of bank beyond 10° should be done with full knowledge of what will happen to the lift.

It should also be obvious that if we had somehow been able to decrease the stab incidence by 1° when the model began to circle, we could have enjoyed a regular 6° angle of attack for the wing and stayed in the 70 ft. circle without appreciable loss of vertical lift due to 15° bank. Or if we had the 5° angular difference between the wing and stab incorporated in the design, and had somehow been able to establish the 70 ft. circle without stalling in the transition between tow and circle, we would also be able to enjoy full lift. As you can see, we are now repeating the problems we had with our own glider, as recorded in the 1952 book.

In designing gliders for other work, like R/C, where tight circling is necessary, notice what shorter moment arms or coupling will do. Basically, Circular Airflow angular changes are dependent on the moment arm and the banking of the wing. For tight circles needed in R/C work, high bank is essential for Centrifugal Force control. In such cases, if the stabilizer is not movable, short moment arm is the answer.

Although we may have used only the Nordic as an example, anyone familiar with gliders, should be able to pick up information which is peculiar to his needs.

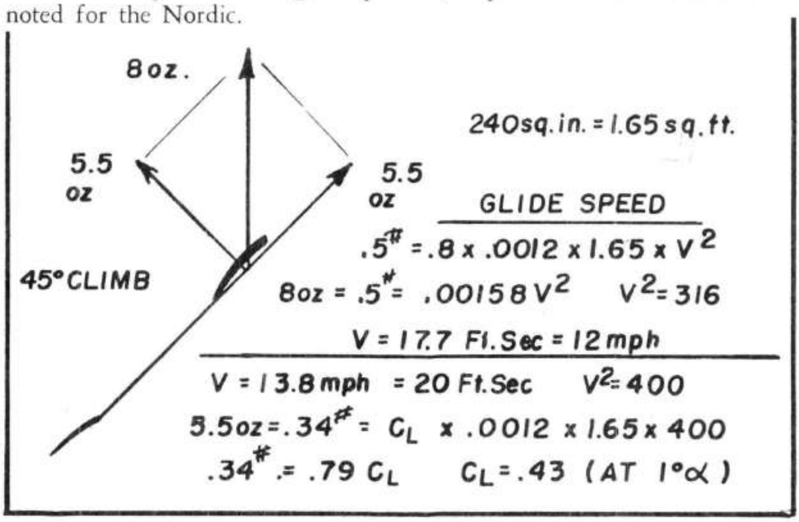
## WAKEFIELD AND CIRCULAR AIRFLOW

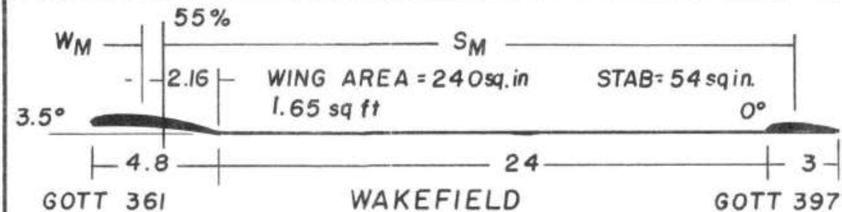
Rules have converted the exciting Wakefield event into a powered Nordic Glider contest. The original rules which called for ROG and cross section rules, were nasty but demanded more than now. Present Wakefield design may be a bit overpowered at the initial burst but the large diameter and wide-bladed prop quickly takes on a partial load of the model's weight and so reduces the climbing speed similar to glide speed or less.

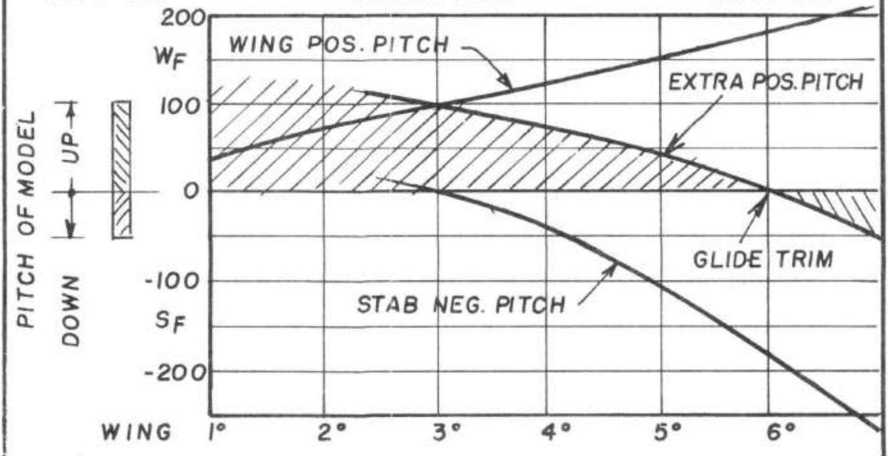
The Glide Trim Pitching Moment graph and calculations are similar to Nordics', with stab having a very good control to keep the wing at 6°. Calculations with airfoils, which are very similar to those used in practice for glide speed, resulted in 12 mph. Without having an exact figure from the field, we can say that it is about right when we consider that the Wakefield wing loading is similar to that of Nordics, which glide between 10 and 13 mph.

On the initial power burst, we will assume the climb to be at 45°. The required 8 oz. of vertical lift breaks into 5.5 ozs. of thrust and 5.5 ozs. for wing lift. Not knowing any better, we will assume 13.5 mph climb speed. To generate 5.5 ozs. at this speed, the wing needs to fly at only 1° angle of attack. To balance the wing at its 1°, the stab needs a −2.7° angle of attack. When we consider that the stab is physically at −2.5° to the flight path, and has a downwash of 2.1°, its angle of attack is −4.6° when the wing is at 1°. This angle is too large by 1.9° Here, again, we have to depend on the Circular Airflow to bring out the needed change.

To bring about 1.9° angular change with the wing at 30° bank, we need a 70 ft. circle or helix. We will not go into Centrifugal Force control as the values we used are more on the imaginative side than factual. But the method used is proven, and the characteristic of the Wakefield exposed. For glide portion, expect same characteristics as noted for the Nordic.



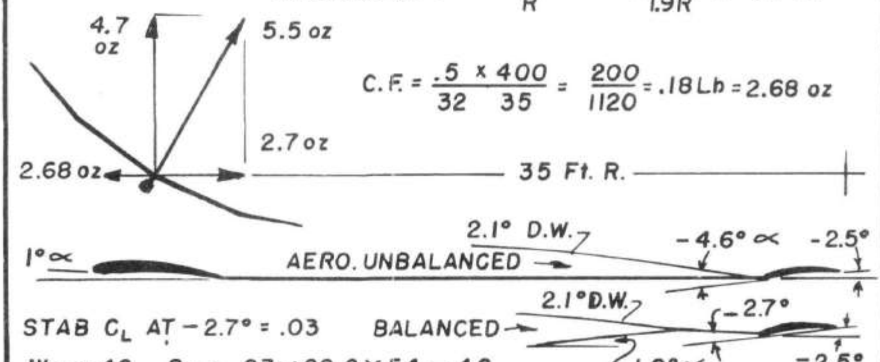



| WING (POS. PITCH) | | | | | | | STAB (NEG. PITCH) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $W\alpha$ | D.W. | C.P. | $C_L \times$ | $W_M \times$ | $W_A =$ | $W_F$ | S. INC∠ | $S\alpha$ | $S_{C_L} \times$ | $S_M \times$ | $S_A =$ | $S_F$ |
| 1° | 2.1 | 46% | .425 | .44 | 240 | 46 | -2.5° | | | | | |
| 2° | 2.5 | 43% | .5 | .60 | 240 | 72 | -1.5° | | | | | |
| 3° | 2.9 | 41% | .58 | .67 | 240 | 92 | -.5° | -3.4° | 0 | — | — | — |
| 4° | 3.3 | 39% | .65 | .77 | 240 | 115 | .5° | -2.8° | .025 | 28.5 | 54 | -38 |
| 5° | 3.6 | 37% | .73 | .87 | 240 | 150 | 1.5° | -2.1° | .075 | 28 | 54 | -117 |
| 6° | 4.0 | 36% | .80 | .91 | 240 | 175 | 2.5° | -1.5° | .12 | 27.5 | 54 | -177 |
| 7° | 4.4 | 35% | .88 | 1.03 | 240 | 215 | 3.5° | -.9° | .175 | 27.5 | 54 | -260 |

30° BANK (SIN .50)   CIR. AIR. $= 1.9° = \frac{2.34' \times 57 \times .50}{R} = \frac{67}{1.9R}$   R = 35 Ft.

C.F. $= \frac{.5}{32} \times \frac{400}{35} = \frac{200}{1120} = .18\ \text{Lb} = 2.68\ \text{oz}$




STAB $C_L$ AT $-2.7° = .03$

$W_F = 46 \quad S_F = .03 \times 28.2 \times 54 = 46$

## FLYING SCALE AND CIRCULAR AIRFLOW

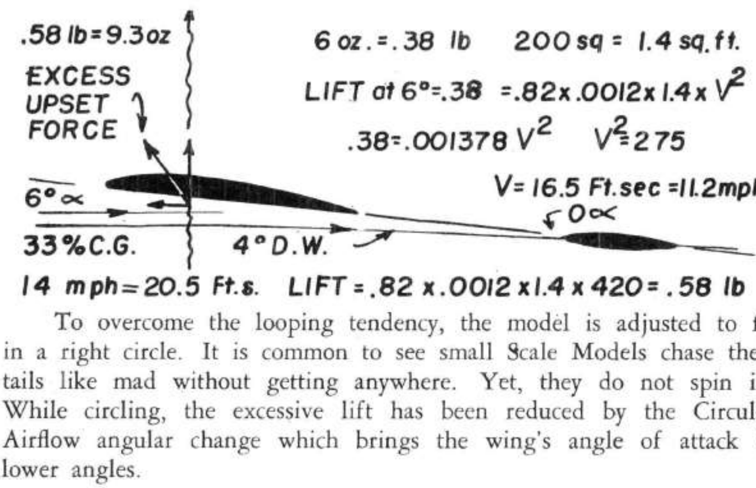
Flying Scale Models are very difficult to fly under power. Any increase of speed above the glide becomes a trim problem, and without good power, the Scale Model is at the mercy of the breeze. Why is it difficult? Because the model has to be faithful to scale.

This means that wing and stab must be in exact ratio to the original prototype. In particular, it implies a small stab on a short moment arm. This forces us to use C.G. at 33% location or very close to it. We dare not move C.G. backward when stab is only 15% (effective) of the wing area. Perhaps the problem will be more apparent as we go through the usual Glide Trim Pitching Moment and Power Trim requirements.

Our example model has a 200 sq. in. wing, a 40 sq. in. stab (which becomes only 30 sq. in. after assuming 75% efficiency), a weight of 6 ozs., Clark Y wing and symmetrical stab.

## FLYING SCALE SENSITIVE TO POWER

Taking 6° as angle of attack for glide trim and using the Lift Formula, we find that the glide speed is 11.2 mph. What happens if we apply enough power so that the model will fly at 14 mph instead of 11.2 mph? Still using the 6° angle of attack because of the strong stab control, the wing will generate 9.3 ozs. of lift at 14 mph. This will tend to loop the model. If the power is not enough to cause a loop, the model will stall. This action is predicted by the force diagram as shown. Details for this action will be found in the 1952 section.

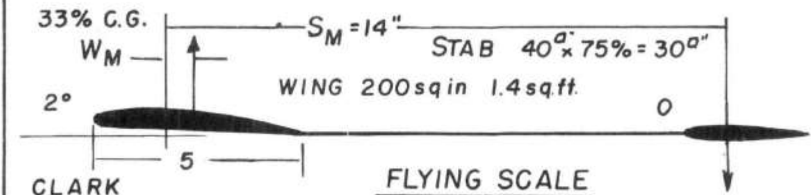



14 mph=20.5 Ft.s.   LIFT=.82 x .0012 x 1.4 x 420=.58 lb

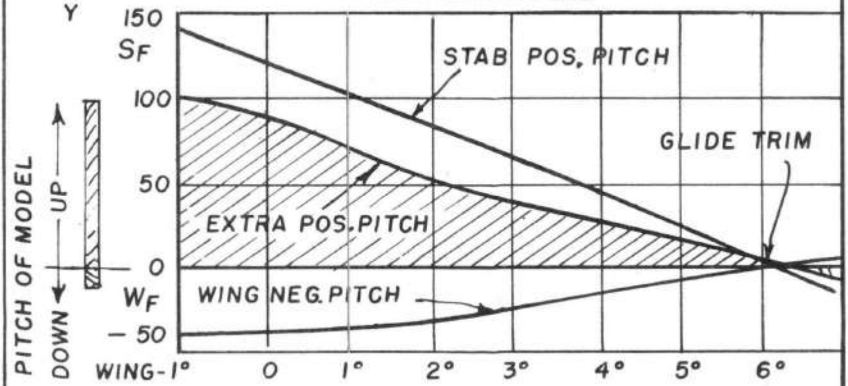
To overcome the looping tendency, the model is adjusted to fly in a right circle. It is common to see small Scale Models chase their tails like mad without getting anywhere. Yet, they do not spin in. While circling, the excessive lift has been reduced by the Circular Airflow angular change which brings the wing's angle of attack to lower angles.

## FLYING SCALE MUST CIRCLE

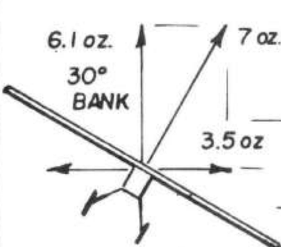
Assuming that our model is flying in a level circle with wing banked at 30°, at which angle of attack will the wing develop a normal lift of 7 ozs. while circling at 14 mph? The Lift Formula resolves the question to a $C_L$ of .55 which occurs at 2°. Checking the Glide Trim chart, we note that at 2° the wing has a diving force of −32 units. To counteract this diving force, we need an "upward" force from the stab of equal value to balance the model. On the stab side of the chart this value lies between −1.5° and −.8° By interpolation, we find that at —1.1° angle of attack, the stabilizer will balance the wing.




FLYING SCALE




| WING (NEG. PITCH) | | | | | | | STAB (POS. PITCH) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wα | D.W. | C.P. | $C_L$ x | $W_M$ x | $W_A$ = | $W_F$ | S∠° | Sα | $SC_L$ x | $S_M$ x | $S_A$ = | $S_F$ |
| -1 | 1.6° | 45% | .33 | -.60 | 200 | -40 | -3° | -4.6° | -.34 | 14 | 30 | 142 |
| 0 | 2.0° | 42% | .40 | -.40 | 200 | -36 | -2° | -4.0° | -.30 | 14 | 30 | 125 |
| 1° | 2.3° | 40% | .47 | -.35 | 200 | -35 | -1° | -3.3° | -.25 | 14 | 30 | 105 |
| 2° | 2.7° | 38% | .54 | -.30 | 200 | -32 | 0° | -2.7° | -.20 | 14 | 30 | 84 |
| 3° | 3.1° | 36% | .62 | -.15 | 200 | -19 | 1° | -2.1° | -.16 | 14 | 30 | 67 |
| 4° | 3.5° | 35% | .70 | -.10 | 200 | -14 | 2° | -1.5° | -.11 | 14 | 30 | 46 |
| 5° | 3.8° | 34% | .76 | -.05 | 200 | -8 | 3° | -.8° | -.06 | 14 | 30 | 25 |
| 6° | 4.1° | 33% | .82 | 0 | 200 | 0 | 4° | -.1° | 0 | 14 | 30 | 0 |
| 7° | 4.4° | 32% | .88 | .05 | 200 | 9 | 5° | .6° | .04 | 14 | 30 | -17 |

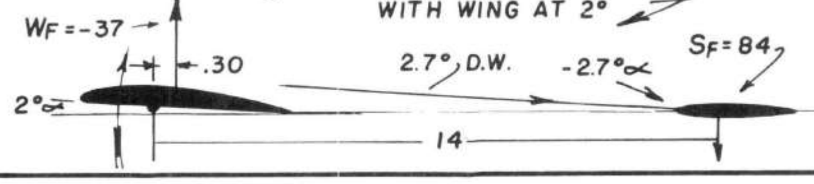



7 oz. = .44 $= C_L \times .0012 \times 1.4 \times 420 = C_L \times .806$

$C_L = \dfrac{.44}{.806} = .55$ AT 2° ON CLARK Y

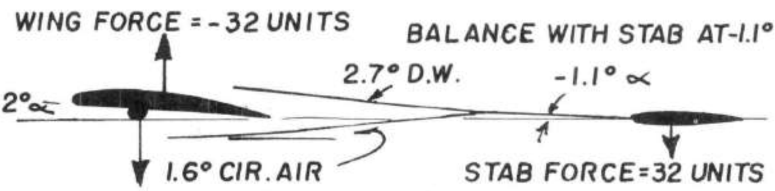
C.F. on 21' R $= \dfrac{.38 \times 420}{32 \times 21'} = \dfrac{160}{67} = .24$ lb. = 3.8 oz.

UNBALANCE IN STRAIGHT FLIGHT WITH WING AT 2°



Placing the wing at 2° in relation to the flight path would physically locate the stab at 0° to the path. But there is a difference between physical and aerodynamical locations. The aerodynamical relationship between wing and stab is −2.7° because of the wing's downwash. Our need, however, is for only −1.1°. What do we do with the extra 1.6°? We can change it physically by using an adjustable stabilizer, or aerodynamically, by Circular Airflow. (Strictly speaking, the adjustable stab would never bring the model into this tail chasing attitude). We have no other choice but use the Circular Airflow angular change.

To obtain 1.6° angular change while the wing is banked 30° and the stab is on a 14 in. moment arm, we need a 42 ft. diameter circle. To check: Does this circle agree with the Centrifugal Force requirement? According to the Formula, a 6 oz. model in a 42 ft. circle would have a C.F. of 3.8 ozs., but we only have 3.5 ozs. of side force to counteract it. So that the actual circle may be a bit larger, say 50 ft. or the bank may be more than 30°.




$$CIR.\ AIR = 1.6^\circ = \frac{1.17' \times 57 \times .50}{R} \qquad R = \frac{33}{1.6} = 21\ Ft.\ R.$$

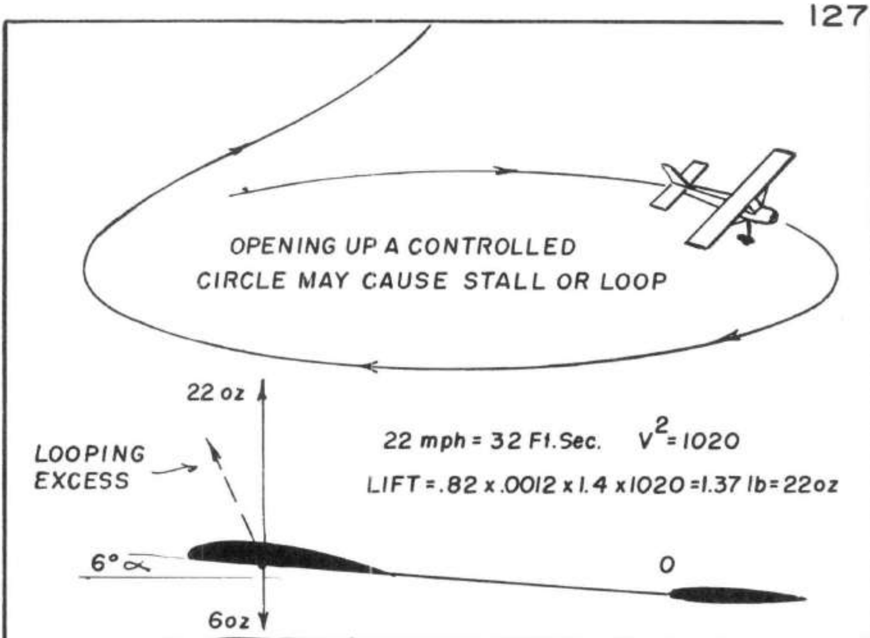
As it has been demonstrated, just a slight opening of the turn would cause a gradual climb. In the case of Flying Scale Models, this opening of the circle is very critical as it is liable to go right back to looping unless corrected by physical means, such as downthrust.

