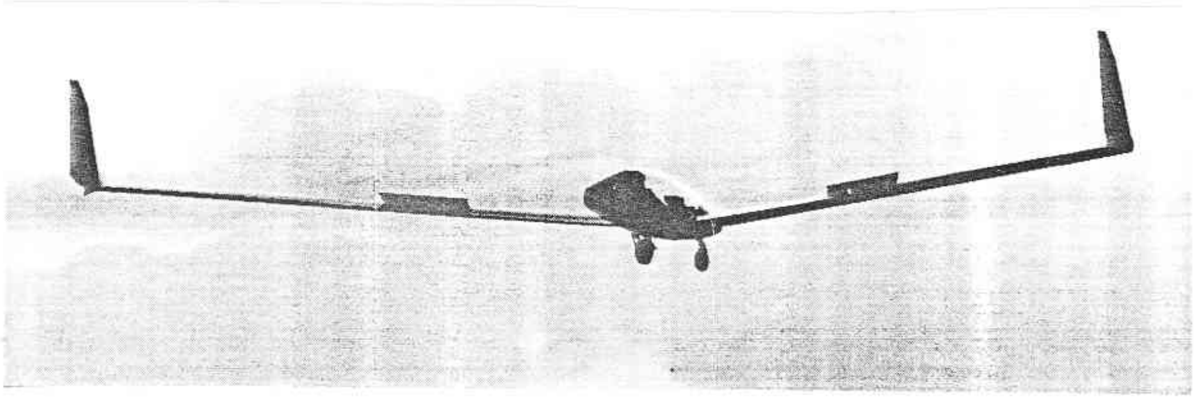
NUMBER 23 MAY 1988

TWITT NEWSLETTER



TWITT
(The Wing Is The Thing)
PO Box 20430
El Cajon, CA 92021
USA

NEXT TWITT MEETING: Saturday, 21 May 1988, beginning at 1330 hours. As always, the location is Hangar A-4, Gillespie Field, El Cajon, California.

