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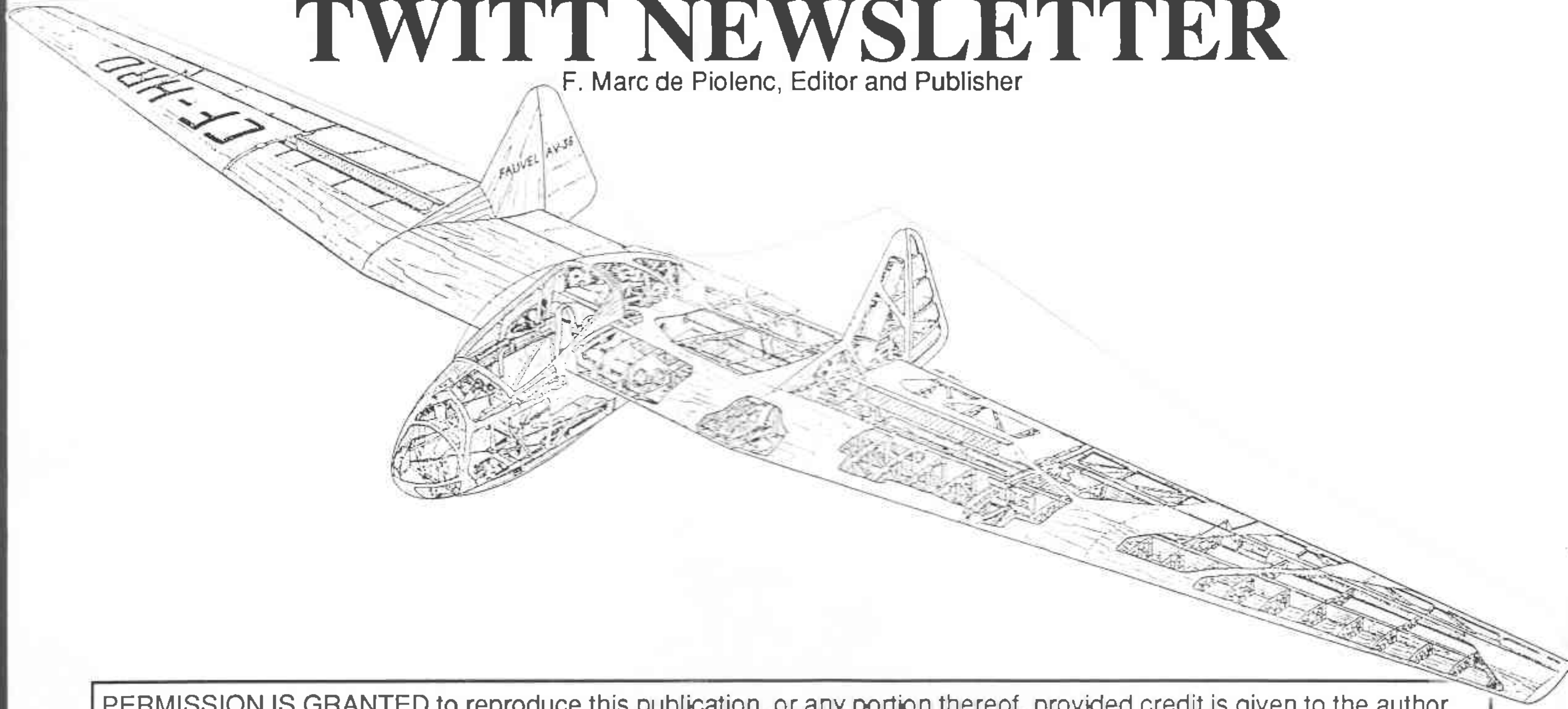
TWITT NEWSLETTER

F. Marc de Piolenc, Editor and Publisher



TWITT
(The Wing Is The Thing)
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NEXT MEETING: 15 October 1988, 1330 hours at hangar A-4, Gillespie Field, El Cajon, California.

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MINUTES OF SEPTEMBER TWITT MEETING

Local TWITTs and their guests assembled on 17 September 1988 at Gillespie Field. Bob Fronius called the 28th meeting of TWITT to order and reminded the gathering that the featured speaker would be Brad Powers, who addressed TWITT months earlier on the subject of dynamic similitude. The raffle prizes were a set of battery cables and a pamphlet containing copies of the drawings from the US Patent issued to the Wright brothers and a copy of the contract between Charles Lindbergh and A.J. "Billy" Edwards, a car dealer, for the construction and delivery of the airplane later known as the Spirit of Saint Louis. Thanks to the generosity of Bruce Carmichael, there was a large pile of free aviation magazines for TWITTs to pick over and take as they saw fit. There had been fewer tailless airplanes at the Tehachapi meet than expected. Klaus Savier showed up with his highly modified U-2, but broke a main wheel on an apparently normal landing. Don Mitchell did not show up with his new machine, which he originally intended to fly down from his home. Engine problems may have been to blame for his absence. Bernie Gross showed up with his Marske Pioneer II, but did not assemble the machine. He felt he was not current and needed to refresh himself before flying for the public. Bob asked if anyone at the meeting had had his newsletter damaged in the mail—nobody had. Bob noted that TWITT will exchange damaged newsletters for fresh copies. He then read a short piece which claimed that on September 20, 1898, Alberto de Santos-Dumont, a Brazilian-born Frenchman, made the first sustained, controlled flight in his No. 1 airship. [Editor's note: Not true: Santos-Dumont was certainly a pioneer, and did much to further both lighter-than-air and heavier-than-air flight, but he was preceded by Renard and by the brothers Tissandier, and possibly by others as well.] Bob noted that he had delayed as long as possible the reading of the historical note in the hope that editor Marc de Piolenc, who is involved in lighter-than-air development, would be there to hear it. He then called on Jerry Blumenthal to present a flying wing idea of his. Jerry took the floor and presented his vision of a flying wing. The machine has wing and fuselage smoothly blended together, and a straight (unswept) spar. The upper surface is not disturbed by any protuberance; the lower surface has a central fairing to accomodate the pilot's *derrière* and the landing gear. The machine is not directionally stable without some vertical tail surface, and Jerry's first draft showed a central fin. He now prefers twin cambered wingtip surfaces, convex inward, which he feels could also function as winglets by reducing induced drag. The surfaces could be smaller than a central fin because the moment of their increased drag due to yaw would be quite large. The vertical fin or fins would have no control surfaces on them; yaw control would be provided by small drag rudders in the form of buckets or troughs deployed below the wing near the tips. The aileron action would be provided by warping the wing[!]; only up aileron would be provided. The inboard elevators would use Harald Buettner's variable camber warped trailing edge invention, eliminating spanwise gaps and leaving a smooth trailing edge contour. An unidentified person (possiby speaker Brad Powers) spoke from the audience to mention a similar project at Convair in the 40's. Bob then led a discussion of the F-14 crash at Gillespie Field, which your Editor did not transcribe because it is not of general interest...except of course to those who were there at the time! Very fortunately, no TWITTs were injured. Bob announced that the AIAA and the San Diego Aerospace Museum were sponsoring a series of Monday lectures by "first flight" pilots about their experiences with notable airplanes. Speakers include Pete Girard (who has attended several TWITT meetings) and Ray Cote, among many others. A short break ensued, following which there was more discussion of the F-14 crash by eyewitness Del Koops, who worked with many other aviators to save as many aircraft from destruction as possible. Bob then introduced featured speaker Brad Powers, who discussed the Convair Skate, a jet–powered swept wing seaplane design intended to fly at a top speed around Mach .85. The Skate was never built at full scale, but was the precursor of an even more radical design, the Sea Dart, a tailless delta–wing jet seaplane equipped with hydro-skis and capable of supersonic flight. At least two were built, of which at least one survives; it stands outside the Aerospace Hall of Fame in San Diego. Brad Powers declared that the biggest problem the Sea Dart had was the enormous shock loads transmitted to the structure through the hydro-skis during the 110-knot takeoff; those loads vary with the square of the speed! The Sea Dart that crashed had literally shaken its engines loose from their mounts. Brad showed a short film of the Skate's 1/10 scale model tests and the model and full- scale tests of the Sea Dart, which made its first flight from San Diego bay on 9 April 1953. After the film, Brad mentioned that the Sea Dart effort was really the seaplane's swan song. They had serious corrosion problems operating from salt water, and any body of water that was convenient for seaplane operations was likely to be swarming with boats, there for the same reason! At Bob Fronius' request, Brad then introduced his articles on the Center of Gravity, which is reproduced in this issue. Your editor will cut these minutes short by letting the articles speak for themselves.

TWITT LIBRARY ACQUISITIONS

"A Synopsis of Flying Wing Development, 1908–1953," by Richard P. Hallion. History Office, Air Force Flight Test Center, Edwards AFB, CA 93523-5000; 9 January 1986. Contributed by Karl Sanders.