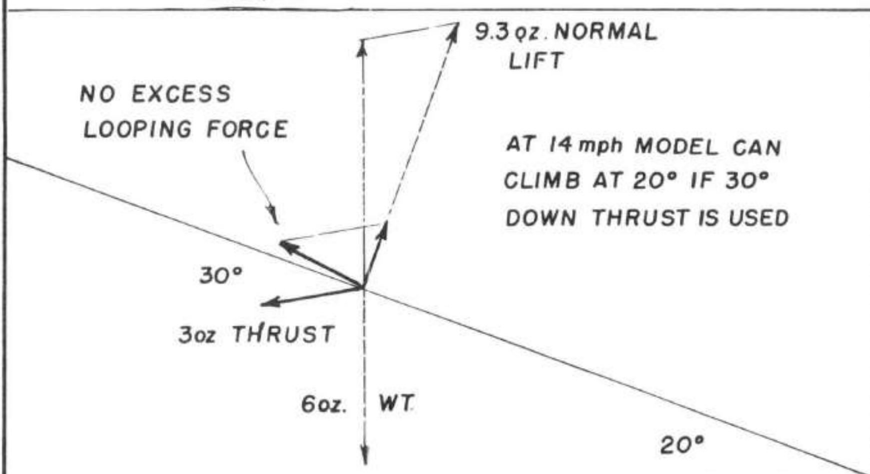
## IMPROVING FLYING SCALE FLIGHT

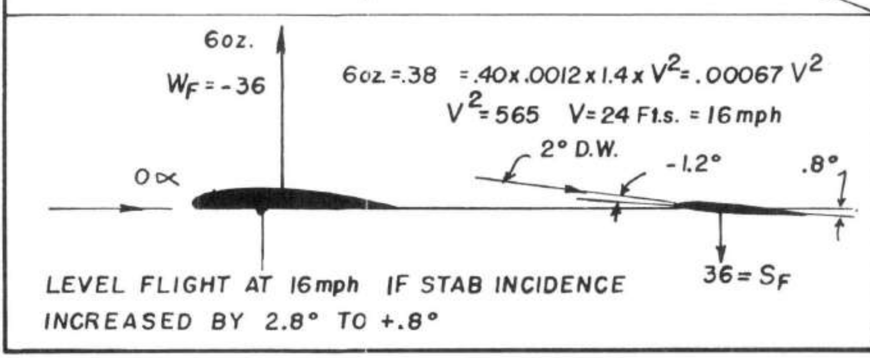
Does the above description of the Flying Scale Model flight have a ring of truth in it? And if it is close to home, what can be done to improve its flight characteristics and still stay within scale?

First, you saw what happened when we increased air speed by only 3.9 mph. You can just imagine what would happen if you doubled it to 22 mph. In a straight forward flight, it would produce a lift of 22 ozs. with the wing trimmed for 6°. What are you going to do with 22 ozs. when you need less than 6 ozs. for a decent climb? As you can see, we are faced again with the old problem of how to reduce lift at high speed.

The classical way is to use downthrust as needed by the model. Even if you need as much as 30°, do it. The other solution is the adjustable stabilizer — just like the full-scale boys have. Don't worry about losing thrust due to excessive downthrust. With a 30° down, you still have 85% of the original thrust available for flight path pull. But the 30° will do wonders to help you balance out the excess lift in a climb.

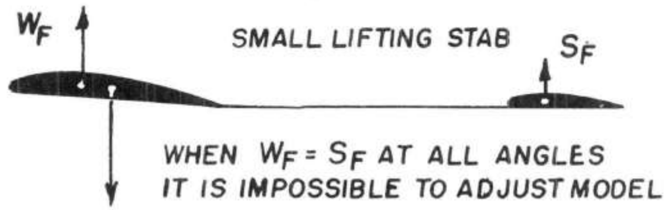

OPENING UP A CONTROLLED
CIRCLE MAY CAUSE STALL OR LOOP
22 oz
LOOPING
EXCESS
22 mph = 32 Ft.Sec. $V^2$= 1020
LIFT = .82 x .0012 x 1.4 x 1020 = 1.37 lb = 22 oz
6° ∝
0
6 oz


9.3 oz. NORMAL
LIFT
NO EXCESS
LOOPING FORCE
AT 14 mph MODEL CAN
CLIMB AT 20° IF 30°
DOWN THRUST IS USED
30°
3 oz THRUST
6 oz.
WT.
20°


6 oz.
$W_F$ = -36
6 oz = .38 = .40 x .0012 x 1.4 x $V^2$ = .00067 $V^2$
$V^2$ = 565 V = 24 Ft.s. = 16 mph
2° D.W.
-1.2°
.8°
0 ∝
36 = $S_F$
LEVEL FLIGHT AT 16 mph IF STAB INCIDENCE
INCREASED BY 2.8° TO +.8°

## LIFTING STAB

What about using a lifting stab on Flying Scale Models? Well, let's make a Glide Trim Pitching Moment chart, using the same areas and distances between surfaces. We will use Clark Y for wing and St. R. Gen 28 for a stab, and C.G. at 50%, which does not seem too far back.



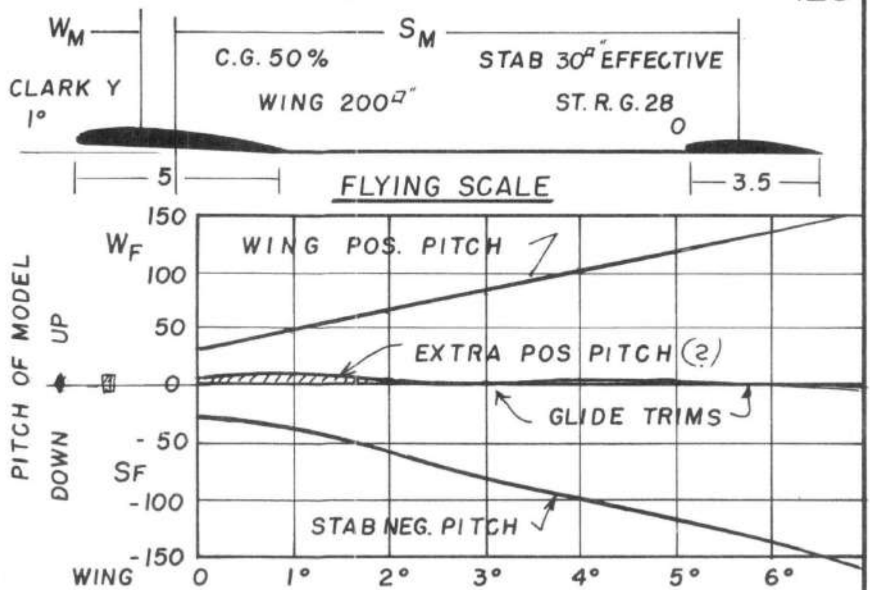

The resulting chart and graph show that we have razor's edge stability. Just a slight change would dive or stall the model. This illustrates what happens when you try to obtain balance by using high stab incidence without backing it up with an increased area. Shifting C.G. and changing to lifting stab is definitely not the thing to do. Note that a shift from 33% to 50% on a 5-inch chord only means a movement of .85 or 7/8 of an inch. Locating the C.G. between these two points will give you stability depending on the final location. So you see that shifting of the C.G. and juggling the stab incidence to suit, is not practical. Get the C.G. to 33% and adjust for good clean glide — then keep your hands off the wing and stab. For power flight, use other means for flight pattern control.

## FLYING SCALE PROBLEMS

We lack field experience to be able to tell you what to do in detail. But then, that is not our job. We are supposed to give you an insight to the overall or basic picture and you take it from there to fit your particular need. To summarize, the flying scale problem is caused by poor higher-than-glide speed characteristics. Believe us, if the full size plane had to use a fixed stab, it would also have lots of trouble. The so-called spiral stability is not caused by lack of sufficient or too small rudder, but simply by inherent need for circular flight to achieve a balance between wing and stab. (NOTE: If dihedral is low, do not enlarge rudder.) If the model is forced to bank too much before it achieves this balance, it will spiral in (not spiral dive), simply because it lacks enough vertical lift.

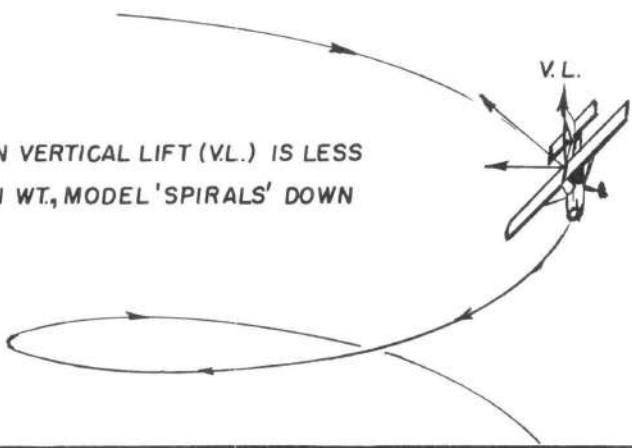
ADJUSTABLE ELEVATOR - VARY WITH POWER

The solution to the scale problems is to have a stabilizer that will vary with power. It may have been obvious all these years, but now that you know that there is no other way out, maybe something will be done. Forget pendelum possibilities. We are playing with relatively high forces which have to be controlled positively. Of course, if you want to be sneaky and add an inch here and there, that is your problem.




| WING (POS. PITCH) | | | | | | | STAB (NEG. PITCH) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W∝ | D.W. | C.P. | $C_L$ × | $W_M$ × | $W_A$ = | $W_F$ | S∠ | S∝ | $SC_L$ × | $S_M$ × | $S_A$ = | $S_F$ |
| 0° | 2.0° | 42% | .40 | .4 | 200 | 32 | -1° | -3.0° | .07 | 14.5 | 30 | -30 |
| 1° | 2.3° | 40% | .47 | .5 | 200 | 47 | 0° | -2.3° | .12 | 14.5 | 30 | -36 |
| 2° | 2.7° | 38% | .54 | .6 | 200 | 65 | 1° | -1.7° | .15 | 14.4 | 30 | -65 |
| 3° | 3.1° | 36% | .62 | .7 | 200 | 87 | 2° | -1.1° | .2 | 14.3 | 30 | -86 |
| 4° | 3.5° | 35% | .70 | .75 | 200 | 1o5 | 3° | -.5° | .23 | 14.2 | 30 | -98 |
| 5° | 3.8° | 34% | .76 | .8 | 200 | 121 | 4° | .2° | .28 | 14.1 | 30 | -118 |
| 6° | 4.1° | 33% | .82 | .85 | 200 | 139 | 5° | 1° | .34 | 14 | 30 | -140 |
| 7° | 4.4° | 32% | .88 | .9 | 200 | 158 | 6° | 1.6° | .38 | 14 | 30 | -160 |

WHEN VERTICAL LIFT (V.L.) IS LESS THAN WT., MODEL 'SPIRALS' DOWN

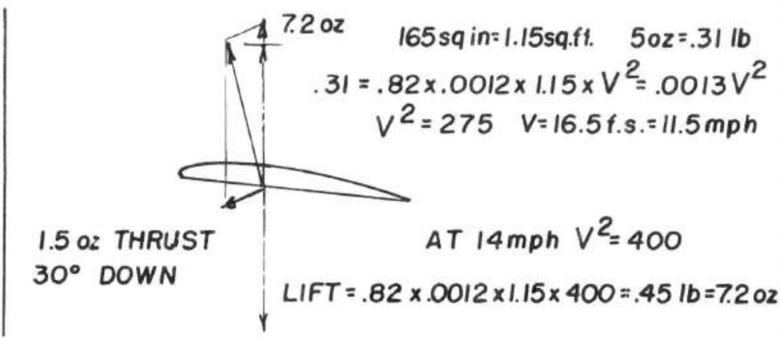


## FLYING WING AND CIRCULAR AIRFLOW

The Flying Wing presents problems because it does not have the ability to adjust automatically to variations in speed to reduce lift. The stabilizing elements — wing tips — are on a very short moment arm so that Circular Airflow angular change is difficult to achieve for changes required. Downwash is also missed.

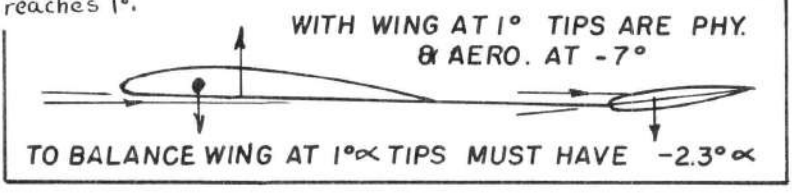
For our example we will use SAILWING 50. It has an 8° decalage, and when the wing is trimmed to a 6° glide angle of attack, the tips are at −2°. (A stab behind the wing would be physically set at 2° so that it would have −2° when 4° downwash is added. While the flying wing needs 8° decalage, a standard model needs only 4°.)

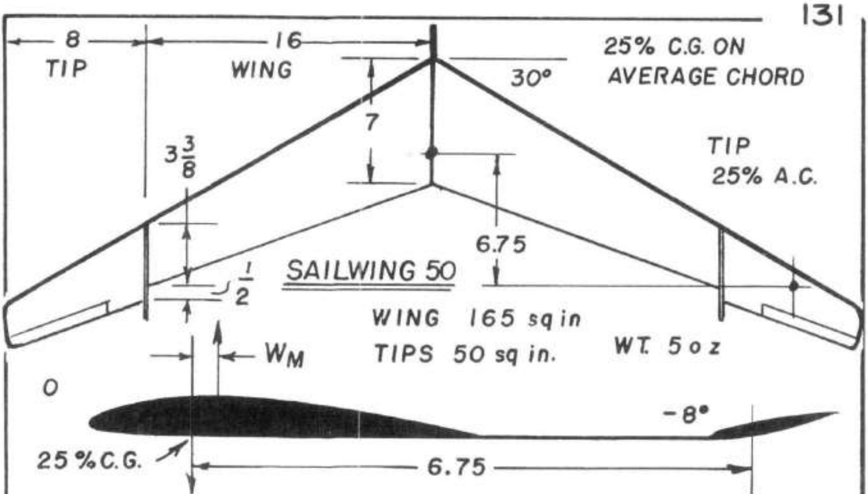
SAILWING, when trimmed to 6°, will have a glide speed of 11.5 mph. If speed is increased to 14 mph, the lift will be 7.2 ozs. at 6°. This extra lift will tend to zoom or stall the wing. The usual solution is to make the wing circle and/or add downthrust. Assuming 1.5 oz. thrust, we can obtain a steady flight by setting the engine at 30° downthrust. This will resolve into a down load of .75 oz., which will be taken from the basic lift, and 1.3 oz. forward thrust, which will slow down the model slightly. Net effect will be a controlled flight.

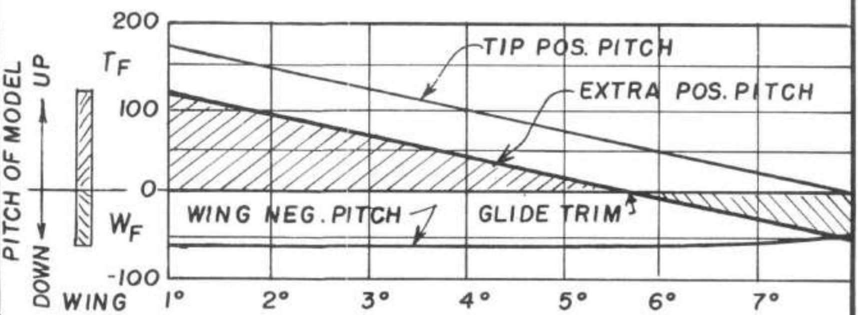



## TIP ANGLE OF ATTACK FIXED

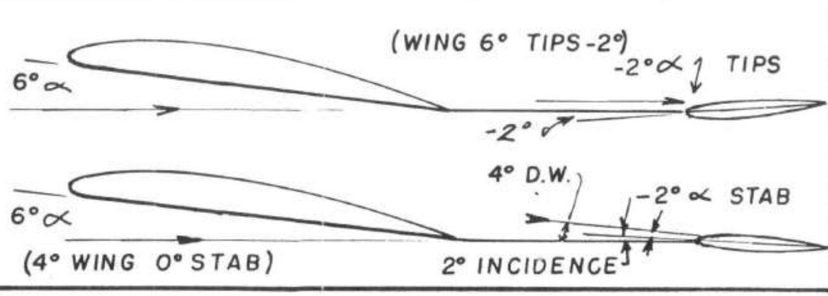
If you take a second look at the Glide Trim graph and chart, you will note almost indentical wing force moment values of 58-60 for every angle of attack. The reason is that as C1 decreases, the M.A. increases just in the right ratio to keep the values similar. In practice, this means that the tip moment force must be similar for all angles of the wing. For example, the tips must be at −2.3° to generate a moment force value of 60 units with which to balance the wing, and it must be −2.3°, regardless of where the wing may be. If we reduce the wing's angle of attack from 6° to 1°, the tips must still have −2.3° when the wing reaches 1°.





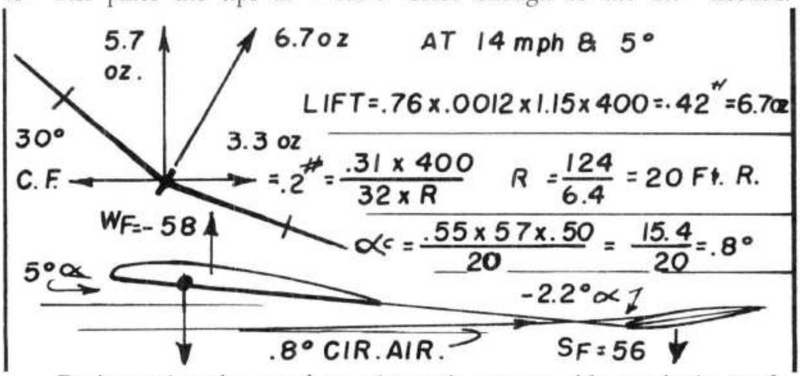




| WING (NEG. PITCH) | | | | | | TIPS (POS. PITCH) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $W\alpha$ | C.P. | $C_L$ × | $W_M$ × | $W_A$ = | $W_F$ | $T\alpha$ | $TC_L$ × | $T_A$ × | $T_M$ = | $T_F$ |
| 1° | 40% | .47 | -.78 | 165 | -60 | -7° | .525 | 50 | 6.75 | 175 |
| 2° | 38% | .54 | -.65 | 165 | -58 | -6° | .450 | 50 | 6.75 | 150 |
| 3° | 36% | .62 | -.57 | 165 | -58 | -5° | .375 | 50 | 6.75 | 125 |
| 4° | 35% | .70 | -.52 | 165 | -60 | -4° | .300 | 50 | 6.75 | 100 |
| 5° | 34% | .76 | -.46 | 165 | -58 | -3° | .225 | 50 | 6.75 | 76 |
| 6° | 33% | .82 | -.41 | 165 | -55 | -2° | .150 | 50 | 6.75 | 51 |
| 7° | 32% | .88 | -.36 | 165 | -53 | -1° | .075 | 50 | 6.75 | 25 |
| 8° | 31% | .95 | -.30 | 165 | -46 | 0 | — | — | — | — |

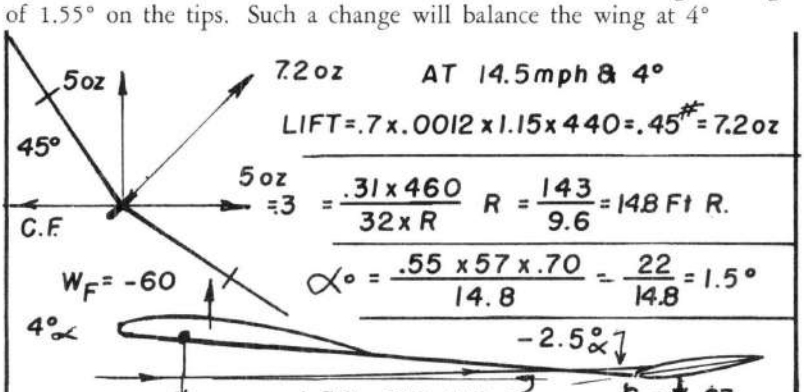


But, the physical tip angle changes automatically when the wing's angle of attack changes. When the wing is at 6° angle of attack, the tips are physically and aerodynamically at −2° as shown on the Glide Trim Chart. And when the wing's angle of attack is changed to 1°, for one reason or other, the tips are physically and aerodynamically changed to −7°. At −7°, the tips have 175 Force Units and would tend to bring the wing into higher angles than 1° because only 60 Force Units are needed to keep the wing balanced at 1°. 60 Tip Force Units are obtained when the tips have −2.3° angle of attack. Obviously, there is a surplus of −4.7°. This surplus cannot be reduced by twisting the wing tips to lower angles as we would thereby upset the basic 6° Glide Trim. Here, again, we have to depend on the Circular Airflow to bring about the needed angular changes without physical changes.