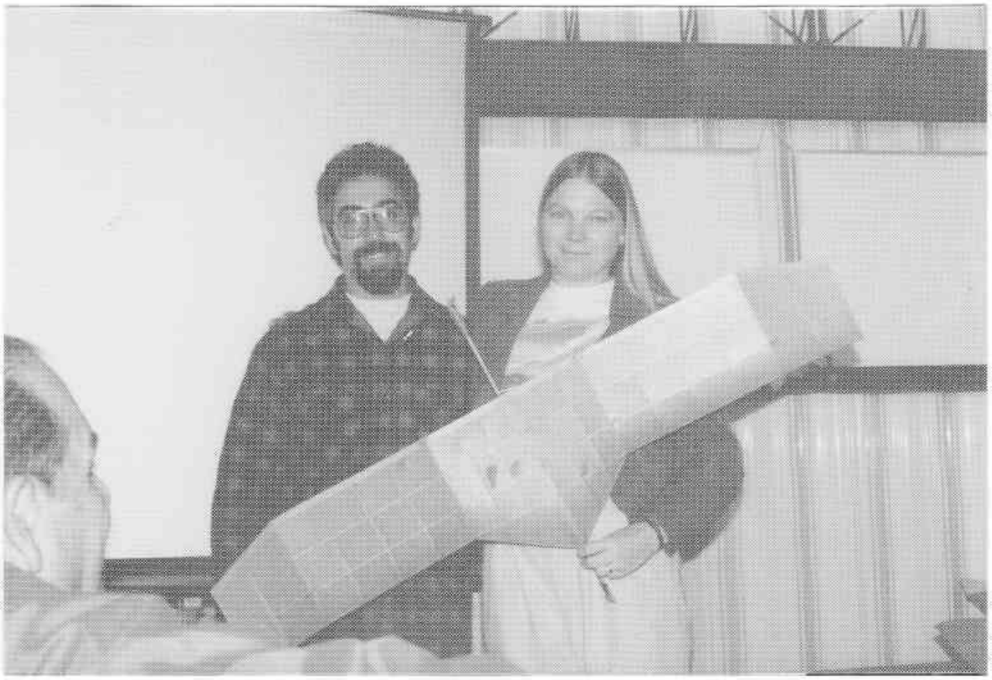
CONTENTS

MINUTES OF TWITT MEETING, 16 April 1988

BOB FRONIUS opened the meeting by pointing out that the glider wing that he uses as a notice board is now nearly full—a wing span extension will soon be needed. The Sailplane Homebuilders Association (SHA) needs speakers for its annual meet at Tehachapi during Labor Day weekend. The last meet had four flying wings in various stages of construction and operation. Flying wing enthusiasts are especially welcome, and more flying wings are expected this year. Contact Bob and June if interested. The Vintage Sailplane Association (VSA) will meet at Sailplane Enterprise in Hemet, California on May 28 and 29, 1988. Johnny Robinson, holder of the world altitude record [presumably for sailplanes—Ed.], will be the featured speaker. Flyers available at the TWITT hangar. Bob also mentioned a publication which TWITT Ed Lockhart receives called *Flypaper*, devoted entirely to the craft of building and flying paper airplanes, among which flying wing designs are heavily represented. A letter has been received from Prof. Dr. Karl Nickel at the University of Freiburg—the SB-13 has flown! [Tasso Proppe has summarized some technical information provided to us in German; it appears elsewhere in this issue—Ed]. Bob then introduced FORTUNATO "Tuto" FIGUEROA, who reminded the gathering that Air/Space America is holding its first air show at Brown Field May 13-22. Three hundred companies have agreed to exhibit there. Exhibits will include a giant Russian transport airplane. A/SA hopes to produce a show that will be a strong rival to Farnborough and Paris, but needs volunteer help in achieving that goal. Call A/S America or "Tuto" himself to volunteer. Tuto also noted in passing that a Concorde will be there and will make several "local" flights out over the Pacific to Hawaii and back without landing, a nice two-hour hop to give passengers a taste of Mach 2. BRUCE CARMICHAEL then rose to introduce the featured speaker, BARNABY WAINFAN. Bruce noted that Barnaby had completed his Masters at the University of Michigan under Prof. Edgar Lesher 1/3 of a century after he, Bruce had been Lesher's student. Presently a senior engineer at ACA Industries working on Joined Wing configurations, he had previously worked for Northrop and Lockheed as an aerodynamicist concerned with configuration design and the design of transonic airfoils. Readers of *Kitplanes* magazine would no doubt know him for his series of articles on airfoil sections. Barnaby has a talent for simplifying the presentation of complex concepts. His model airplane designs have appeared in *Model Builder*. He is a private pilot licensed for single-engined land planes and for gliders. BARNABY WAINFAN then took the floor, explaining that his motive in becoming involved with flying wings is that he does not believe anything until he does it himself. Since 1979 he has been working on flying wing models with the goal of making them competitive with conventional models, a pursuit made all the more rewarding because of the number of people who said it was impossible. He flies indoor free-flight with a club in Burbank which meets monthly. Barnaby noted that there were no competition classes designed for flying wing models, but many in which they are specifically forbidden, e.g. RC racing, where only flying wing designs could win unless they were specifically excluded. In FF they are not specifically excluded, but are handicapped by recent rule changes which place no limits on tail area, so Barnaby created the Hawthorne Flying Wing class for club competition, named after the place where the Northrop flying wings were built. The class requires:

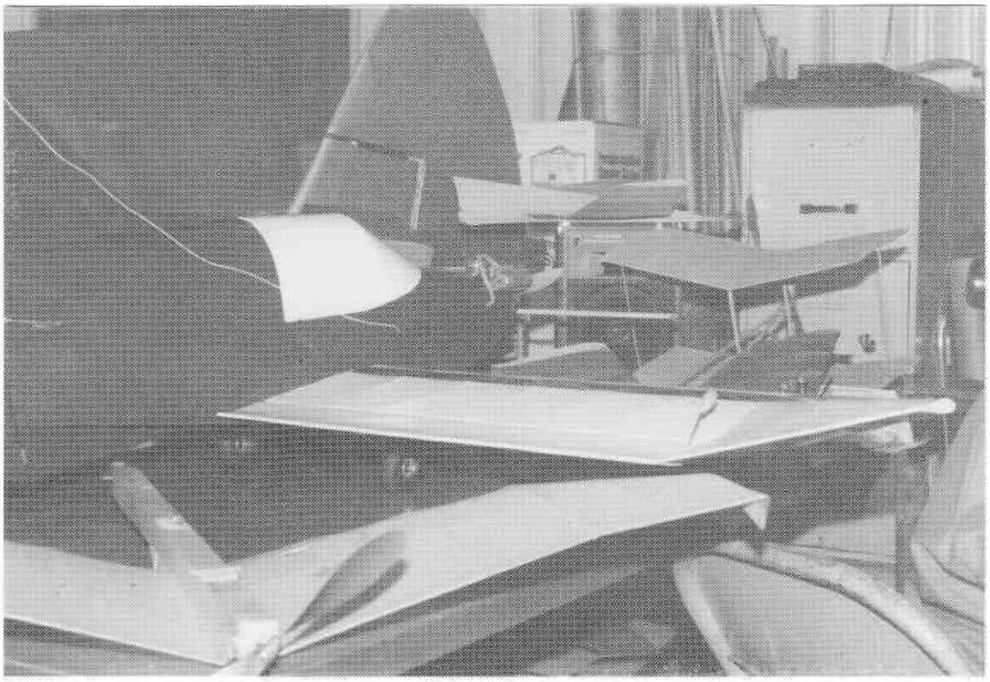
- a plastic propeller
- a minimum weight of 14 grams
- no tail
- a model that will fit inside an 18 inch [46 cm] cube.

The first Hawthorne class contest was held in 1979. The last rule was used as an alternative to a limit on wingspan, and has produced some very interesting shapes, among them a rhomboidal airplane with a cutout for the propeller. The winning time in 1979 was 43 seconds. Barnaby has also competed in the yearly Northrop Flying Wing Contest, formerly run by the Northrop Model Airplane Club but now orchestrated by the Flightmasters. The competition is for free-flight models only, in three classes: rubber, gas/electric and towline. The only rule is that anything that looks like a horizontal tail is forbidden. Barnaby won with his first airplane in 1979, but the 'plane was still not entirely satisfactory, suffering from a divergent phugoid under high thrust. It was retired after that one contest. At about this time, Barnaby found a NASA Technical Memorandum with the title: "Procedures for the Design of Low Pitching-Moment Airfoils." Two of the three procedures baffled him, but the third procedure—incorporated into a computer program— allows the selection of C_{m_0} as an independent parameter. The camber line is defined by superimposing a series of sinusoids, of which only the first two harmonics determine pitching moment. Varying these and other coefficients gives airfoil camber lines of nearly any desired shape. Coefficent a_3 controls the location of the point of maximum cam-