"Tests in the NACA Two-Dimensional Low-Turbulence Tunnel of Airfoil Sections Designed to Have Small Pitching Moments and High Lift-Drag Ratios," by Neal Tetervin. NACA Confidential Bulletin 3I13 (Wartime Report L-452), September 1943. Contributed by Karl Sanders.

DELTA, Vereinsmagazin des FSV Versmold, issues number 4, 5, and 7 (August 86, November 86 and ?). Editor: Reinhard H. Werner, Schloerstrasse 4, 4802 Halle, West Germany. Contributed by R. H. Werner.

A POLISH TAILLESS GLIDER: THE SZD-6X NIETOPERZ

The following information on an obscure eastern European tailless sailplane comes to us through the courtesy of Reinhard Werner, editor of the west German model magazine DELTA.

The SZD-6X Nietoperz (Bat) is a small wooden midwing single seater built in Poland in 1950. It made its first flight on 12 January 1951. It was subsequently tested in three configurations, differing primarily in respect to the means of control. All participating test pilots agreed that this type was not destined for quantity production, that it should only be used for tests and that the installation of an ejector seat was an advisable safety precaution! Generally speaking, the longitudinal stability of the Bat was adequate, but everything else was a total fiasco. Eventually everybody had as much as he could take and the machine was packed off to the Technical Museum in Warsaw.

Construction Data:

Fuselage and Vertical Fin: hexagonal frame fuselage covered with plywood. Integral stabilizing surface with removable cloth covered rudder. Spring loaded wooden skid.

Wing: Three piece wooden structure with twin spars. The center section integral with the fuselage, the outer panels removable. Airfoil section NACA 23012. Inboard ailerons made of wood, outboard ailerons metal. Camber flaps on the center section with a deflection of +/- 10°.

Technical Data:

Span:	12 m
Overall Length:	4 m
Height:	1.3 m
Wing Area:	14.4 m^2
Aspect Ratio:	10
Empty Weight:	150 kg
Flight Weight:	235 kg
Wing Loading:	16.3 kg/m^2
Glide Ratio:	17.5
Rate of Sink at V=100 km/h:	1.7 m/s
Rate of Sink at V=140 km/h:	3.5 m/s
Minimum Speed:	54 km/h
Never-Exceed Speed:	300 km/h

LETTERS

LOW PITCHING–MOMENT SECTIONS

Karl Sanders writes:

In the May issue of TWITT letter on p. 2 you mentioned a NASA Tech Memorandum on low C_m sections. This document is actually NASA TN–D–7982 (1975)! Enclosed is a 1943 (!) attempt! Please feel free to mention it in one of the upcoming issues.

Karl

[Karl enclosed a copy of NACA Confidential Bulletin No. 3I13. See "TWITT Library Acquisitions" elsewhere in this issue.)

NEEDS INFO ON OBSCURE US TAILLESS DESIGNS

This from Phillipe Vigneron, whose address is reproduced below:

First, sorry for my terrible English...

I permit myself to write after reading your address and goals in the book "Modern Aircraft Design" by Martin Hollmann.

Since several years, I'm collecting documentation on the history of different tailless and flying wing aircraft built till the first world war, but can't find informations on several american homebuilt aircraft (Scroggs Dart 1929, Sebring Wee-Wing 1949, etc.). Could you accept to help me in my search? For my part, I have collected data (more historical than technical) on around 500 aircraft projects and patents. If you are interested, I will be glad to send some on your request.

M. Vigneron's address is:

Résidence La Carraire
Bâtiment La Réale
13140 MIRAMAS
FRANCE

NOT A TAILLESS FAN

Victor Mead Saudek of Los Angeles writes:

...I shall make a few comments on your TWITT movement at this point: It has been very well established that nothing in the way of sailplanes can be cleaner than the conventional tail–in–the–rear configuration. To claim otherwise is to allow emotions to overcome hard won knowledge. With the prospect of making even incremental gains in performance giving one manufacturer great increases in sales you can bet the farm and your family that G. Weibel, Klaus Holighaus and others have examined this field very diligently. It is true that some features have recently been discovered—such as Les (?) Shueman [?] who figured out the double sweep back near the wing tip—and Holighaus now builds the Discus, but this is a small advantage. You should realize that when racing sailplanes are costing $ 45,000 in the US, there are great incentinves to examine every possible detail to get an advantage.

Recall the idea of tail-first concepts by Burt Rutan and how they were advertised as being "stable" and "clean." Well, it isn't so and Technical Soaring for July 1988 has an article on the subject: "Canards: the Myths and the Realities" by Albert W. Blackburn. Any way you cut it, the forward surface should be several times the aft surface area for performance. The reasons for this have long been known. And the tailless designs are inherently poorer than tailfirst! All-wing aircraft have tails—the reflexed trailing edge of the airfoil—but this is too close to the lifting part of the wing and must always reduce that lift. With a smaller surface further aft, the tail can balance the overturning (tendency to dive) moment of the airfoil with a light downward load and little drag while the wing can have an optimum low drag airfoil.

To increase L/D of sailplanes one can reduce the waviness of airfoil surfaces (see Soaring, Dec 1987), use endplates on wingtips (carefully) and minimize interference drag at intersections (wing–to–fuselage). The next big step will be active boundary layer control (using solar cells?) which should give L/D of 100 or so. If I haven't convinced you, I am not surprised or sad unless you invest too much money in the chasing of the tailless "Will of the Wisp."

Vic Saudek

[Editor's Comments: It seems naïve to advance non–use as proof of lack of merit. I must candidly confess my ignorance of the intricacies of sailplane design, but areas of technology with which I am familiar—and there are a few of those—are littered with meritorious ideas which are simply left unused. Some are very complicated to analyze (e.g. free–piston engines) while others cannot leap the retooling barrier; others are neglected out of sheer ignorance. In this connection, the high cost and low sales volume of high–performance sailplanes would seem to provide a <u>dis</u>incentive to innovation; I know of no practical way to squeeze "great increases in sales" from a miniscule market. There is no ***technical*** *reason to discount tailless sailplanes a priori; the induced drag argument fails to consider the aircraft as a whole when considering the conventional layout. It is the downwash distribution in the wake of the aircraft—****due to the entire aircraft****—which determines whether the aircraft will have minimum induced drag. Optimum downwash gives optimum induced drag,* ***regardless of how it is achieved.*** *There is good reason to believe that a tailless design could have <u>better</u> induced drag, at equal span, than a conventional machine. If wake displacement is taken into account, the advantage of the tailless airplane would seem to increase at off–design lift coefficients. The lower skin–friction drag of the tailless, and the near absence of crossflow drag in curvilinear flight, seem to favor it even more. It is not clear to me why Mr. Saudek mentions canards in connection with flying wings, as they have little in common. The basis for his claim that flying wings are somehow "worse" is equally obscure. The record of the Horten machines in international and national competition suggests very strongly that the big problem of tailless sailplanes is not aerodynamic at all—they have atrocious ground handling qualities and are vulnerable to damage during out–landings. It would actually be easier to apply boundary layer control to a tailless machine, and the availability of power for suction raises the intriguing possibility (which certain TWITTs are investigating) of using* ***active stabilization*** *as well, allowing operation with the cg behind the neutral point of the aircraft.]*

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Brad Powers will be returning for the October meeting to discuss his article further. Please make sure and bring your newsletter to the meeting so you will be able to reference the figures and formulas as he continues his presentation.

Let's Talk About The CG

by Brad Powers

Part I

On the plans accompanying model kits are sometimes shown two CG locations: one for experienced flyers, and a half inch or so forward of this is one labeled "For Beginners." From this we can infer that the CG location or "Balance Point" must be of some importance, and that flying at the aft CG requires greater flying skill. And this is true. At the aft CG location an experienced flier can perform spine tingling spins and snap rolls at will, whereas a beginner like myself will also perform spine tingling spins, etc. unintenionally. In fact, if the CG is moved further and further aft, even an expert will encounter increasing difficulties until finally the airplane becomes so unstable that it is extremely difficult and even dangerous to fly. It will have become so sensitive that with little or no provocation it will embark on adventurous maneuvers of its own, usually with disastrous results.

On the other hand, moving the CG progressively forward increases stability and improves so-called "penetration," but as we move it forward the airplane becomes less and less sensitive to elevator control until the elevator power is inadequate to pull the nose up sufficiently to effect a slow, safe landing. It is evident then, that a safe and sensible CG range must lie between these two extremes.

In conjunction with the relative incidence between the wing and horizontal tail, the fore-and-aft position of the CG is the most powerful single factor in achieving Static Longitudinal Stability, and is therefore something that should be understood by anyone flying any kind of aircraft, large or small. So let's look at three aspects of the matter.