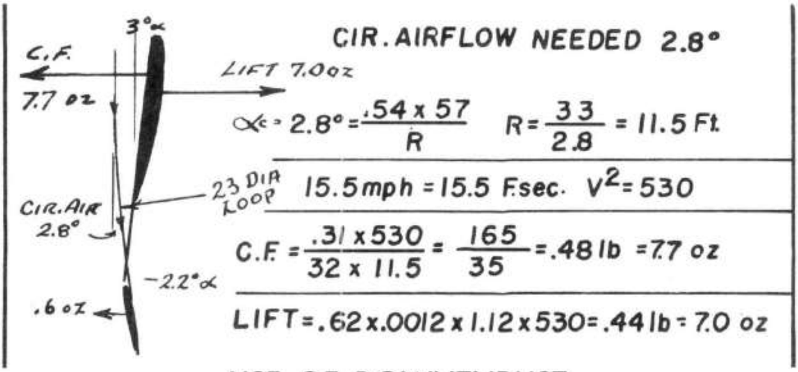
By placing the wing into a 30° bank and a 40 ft. circle, a fair compromise is reached. Note that at 5° and 14 mph the wing generates 6.7 ozs. lift. At 30°, this breaks up into 5.7 ozs. of vertical lift and 3.3 ozs. of side force. The Centrifugal Force is satisfied with 3.3 ozs. in a 40 ft. circle and 14 mph. While the Circular Airflow change of .8° will place the tips at −2.2°. Close enough to the 2.7° needed.




By increasing the speed to 14.5 mph, we are able to obtain 30 ft. circles with wing banked 45°. At this speed and circle, the C.F. will be satisfied with 5 ozs. side force, and Circular Airflow will bring a change of 1.55° on the tips. Such a change will balance the wing at 4°



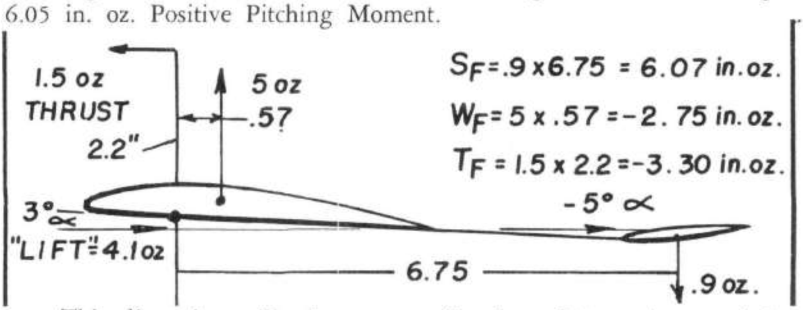
This is about as far as we can go in obtaining balance with the aid of Circular Airflow. Any effort to decrease the size of the circle bumps against the C.F. limitation and loss of vertical lift, when wing is banked beyond 45° to obtain enough side force for C.F. control. In fact, it is not even possible to obtain a balanced loop for the 3° angle. In a 23 ft. diameter loop, the wing would have a 3° angle of attack, but not enough lift to balance C.F.




## USE OF DOWNTHRUST

Downthrust comes in two packages. You can mount the engine in front with a negative tilt, or mount it on a pylon so that its thrust will be over C.G. You already know how a tilted engine can reduce the forward thrust and lower the wing lift by direct subtraction. We will now check the high thrust.

How high should we place the 1.5 oz. thrust engine over the C.G. to balance the extra moment force of the tips while the wing is at 3°? The chart shows that at 3° the wing has 58 moment force units and the tips have 125. (The tips are 2.2 times stronger than the wing.) Assuming that the wing lifts 5 ozs. on a .57 in. moment arm, we can see that its moment force in units is 2.75 in. oz. It follows that tips have 2.2 as much, or 6.05 in. oz. Thus the tips have 3.3 in. oz. more moment force than the wing. To balance this with the 1.5 oz. thrust engine, we place it 2.2 in. over the C.G. Now we have a negative Pitching Moment of the wing's 2.75 in. oz., and 3.3 in. oz. of the engine to balance the tips' 6.05 in. oz. Positive Pitching Moment.

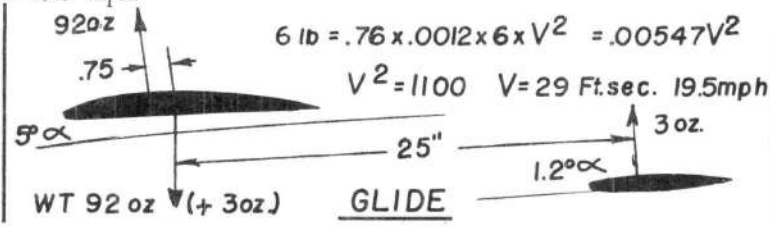



This discussion will give you an idea how flying wings, and for that matter, any short coupled designs, can be balanced.

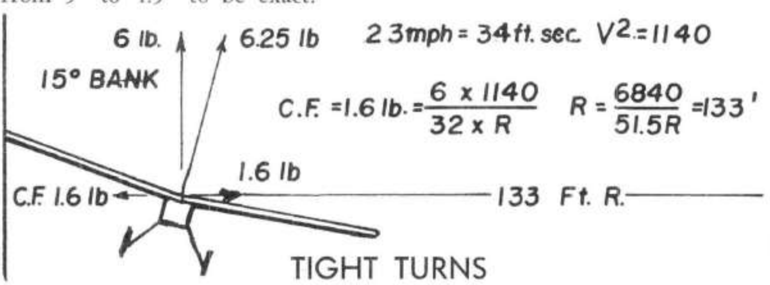
## R/C MODELS AND CIRCULAR AIRFLOW

With multi-channels, the effect of the Circular Airflow angular change is academic. The flyer automatically adjusts for such changes. Since the loops are more than generous when compared with control line, the angular change on the fixed stabilizer does not have to be considered. However, for the rudder-only models, the Circular Airflow should be considered.

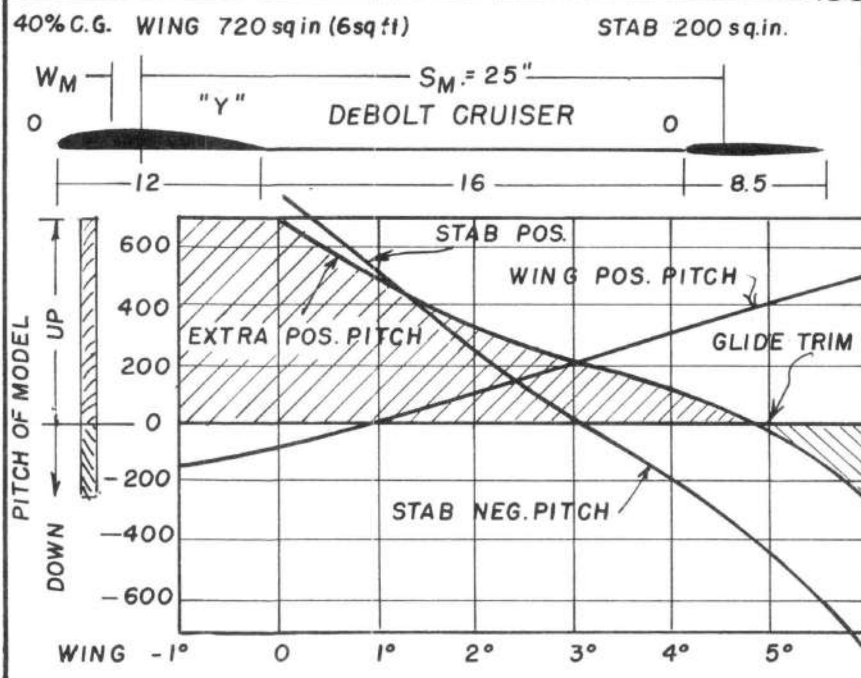
For our example, we will use DeBolt's CRUISER. Its layout is shown diagrammatically. We assumed its Glide Trim at 5° angle of attack. At this angle and 6 lbs. weight, the calculated glide speed is 19.5 mph.



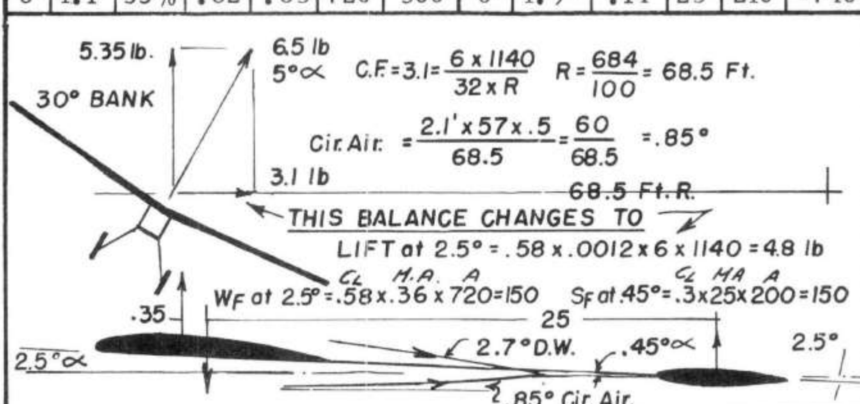

With enough power to increase speed to 23 mph, we obtain 6.25 lbs. of lift which would indicate a normal climb. This extra lift is also enough to keep the model in a level circling flight when wing is banked 15°. At this attitude there is a side component of 1.6 lbs. which is high enough to satisfy the Centrifugal Force generated in a 266 ft. circle. In this size circle and with the wing banked 15°, the Circular Airflow angular change has increased the angle of attack of the fixed stab by .2°. This change will tend to nose down the model slightly, from 5° to 4.9° to be exact.



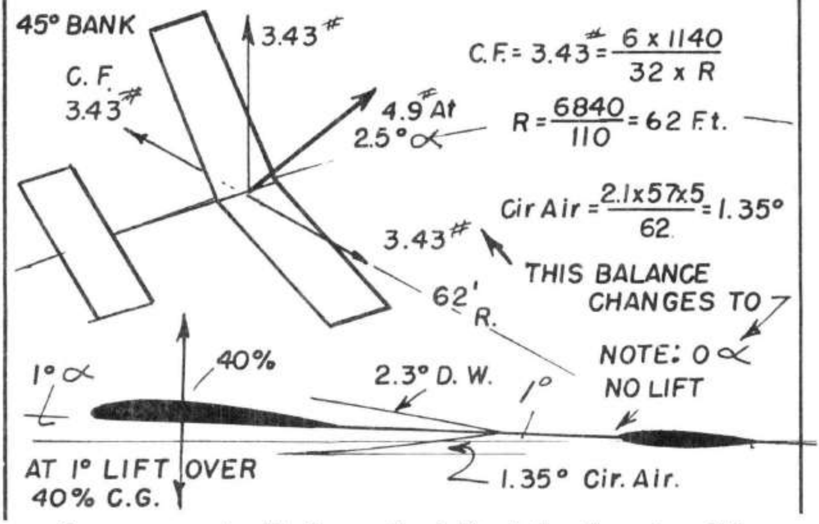

If the model is kept in this circle, there will be no problems. But if the turn is tightened to a 30° bank, the conditions change to those shown on the diagram. Note that we still have a fair vertical lift of 5.35 lbs. and a side force of 3.1 lbs. This side force allows the model to assume a 137 ft. circle in which it balances the C.F. The change for the worse is in the increase of the Circular Airflow angle to .85°. This is like saying that we increase the stab's incidence by .85° By doing so, the wing is forced to fly at a 2.5° angle of attack, at which the lift drops to 4.9 lbs. We are, of course, assuming that the speed is still 23 mph which really is not true to fact. With reduction of the angle of attack, drag is reduced and the same power will cause higher speeds which will cause higher lift and so on. But for sake of illustration, it is better to leave the speed at 23 mph.




| WING (POS. PITCH) | | | | | | | STAB(NEG.PITCH) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W∝ | D.W. | C.P. | $C_L$ x $W_M$ x $W_A$ = $W_F$ | | | | S∠ | S∝ | $SC_L$ x $S_M$ x $S_A$ = $S_F$ | | | |
| -1° | 1.6° | 45% | .33 | -.6 | 720 | -142 | -1° | -2.6° | -.19 | 25 | 210 | 1000 |
| 0 | 2.0° | 42% | .40 | -.25 | 720 | -72 | -0° | -2.0° | -.15 | 25 | 210 | 787 |
| 1° | 2.3° | 40% | .47 | 0 | 720 | 0 | 1° | -1.3° | -.10 | 25 | 210 | 528 |
| 2° | 2.7° | 38% | .54 | .25 | 720 | 97 | 2° | -.7° | -.05 | 25 | 210 | 264 |
| 3° | 3.1° | 36% | .62 | .47 | 720 | 210 | 3° | -.1° | 0 | — | — | — |
| 4° | 3.5° | 35% | .70 | .60 | 720 | 300 | 4° | .5° | .035 | 25 | 210 | -185 |
| 5° | 3.8° | 34% | .76 | .75 | 720 | 416 | 5° | 1.2° | .08 | 25 | 210 | -420 |
| 6° | 4.1° | 33% | .82 | .85 | 720 | 500 | 6° | 1.9° | .14 | 25 | 210 | -740 |

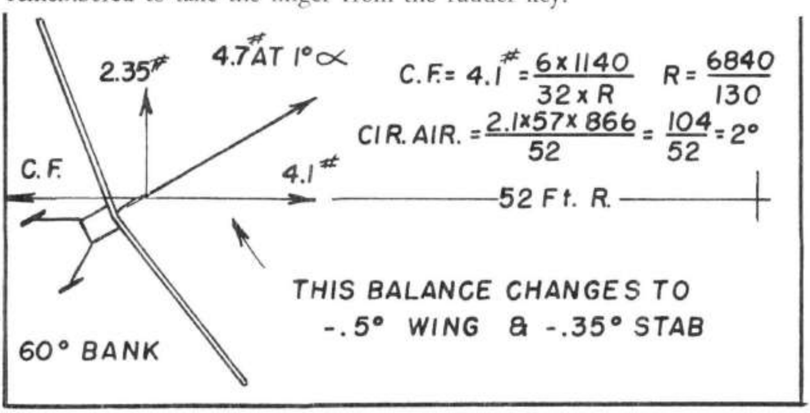


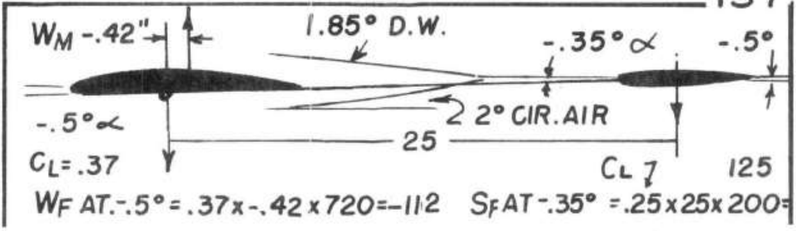
To obtain a tighter turn, we increase the bank to 45°, and we find that the resulting side lift component will balance the C.F. at 62 ft. The new Circular Airflow angle will be 1.35°. Diagramming this value, we find that the wing will be brought down to 1° angle of attack, where the lift now is 4.7 lbs.



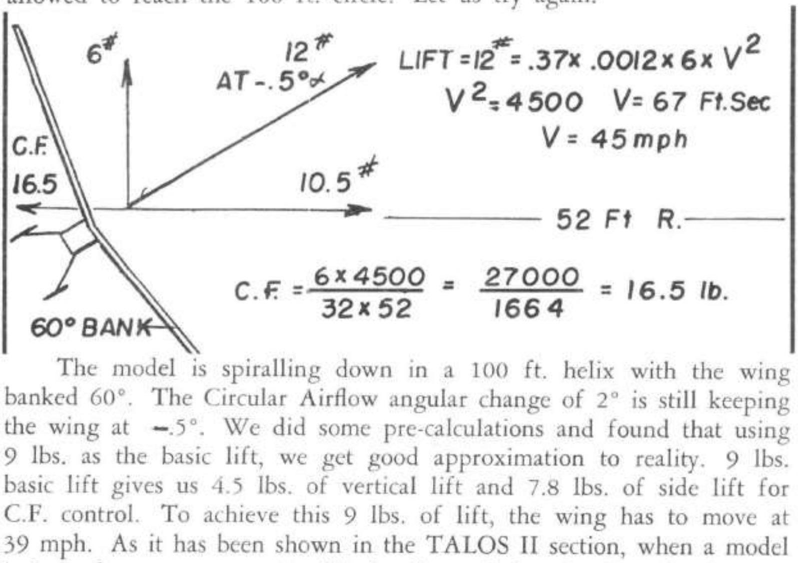

By now, you should discern the drift of the discussion. We are following the model as it gets into steeper and steeper bank, caused by holding the rudder full without easing it by blipping.

Forcing the model into a 60° turn, and still assuming 23 mph, we find that we have 4.1 lbs. for C.F. balance. This will be satisfied at 52 ft. radius. Following through for Circular Airflow angular change, we find it to be 2°. With this change in the aerodynamical airflow, we find the wing moved to $-.5°$ angle of attack. Here we begin to lose lift rapidly. At $-.5°$ the basic lift is only 3.5 lbs. of which 1.75 lbs. is used for vertical sustenance. This is as good a place as any to stop, as by now the model is very likely digging a hole or someone remembered to take the finger from the rudder key.

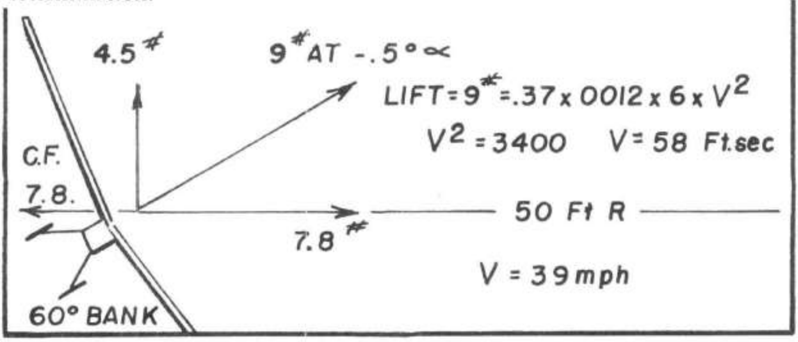





In reality, the situation may not be as bad as pictured. Let us try again by assuming a 60° bank, 100 ft. circle and −.5° angle of attack for the wing. This is geometry. To start being realistic: At what speed will the wing lift, at −.5°, enough to hold the model in a level flight? If vertical lift need is 6 lbs., then at 60° bank, the basic lift should be 12 lbs. Using the Lift Formula, we find that the new flying speed is 45 mph. and the C.F. is 16.5 lbs., for which we only have 10.5 lbs. of counter force. It is evident that at such speeds, the model is never allowed to reach the 100 ft. circle. Let us try again.




The model is spiralling down in a 100 ft. helix with the wing banked 60°. The Circular Airflow angular change of 2° is still keeping the wing at −.5°. We did some pre-calculations and found that using 9 lbs. as the basic lift, we get good approximation to reality. 9 lbs. basic lift gives us 4.5 lbs. of vertical lift and 7.8 lbs. of side lift for C.F. control. To achieve this 9 lbs. of lift, the wing has to move at 39 mph. As it has been shown in the TALOS II section, when a model is in a descent, we use the "shadow" speed for the Centrifugal Force determination.