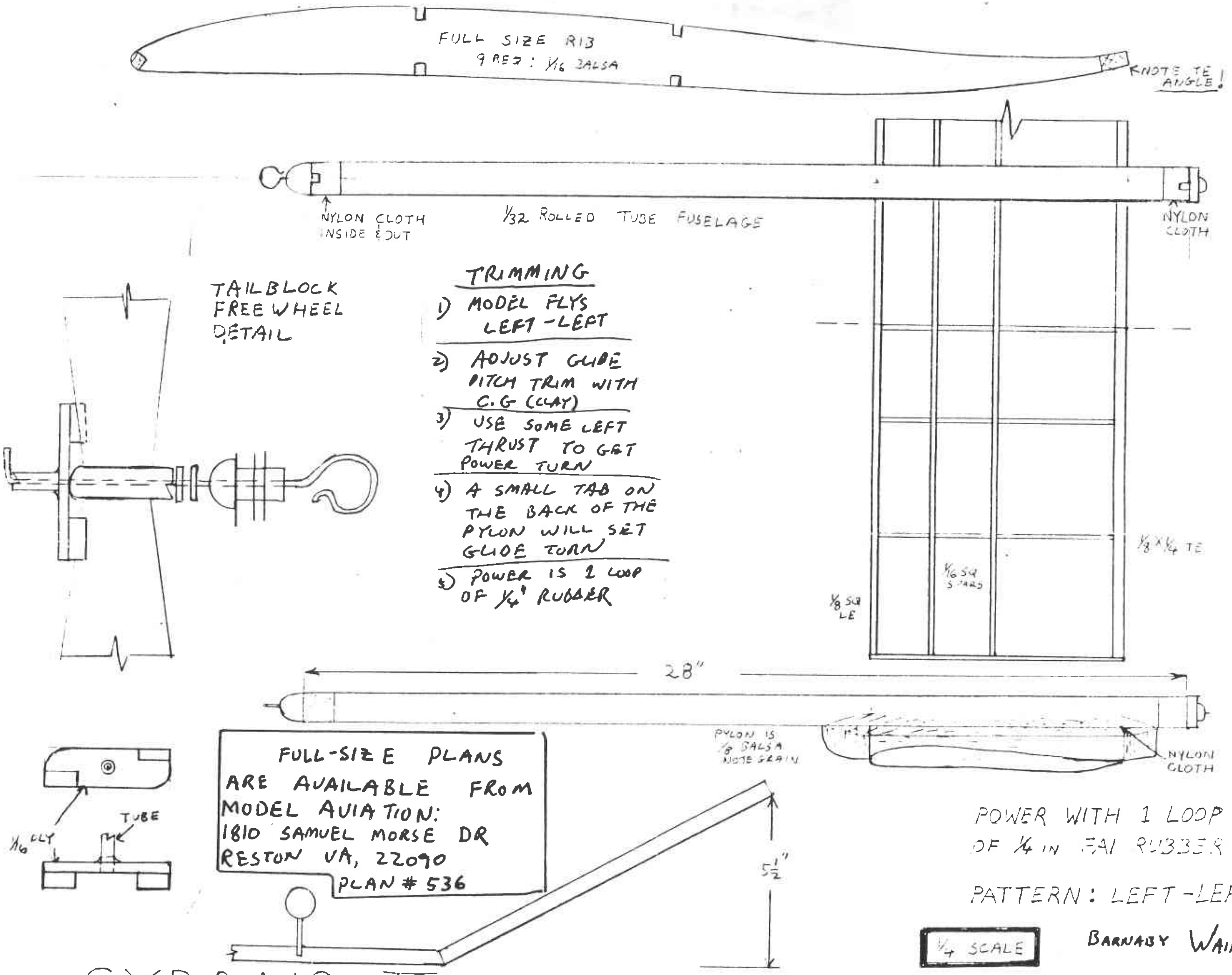


Barnaby and Lynne Wainfan with one of Barnaby's models.

A sample of the fleet of models that the Wainfans brought with them—note the 1/4 scale model of Barnaby's manned airplane design at left center.