First: What determines acceptable CG limits?

Second: Where, physically, are these limits?

Third: During the design and construction phase of a large 1/4 scale model, is there some way to figure where to place things so that the CG will wind up where it's supposed to be?

In this article we will discuss the first item. In subsequent parts we will discuss items two and three.

Any discussion of CG location must necessarily involve a discussion of Stability. Stability, by definition, is the tendency to return to an original set of conditions if distrubed. In Fig. 1 are shown three cones. Cone A is resting firmly on its base, and if something tried to tip it over, it will tend to return to its original position (as long as the disturbance isn't so great as to knock it off the table). This condition is a Stable one.

At B, the cone is lying on its side. If disturbed, it will continue to remain on its side, but will roll around to a new position making no effort to return to the original condition. This may be said to be a Neutral condition, where corrective action must be taken.

At C, the cone is shown in the unlikely attitude of balancing on its point. Obviously, the slightest disturbance will cause it to fall down with no hope of restoration to the original position. This is an Unstable condition.

An airplane can turn, roll and pitch. It can perform each maneuver singly, or in combination with the others, i.e., a "climbing turn," a "rolling dive," etc., and it must have stability about all three axes. In other words, it should be directionally stable, laterally stable and longitudinally stable. It is the latter, longitudinal stability about the lateral axis, the ability to recover from inadverent changes in pitch or attitude, that we will concern ourselves with, because longitudinal stability is almost entirely dependent on CG location.

Stability about the lateral axis is of two kinds: Static and Dynamic. If the airplane is longitudinally stable it will tend to automatically re-establish its original Speed and Attitude if disturbed. Thus, if it encounters a gust tending to initiate a stall, causing it to nose up and slow down, instead of stalling, it will drop its nose and recover, speeding up and assuming its original flight attitude. If it does this quickly and smoothly it is both Statically and Dynamically Stable. If it recovers, but has increasing difficulty in re-establishing its original attitude because of "overshooting" or "hunting," it is said to Dynamically Unstable. We will only concern ourselves here with Static Longitudinal Stability.

As we said, the model is Longitudinally Stable if it recovers from an impending stall or dive by itself. If it is Neutrally Stable, and is disturbed, it will require prompt corrective control on your part to prevent a stall (or dive), and will indeed require your attention all during its flight if it is to stay "in the groove," so to speak. On the other hand, it will be very maneuverable and undoubtedly to the liking of a skilled pattern flier.

If the model is Unstable, it will be very difficult to keep it under control, and a sudden distubance can cause it to stall before you can do much to prevent it. Further, its sensitivity will engender high "G" maneuvers, vertical-banked, tight turns, etc., which might cause structural failure.

Flight is maintained when the forward surface is inclined at a greater angle to the relative wind than is the rear surface. The wing produces the lift; the rear surface "trims" it and holds it to its proper angle of attack. The angular difference between the two surfaces is sometimes call "decalage," a French word which roughly translates to mean "wedge-shaped," implying an angular difference. It is necessary also that the forward surface fly at a higher angle from the standpoint of stability, so that it will stall first, thus contributing to recovery. This is true for all types of aircraft, tailless, conventional, canard, or anything else.

In conventional and tailless configurations, the forward surface is trimmed by the aft surface - the horizontal tail on the conventional, and the "elevon" on the tailless. In the case of the canard, it is the other way around; the rear surface provides most of the lift and is trimmed by a smaller forward surface which, nevertheless, being the forward surface, must fly at a higher angle of attack than the main wing to the rear, so that it, too, will stall first.

However, an angular difference in wing and tail settings does not in itself insure stable flight. There must always be the proper relationship between the forces at play so that the tendency to effect recovery from a dive or stall will always be present.

Wehrner von Flintstone, a research and development engineer who lived about thirty thousand year ago, and operated out of a cave high in the foothills of the Cantabrain Cordillera, discovered that a stick (a free body), if thrown, would rotate about its balance point (CG). After all these years this principle still holds good and so we can apply it here.

In Fig. 2 the weight is constant and acts at the CG. The Lift (L) varies with angle of attack and is at the arm (l) behind the CG. The tail force (T) also varies, and is at the arm (t) from the CG.

In a stable airplane these factors act together to produce moments that will cause the airplane to recover from an inadvertent maneuver that might be due to a gust of wind such as encountered when passing through a thermal. This recovery must be accomplished "automatically" with no change in tail setting. So let's see if we can figure out how this might be done.

A moment is the product of a force times a distance (or sometimes an area times a distance). Thus, a large tail will produce a larger moment than will a small tail at the same arm. Or conversely, at a longer arm, a small tail can produce a moment equal to that of a large tail at a shorter arm, etc.

Let's call "stalling" or nose-up moments positive, and "diving" or nose-down moments negative and take another look at Fig. 2, a "free flight" glider, let's say, with no means of corrective control on our part, and see how it behaves as we move the CG back and forth.

The Lift (L) times its arm (l) produces a moment (L)(l) about the CG. The tail also produces its moment (T)(t) about the CG. Then to maintain level flight these moments must balance each other. If they don't the airplane will nose up and stall or nose down and dive. So, to sustain level flight at constant speed, (L)(l) equals (T)(t), or (L)(l)-(T)(t) must equal zero. To say it another way, the sum of the moments must be equal to zero.

In Fig. 2 we have things arranged so that the CG is forward of the Lift. Let's see if this works OK for stalls and dives. If we try a stall first, in Fig. 3 we see that Lift has greatly increased due to a large angle of attack, thus producing a much greater negative moment than it did in level flight, tending to push the nose back down. And because the attitude of the glider is now pointing up, the horizontal tail is forced upward by the relative wind to also produce a negative or diving moment, thus contributing further to recovery. So far, so good. Now let's try a dive.

If the nose drops about 3 degrees, the wing is at the angle of zero Lift, thus producing no moment about the CG, while the tail still produces a positive moment tending to push the nose back up where it belongs, as shown in Fig. 4.

Thus, we see that having the CG forward of the Lift produces a stable arrangement, providing recovery from both stalls and dives. At this point it might be well to put this information down on a graph. (Fig. 5)

Let's say that our glider maintains level flight when the wing is at 3 degrees angle of attack. Since we said that level flight means zero moment, then it is represented by point A, at the intersection of zero moment and 3 degrees angle of attack.

The approaching stall condition, let's say, was a 9 degrees angle of attack, and the moments were all negative ones, a condition shown at point B.

The dive condition at zero angle of attack was accompanied by the positive moment due to the tail. This condition is shown at point C. Thus, we see that with the CG forward of the Lift we have a stable configuration, and that a plot of moment versus angle of attack produces a curve having a negative slope. In other words, as the angle of attack increases, the moments must become more and more negative, acting sort of like a spring to restore equilibrium.

Now, just to be sure, let's try the other extreme and place the CG behind the Lift as shown in Fig. 6.

Here again, if the dive is assumed to be at zero lift, or an angle of attack of zero, there will be no moment other than that of the tail, and so this condition will duplicate our first dive condition and will also lie at point C on our chart.

In the level flight condition, however, as shown in Fig. 7, the moments don't reduce to zero, but become increasingly positive. The lift on the wing has increased and our tail setting is still such as to produce its positive moment, both conditions tending to raise the nose, placing the level flight condition (which now appears to be only momentary at best) at point A on our chart.

In Fig. 8, the relative wind on the tail will produce a negative moment, but it will be insufficient to overcome the large amount of positive moment produced by the wing at high angle of attack, and so the glider will stall. This condition will lie at point B on the chart. And so we see that having the CG behind the Lift is Unstable and produces a curve as shown by the dashed line. This curve has a positive slope and denotes Instability.

Neutral Stability occurs when the CG and the Lift coincide, acting in pure opposition, thus producing no moment. It is thus very sensitive to control, or lack of it, and will demand constant attention. This condition then, is analogous to our dive conditions, where the wing produced no moment about the CG because of zero Lift, and the only moment present was that due to the decalage producing a positive moment. So that a dive condition for neutral stability will also be plotted at C. And since the moment of the tail will remain unchanged, the Neutral Stability curve is simply a horizontal line originating at C. As can be seen, it is the line of demarcation between stability and instability.

Thus, it is clear that stability simply means placing the CG forward of the lift. Before going further, we had better pin down just what is meant by "the Lift."

If you were to hold a model wing having a symmetrical airfoil between your fingertips, placing a finger at 25% of the chord of each wing tip, and could run fast enough, you would feel the wing develop some lift and still maintain its attitude. If you had placed your fingers forward or aft of 25%, the wing would tend to rotate. This shows that there is a place along the chord on a symmetrical airfoil where there is no moment, or where the moments along the chord are in balance.