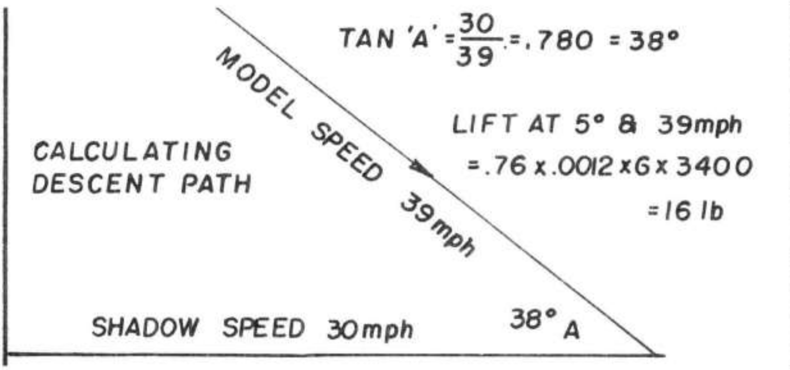


AT WHAT SPEED WILL C.F. BE 7.8 lb WHEN R.=50'

$$7.8 = \frac{6 \times V^2}{32 \times 50} \qquad 12480 = 6\,V^2 \qquad 2080 = V^2$$

$$V = 45 \text{ Ft. Sec} = 30\text{mph}$$

Again, by doing a bit of pre-calculating we found that if the model makes a descent in a 38° helical path, the C.F. will be satisfied.



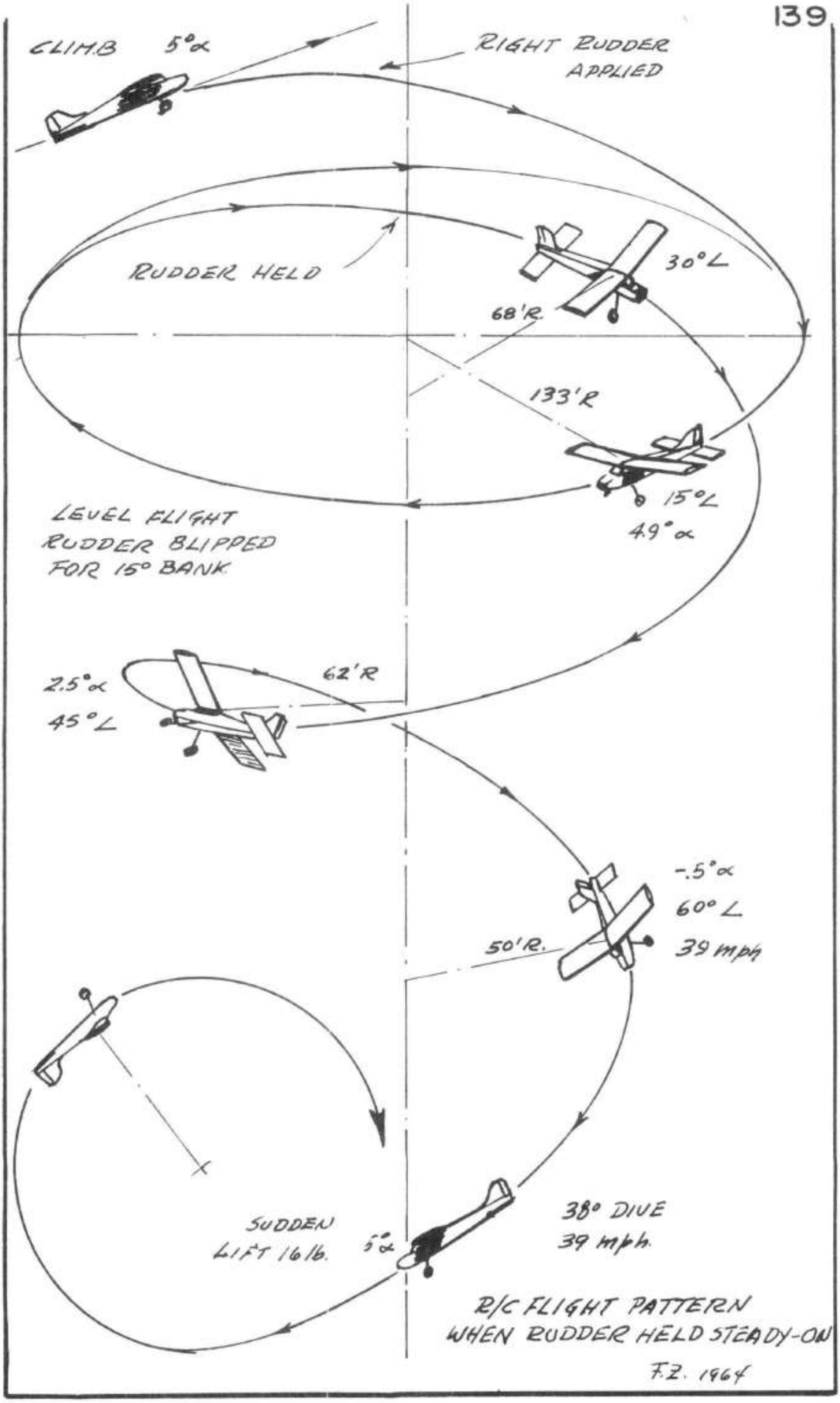

## LOOPING WITH RUDDER

We have now achieved a balanced condition in which all forces are satisfied or balanced. It is too bad that the model has to be diving down at 39 mph to achieve such a balance. But, on the other hand, this is a necessary characteristic for rudder-only R/C models. Just think, you now have a model moving at 39 mph in spiral descent which is controlled by the rudder. Now, by sudden removal of rudder pressure, a good design should straighten its flight path. While doing so, the wing automatically has its angle of attack increased. So, with speed at 39 mph and with the wing suddenly swung into a 5° angle of attack, how much lift will the wing generate for a short moment? 16 lbs., according to the Lift Formula. With 16 lbs. lift, you should have no trouble making a 6 lbs. model loop.

The rudder-only R/C model can be made less prone to spiral dives when full rudder is kept on, instead of being blipped, by moving the C.G. close to the 33% spot, and with corresponding angular repositioning for the stab. For example: When the Glide Trim is at 5° the downwash on the stab will be 3.8°. Therefore, the stab should be so fixed to the fuselage that it will have a 1.2° less incidence than the wing.

When we had a 2° Circular Airflow change in the 40% C.G. model (60° Bank and 51 ft. helical descent), the wing shifted to −.5°. What will the shift be with the 33% C.G.? Roughly, the wing will shift to 3°. Using **23** mph speed, the wing would supply 2.6 lbs. of vertical lift in contrast to the 40% wing where the lift was 1.75 lbs.

Another method for obtaining smaller circles without instant spiral dive, is to shorten the moment arm. Check the Circular Airflow formula for this. By combining shorter moment arm with C.G. at 33%, it is possible to obtain safe small diameter circles. However, you lose the choice of making maneuvers with rudder-only control.


CLIMB 5°α
RIGHT RUDDER APPLIED
RUDDER HELD
30°L
68'R.
133'R
15°L
4.9°α
LEVEL FLIGHT RUDDER BLIPPED FOR 15° BANK
2.5°α
45°L
62'R
-.5°α
60°L
39 mph
50'R.
SUDDEN LIFT 16 lb.
5°α
38° DIVE
39 mph.
R/C FLIGHT PATTERN WHEN RUDDER HELD STEADY-ON
F.Z. 1964

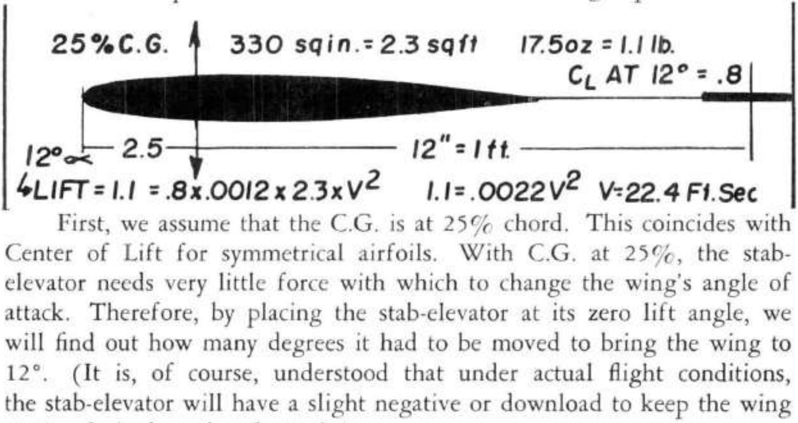
## CONTROL MODELS AND CIRCULAR AIRFLOW

The importance of the Circular Airflow on Control Models cannot be over emphasized. After all, Control Models are in a constant circular motion. Sometimes only in the horizontal plane, but most often in both, horizontal and vertical. We stressed the dependency of Control Models on the Circular Airflow in the 1951/52 Year Book. But it seems that no one took our recommendations seriously until a few years ago.

If you recall, in the 1951/52 Year Book, we brought out the fact that tight circles or loops, so common in combat and acrobatics, bring about Circular Airflow angles in which the fixed portion of the stabilizer works in opposition to the movable elevator. So, it is with pleasure that we see combat models using completely movable stabilizers.

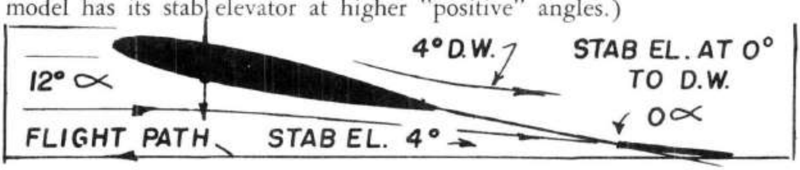
## COMBAT CONTROL DESIGN

The place of Circular Airflow in the Control Model field can be best illustrated with a combat design which uses a movable stabilizer for control. Let us start by making a few basic calculations. Using the model shown in the diagram, we find that its lowest level flight speed is 15 mph (In this case we use 12° angle of attack, which is close to stall.) Let us find the position of the stab elevator in this flight path.

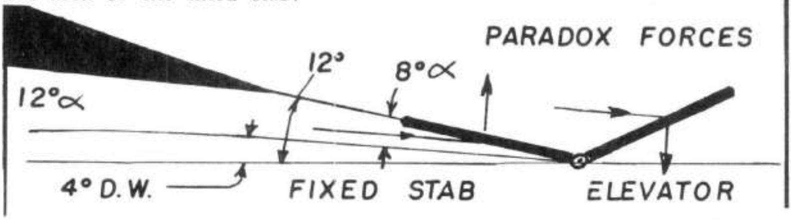



First, we assume that the C.G. is at 25% chord. This coincides with Center of Lift for symmetrical airfoils. With C.G. at 25%, the stab-elevator needs very little force with which to change the wing's angle of attack. Therefore, by placing the stab-elevator at its zero lift angle, we will find out how many degrees it had to be moved to bring the wing to 12°. (It is, of course, understood that under actual flight conditions, the stab-elevator will have a slight negative or download to keep the wing at the desired angle of attack.)

With the wing at 12°, what will determine the position of the stab-elevator? Answer: The downwash of the wing. At 12°, the downwash for the symmetrical airfoil is 4°, and by placing the stab-elevator at 4° to "base" line, the condition for stab-elevator 0° angle of attack will be satisfied. (Actually, with the stab-elevator so close to the wing, the downwash will be greater than that given by our factor of 5. We are mentioning this fact, should you find that your combat model has its stab elevator at higher "positive" angles.)

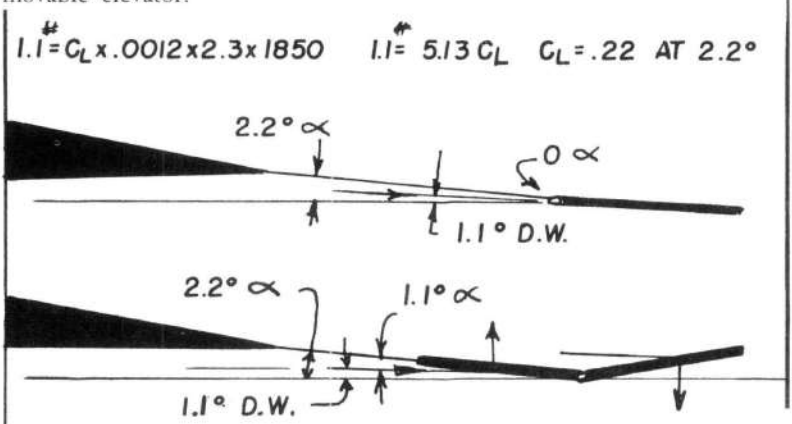


For comparison, let us see what would happen, had we used a fixed stab and movable elevator. Obviously, the stab will be at 12° to the flight path, but with 4° downwash, its angle of attack will be 8° This is a positive angle of attack which tends to dive the model. To counteract this diving force, the elevator must generate extra high force with a lot of "up" control. The amount of "up" control will depend on the area of the fixed stab.




From this illustration, you can see why it is necessary to have a greater elevator area, than is needed to control the wing alone, when a fixed stab is used. At the same time, you can also see that under such conditions, you are bulldozing a regular drag factory around the circle.

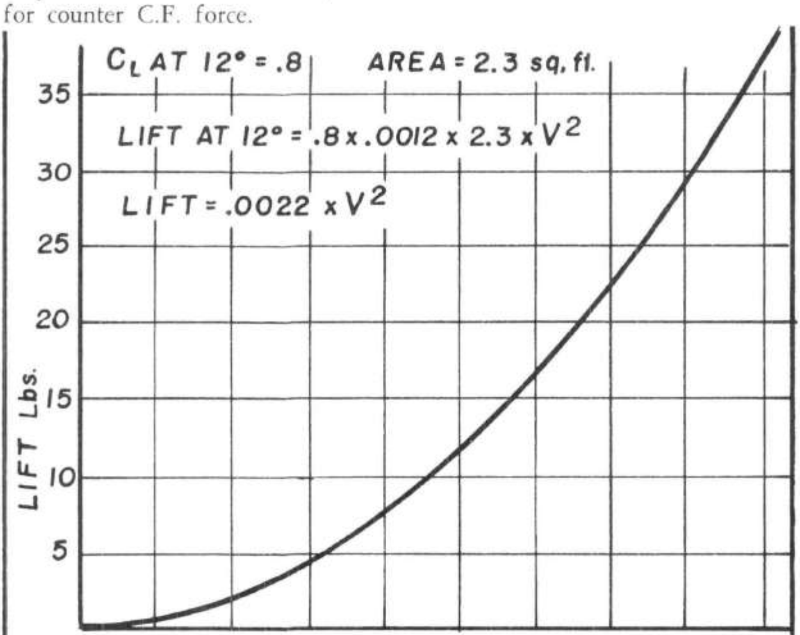
It is true that Control Models very seldom speed around at 15 mph. Let us see what happens at 30 mph. At such speed, the wing needs only 2.2° angle of attack to lift 17.5 ozs. Placing this in a level flight, we find that the stab-elevator has to be raised 1.1° to make up for the 1.1° downwash. While with the fixed stabilizer and movable elevator combination, the stab still has a diving force which is generated by its .9° angle of attack, and the elevator needs an extra "down" load to balance the stab. It should be obvious by now that no matter in what attitude we place the model, the fixed stab will work against the movable elevator.




This fixed stab problem is not limited to a straight flight path. It becomes even more severe when the model is stunting and/or looping. But before we go into this, let us check the model at different speeds and their effect on the minimum possible size loop diameters.

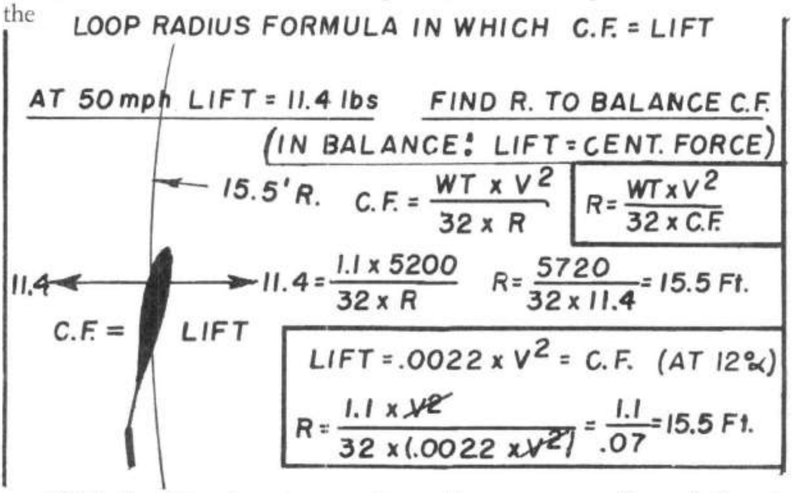
The 12% symmetrical airfoil has its highest lift at 12° before it goes into stalling condition. Mind you, the airfoil may lift the same at angles beyond 12° as it does at 12°, but you pay with excess power. Also, as you will note, since higher angles than 12° do not contribute more lift, the diameter of the loop will not decrease. You might say that a certain point no amount of "up" elevator will tighten the loop. The model may actually slow down and become sluggish. It should also be mentioned that the main reason for using high angles to obtain tight loops is to develop high lift with which to counteract the Centrifugal Force.

We made a series of lift calculations for a 330 sq. in. wing at different speeds. The results were graphed. For example, at 50 mph, the model can lift 11.4 lbs. Since the model only weighs 1.1 lbs. the remaining 10.3 lbs. are used for C.F. control. Knowing the weight of the model and its excess lift, we can calculate the minimum diameter loop. For ease of calculation, we will use the entire lift of the model for counter C.F. force.

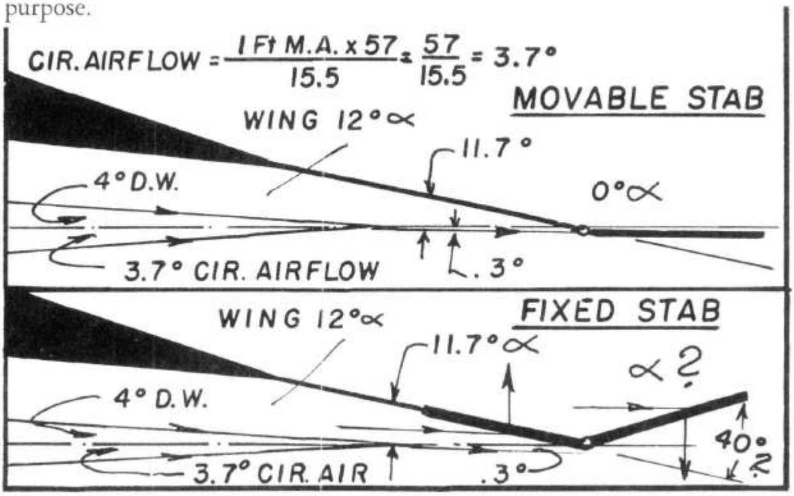



| mph | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
|---|---|---|---|---|---|---|---|---|---|
| LIFT Lbs | .46 | 2.0 | 4.2 | 7.4 | 11.4 | 16.5 | 22.4 | 29 | 37 |
| $V^2$ | 210 | 890 | 1900 | 3350 | 5200 | 7500 | 10200 | 13100 | 17000 |

At 50 mph the loop radius is found by the C.F. formula. The answer is 15.5 ft. radius or 31 ft. diameter. Making more calculations, we arrived at an unexpected situation. No matter how much faster the model flew, this particular design made identical loops. From this revelation, you should realize that extra power will only enable you tc execute identical maneuvers at higher speeds. The geometry will not change. (Reason for identical loops, regardless of speed, is found in the




With the loop diameter remaining the same, regardless of the air speed, we can inspect the Circular Airflow angular change on this particular loop of 31 ft. Using the Circular Airflow formula with a 12 in. moment arm, we have an angular change of 3.7°. Placing this value in the airflow diagram, we find that the stab-elevator is at .3° to base line. With the wing at 12°, we have a physical difference of 11.7° between wing and stab elevator. But in the case of fixed stab and movable elevator, we have a different story. The fixed stabilizer has a resultant airflow of 11.7° with which to generate diving lift. We arrived at the 11.7° by assuming a physical relationship of 12° to base, and adding the difference between downwash and angular change. With fixed stab at 11.7°, you can imagine how hard the movable elevator has to work just to balance this inherent load which serves no genuine purpose.