ber, for instance. Nose shape is critical to C_{lmax} because it determines the angle of attack at which separation begins. A large amount of forward camber will delay the stall at low speeds; the only drawback is that a very "hooked" nose will cause lower surface separation at high speeds. His first indoor model was a 20 by 8 inch [50 x 20 cm] slab wing with a stick on top. It had winglets at first, because Barnaby believed that his biggest problem would be a lack of directional stability. In fact, FF models need spiral stability [which decreases with excess vertical tail area—Ed.], and so the winglets were first cut down, then removed, eliminating a spiral dive tendency and allowing Barnaby to recapture the duration record from his wife Lynne with an 80 second flight. Biplanes are permitted under Hawthorne rules, provided they have no stagger or decalage. Barnaby built a biplane that flew 1:52. Barnaby also competes in a class called P30 outdoor rubber. In 1980 he won the Northrop competition with a flying wing P30 model, and in 1984 took the National competition against 91 airplanes with tails, proving to his satisfaction that flying wing models are competitive. His winning design was published in *Model Aviation*. Lynne is fond of low aspect ratio airplanes; one of her designs took second in the 1986 Northrop contest. Besides his custom airfoil sections, Barnaby uses raked wingtips to reduce induced drag. His biggest



TRIMMING

1) MODEL FLYS LEFT-LEFT
2) ADJUST GLIDE PITCH TRIM WITH C.G (CLAY)
3) USE SOME LEFT THRUST TO GET POWER TURN
4) A SMALL TAB ON THE BACK OF THE PYLON WILL SET GLIDE TURN
5) POWER IS 1 LOOP OF 1/4" RUBBER

FULL-SIZE PLANS ARE AVAILABLE FROM
MODEL AVIATION:
1810 SAMUEL MORSE DR
RESTON VA, 22090
PLAN # 536

POWER WITH 1 LOOP
OF 1/4 IN FAI RUBBER (1.0 G

PATTERN: LEFT-LEFT

1/4 SCALE

BARNABY WAINFAN

CYRANO II P-30

WINNER: 1984 NATS

problem now in outdoor flying is building a reliable dethermalizer; in his latest design, the fuselage and wing separate completely and are held only by a tether. Barnaby reviewed some of the obstacles confronting flying wings in mainstream competition. In towline, minimum wing loading and maximum projected area are prescribed, handicapping f.w. models in Nordic competition. In gas, the AMA rules impose no limit on airframe design. The classic design has a swept wing with a pylon-mounted engine. Barnaby's first had a centerline- mounted engine with 30° of downthrust. The engine was a Cox Tee Dee .020. The airplane was not satisfactory. Barnaby went to electric power for a plank model called "Circuit Board," built for the Astroflite contest; he eliminated the need for downthrust by giving the center-section an airfoil section with a very strongly negative C_{mo}, forcing the nose down when it is immersed in the propeller slipstream. A new class called Pee Wee 30, requiring the model to rise from the ground (ROG), has been started by the San Diego Orbiteers. Dethermalizing is a problem, but spoilers are permitted and appear to work. On the subject of the Eppler Code [an airfoil section design and analysis program devised by Richard Eppler and Dan Somers—Ed.], Barnaby commented that when the code is given airfoils with enhanced pressure recovery like those used on the Gossamer Albatross it "blows up" and refuses to give results. Barnaby finally found a reflexed NACA airfoil for which it will give results, the 5H15, and ran the Eppler code against the wind tunnel results. They show good agreement at high Reynolds numbers; the bottom of the drag bucket is accurately predicted, but agreement falls off at higher drag values. Agreement is poor at lower N_R. Conclusion: the code is optimistic about drag, but fairly good at predicting the best drag lift coefficient at high Reynolds numbers. Barnaby noted that the code is designed to predict lift curve slope and drag after separation, but that it will not accurately predict pitching moment in separated flow. Designing simple manned single-place tailless airplane with tractor propeller. Twenty-two foot [7 m] span, 80 square feet [8 m2] area, 30-45 horsepower. Barnaby showed off a quarter-scale model of the machine, which he hopes to begin building at full scale very soon. The model flies very well, with docile stall characteristics and very little sensitivity in pitch. No adverse yaw noted. Nosewheel-first landings are very nasty due to lack of pitch damping. The model has an adjustable-length nose gear to adjust ground angle, but the initially-set angle seems correct. He predicts 140 knots and 900 ft/min initial rate of climb. He plans use of precured composite honeycomb for fuselage and part molded, part hot-wired foam wing. He gave some details of construction which were hard to reconstruct from audio tapes. Controls are expected to be light in pitch and rather heavy in roll. He noted in passing that he is only a mediocre RC flier; after rapidly converting several powered conventional models to kindling, he followed Lynne's lead and built himself an RC plank glider with a 2 meter span and used that to teach himself to fly. The conversation turned to the apparent paradox of high performance, low aspect ratio models. Barnaby noted that induced drag is a function of span loading and wing (area) loading; in span-limited classes span loading is fixed, especially if a minimum weight is required. The designer is only free to choose chord length; by extending the chord, he reduces wing loading. Another factor, Reynolds number, is at work in models as well; by extending chord, a designer can often push his model over the magic chordwise N_R of 50,000, achieving a reduction in parasite drag and essentially getting extra wing area "free of charge." Barnaby noted, in response to a question from Bruce Carmichael, that very often thermal updrafts near the ground are small even in relation to the size of the model, and that a model whose wing is fully immersed in the thermal often has an advantage over a larger-span model. The discussion then broke up for a trip to Harald Buettner's shop.