This point is called the Aerodynamic Center or AC, and is at 25% of the chord on most airfoils. For cambered sections, the 25% point is also the AC and is the point of constant, rather than zero, moment. For a wing alone, the Lift may be considered to act through this point, and if we were designing an airplane having only a wing, the CG would want to be placed forward of the 25% point for stability. (Disregarding the elevon.)

However, when the elevon, or as on our glider, a tail is present, then something equivalent to the AC, but representative of the airplane as a whole, must be considered as the point forward of which the CG must lie. This point is called the Neutral Point N, and its position is determined by the total moment produced by all the factors capable of affecting the trim of the airplane.

These factors include the destabilizing effects of power when the thrust line is below the CG, tending to push the nose up, the front end of the fuselage, nacelles, if any, horizontal stabilizer, etc. Factors which tend to produce positive moments and raise the nose are destabilizing and tend to move N forward. Factors such as flap deflection, fixed landing gear, floats or other items producing negative moments, are stabilizing and tend to move N aft.

The determination of N is a laborious process and involves detailed information about a specific design, so we can treat it here only in a very general way. The proper procedure is to evaluate and add together the slopes of the moment curves of the various items mentioned above to ascertain their total effect. Since we can't attempt all this here, we will treat the matter in a more simplistic, yet valid, I believe, manner by determining N as a simple problem in Statics.

If, for purposes of explanation, we assume a condition where the Neutral Point will lie at the resultant of the wing and tail, then by regarding them as weighted areas, where each will have a value proportional to its area times its unit loading, we can take moments and find the position of N.

In Fig. 9 is shown a plan view of the wing/tail configuration of our glider. We said the decalage is 3 degrees. If we assume the airplane to be at an attitude where the tail is at 1 degree and the wing is at 4 degrees, and that lift varies directly with angle of attack (which it does), then the wing will have a loading of 4 units (onces, grams, etc.) per sq. in. and the tail will have a loading of 1 unit. Thus, in Fig. 9, the wing will have a weighted area of 600 x 4, or 2400 units, and the tail will have 100 x 1, or 100 units. So taking moments about the AC of the wing:

Moment of Wing 2400 x 0 = 0
Moment of Tail 100 x 30 = 3000
2500(1.2) = 3000

And the arm to the Neutral Point is 3000/2500, or 1.2 inches aft of the AC of the wing. This places it at 2.5, plus 1.2 inches or 3.7 inches aft of the leading edge of the wing. Since the wing has a chord of 10 inches, this amounts to 37% of the Chord. This point, presupposing an up-load on the tail, is the most aft position of N. If there are destabilizing factos present, they will act to move this point forward. Let's look at Fig. 2 again and see if any exist.

The horizontal tail will now produce a positive moment. In addition, we have a generous nose section forward of the wing which lies on the induced upflow ahead of the wing, which will tend to produce a stalling or positive moment, particularly at high angles of attack. Also the drag of the veritical fin will produce a moment tending to push the tail down (the nose up) which is also destabilizing. Without attempting to establish values (which we said is laborious), let's assume that their affect will be such as to move the Neutral Point forward 4% or up to 33% of the chord. If we give ourselves a stability margin of 5% forward of that, our CG will lie at 28% of the chord for our glider.

If the tail is larger, or the tail arm longer, the Neutral Point will be further aft and will thereby permit a further aft CG. For example, some free-flight powered models are seen with CG locations way back, at or near the trailing edge of the wing. How come?

If the decalage is reduced, the tail made very large, the tail arm very long, with maybe a lifting airfoil for the tail (which is normally of no value), and if the fuselage is very slender and the nose very short, with maybe an inverted fin, it is possible to push the Neutral Point aft far enough to have it aft of the trailing edge, and thus obtain stability even with the CG at the trailing edge of the wing. But such an arrangement can get pretty touchy and demand considerable fine tuning when no control is available.

Now, let's fatten up the fuselage on our glider and put an engine in it keeping the same wing and tail, as shown in Fig. 10. In addition to the destabilizing effects we had as a glider, we have some new ones.

1) The engine thrust is below the CG and will produce a nose-up moment which is destabilizing tending to move N forward.

2) The propeller slip stream increases the downwash over the tail, loading it up more, pushing the tail down (nose up) which again is destabilizing and pushes N further ahead.

3) The fatter fuselage is presenting greater area into the upflow ahead of the wing (more instability). N moves forward again.

4) The fixed landing gear is stabilizing. It tends to pull the nose down and cancel the effects of the other items to some extent.

The net result then, for most scale models of similar basic configuration is that the Neutral Point usually winds up at of very close to 30% of the chord of the wing. Thus, a good, safe and comfortable CG location is about 5% forward of the 30% Neutral Point or 25% of the chord.

So now we understand why the CG is forward for beginners and can be further aft for experts. As a matter of fact, I have several models, all balanced at approximately 25%, and it tickles me to see the little birds recover nicely from a stall, and be generally forgiving of my mistakes in controlling them. Many fliers don't seem to pay all that much attention to CG location. They just balance the airplane at "about a third of the way back" as they put it, and seem to do fine. This is because they are pretty good fliers who, I would guess, may be struggling against some instability without realizing it. The way to be sure, of course, is to test fly your model at varying CG locations. Move the CG forward a little bit at a time until it's hard to get the nose up so you can slow down for a landing, then move the CG aft in small increments until it becomes sensitive and skittish. Ease back a little at both extremes and let these be your limits. But for beginners, CG location of 25% of the chord is a good place to start.

Part II

We have been expressing the CG location as a percent of the chord because we have used a constant chord, rectangular wing for our example. Not all airplanes are made this way, of course. For a rectangular planform, one having no taper, the chord is constant. But what about a tapered wing as on a Mustang, or the elliptical wing of a Spitfire, or the delta shape of a Mirage? What about flying saucers? And what about biplanes?

If we assume that a wing is uniformly loaded - that the Lift is evenly distributed over its surface - the lift may be regarded as acting along a chord lying at the center of the area of each wing panel, so that the resultant total ligt from both panels lies on the center line of the airplane as shown in Fig. 1.

For wings of high taper or sweepback, and where the tips are square rather than rounded, the assumption of uniform loading may not be quite true, but when it is not, the disparity is small and is usually neglected, so that the usual criterion is as just mentioned; that the lift acts along a chord at the center of area, or centroid of each wing panel. Such a chord is called the Mean Aerodynamic Chord or MAC. It is along the MAC that we must balance our airplane. While often shown on plans as being on the chord line of the wing, the CG is rarely so disposed vertically. On high-wing models, the CG is below the wing and on low-wing models the CG is above the wing. But this is of little consequence as far as longitudinal stabilty goes. The important thing is to have the fore and aft position of the CG properly located.

For a straight wing of rectangular planform, placing the CG at the quarter-chord point is not a problem, but if the wing is swept or tapered or both, it is essential to accurately determine the length and position of the MAC if the airplane is to be correctly balanced.

The MAC is sometimes confused with the average chord. The average chord is the wing area divided by the span and always lies halfway out along the semi-span of the wing. The MAC varies in length with taper ratio and is at the mid-point of the semi-span for a rectangular wing only. If moves inboard waith increasing taper until, for a delta wing (which has infinite taper), it lies at 1/3 of the semi-span, as shown in Fig. 4.

Now let's find the MACs for the wing shapes mentioned in the beginning:

For a rectangular planform the MAC is the average chord and lies halfway out along the semi-span as shown in Fig. 2. For tapered planform the MAC can be found graphically by adding the root chord to the tip chord, and the tip chord to the root chord and drawing a diagonal whose intersection with the 50% chord line determines the centroid of the panel. This graphic method should be accurate enough for models, however, if more precision is desired, the MAC and its lateral and longitudinal positions may be calculated from the relationships shown in Fig. 3. As long as the span is held constant, the effect of sweepback is to increase m while d is unchanged. Getting back to the delta wing shown in Fig. 4, it is convenient to know that the MAC is always 2/3 the length of the root chord C, and m is always 1/3 of C. Further, the 25% point of the MAC coincides with the 50% point of the root chord. Note that for tailless designs, the CG is at 20% MAC.

Before going further it should be emphasized that in general, (unless the fuselage is extremely large or very dirty aerodynamically, or in the case of the lower wing of some biplanes) the effect of the fuselage on the lift distribution over the span of the wing is negligible, so that the lift developed by the wing, and therefore, the position of the MAC, may be considered to be the same whether the wing has a fuselage attached to it or not.

Ellipses and circles are members of the same family. Thus, Spitfires and flying saucers are of the same parentage. (If you hold up a coin and view it square on, it is a circle, but when turned sideways it is an ellipse.) So the spanwise position of the MAC is the same for both as shown in Fig. 5. Even when the planform consists of a fuller ellipse aft of the quarter-chord line than the one forward, the spanwise location is the same for both.