This particular problem of having a fixed stab in a highly manueverable model is compounded by any increase of the moment arm. We used only 12 in. in our example. An 18 in. moment arm would produce an angular change of 5.5°. In this case, the fixed stab would have an angle of attack of 13.5°, while the stab elevator would need an additional "up" of 1.8°. There is no reason to go through more examples. You can judge for yourself what you want to do.

The need for some fixed stabilizer is often dictated by the function of the model. On any model that needs help to keep it on a level flight, a fixed stab is fine. In speed models, with C.G. ahead of 25% point, the wing tends to dive the model. Here a fixed stab would help take the load off the handle, while the slight "up" needed on the elevator to control the wing, will give the flyer the needed feel of the flight. In fact, wherever the maneuvers are of large dimensions, some fixed stabilizer area is desirable.

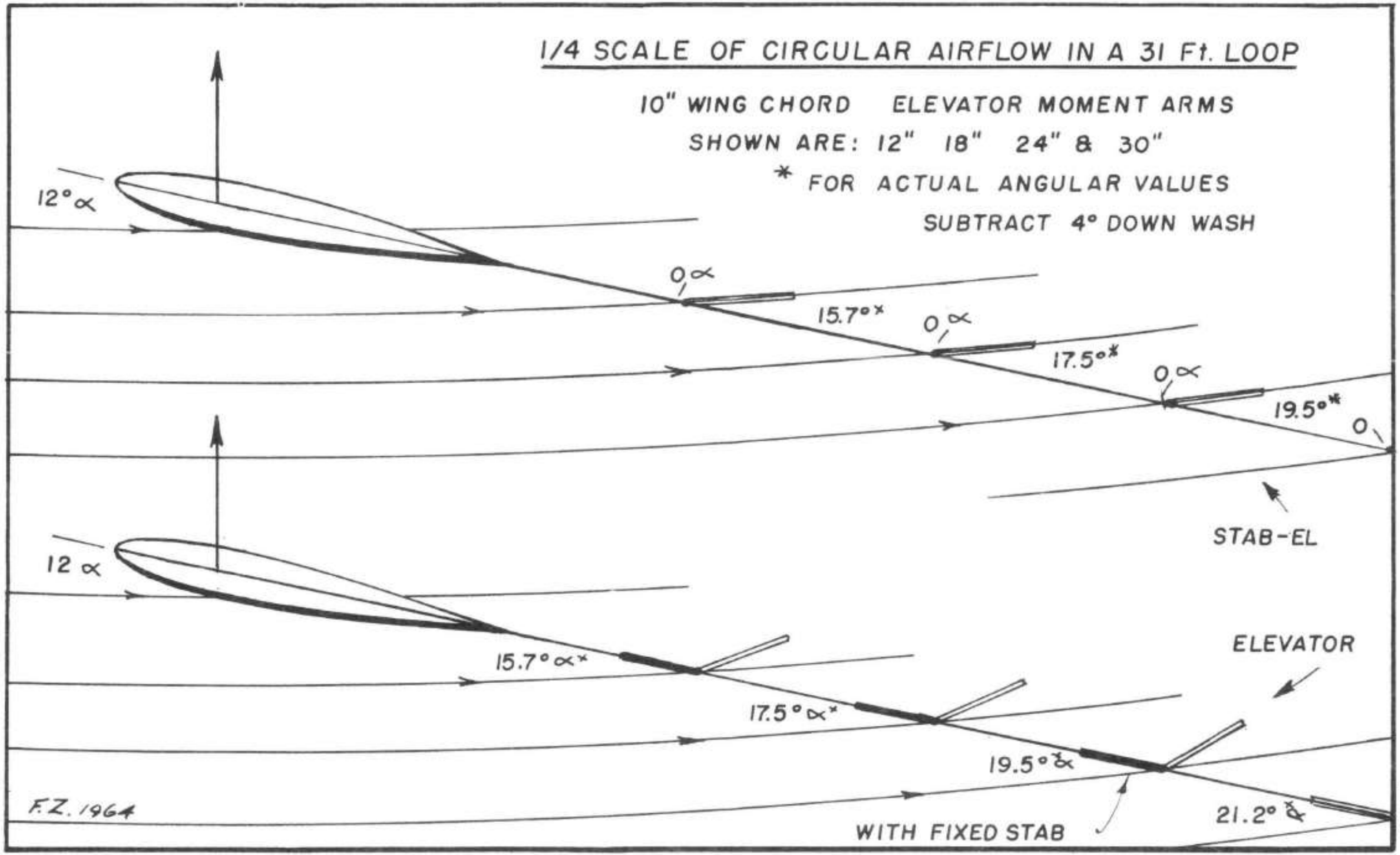
When flying with stab-elevator, the control will be much more sensitive. The amount of stab-elevator movement will be relatively small in comparison with regular fixed stab models. The stab-elevator movements in angular value are almost identical to those on the wing, with the only variable being the downwash. Note how the stab-elevator is very close to the base line at all times. The maximum change we have noted for the 31 diameter loop is 11.7°. This is quite in contrast with the fixed stab model for which the plans often call for 40° up and down elevator movement.

## WING FLAPS

We also mentioned in the 1951/52 Year Book, that if wing flaps are used, the wing will produce similar lift at lower angles of attack when compared with a wing without flaps. This means that the fixed stab will also have lower angle of attack for diving. So, if fixed stab is needed, flaps should be considered. It should also be obvious that if you have power to spare, flaps will give a much tighter loop, as such a wing is capable of developing almost twice as much lift as one without flaps. Airfoil report books show that the maximum lift is obtained at 8° angle of attack for wings on which the flaps are depressed 30°.


This extreme control model design, the combat ship, demonstrates that Circular Airflow plays a most important part in the control model aircraft design and flight.

NOTE: This coverage of the control models is purely analytical. We have no practical experience in this field with which to hedge our observations. So, if there is a grain of fact in this, we may have a very good base for mathematical designing.


1/4 SCALE OF CIRCULAR AIRFLOW IN A 31 Ft. LOOP
10" WING CHORD ELEVATOR MOMENT ARMS
SHOWN ARE: 12" 18" 24" & 30"
* FOR ACTUAL ANGULAR VALUES
SUBTRACT 4° DOWN WASH
12° α
0 α
15.7°*
0 α
17.5°*
0 α
19.5°*
0
STAB-EL
12 α
15.7° α*
17.5° α*
19.5° α
21.2° α
ELEVATOR
WITH FIXED STAB
F.Z. 1964

## TILTED STAB FOR TURN CONTROL

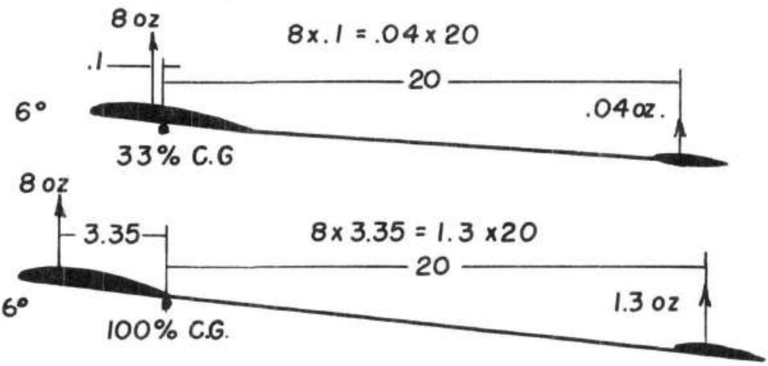
The basic purpose for tilting the stab is to provide a turning tendency during the glide only. Increase of speed should have no effect on it. It is, or should be, an automatic turn adjustment which will vary in our favor with change in speed.

As we have seen in the 1951 book, to retain longitudinal balance about the C.G., both surfaces, wing and stab, must have similar moment forces about the C.G. In the glide, this occurs when the wing has an angle of attack of about 6°. Under high-power conditions, this balance may occur when the wing has a negative angle of attack.

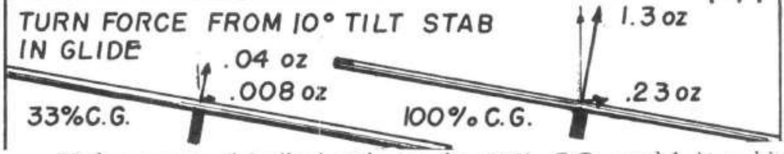
Effectiveness of the tilted stab depends on the force value of the side component of the normal lift when the stab is angled. Therefore, and this is the basic fact about tilted stabs, if the normal lift is large, the side or turn-inducing component is large. But if the normal lift is low, the turn-inducing component is also low.

As we have shown, the lift of the stabilizer depends on the C.G. location. With C.G. at 33% the need for stabilizer's lift is minimal. But with C.G. at 100%, the stab carries quite a load which is shown in form of lift. Therefore, the tilted stab will have practically no turn force with C.G. at 33%, but it will have maximum effect with C.G. at 100%.

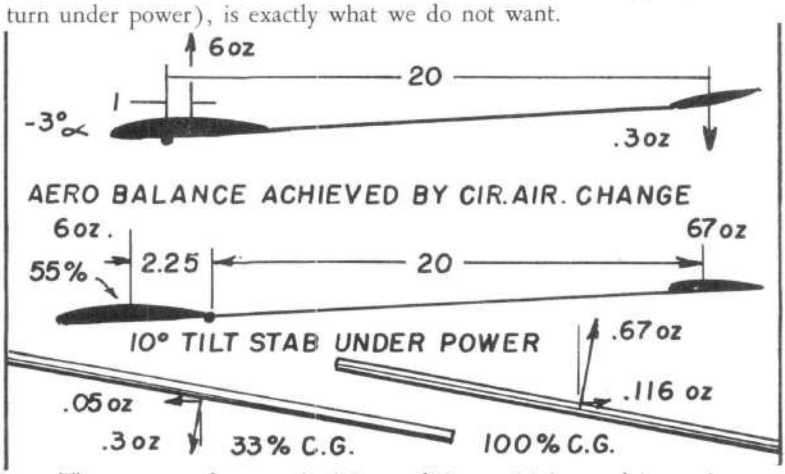
Let us check the 33%, C.G. model. When balanced, the stab has no moment force about C.G., so that its lift can be zero. But to prove a point, assume that Center of Lift is moved 1/10 in. ahead of the 33% spot. On a 1/10 in. moment arm, a wing lift of 8 ozs. will have a force of .8 in. oz. To balance this we need only .04 ozs. of lift from the stab when it is on a 20 in. moment arm. Just how much side component can you expect from .04 oz. of normal lift?




On a 100% C.G. the wing would have a moment force of 26.8 in. oz. if the chord was 5 in. To balance this on a 20 in. moment arm, the stab would have to lift 1.3 oz. Now, a stab that has 1.3 oz. of normal lift will have a side component of .23 oz. when tilted 10°. Note the small loss of vertical lift, only .02 oz. With .23 oz. at the end of a 20 in. moment arm, the tilted stab should have no trouble forcing the model into a turn.




Under power, the tilted stab on the 33% C.G. model is a bit complicated. You will note that at high speeds, the wing operates at negative angles and that its center of Lift moves toward the trailing edge. To balance the wing under such conditions, the stabilizer needs "down" load, and such loads have greater values than those needed in the glide. Of special interest to us at this moment is the resolution of forces on the tilted stab. The basic lift is down, and its side component would favor a left turn. This situation (no side force in glide, but left turn under power), is exactly what we do not want.




The situation for 100% C.G. condition at high speed is much more favorable for the tilted stab. At high speeds, the wing actually contributes less lift than it does in a glide, say 25% less. Our example wing now has only 6 ozs. of lift. By being in a negative angle of attack attitude, the Center of Lift moves towards the trailing edge, thus requiring less correcting force from the stabilizer. Specifically, the wing has a 2.25 in. moment arm which gives it a 13.4 in. oz. force. With stab 20 in. away, the stab only needs a lift of .67 oz. for balance. When .67 oz. is resolved into a side component in a 10° stab tilt, we only have .115 ozs. Can you see the contrast? Although the model is flying much faster than it did in the glide, the tilted stab turn control is less powerful than it is in the glide. And it is also in the direction we want.

The turning force developed by rudder or wing washin will increase as the square of the speed. This means that if the rudder has 1 oz. force at 10 mph., it will have 4 ozs. at 20 mph. And doubling of glide speeds for high powered models is not unusual.

For C.G. locations between the two extremes, 33% and 100%, the turning effect of the tilted stab will naturally be determined by the exact location of the model's C.G. Close to 33%, less effect, and turn effect increasing as C.G. moves towards 100%.

# TORQUE CONTROL & ROTATING MODELS

Some of the power models published in the Year Books have a 0-0 thrust, flat stab, no rudder deflection notation and washin on right wing. Yet the flight pattern is right-right. It could be that the flyer used unmentioned fine adjustments to obtain a right climb in which the left wing gets the needed torque control force. Still, we wondered if it is possible to obtain right climb without fine and petty adjustments just by the way the model behaves at very high climb attitude.

To begin, a good "15" has 25 in. oz. torque at its peak. This means that one ounce of lift on the left side on a 50 in. wing span will balance it. It is easy to see that a relatively small increase of angle of attack on the left wing would control it. Right thrust, right rudder, and/or tilted stab would bring the left wing into side slip in which the required extra angle of attack is obtained. But how will we understand a right climb when no such adjustments are mentioned, and in their place we note instructions to have WASHIN on the RIGHT wing? Perhaps the right washin may have something to it.

To start, assume a straight vertical flight. What effect will the torque have on the wing? Reason tells us that it will tend to rotate to the left, just like a rubber model does when we hold its prop. The model is now enjoying a vertical flight in which it is also rotating. But we notice that the rotation is much slower than it would be if the model was let to rotate while the prop was held. (Just a figure of speech, thank you.) Something must have been added when the model is climbing.

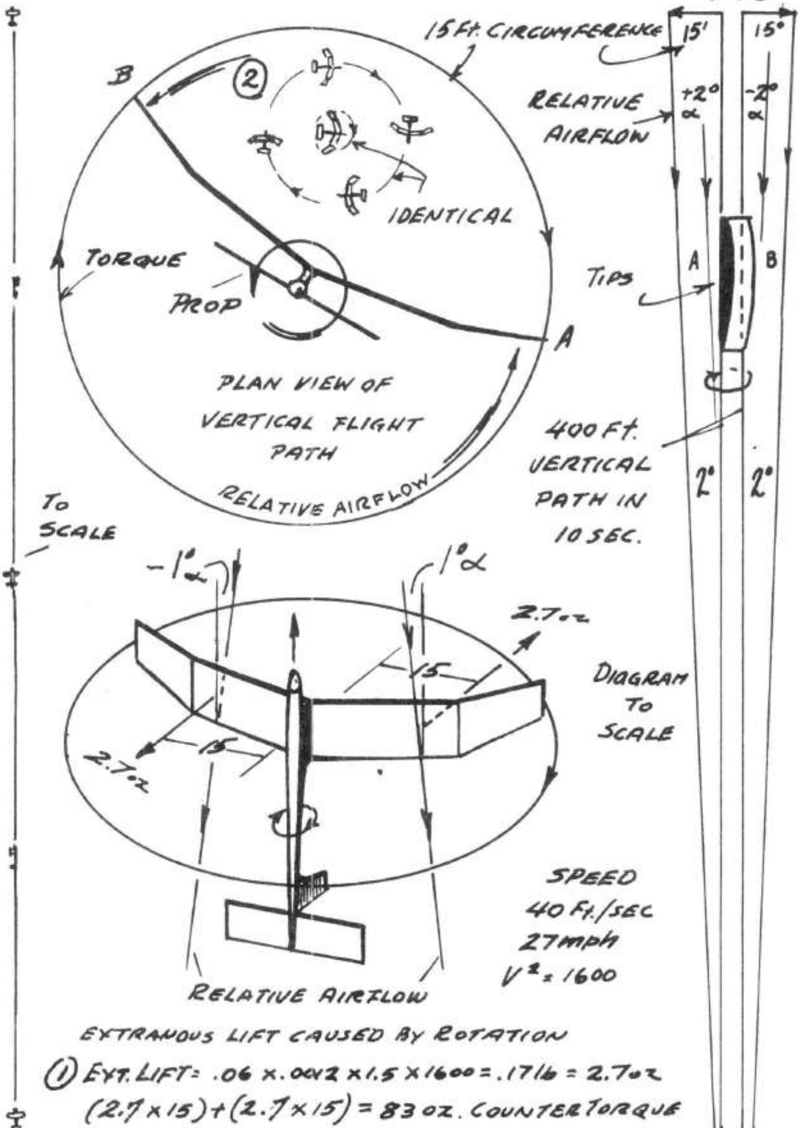
Let us assume our model has a 5 foot span and the the wing makes one countertorque revolution as the model climbs to 400 ft. in ten seconds. In one revolution the wing tips will travel 15 ft. Using the tangent formula, we find that the left wing tip has an increase of 2° of relative airflow, while the right tip has a decrease of 2°; conditions which are favorable for torque control. The next step comes in calculating the values in ounces for such angular changes.

A tip angle of 2° decreases to 0 at the root of a rotating wing. We can, therefore, assume an overall average change of 1° for the entire wing half. Using the 400 ft. climb in 10 sec. we have the air speed for the Lift Formula. (A change of 1° represents a change in $C_L$ value of .06). Using 50% of the 3 sq. ft. wing, we obtain the following results: (1)

We have a "positive" lift increase of 2.7 oz. on the left side and a "negative" decrease of 2.7 oz. on the right side. This produces a couple which has a force of 5.4 oz. on a 15 in. moment arm for a total of 83 in. oz. But the engine only has 25 in. oz. torque, and we have 83 in. oz. available.

Obviously, our one turn rotation was too much for the torque. By back-tracking and using the Lift actually needed for the torque in the Formula, we find that only about 90° rotation of the wing is needed to obtain the required torque control in a vertical climb.

You can see that it is quite a problem to decide where we go from here to obtain a right spiral climb under such circumstances. In practice, the flyers find that without right washin the model tends to right spiral dive.




Without drawing any conclusions at this moment, because we do not know the answers, let us summarize the situation. When a model is climbing vertically, it tends to rotate the wing clockwise, and thus produce airflow vector which flows positive on the left wing and negative on the right. Reaction from this airflow vector counters the torque force.

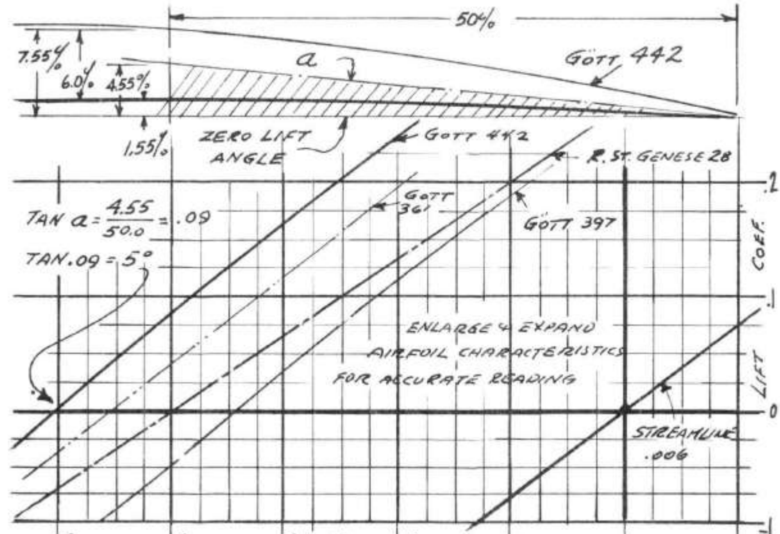
When the model makes one circle, the wing makes one revolution about the fuselage axis. ② The airflow vector varies with the angle of climb. It is maximum in a vertical climb and zero in a horizontal flight.