FROM TWITT NUMBER ONE:

We have been an active group for almost two years now. We send the Newsletter to Switzerland, Germany and Australia. We are corresponding with Flying Wing believers in other countries. We have in our group aircraft engineers, designers, airline pilots and others whose background in language helps translate the letters we receive in languages other than English. We have composites experts, model builders and willing workers. WE HAVE NOT USED THE TALENT OFFERED TO US. We will soon be organized as an entity with officers and by-laws. We will continue to operate on a non-profit level. We will conduct a raffle at each TWITT meeting and offer an attractive prize. Profits, if any, will be used for the benefit of TWITT. The position of Editor of the newsletter is important enough to make him a voting member of the Board of Directors. I do not want to be an officer, but will serve on the Board of Directors.

Bob Fronius

MEETING ANNOUNCEMENT

TWITT's next meeting will take place Saturday, 21 May 1988 at Hangar A-4, Gillespie Field, El Cajon, California. Our emphasis will be on wind tunnel testing, and our featured speakers will be Jerry Blumenthal, who will discuss General Dynamics/Convair's low speed wind tunnel; Mark Wollen, who will discuss the design of a small wind tunnel which he and

Jim Witham are offering to universities and small research organizations; and finally Bud Klayser, chief engineer of Scanivalve, Inc. (San Diego, California) will discuss wind tunnel instrumentation. Jerry Blumenthal has spoken at TWITT meetings before; his emphasis this time will be on his experience as a builder of wind tunnel models. Mark and Jim will discuss the many issues involved in designing the wind tunnels themselves, based on their successful design of a small wind tunnel. Bud Klayser, who holds a degree in Physics from UCSD, will base his talk on his extensive experience in designing wind tunnel instrumentation used around the world. Wind tunnel hardware, models and instrumentation components will be on display. BE THERE.

STATUS OF THE SB-13 PROJECT AS OF MARCH 1988

Condensed translation by Tasso Proppe of material provided by Prof. Dr. Karl Nickel

The SB-13 is the first flying wing constructed in composite material technology. The design goal was a Standard Class sailplane, meaning 15 m span, no variable camber (flaps) which would achieve better flight performance by the elimination of fuselage and empennage drag. The tip rudders will also decrease induced drag. The problem remained to avoid sacrificing advantages in other areas.

The SB-13 flew in March 1988. First, taxi and lift-off tests, and on 18 March two aerotows. Controllability was satisfactory on all three axes.

Design features:

- elliptical lift distribution for efficiency in high speed flight
- elevator integrated into the wing

In a swept-back flying wing, the elevator operation is a paradox: in slow flight, the control surfaces go up for higher angle of attack (but we really want them to go down for higher lift coefficient).

A new airfoil section had to be developed for zero moment (and maximum laminar flow—89% was achieved), and a special airfoil for the control surfaces as well.