For odd shapes, such as butterfly-wing planforms, etc., the simplest procedure for finding the MAC is simply to draw the panel on a piece of cardboard, cut it out and balance it on a triangular scale or a table edge. Balance it a least three times, marking it each time. The marks will intersect at the centroid of the figure, and the MAC may usually be regarded as the length of the chord through that point.

Sometimes wings have a center panel with outer panels as shown in Fig. 6. The MAC of such an arrangement is found by taking moments of the areas of both panels and solving for "d."

The moment of the center section from the center line of the airplane is its area times d', or d'Sc.

The moment of the outer panel is its area times d", or d"Sp.

The total wing area S equals Sc + Sp. So;. dS = d'Sc + d"Sp and d = (d'Sc + d"Sp) / S.

For models, the MAC length is simply the chord between the dashed lines in Fig. 6. Again, if greater precision is desired the length of the MAC is: MAC = Cp + ((Cc - Cp)(d" - d)) / (d" - d'), where Cp = MAC of outer panel (see Fig. 3).

Cc = MAC of center section (see Fig. 2).

But for models, graphical methods should be adequate, since you can probably draw these relationships more accurately than you can build them anyway.

This configuration is found on the AT6 Texan, the PBY flying boat, many gliders and on the upper wing of some biplanes. I am sure that I have overlooked other arrangements, but I can't think what they might be, so let's go on and take a look at biplanes.

These wonderful airplanes became extinct before my time and so anything I have to say about them is probably presumptuous. But their wealth of detail, character and realism make them ideal subjects for models, so let's have a critical look.

While not always the case, the upper wing is often mounted forward of the lower wing, sometimes with greater incidence to make it stall first, thus contributing to recovering as mentioned in Part One. The upper wing flies in somewhat less disturbed air which contributes to greater efficiency, so that it often carries the greater share of the load. The lower wing is more affected by disturbances generated by the fuselage and its protuberances and by the landing gear. The interplane struts also are more disruptive to the flow over the lower wing.

Aside from the fact that the biplane is dirty aerodynamically, it has the additional disadvantage that it is inherently less efficient than a monoplane having equivalent area. This is due to so-called "mutual interference" where the high-pressure region under the upper wing is rendered less effective by the proximity of the low-pressure region above the lower wing, and vice verse - the low-pressure region above the lower wing is at a higher pressure than it would be otherwise. Many early designers realized this, and men such as Bleriot stuck to monoplanes, albeit pretty "dirty" ones, draped with lots of wire bracing.

The biplane configuration was selected by early designers to enable them to build a light, strong structure with available materials. The biplane is just a truss.

The Nieuport biplane has a large upper wing while the lower wing is relatively small, particularly the chord. Why this is so, is open to conjecture. I suspect that the designer, aware of the inherent shortcomings of the lower wing, decided to minimuze it, but nevertheless keep it, so he could use it at the bottom of his truss.

Before we can go furhter, we must learn some biplane terminology.

Decalange: In the case of biplanes, decalage is the relative incidence between the upper and lower wings. Since biplanes are no longer built, the term has been used more recently to describe the relative incidence between the wing and tail, as discussed in Part I.

Gap: The vertical distance between the leading edges of the wings.

Gap/Chord Ratio: The gap expressed as a percent of the chord. If the wings are tapered, or have unequal chords, the chord is the MAC of the pair.

Stagger: The positioning of one wing forward of the other. If the upper wing is forward of the lower wing, the stagger is positive. If the lower wing is forward, as on the Beechcraft Staggerwing, the stagger is negative.

Fig. 7 shows the simplest case where there is no stagger, no decalage, and the wings are of equal area. The MAC is, therefore, equal to the chord of either of the wings and lies vertically halfway between them if the loading on each wing is the same. However, as we mentioned earlier, the upper wing will carry a larger share of the load and the vertical position of the MAC will be somewhat closer to the upper wing. Since there is no stagger, the fore and aft position will be the same as that of the wings themselves, and the CG location will not be affected by the vertical position of the MAC.

In Fig. 8 the wings are again identical with no decalage. However, this time we have some positive stagger. This will tend to load up the upper wing for sure, in an amount depending on the degree of stagger, and also in inverse proportion to the Gap/Chord Ratio. Because of the stagger the horizontal position of the MAC will now be influenced by the vertical position.

If the wings differ in area, (the upper wing larger) then the MAC position will move upward and forward further still, and if there is decalage the upper wing will further influence the MAC position. Thus, the determination of the MAC length and position for a biplane is complex, because so many factors are involved.

Fig. 9 shows the method for determining the MAC of a biplane where no decalage is involved, and should be adequate for most modelers' use. It is purloined from an old aerodynamics text, "Elements of Practical Aerodynamics," by Bradley Jones, published by John Wiley and Sons. My copy is the third edition, printed in 1942. I don't suppose it is still in print, but if you run across a copy, buy it if you want a clearly written and understandable, yet thorough treatment of the subject of the fundamentals of aerodynamics covering sub-sonic, propeller-driven aircraft.

Looking at the sub Fig. 94 in Fig 9 showing reltive loading versus stagger, we see that, for the condition shown in Fig. 7, where the Gap/Chord Ratio is unity and the stagger is zero, the upper wing is loaded to 110% of that of the lower wing, due to mutual interference alone, and solving for the MAC position, g, will determine the vertical position we were just speculating about. The condition shown in Fig. 8, where we have 10 degrees of stagger and the same Gap/Chord Ratio of unity, runs the relative loading, e, on up to 118%, and will drive the MAC higher and further forward considerably.

A further approximation of my own account for decalage would be as follows: before solving the expression in Fig. 9 for the MAC, multiply the upper wing area, Su, by (1.08)exp n. Where the exponent "n" is the decalage in degrees. Thus, if the upper wing has, say, 1000 sq. in. of area and there is an angular difference (decalage) between the incidence of the two wings of 2 degrees, then multiply Su (the upper wing area) which is 1000 sq. in. by (1.08)exp 2 or 1.17, so that Su will become 1170, and use this value to solve for the MAC. This is because for most wings the lift increases at a rate of about 8% per degree increase in angle of attack. (Which in this case amounts to the decalage.)

This, then, should enable you to determine the MACs of the various configurations we have dicussed and thus pinpoint precisely where the 25% MAC position--CG location--will be. Now that we know exactly where the CG belongs, how can we be sure that it will wind up there on our big quarter-scale model that is still on the drawing board?

In Part III's exciting climax we will dicuss how to figure the balance of the airplane while it is still on the drawing board and a gleam in your eye, thus saving us the expense of lead ballast.

Part III

Most airplane factories have a huge room full of engineers who sit at big drafting tables designing landing gears, wing ribs, engine mounts, fuselage bulkheads, etc. Periodically, usually every day, each designer is approached by one of many "Weights Engineers" whose job it is to keep track of how much things weigh and where they go.

Weights engineers wem to have a built-in resistance to adding anything or making changes which will add weight. They are also sort of sneaky. If a designer wants to add a bracket to support an autopilot, let's say, and estimates it to weight 1.5 pounds, the Weights Engineer will probably convince him that 2 pounds is a more realistic figure. If the designer later finds that he can do without the item, the Weights Engineer will usually begrudgingly give he back only a pound and a half.

Actually, of course, there are thousands of items in an airplane and if a very close and stingy policy regarding weight were not followed the airplane could wind up being seriously, or even disastrously overweight, because an airplane is designed to a stipulated Gross Weight which is made up basically of two parts: the Weight Empty and the Useful Load.

Since, for stuctural and performance reasons, the Gross Weight must be held, any overweight items making up the Weight Empty will reduce the Useful Load. The Spruce Goose was a classic example of this. The poor choice of material (wood) for a large airplane demanded so many upward revisions of the original weight estimate that finally nothing was left for Useful Load. So, if the weights engineers seem tight-fisted, they have good reason to be that way. And this is a good way for modelers to think also. John Preston wrote an article (MA, Jan 1978) praising the virtues of keeping the weight down and with this there can be no valid argument.

Now let's take a look at what these "Weights Engineers" are up to. It is their job to keep a running tab on the weight, and equally important, to keep watch on distribution of the weight to be sure that the CG limits are not exceeded. Now how can they do this while design is still on paper?

Fig. 1 shows a sawhorse supporting a teeter-totter with two pounds of butter on one side balanced by on pound on the other. It's easy to see that one pound of butter will balance two pounds of butter if it is placed further from the support point. (Ignoring the weight of the teeter-totter itself.) In fact, the product of the weight times its distance or "arm" from the support point is called its "Moment," because of its relative importance--as a matter of great moment, or momentous. Not because it bears any relation to a moment of time.