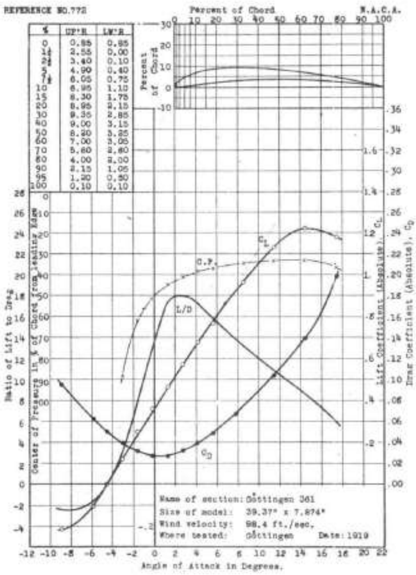
Perhaps someday this observation will fall into its proper perspective, and right spiral climb, with only right washin adjustment, explained.

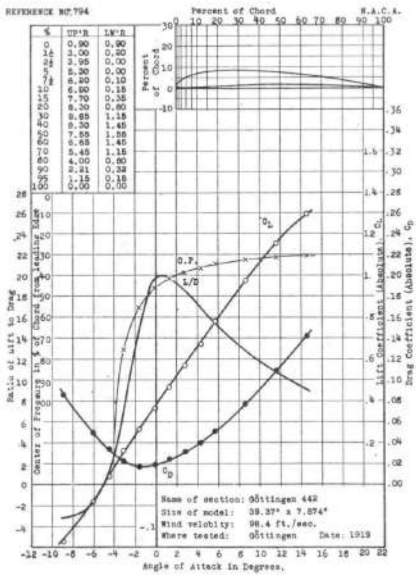
Your best introduction to DESIGN PROCEDURE is to take one of your own designs and run it through the calculations as we did in our examples. You will enjoy doing it, especially after you see that it makes sense. It may take a while before you become familiar with the technique. But in time you will be able to check changes that would occur if you changed C.G., angles, areas, etc.

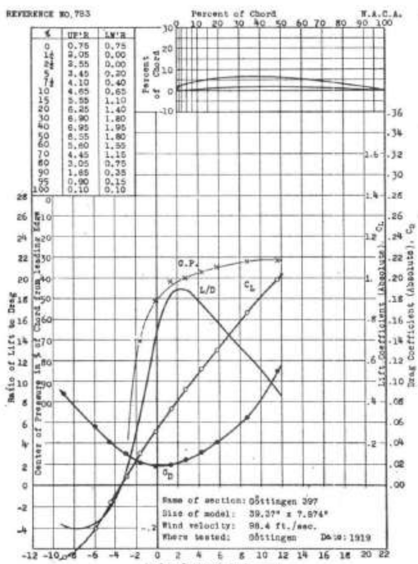
Initially, your major problem will be to determine the exact Lift Coef. of the stab because its angle of attack will be determined by the wing's downwash, and it will be in fractional, and at times, in negative degrees. The solution to this problem is to enlarge the airfoil characteristics chart as shown below. By doing so, it is easy to determine the exact Coef. Do likewise for C.P. travel.

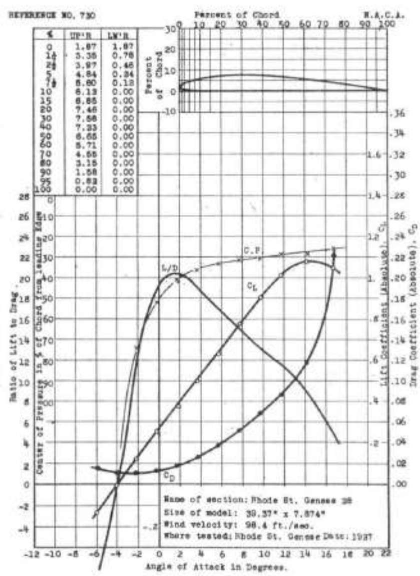
It may be fun to Zip your own, or use other Zips for which there are no characteristic data. But what do you do when you would like to make calculations, as we have, to find more about the model before it is flown? This question would be very easy to answer if the method shown below for finding Zero Lift Angle (ZLA) would work for all airfoils we use. It would be just a matter of calculating the ZLA, and then use Clark Y Lift graph through the ZLA point on the Zip chart. Sad to say, this method seems to work only for airfoils with flat or slightly undercambered bottom surface. For deeply cambered airfoils the ZLA calculations give higher angles than shown on the charts. Calculated ZLA for Gott 381 is $-6.5^{\circ}$. On chart it is $-4.6^{\circ}$. Our suggestion is to match your Zip with a "certified" airfoil which has similar outline. Check its theoretical ZLA with your Zip's. Note how close they match each other. Then, using the "certified" ZLA position as reference, locate ZLA for your Zip, using plus or minus as dictated by their theoretical relationship. Through this ZLA point draw the Lift graph of the "certified" airfoil. --- Use "certified" C.P. travel for your Zip with corrections. Compare airfoils for help in method.






## LIFT FORMULA

LIFT (lbs.) = $C_L \times \rho/2 \times S \times V^2$

$C_L$ = Lift Coef. S = Wing Area (sq.ft.)
$\rho$ = Air Density .00238 (15°C 760mm)
V = Air Speed ( ft. per sec.)

## DOWNWASH

D. W. (in deg.) = Lift Coef. x 5

0.68 x Feet per Sec. = MPH

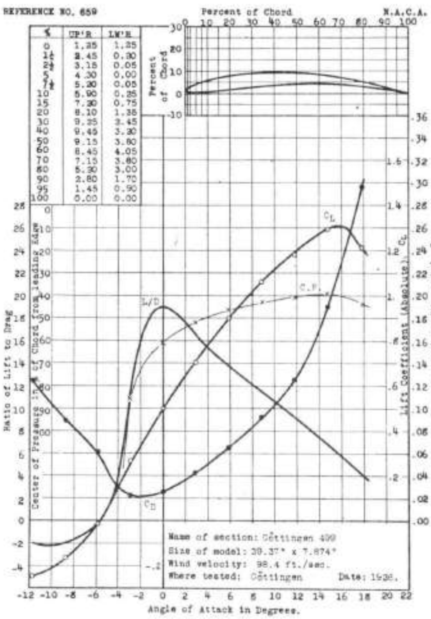
## CENTRIFUGAL FORCE

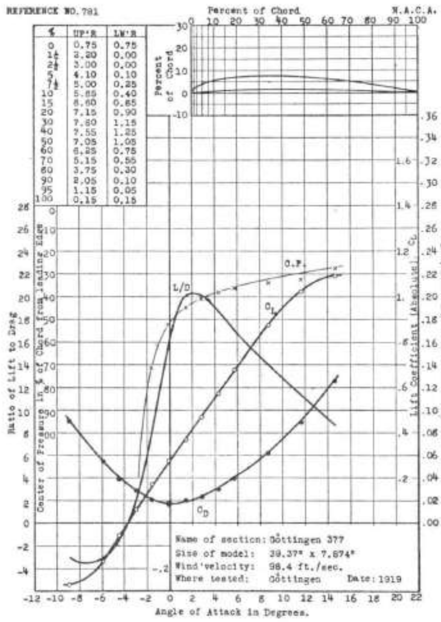
$$\text{C. F. (lb)} = \frac{\text{Wt. of Model (lb.)} \times V^2}{32 \times \text{Radius of Turn (ft.)}}$$

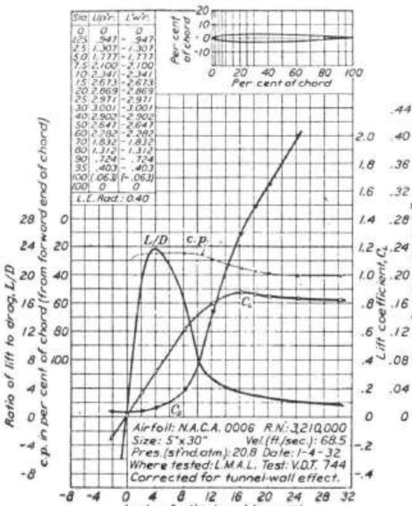
## CIRCULAR AIRFLOW

$$\text{C. A. (°)} = \frac{\text{M. A. (ft.)} \times 57 \times \text{Sin. of Bank}}{\text{Radius of Turn (ft.)}}$$

1.467 x MPH = Feet Per Sec.






Its all yours! Have fun.

## 1987 ADDENDUM

The CIRCULAR AIRFLOW was published in 1964. The application of right wing wash-in was used for flight adjustments, but its relationship to the over-all adjusting was not clearly understood.

While developing the X-18, the function of the right wing wash-in was clearly defined, as was the relationship between the vertical fin area and the side thrust. The "experience" was published in the 1976 NFFS SYMPOSIUM. It was reprinted in the 1976-1977 AEROMODELLER ANNUAL.

The flying instructions for the G-24 Hi-Start glider are included to show one way of adjusting the glider so that it will go thru the launch-glide cycle with built-in configurations.

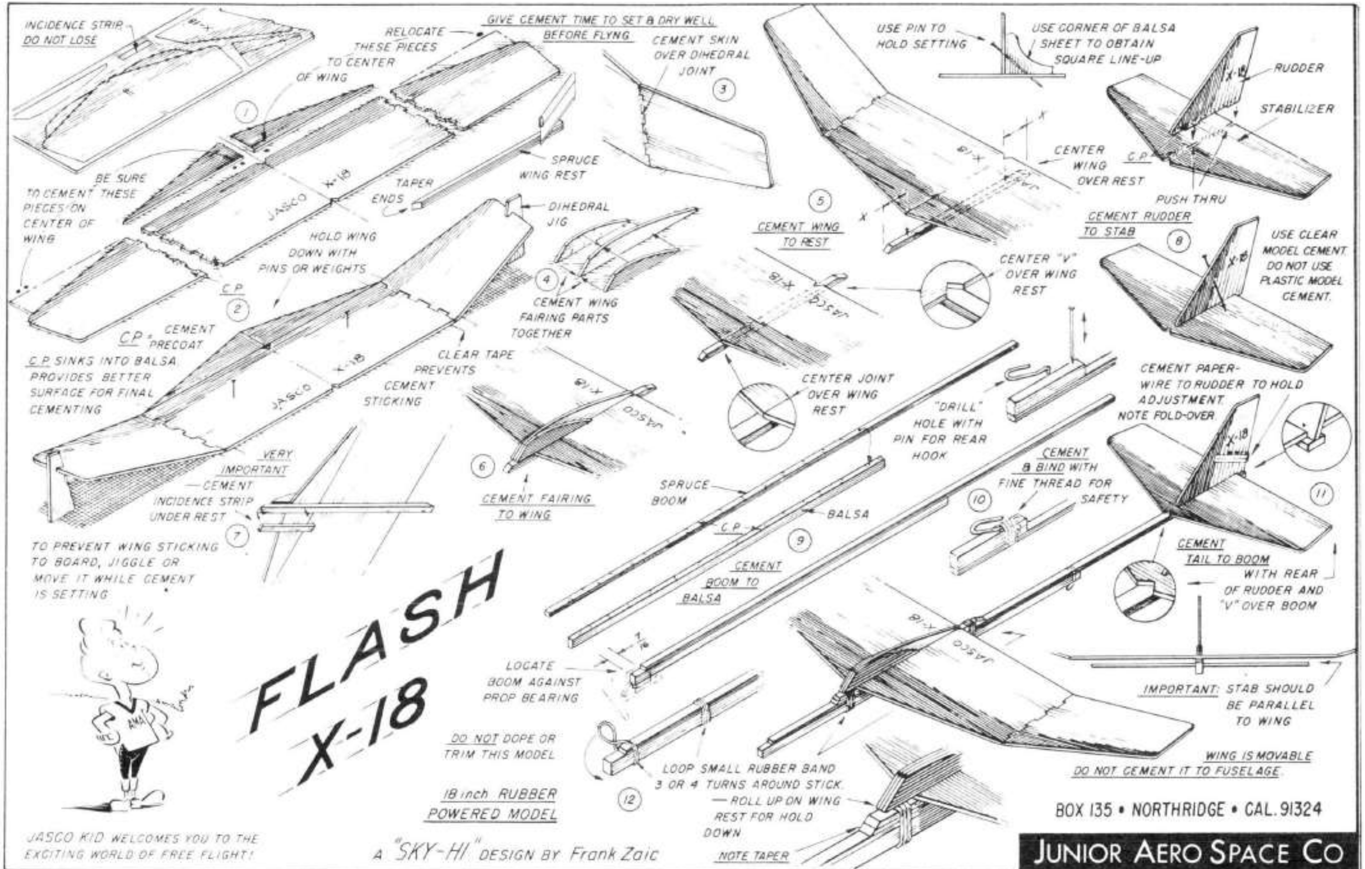
## DEVELOPMENT OF FLASH X-18

**by Frank Zaic**

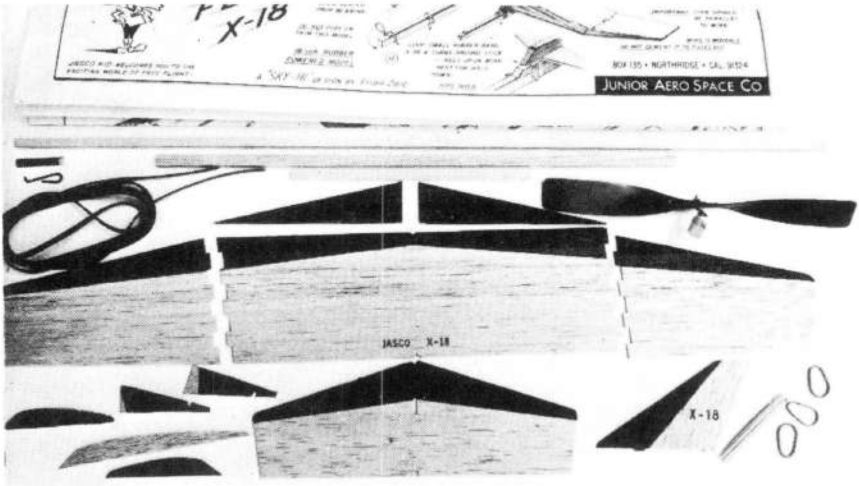
*How a simple yet efficient all-balsa model was produced to achieve a fast climb pattern—from N.F.F.S. 8th Annual Symposium papers*

THE INITIAL objective of the development of X-18 was to provide for youngsters a model which would be similar in action and behaviour as the fast climbing free flight models. By giving the kids a taste of free flight and thermal hunting excitement and exhilaration, they may become candidates for future internationals. But as the programme progressed, a second objective arose which in the end proved to be especially interesting: How to determine the rudder or fin area?

In designing free flight models for the beginner (whose age may be between 8 and 10 years and whose father is not a model builder) we have to assume that the price of the kit must be relatively low so that the father will not hesitate to "risk" his money to find if his youngster would like the model 'plane building. Also, the construction time should be limited to one or two evenings, and assembly as easy and simple as a plastic model to prevent boredom and frustration. The construction time element eliminates framework and paper covering. (It is sad but true that most of the scale model kits begun by youngsters are never completed.) The low price and building time spell out a simple stick type of model for the beginners. How to convince the youngsters to start with such a model is another story.



INCIDENCE STRIP DO NOT LOSE
RELOCATE THESE PIECES TO CENTER OF WING
GIVE CEMENT TIME TO SET & DRY WELL BEFORE FLYNG
CEMENT SKIN OVER DIHEDRAL JOINT
3
1
SPRUCE WING REST
BE SURE TO CEMENT THESE PIECES ON CENTER OF WING
TAPER ENDS
JASCO X-18
DIHEDRAL JIG
HOLD WING DOWN WITH PINS OR WEIGHTS
C.P.
2
4
CEMENT WING FAIRING PARTS TOGETHER
C.P. = CEMENT PRECOAT
C.P. SINKS INTO BALSA PROVIDES BETTER SURFACE FOR FINAL CEMENTING
CLEAR TAPE PREVENTS CEMENT STICKING
VERY IMPORTANT
CEMENT INCIDENCE STRIP UNDER REST
7
6
CEMENT FAIRING TO WING
TO PREVENT WING STICKING TO BOARD, JIGGLE OR MOVE IT WHILE CEMENT IS SETTING
USE PIN TO HOLD SETTING
USE CORNER OF BALSA SHEET TO OBTAIN SQUARE LINE-UP
RUDDER
STABILIZER
CENTER WING OVER REST
C.P.
PUSH THRU
5
CEMENT WING TO REST
CEMENT RUDDER TO STAB
8
USE CLEAR MODEL CEMENT. DO NOT USE PLASTIC MODEL CEMENT.
CENTER "V" OVER WING REST
CENTER JOINT OVER WING REST
"DRILL" HOLE WITH PIN FOR REAR HOOK
CEMENT PAPER-WIRE TO RUDDER TO HOLD ADJUSTMENT. NOTE FOLD-OVER
CEMENT & BIND WITH FINE THREAD FOR SAFETY
SPRUCE BOOM
BALSA
C.P.
9
10
11
CEMENT BOOM TO BALSA
CEMENT TAIL TO BOOM WITH REAR OF RUDDER AND "V" OVER BOOM
FLASH X-18
LOCATE BOOM AGAINST PROP BEARING
IMPORTANT: STAB SHOULD BE PARALLEL TO WING
DO NOT DOPE OR TRIM THIS MODEL
WING IS MOVABLE DO NOT CEMENT IT TO FUSELAGE
LOOP SMALL RUBBER BAND 3 OR 4 TURNS AROUND STICK — ROLL UP ON WING REST FOR HOLD DOWN
12
18 inch RUBBER POWERED MODEL
NOTE TAPER
BOX 135 • NORTHRIDGE • CAL. 91324
JUNIOR AERO SPACE CO
JASCO KID WELCOMES YOU TO THE EXCITING WORLD OF FREE FLIGHT!
A "SKY-HI" DESIGN BY Frank Zaic




Layout of the kit parts for Flash X-18.

Since we hope to interest the youngster in free flight, we must provide him with a model that has spectacular, rocket-like, flight performance—practically the same features we want for ourselves and which we achieve with a lot of petty adjustments. While the only adjustment we should expect from the youngsters, at the most, is to move the wing back and forth and warp the rudder for a turn. Of course, the model should be structurally strong to survive the initial "get acquainted" period, and easily repaired on the field.

Finally, the building and flying instructions should supply all of the information needed so that father and son can build and fly the model without going to anyone else for help. We should realise that newcomers are in a strange world when it comes to model planes. The kit should be self-sufficient in all respects.

How did X-18 meet all these requirements?

The plans for the model, taken directly from the kit, are illustrated with this article.

Structurally, the motor stick is reinforced by a spruce strip which also serves as a tail boom. This laminate removes the insecurity of balsa strength variations and provides stiffness needed for relatively high power. The wing utilises the full area of a $\frac{1}{20} \times 3 \times 18$ in. sheet by die-cutting. It has the rigidity of a tapered wing. Note the dovetail dihedral joints. This provides extra cement areas as well as clamping effect during assembly. The dihedral breaks are also angled to provide wash-in and wash-out on the appropriate sides of the wing. Tail parts are also die-cut with rudder jigged to stab for true line-up. Thanks to Bill Warren, the rudder warp is held in position by a paper-wire wrap strip.

Aerodynamically, the X-18 has a flat wing surface so that, with just a slight help from "circular airflow" during the spiral climb, the wing has practically zero lift. The only need for the wing is to provide lift when it comes time for slow glide. The wing has right wash-in and left

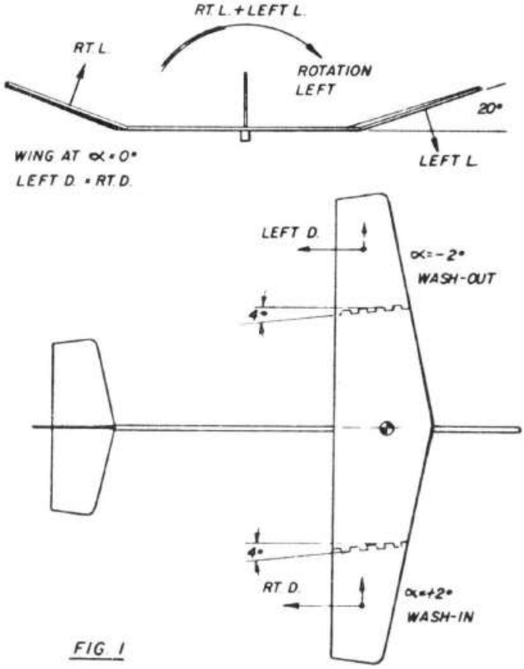


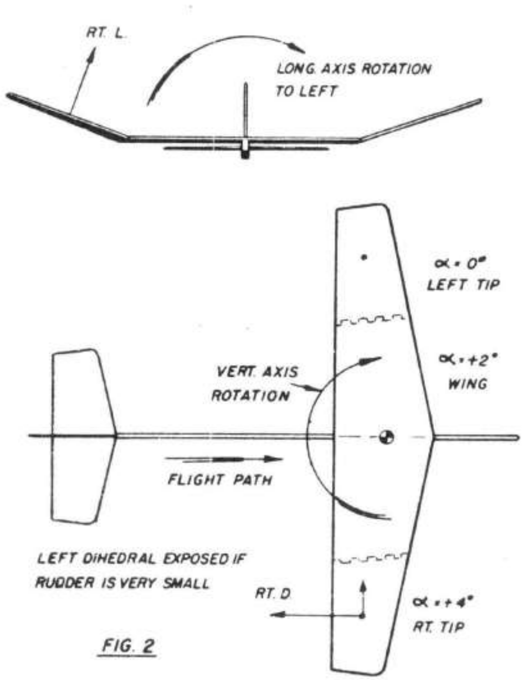

FIG. 1

wash-out of about 2° each. (4° angled dihedral break and 20° dihedral give 2° wash-out or wash-in. See *Fig.* 1.)

Besides having low lift under power, the flat wing also makes it possible to have the wing plus or minus ½ in. from the optimum position.

For the spectacular climb the North Pacific 7 in. plastic prop is powered by a loop of ¼ in. or 4 strands of ⅛ in. Pirelli. It runs in a nylon bearing which has down and right thrust built in. The 7 in. prop and a loop of ¼ in. Pirelli is a combination that is capable of pulling X-18 straight up for 10–15 secs. This high power–weight ratio is more than most of us use on rubber or engine powered models. And we are going to hand this "powerful" machine to a youngster who may have never flown a model. It should now be obvious why it is essential that all basic control settings must be built in.

During the testing stage I found that X-18 had to be launched at about 70°. A launch straight ahead might end up with the model biting the dust. The logic behind high launch, if you have enough power, is that as long as the model points up, it can gyrate all it wants without getting into crashing trouble.




Of particular interest to me was the check testing to determine the correct rudder size by trimming or adding to its area to see what happens with different sizes. At one time, with relatively small rudder, X-18 was determined to catch its tail right after launch, or it would dive after a turn or so. At first I thought to cure the problem by moving the wing forward to increase the wing moment around the C.G. and so cause a zoom up. But this adjustment did not work, even when the wing was almost at the prop. Then I recalled using a very large rudder to offset the right glide rudder setting. I tried this approach gradually, adding more area with each succeeding flight. The spiral dive disappeared. Then I got flights which were just right—smooth spiral with good transition. But I did not stop there, but kept adding more area until X-18 was looping after launch. The normal rudder turn warp was not effective with extra large rudder.

So, here we had a model on which the only change made was rudder area, and the flight pattern of the model changed from spiral dives with small rudder to looping with larger rudder area. In the meantime I was also intrigued by seemingly complete lack of help from the wing wash-in and wash-out. Where was right wash-in's lift to prevent right spiral

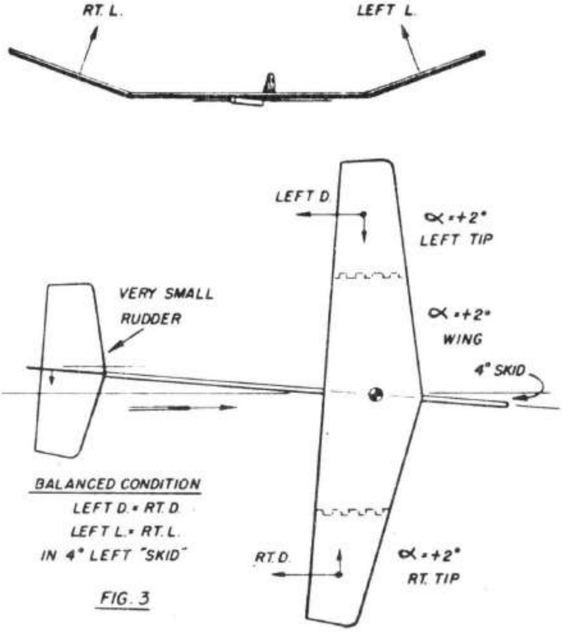



FIG. 3

dives? Why was change of rudder area so effective in bringing about changes almost at will?

The correct rudder area for X-18 was finally determined. The model has a steep right spiral climb under full power of $\frac{1}{4}$ in. loop of Pirelli. It has enough right turn rudder setting to transition the model into a smooth, fair size, right circling glide. Let us now cover the second objective:

Why did X-18 behave as it did when rudder area was changed?

Before we go further, we should review the effect of rudder area in relation to a wing which has right wash-in and left wash-out configuration. The basic purpose of the rudder is to give the model a sense of facing the prevailing wind or relative airflow—the familiar weather vane effect. When both wing halves have equal values of lift and drag, the rudder area may not be critical. As long as the "centre" of side area is behind the C.G. the model will face the wind. But change the lift and drag values of the wing by warps, wash-in and wash-out, and the rudder area becomes critical. For example:

When a wing with right wash-in and left wash-out faces an airflow, its reaction is to create greater lift and drag forces on the right side (see

*Fig.* 2). The lift will tend to rotate the wing into a left bank, while the higher drag will tend to rotate the wing in the vertical axis to the right. As the wing rotates to the right due to higher drag value, it exposes the left side to greater angle of attack due to the dihedral. This in turn creates more lift and drag on the left side. The rotation on the vertical axis continues until both sides have equal drag values, which also indicates that their values are similar. Hence, it is quite possible that we may have a model, which has exceptionally small rudder area, gliding straight ahead with the fuselage at an angle to the flight path (see *Fig.* 3). It seems that the drag acts to rotate the model in the vertical axis before the lift rotates it on the longitudinal, so that we do not have the bank to left, before rotation to right.

Let us now assume that we have a tremendous rudder area (see *Fig.* 4). As the higher drag force of the right half rotates the model in the vertical axis, it exposes the left side of the rudder. The slight angle of attack on the rudder produces enough side lift (which tends to rotate the model to the left) to balance the greater wing drag force. So now we have produced a balance condition about the vertical axis and the model no longer can rotate to the right. But we still have higher lift on the right than on the left. The model has no choice but to rotate on the longitudinal axis, and

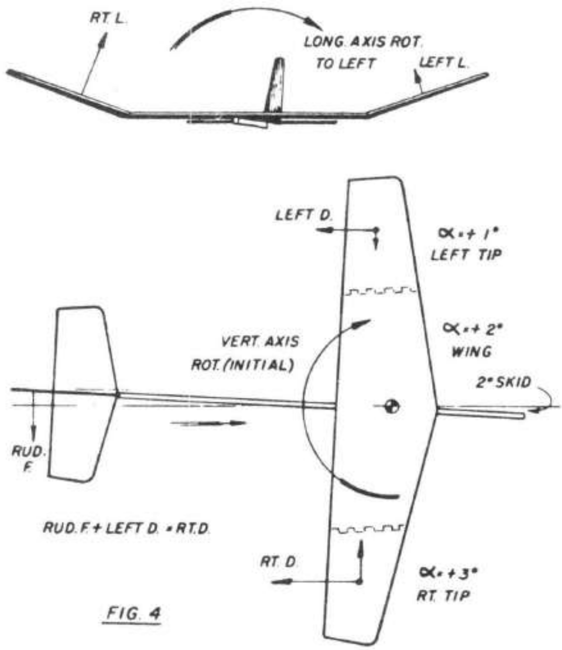



FIG. 4

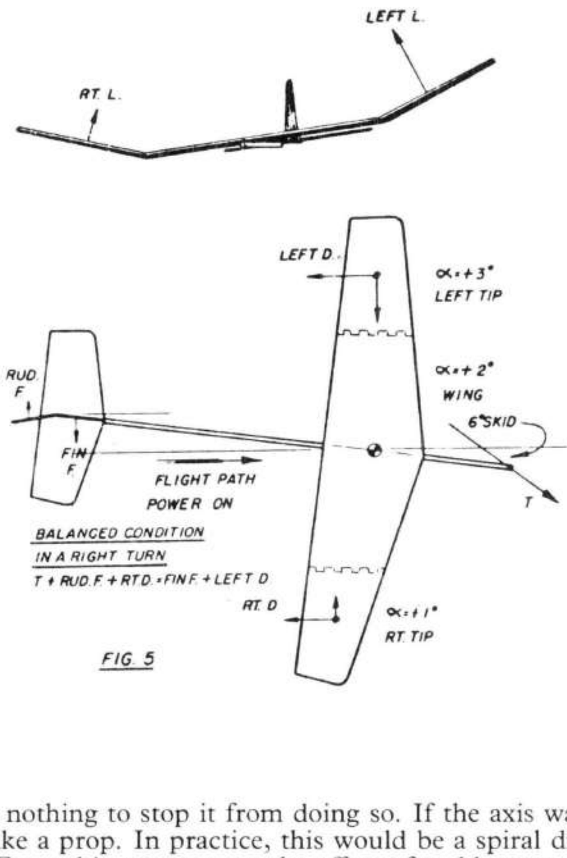


FIG. 5

here is nothing to stop it from doing so. If the axis was fixed, it would rotate like a prop. In practice, this would be a spiral dive to the left.

From this, one can see the effect of rudder area in relation to the wing which has wash-out and wash-ins or warps. A small rudder area will tend to produce a turn to the right, and a larger rudder, turn to the left. If the small rudder also had a right turn setting, the model may spiral down to the right.

Now let us introduce right side thrust into these situations.

Why do we need side thrust if it seems to be working against the rudder? Side thrust is used to produce safe circling patterns during power run. As we know, circling is needed to produce "circular airflow" effect in which the lift is reduced to minimal values. Under power, right thrust will tend to rotate the model about the vertical axis and counteract the rudder effect, which may normally balance the higher drag of the right side with its wash-in. The angled thrust line force should be allowed by the rudder area to swing or rotate the model until the lift due to dihedral effect of the left is greater than the right side (see *Fig.* 5). This greater lift will bank the model into the right turn and so determine the right spiral climb pattern. So that now, we have a condition in which the wing lift and drag are almost similar on both halves, with left having slight edge in lift. The extra drag of the left side is now controlled by the side thrust. In case of X-18 which has $2^\circ$ wash-in and wash-out, the model has to be rotated on vertical axis by the side thrust $4^\circ$, plus whatever the left dihedral needs (say $1^\circ$) to provide the right bank. This also means that the rudder has $4^\circ$ plus angle, which tends to rotate the model to the left. This left rudder force has to be balanced by side thrust to maintain a balanced right turn. This demonstrates the interaction or dependence of rudder area and side thrust as well as the value of wash-in and wash-out forces.

If, by chance, the rudder area is too small to balance the side thrust, the side thrust force will rotate the model so that the left dihedral effect will be greater than the lift of the right side. The result will be the familiar spiral power dive (see *Fig.* 6). And if the rudder area is too large, the side force may not be able to bring about the extra lift needed on the left side, and you may have looping or an undermined or unsatisfactory pattern. You may spend days making hopeful adjustments without achieving the right combination.

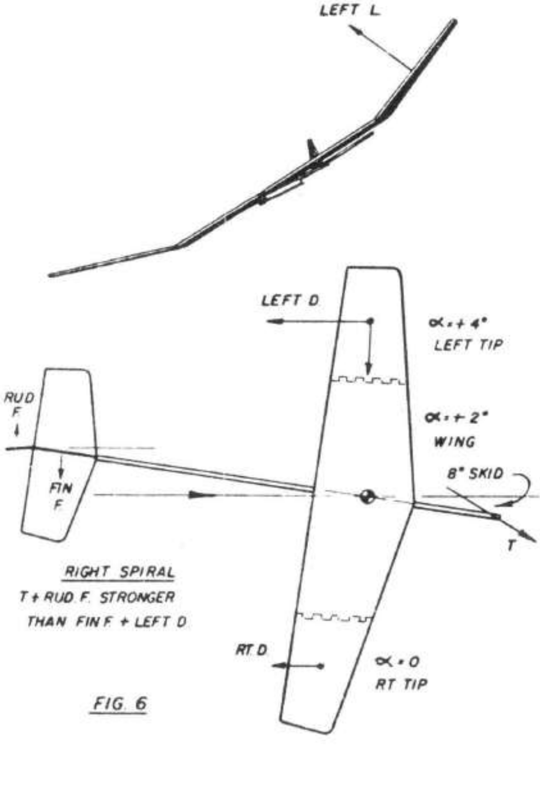
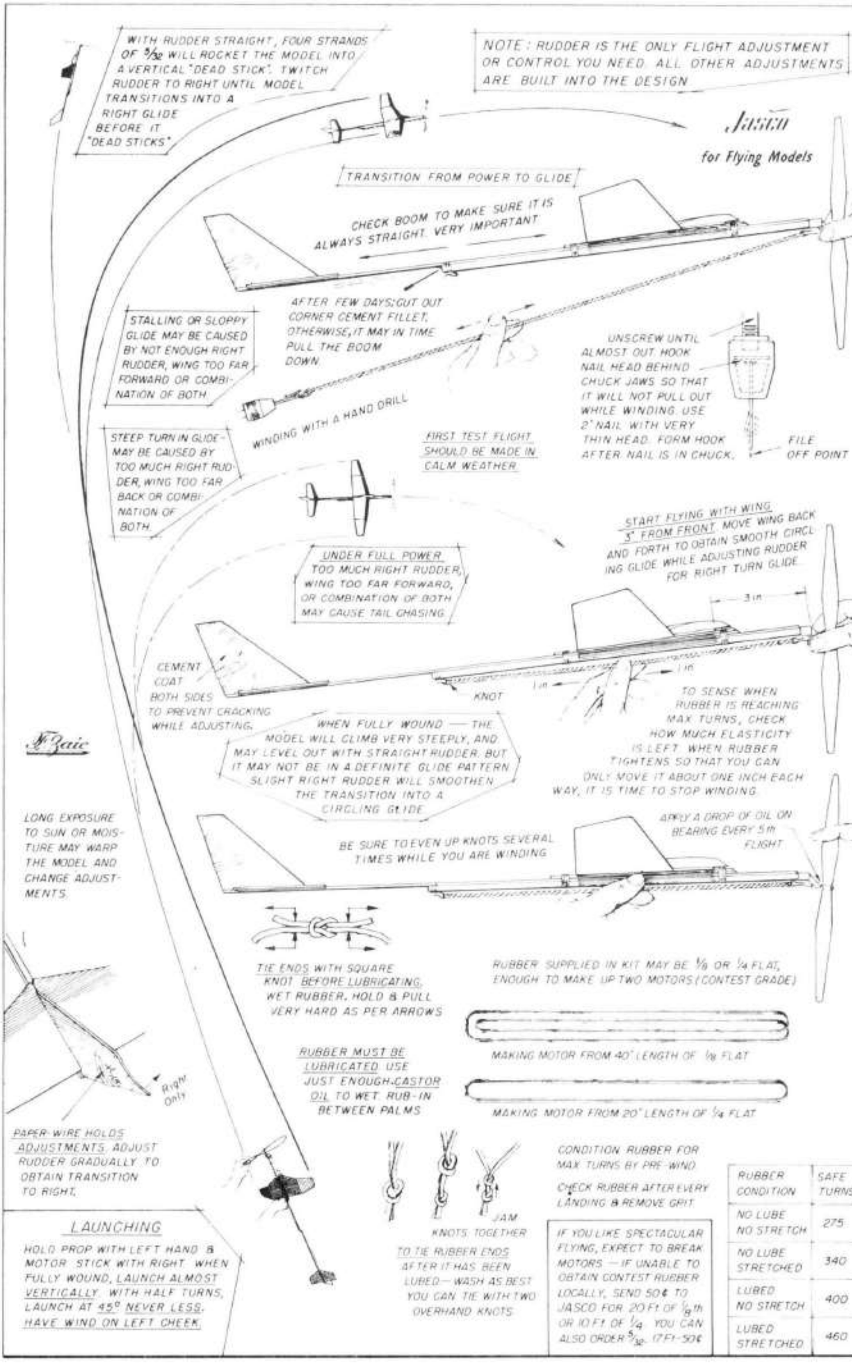



FIG. 6




| RUBBER CONDITION | SAFE TURNS |
|---|---|
| NO LUBE NO STRETCH | 275 |
| NO LUBE STRETCHED | 340 |
| LUBED NO STRETCH | 400 |
| LUBED STRETCHED | 460 |

The observation of needing extra lift on the outside wing can also be applied to models which have different area on the two halves, asymmetricals. A good example is the indoor model, on which the left wing has greater length or span. The standard setting is to set the rudder for left turn. This setting tends to rotate the model so that it exposes the right tip to dihedral effect, and lowers the left. If both sides of the wing had equal areas, the model may bank too steeply or the control may be too delicate. But with asymmetrical areas, the larger left area balances the greater right dihedral effect and so produces a balance of lift on both sides while the model is in a circling mode. Some may attribute the need of a larger inside area to the difference in air travel distance swept by inside and outside tips. This would be valid if the wing was flat and had no dihedral effect. It may contribute some help, but not as much as is thought. Perhaps some day someone will make a true asymmetrical area wing. I can just see a flat wing with a 5 in. chord on the inside tip and a 3 in. chord on the outside tip with the turn determined by rudder only.

*In summary:* A balanced model should allow its side thrust to balance the effect of the rudder to the extent that the left dihedral angle will be exposed enough to allow the required bank to the right to produce the spiral climb. (Rudder can be set for a right glide if the overall rudder or fin area is increased to offset this help to the side thrust.)

The desired situation is to have both sides with almost equal lift with enough extra lift on the left side to produce a bank for the right climb. This particular arrangement is also needed for gliders. When the circle is developed we need similar lift values on both wing halves. Yet to make it turn, the glider needs more lift on the outside wing to produce the bank. Without the wash-in and wash-out, the rudder adjustment can be very delicate. This can be observed very nicely on R/C gliders on which the wash-in and wash-out are not used. All you need is to touch the rudder, on a model having polyhedral, and the glider will turn into steep turn or even spiral. Of course, having the elevator control, it is easy to force the glider into higher angles of attack and thus obtain more lift and thus sustain a steady turn. Wash-in on the inside wing will let you make turn adjustments with greater safety.

Incidentally, the discourse so far should also help explain why small rudders are so essential for Nordic or towline gliders. A small rudder area lets the wing adjust itself to the difference in drag and lift values of the two halves and allows a straight tow. And the small rudder also lets you have the wash-in on the inside wing for turning. And since the auto-rudder kicks on after the tow, it brings the outside dihedral into play. At the same time, you had better watch out for cross wind launching. The small rudder may not be able to swing the glider into the wind fast enough to prevent the wind from catching the wing from the side and rotating the model into ground.

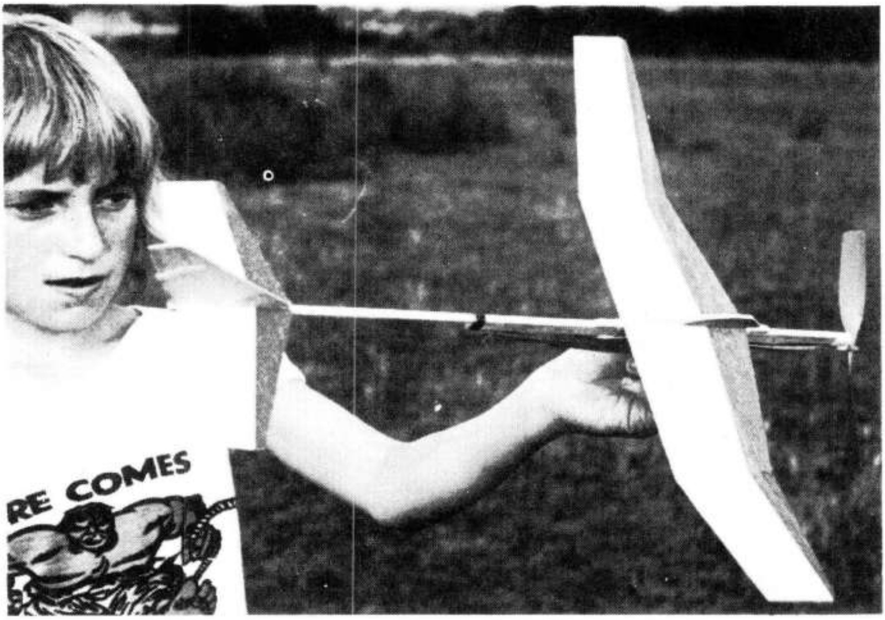
Back to the X-18. To check the correlation of the rudder area, setting, etc., I wanted to know if the X-18 could be made to fly a left pattern if the flight adjustments were reversed. That is, all adjustments except the prop rotation or torque effect. I took an X-18 die-cut wing stock and placed it upside down so that now the dihedral breaks gave me a right wash-out and left wash-in. The nose bearing was twisted to give left thrust; same size rudder with left warp for left glide; worked up to full power.