The basis for balance then, is simply that the moments produced by each of the two objects about the support or balance point must be equal. Thus 2 lb. x one foot, equals 1 lb. x two feet; or 2 ft.-lb. equals 2 ft.-lb. If we assign positive values to the moments on one side of the support point and negative values to those on the other side, then 2 ft.-lb. + (-2 ft.-lb.) = 0, and satisfies the basic definition of Equilibrium, that the sum of the moments equal zero. Now let's put an extra pount of butter on the right-hand side and see where our two-pound package must move to balance, as shown in Fig. 2.

Adding the extra pound on the right side moves the two packages on the left side over a bit away from the support, as we knew it would. We can do this in still another way. We can place our sawhorse off to one side and call it our "Reference Line" and let the moments act in opposition Up and Down, as shown in Fig. 3.

This is simply another way of expressing the same set of conditions as those shown in Fig. 2. Using this method, we can run a continuing Weight and Balance Summary of the butter together with a couple of bottles of milk, plus a dozen eggs, if we want to. In fact, we could even keep a running balance on a model airplane this way, I'll bet!

Before going further, we should probably digress for a bit and be philosophical. On a real airplane even the smallest parts (with the exception of the rivets--which are allowed for, along with the paint, in a general way) must be accounted for, because their total effect is important. On the other hand, if you are building a kit, or even if you are designing from scratch, it is unreasonable and impractical to account for each of maybe a hundred small fuselage parts in order to estimate the weight and the balance of the fuselage, or of the wing, or even of the tail. So following the plans, these items should be built to rough completion, weighed on a bathroom or baby scale and balance on your finger or a string to find the weight and CG of these major items. Then the CG of each item should be accurately marked on the plans.

While real airplanes begin with a fixed Gross Weight, it is of no consequence really, if my quarter-scale Concept Bipe has a fuselage which weighs a few onces more or less than yours, or if my final gross weight is not quite in agreement with the one mentioned in the instruction book, so long as it is in the ball park. I do want it to fly. (End of philosophical section.)

So, let's say you are building a kit and have indicated with small pencilled notes and crosses the CGs of the fuselage, wing and tail together with their weights, accurately in a fore and aft direction--along the thrust line if you wich. The vertical locations aren't critical.

If the plans show servo and receiver locations and you know where you wish to place the battery or batteries, cameras, smoke generators, etc., and of course, the engine and landing gear, now is the time to weigh these items and mark their weights on the plan. In fact, at this point you should start a Weight and Balanc Sheet as shown in Fig. 5.

In order to do this it is necessary to establish an arbitraty "reference line" as in Fig. 3, from which the moment arms of all the items can be taken. This line can be the center line of the propeller, or an inch or so forward of it. Its location has no effect on the balance, but keeping it, once chosen, is important. Our model, like a real airplane, has both a Weight Empty condition and a full Gross Weight condition. Even if the payload consists of only fuel, this must be placed on, or near, the CG so that its depletion will not cause a serious shift in balance. This is equally true of course for all removable or disposable items.

If you have a spring-loaded pilot who upon command, pops out of a seat way to the rear and makes a spectacular parachute jump, it's just possible that the airplane will be thrown off balance by so much that it will make a nose-first landing while he is still floating high in the air. So cameras, bombs, etc., which are either dropped or only used occasionally, should be placed at the CG, like the fuel, if possible. Otherwise, their effect on the CG should be determined as we will discuss further on.

Fig. 4 shows an Inboard Profile for a hypothetical model that looks something like a Cessna. Off to the left is placed a zero reference line, arbitrarily placed 20 inches forward of the leading edge of the wing at the root.

Let's assume that we have carefully figured our MAC and its location based on a planform similar to Fig. 6 in Part 2. The leading edge of the MAC is at Station 20.75" aft of the Reference Line, and the MAC is 12" long. The model is to weight approximately 20 lbs. with full fuel and a movie camera payload. We have built the wing and fuselage, leaving ourselves room to do further work in the way of installing the radio, etc. We have weighed all the items to be installed and have indicated on the drawing where we plan to install them; the prop and spinner weigh 4 oz. and are at Sta. 10", etc.

Fig. 5, our Weight and Balance Sheet, enables us to ascertain our final weight as well as to determine the Balance. The weights of all the items in the Weight Empty condition add up to 270 ozs. or 16.875 lbs. Adding 1 lb. of fuel and our movie camera, complete with film at 34 ozs., brings the Gross Weight up to 20 lbs. (320 ozs.).

Now let's have a look at how the airplane balances. Being good conscientious designers we have been honest and conservative in our figures, thus assuring believable answers. This is the only sensible attitude to have. If something weighs 6 ozs., that's what its weight allowance on you sheet must show, or even a little more to allow for support, wiring, etc. If you are conservative, things will come out pretty well. If you don't make the proper allowances both for weight and space as well, problems invariably ensue. This isn't to morilze. This is just the way it works.

In Fig. 5, the sum of the moments for the Weight Empty condition adds up to 6400 in. oz. Solving for arm a gives, a = 6400/270 = 23.70". This is the distance of the Weight Empty CG from our Reference Line. To express the CG in terms of the MAC, we subtract the distance from the Ref. Line to the LE of the MAC and then divide by the length of the MAC: CG = (23.70 - 20.75)/12 = 2.95/12 = 24.6% MAC. Since we are shooting for 25% MAC this is very good indeed. No need to try to improve this since it is well within our Stability Limits of about 22% for the forward limit based on good control, and the aft limit for Stability of about 30%.

Now, if we add the fuel and the movie camera payload, the CG shouldn't change much since we located them on the desired CG location of 25% (Sta. 23.75). So the Gross Weight adds up to 320 ozs. (20 lbs) having a total moment of 7587.5 in. oz. As shown, this gives a CG location of 24.66%, essentially the same as the Weight Empty condition as we expected. So it appearts that we are in good shape and won't need to add any ballast or rearrange things.

But suppose the balance had been at, say, 27%, which is an acceptable CG location--but we are perfectionists and want to keep our good 5% stability margin. How do we figure what to do to bring it 2% forward?

The Gross Weight of 20 lbs times the MAC of 12" is 240 in. lb. of work and represents 100% CG travel, the equivalent of moving the total weight the full length of the MAC. A percent ofCG times travel then, is one percent of 240 in. lb. or 2.4 in. lb., which is the same as 38.4 in. oz. So a 2% shift in CG amounts to 2 x 38.4 or 76.8 in. oz.

The two tail servos at M weight 6 oz. Their support structure will weigh about 2 oz. We can move them about 6" forward before we get involved with the solid bulkhead that picks up the landing gear load. So by moving these servos forward, we pick up (6 + 2) oz. x 6" = 48 in. oz. So we still need to do more juggling of equipment to pick up the difference of 76.8 - 48 or about 29 in. oz., if we are going to achieve our shift of 2%. This can probably be accomplished by moving the receiver and the throttle servo forward as far as possible, or placing the servos forward of the bulkhead. Under no circumstances should we move the fuel tank or the camera mount away from the CG if it can be avoided.

Now, let's suppose that the CG is 5% aft of where we had hoped it would be, say, at 30% MAC. This would require extensive changes of almost 200 in. oz. and would cause serious practical problems. What do we do?

If we aren't too far along in construction, the simplest answer is just to move the wing 5% aft. This amounts to 5% x 12" or .6 of an inch. If this can't be done, say, because of the windshield structure or something, the next best solution is to sweep the wing in such a way that the MAC is moved .6" aft. Moving the wing such a small amount has a very powerful effect on the balance while the effect on the tail arm is negligible. Sweepback should be held to a minimum however, since too much can cause tip stall problems.

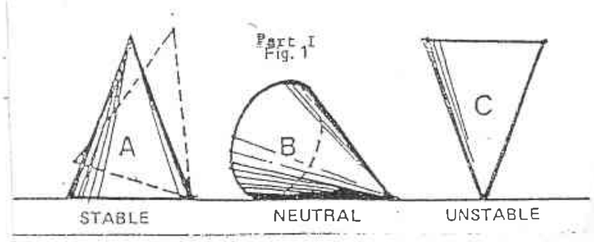
If you are building a scale model of a Jenny or a Sopwith Camel, you will certainly have balance problems since the proportion of engine weight to total weight on the model is much less than for the real airplanes, and as a result, because of the short nose, the model will tend to be quite tail-heavy if faithfully scaled down. Since we purists can only regard lead ballast as a sacrilegious last resort, what can we do in a case like this?

First, examine all the details aft of the CG and reduce, sand and even remove all that is oversize or redundant, by whittling and sanding, etc., particularyly well aft, near the tail.

Second, beef up the engine mounts real good , add reinforcement here and there, forward of the CG. And if this isn't enough, now is the time to add a D cell to heat the glow plug, or a smoke generator, or a relly effective muffler. If this still doesn't do it, try a brass boat flywheel under a heavy metal spinner. (Even on a Jenny you have to have a spinner for the starter to engage, don't you?) And if the worst comes to the worst, get some lead fish weights (but bury them in Epoxolite...as I do so nobody will find them).

A handy kink that I have found useful is to place a small screw in some blocking at the 25% MAC point in the bottom of each wing panel. The projecting screw head serves as a guide for your fingers so you can lift the airplane at these two points and make a final balance check. If the airplane remains level when supported in this fashion, then it is properly balanced.

I hope this series of whys and wherefores of the CG has been of interest. I would like to hear from those of you who may have some topic you would like to have me try to cover--if I feel qualified to do so. Otherwise, the editor and I will conjure up subjects that seem to need some light thrown on them.


Part I Fig. 1

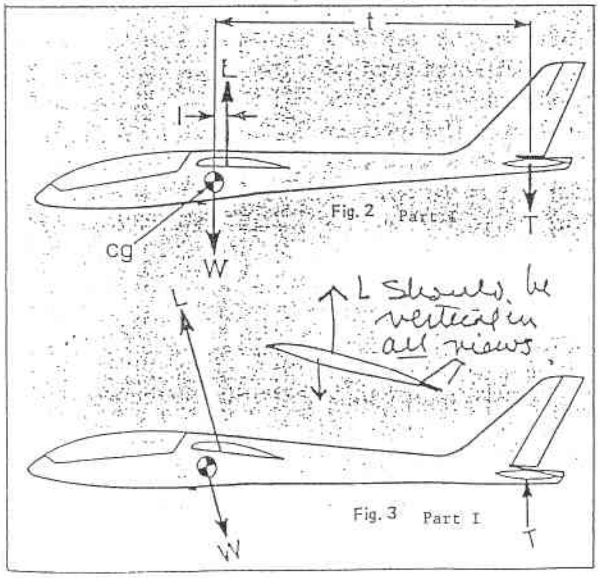


Fig. 2 Part I

Fig. 3 Part I

Part I

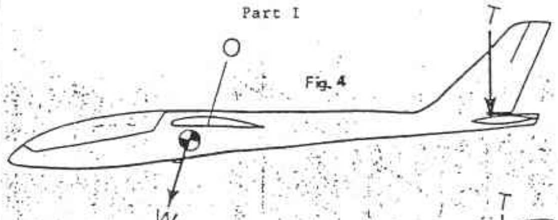


Fig. 4

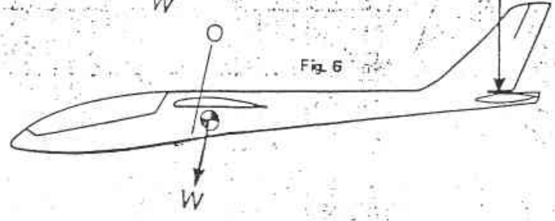


Fig. 6

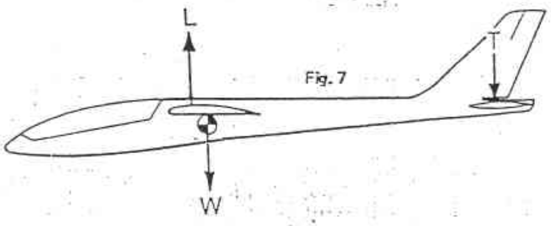


Fig. 7

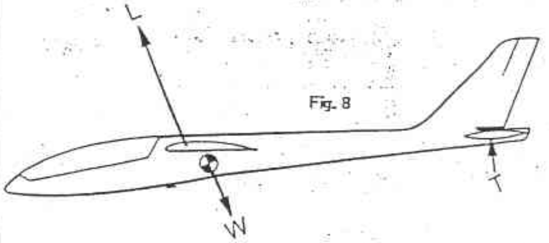


Fig. 8

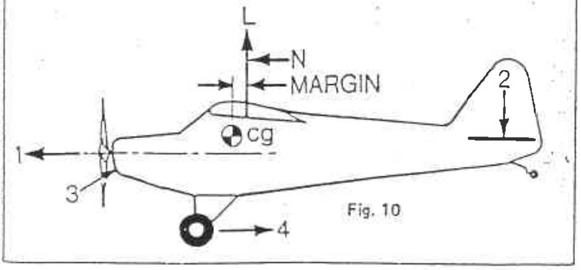


Fig. 10

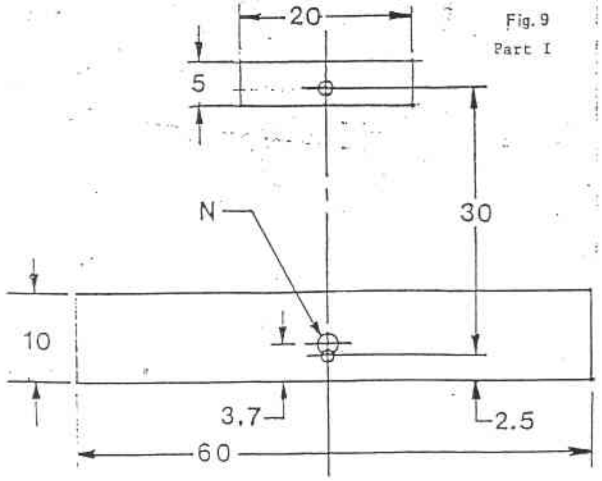


Fig. 9 Part I

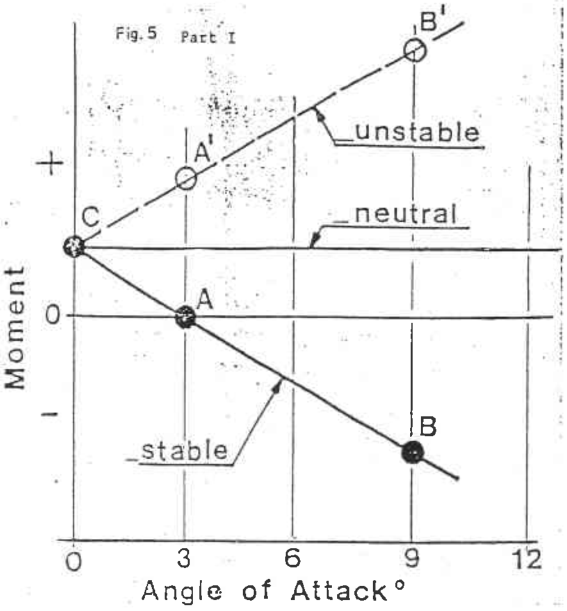


Fig. 5 Part I

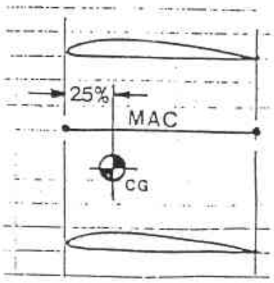


Fig. 7 Part II

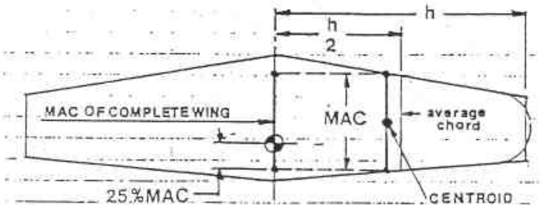


Fig. 1 Part II

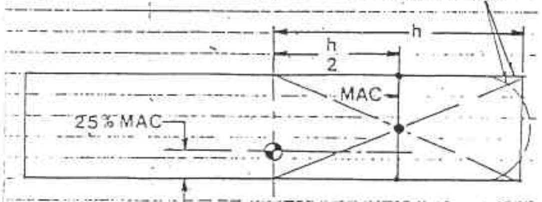


Fig. 2 Part II

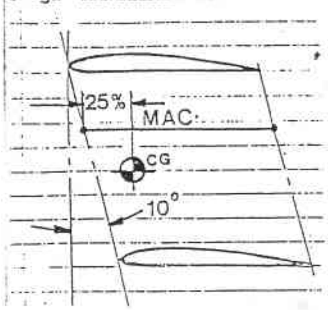
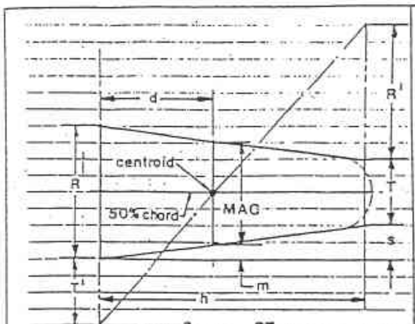