Jonathan and Reynard make a simultaneous launch and demonstrate the power model type climb angle of the Flash X-18. At right, the ultra simple model shows off its angled dihedral joints, short motor, long tail moment arm and small rudder

Sure enough, the model climbed in a left spiral and transitioned into a left glide as though it was a mirror image of the original right pattern. Surprisingly, torque did not seem to have any effect.

Up until now the X-18 power was high-grade Pirelli. But with prices going up and delivery uncertain I tried domestic products. I checked F.A.I. Supplies rubber and found that it had a higher initial torque than Pirelli. Higher initial torque also meant that the side thrust force was greater than Pirelli for which the X-18 was designed. This showed up in the right spiral power dive tendencies of tail chasing.

The fix was to increase the rudder area. The change, however, is slight enough so that X-18 can still handle Pirelli without tendency to loop. The right rudder warp can be increased with Pirelli but not for F.A.I. Supplies. This indicates that the model should be designed or adjusted for the highest expected power.

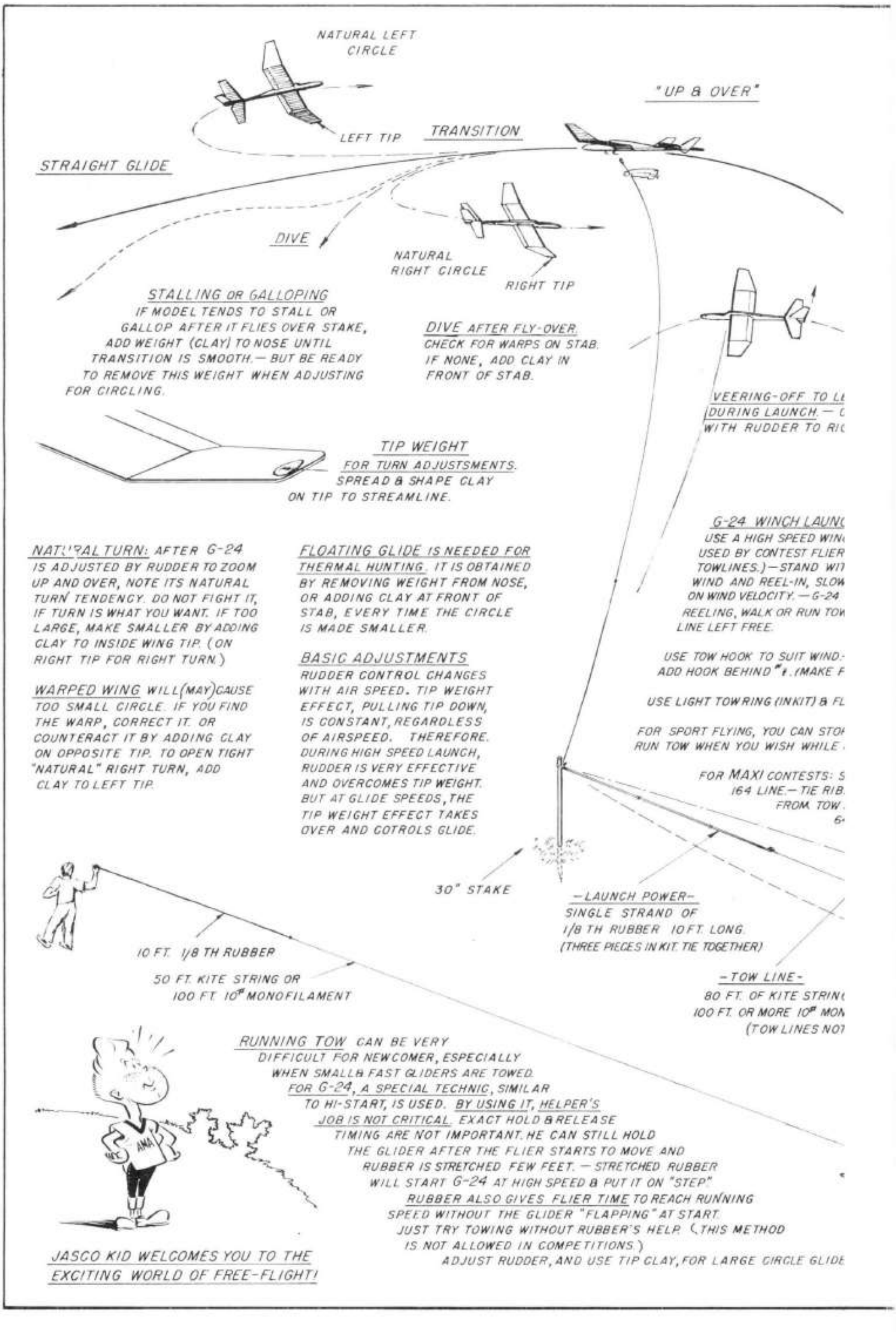


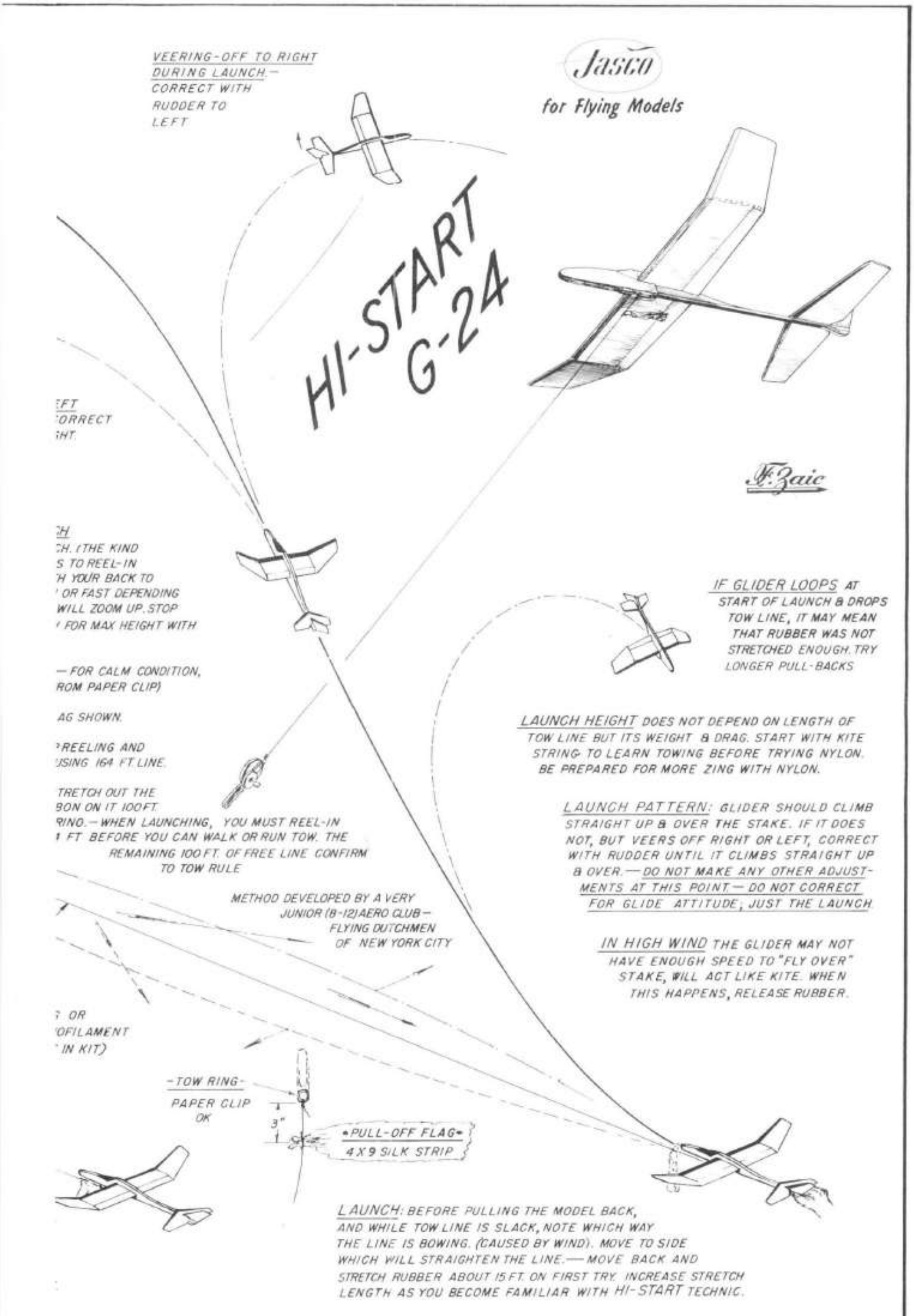

The last statement might be a hint why some of the models which fly well for the original builder do not behave as well for others. The power used on the original model might be less than on models built by others. If you build from plans or kits, it is well to keep in mind that if your model does not behave like the original, you might have more power than the original. So, find the power level at which the model behaves and don't force it into phase for which it was not designed. Of course, if you were able to follow the article so far, you *might* do better than the original!

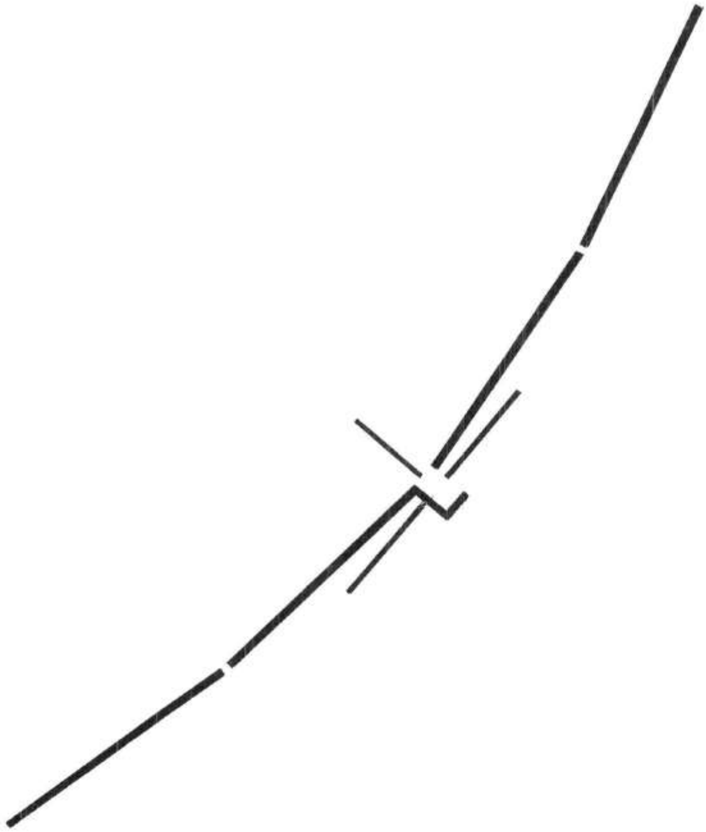
So far, over 15,000 youngsters have made and flown Flash X-18. No complaints so far. Have reports of 10 min. thermal flights and schoolgirls almost winning contests. It looks like X-18 met the basic objective, a model with spectacular climb when flown by beginners.

To me, X-18 has a very special significance. Ever since 1926 I have been wondering how the rudder area is determined. Now, I think that I know how it is done, or at least how when the rudder is too large or too small. This knowledge in combination with the Circular Airflow concept rounds out the basic design requirements of model aircraft. Now that we know (?) how to design the complete free flight model with inherent or built-in controls, is it still necessary to have gadgets? Gadgets mean pre-programmed flight, not free flight. To me a free flight model is on its own the moment you release it into the sky. To me, now, gadgets mean that one is not sure of what he is doing. It is a crutch. Some may call it insurance.

The joy of free flight comes only when your model is on its own, fighting in a three-dimensional world with your intelligence. It is a partnership that is wonderful beyond words!


NATURAL LEFT CIRCLE
"UP & OVER"
LEFT TIP
TRANSITION
STRAIGHT GLIDE
DIVE
NATURAL RIGHT CIRCLE
RIGHT TIP
STALLING OR GALLOPING
IF MODEL TENDS TO STALL OR GALLOP AFTER IT FLIES OVER STAKE, ADD WEIGHT (CLAY) TO NOSE UNTIL TRANSITION IS SMOOTH.— BUT BE READY TO REMOVE THIS WEIGHT WHEN ADJUSTING FOR CIRCLING.
DIVE AFTER FLY-OVER.
CHECK FOR WARPS ON STAB. IF NONE, ADD CLAY IN FRONT OF STAB.
VEERING-OFF TO LE
DURING LAUNCH.— C
WITH RUDDER TO RI
TIP WEIGHT
FOR TURN ADJUSTSMENTS. SPREAD & SHAPE CLAY ON TIP TO STREAMLINE.
NATURAL TURN: AFTER G-24 IS ADJUSTED BY RUDDER TO ZOOM UP AND OVER, NOTE ITS NATURAL TURN TENDENCY. DO NOT FIGHT IT, IF TURN IS WHAT YOU WANT. IF TOO LARGE, MAKE SMALLER BY ADDING CLAY TO INSIDE WING TIP. (ON RIGHT TIP FOR RIGHT TURN.)
WARPED WING WILL(MAY)CAUSE TOO SMALL CIRCLE. IF YOU FIND THE WARP, CORRECT IT. OR COUNTERACT IT BY ADDING CLAY ON OPPOSITE TIP. TO OPEN TIGHT "NATURAL" RIGHT TURN, ADD CLAY TO LEFT TIP.
FLOATING GLIDE IS NEEDED FOR THERMAL HUNTING. IT IS OBTAINED BY REMOVING WEIGHT FROM NOSE, OR ADDING CLAY AT FRONT OF STAB, EVERY TIME THE CIRCLE IS MADE SMALLER.
BASIC ADJUSTMENTS
RUDDER CONTROL CHANGES WITH AIR SPEED. TIP WEIGHT EFFECT, PULLING TIP DOWN, IS CONSTANT, REGARDLESS OF AIRSPEED. THEREFORE. DURING HIGH SPEED LAUNCH, RUDDER IS VERY EFFECTIVE AND OVERCOMES TIP WEIGHT. BUT AT GLIDE SPEEDS, THE TIP WEIGHT EFFECT TAKES OVER AND COTROLS GLIDE.
G-24 WINCH LAUN
USE A HIGH SPEED WIN
USED BY CONTEST FLIER
TOWLINES.)—STAND WI
WIND AND REEL-IN, SLOW
ON WIND VELOCITY.— G-24
REELING, WALK OR RUN TOW
LINE LEFT FREE.
USE TOW HOOK TO SUIT WIND.-
ADD HOOK BEHIND # 1. (MAKE F
USE LIGHT TOWRING (IN KIT) & FL
FOR SPORT FLYING, YOU CAN STO
RUN TOW WHEN YOU WISH WHILE
FOR MAXI CONTESTS: S
164 LINE.— TIE RIB.
FROM TOW
30" STAKE
—LAUNCH POWER—
SINGLE STRAND OF 1/8 TH RUBBER 10 FT. LONG. (THREE PIECES IN KIT. TIE TOGETHER)
10 FT. 1/8 TH RUBBER
50 FT. KITE STRING OR 100 FT. 10# MONOFILAMENT
—TOW LINE—
80 FT. OF KITE STRIN
100 FT. OR MORE 10# MON
(TOW LINES NOT
AMA
RUNNING TOW CAN BE VERY DIFFICULT FOR NEWCOMER, ESPECIALLY WHEN SMALL & FAST GLIDERS ARE TOWED. FOR G-24, A SPECIAL TECHNIC, SIMILAR TO HI-START, IS USED. BY USING IT, HELPER'S JOB IS NOT CRITICAL. EXACT HOLD & RELEASE TIMING ARE NOT IMPORTANT. HE CAN STILL HOLD THE GLIDER AFTER THE FLIER STARTS TO MOVE AND RUBBER IS STRETCHED FEW FEET. — STRETCHED RUBBER WILL START G-24 AT HIGH SPEED & PUT IT ON "STEP". RUBBER ALSO GIVES FLIER TIME TO REACH RUNNING SPEED WITHOUT THE GLIDER "FLAPPING" AT START. JUST TRY TOWING WITHOUT RUBBER'S HELP. (THIS METHOD IS NOT ALLOWED IN COMPETITIONS.)
ADJUST RUDDER, AND USE TIP CLAY, FOR LARGE CIRCLE GLIDE
JASCO KID WELCOMES YOU TO THE EXCITING WORLD OF FREE-FLIGHT!


VEERING-OFF TO RIGHT DURING LAUNCH.— CORRECT WITH RUDDER TO LEFT
Jasco
for Flying Models
HI-START
G-24
F. Zaic
:FT
:ORRECT
:HT.
:H
:H. (THE KIND
S TO REEL-IN
H YOUR BACK TO
OR FAST DEPENDING
WILL ZOOM UP. STOP
FOR MAX HEIGHT WITH
— FOR CALM CONDITION,
ROM PAPER CLIP)
AG SHOWN.
REELING AND
USING 164 FT LINE.
TRETCH OUT THE
BON ON IT 100FT.
RING.— WHEN LAUNCHING, YOU MUST REEL-IN
FT BEFORE YOU CAN WALK OR RUN TOW. THE
REMAINING 100 FT. OF FREE LINE CONFIRM
TO TOW RULE
METHOD DEVELOPED BY A VERY JUNIOR (8-12) AERO CLUB— FLYING DUTCHMEN OF NEW YORK CITY
IF GLIDER LOOPS AT START OF LAUNCH & DROPS TOW LINE, IT MAY MEAN THAT RUBBER WAS NOT STRETCHED ENOUGH. TRY LONGER PULL-BACKS
LAUNCH HEIGHT DOES NOT DEPEND ON LENGTH OF TOW LINE BUT ITS WEIGHT & DRAG. START WITH KITE STRING TO LEARN TOWING BEFORE TRYING NYLON. BE PREPARED FOR MORE ZING WITH NYLON.
LAUNCH PATTERN: GLIDER SHOULD CLIMB STRAIGHT UP & OVER THE STAKE. IF IT DOES NOT, BUT VEERS OFF RIGHT OR LEFT, CORRECT WITH RUDDER UNTIL IT CLIMBS STRAIGHT UP & OVER.— DO NOT MAKE ANY OTHER ADJUSTMENTS AT THIS POINT — DO NOT CORRECT FOR GLIDE ATTITUDE, JUST THE LAUNCH.
IN HIGH WIND THE GLIDER MAY NOT HAVE ENOUGH SPEED TO "FLY OVER" STAKE, WILL ACT LIKE KITE. WHEN THIS HAPPENS, RELEASE RUBBER.
OR
OFILAMENT
IN KIT)
-TOW RING-
PAPER CLIP OK
3"
•PULL-OFF FLAG•
4 X 9 SILK STRIP
LAUNCH: BEFORE PULLING THE MODEL BACK, AND WHILE TOW LINE IS SLACK, NOTE WHICH WAY THE LINE IS BOWING. (CAUSED BY WIND). MOVE TO SIDE WHICH WILL STRAIGHTEN THE LINE.— MOVE BACK AND STRETCH RUBBER ABOUT 15 FT. ON FIRST TRY. INCREASE STRETCH LENGTH AS YOU BECOME FAMILIAR WITH HI-START TECHNIC.



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