Fig. 8 Part II



$MAC = \frac{2}{3}\left(R+T-\frac{RT}{R+T}\right)$

Fig. 3 Part II

$d = \frac{h}{3}\left(\frac{R+2T}{R+T}\right)$

$m = \frac{ds}{h}$

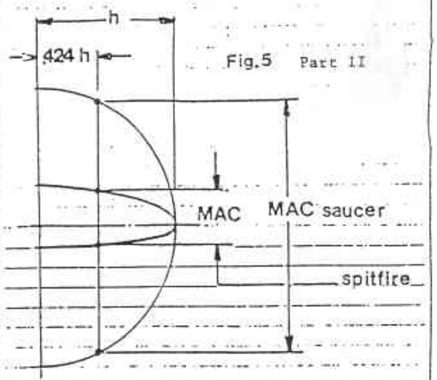


Fig. 5 Part II

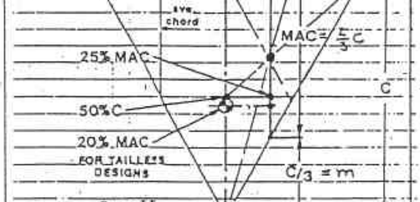
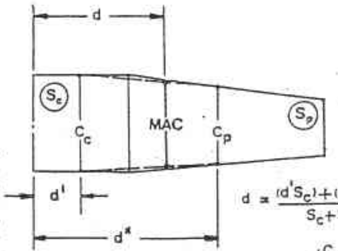


Fig. 4 PartII



$d = \frac{(d'S_c)+(d''S_p)}{S_c+S_p}$

$MAC = C_p + \frac{(C_c-C_p)(d''-d)}{d''-d'}$

C_c = (See FIG 2)

C_p = (See FIG. 3)

Fig. 6 PartII

For biplanes, the M.A.C.'s for the upper and lower wings are found separately. The length of the M.A.C. of the biplane is

$$\text{M.A.C.} = \frac{eC_US_U + C_LS_L}{eS_U + S_L}$$

S_U = area upper wing
S_L = area lower wing
C_U = M.A.C. upper wing
C_L = M.A.C. lower wing
e = relative efficiency of upper wing (see Fig. 94)

Fig. 9
Part II

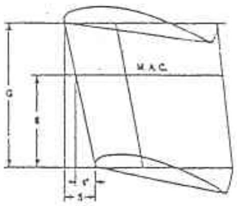


FIG. 93. Mean aerodynamic chord of biplane.

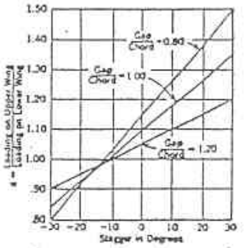


FIG. 94. Relative wing loading in a biplane.

The relative loading e of the upper wing as given in Fig. 94 is only approximate but may be used for all angles of attack. For accurate work N.A.C.A. Report 458 should be used.

The vertical distance of the leading edge of the M.A.C. of the biplane above the leading edge of the M.A.C. of the lower wing is g, where

$$g = G\frac{eS_U}{eS_U + S_L}$$

G = gap

The horizontal distance of the leading edge of the M.A.C. of the biplane ahead of the leading edge of the lower M.A.C. is s', where

$$s' = \frac{sg}{G}$$

s = horizontal distance between upper and lower leading edges

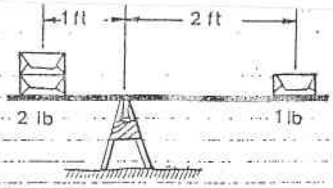
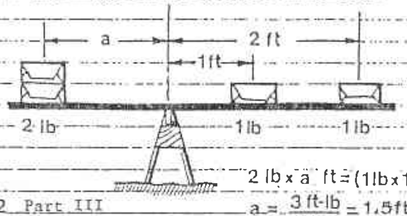


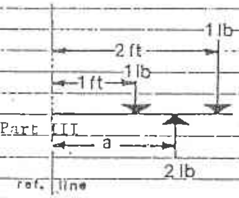
Fig.1 Part III



$2\text{ lb} \times a\text{ ft} = (1\text{lb} \times 1\text{ ft}) + (1\text{lb} \times 2\text{ ft})$

Fig. 2 Part III

$a = \frac{3\text{ ft-lb}}{2\text{ lb}} = 1.5\text{ft}$



weight	arm	moment
1 lb	1 ft	1 ft-lb
1 lb	2 ft	2 ft-lb
2 lb	a	3 ft-lb

a = 1.5 ft

Fig. 3 Part III

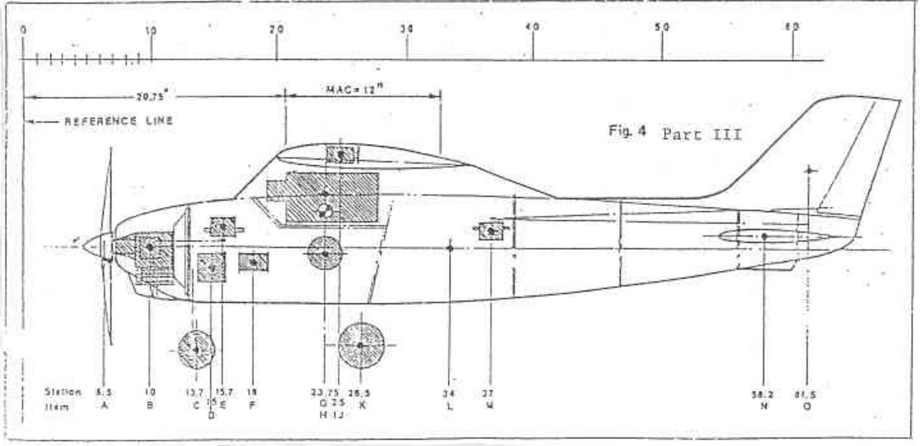


Fig. 4 Part III

Fig. 5 Part III

WEIGHT AND BALANCE SUMMARY

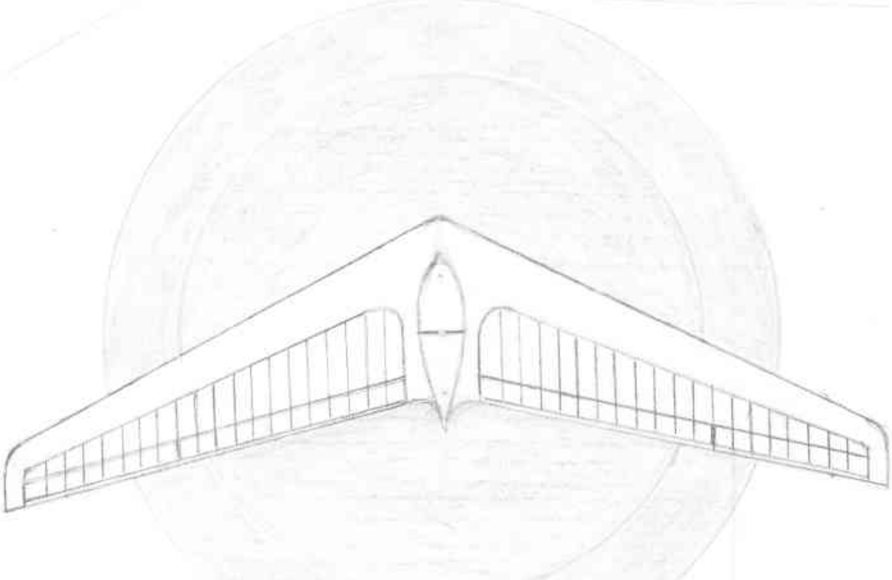
	ITEM	WEIGHT-OZ	ARM-IN.	MOMENT OZ-IN.
A	Prop and Spinner	4.0	6.5	26.0
B	Engine	88.0	10.0	880.0
C	Nose Gear	6.0	13.7	82.4
D	4 "C" Nicads	8.0	15.0	120.0
E	Throttle Servo	3.0	15.7	47.1
F	Receiver	6.0	18.0	108.0
G	Fuel Tank	3.0	23.75	71.25
H	Movie Camera Mount	3.0	23.75	71.25
I	Aileron Servo	3.0	25.0	75.0
J	Wing	50.0	25.0	1250.0
K	Main Gear	10.0	26.5	265.0
L	Fuselage	62.0	34.0	2108.0
M	Tail Servos (2)	6.0	37.0	222.0
N	Horizontal Tail	10.0	58.2	582.0
O	Vertical Tail	8.0	61.5	492.0
	WEIGHT EMPTY	270.0	(23.70)	6400.0

$$CG = \frac{23.70 - 20.75}{12} = 24.6\%\ MAC$$

USEFUL LOAD

	WEIGHT-OZ	ARM-IN.	MOMENT OZ-IN.
Fuel, 1 pint	16.0	23.75	380.0
Movie Camera	34.0	23.75	807.5
GROSS WEIGHT	320.0	(23.71)	7587.5

$$CG = \frac{23.71 - 20.75}{12} = 24.66\ \%\ MAC$$



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This is his proposal for a TWITT logo and would appreciate any suggestions or comments.