A 1/3 scale model revealed wing spar flutter at a speed equivalent to 120 km/h at full scale). There is no known technical remedy (like balancing flaps).

A new approach was developed:

- de-sweeping the spar
- use of carbon fiber for stiffness
- "HM" (high elastic modulus) carbon fiber.

Flutter speed is now 270 km/h.

This material is not FAA approved. It is difficult to handle because of its brittleness, and the need to place many rovings together with the resin into a mold caused further problems due to the short pot life of the resin. The newly-developed production method worked; about 30 rovings are fed via conveyor belt through a resin bath and past a squeezer arrangement (to control the resin-to-fiber ratio), onto a bed of foil for smoothing and from there to the mold. A static bending load test intended to be carried to destruction had to be terminated after reaching 2.3 times the safe maximum load. Since elasticity requirements drive the design layup, it exceeds all bending stress requirements.

The control system design required special development. Two sets of control surfaces are provided on the outer wing panels, the inner ones acting as ailerons, the outer ones as elevators. A mechanical mixer translates stick movements differentially into the four control surface deflections via carbon-fiber rods. In turning, the inner rudder deflects 70° and the outer deflects 15°.

The two tandem landing gear wheels retract simultaneously; the main wheel is equipped with springs and shock absorbers.

The fuselage is made of glass fiber for greater energy absorbtion (crashworthiness). The field of view is very good due to the large canopy.

LETTERS

Tasso Proppe of Lemon Grove, California, our March speaker, contributed this letter from his correspondent Owen Babcock in Tasmania with interesting data on the Mitchell U-2.

Dear Tasso,

It is good to hear from you again.

I now have 100 hours up in my U-2 and have made some modifications since I last wrote to you. The two main ones being fitting a canopy (genuine Mitchell) and a reduction drive unit. As a result, my U-2 is now much quieter with improved performance with my 22 hp Konig. Max. level speed is 70-75 mph [112-120 km/h], and cruise approx. 65 mph [104 km/h]. Min. sink is estimated at approx. 450 feet per minute [2.3 m/s], so it certainly can't be classed as a terrific soaring machine! I use it mainly for cross-country flights (40-90 miles [64-144 km]), just occasionally thermalling. Our rules limit us to 500 ft. [154 m] max, so soaring can't be done legally.

My c of g is 2 1/2 inches [6.4 cm] behind the rear spar—it was originally at the spar—and after this change performance was noticeably improved but adverse yaw was very pronounced. I now fly using only rudders for roll and find it completely satisfactory.

Your comments concerning the cause of this adverse yaw sound feasible, but if with the cg forward and the up (negative) elevon stalled, why didn't the nose drop? Also I fitted wool tufts to the underside of the elevon and this showed an extreme turbulence. With this forward cg, the aileron function worked very well with minimum adverse yaw.

With my present cg, roll rate using rudder only is 4 sec from 45 degrees to 45 degrees. I do vertical wing overs with an entry speed of 80+ mph [128 km/h]. My max. speed has been 95 mph [152 km/h] in a dive. I have hands off stability in calm air, but am kept busy in rough air. Pitch control is very light and fairly sensitive. On takeoff the machine will rotate at 25 mph [40 km/h] and can be lifted off at about 30 mph [48 km/h]. The strips I use are only paddocks, usually sloping and sometimes rough, but with my suspension system I am amazed how well it handles these conditions.

Empty weight is 286 pounds [130 kg]. I weigh 150 pounds [68 kg] and carry 3 imperial gallons [? liters] of fuel. Main wheel fairings are not fitted.

The offer made to you on a part built U-2 sounds very attractive, although I would be hesitant to put my life in the hands of several other people's (unskilled?) workmanship. A visual inspection would help but you can never be sure! As regards soaring, I consider the performance not satisfactory, although possible in strong lift.

Please let me know what you do and don't hesitate to contact me if you think I can be of further help.

Best regards,

Owen

This one is from frequent and prolific Newsletter contributor Bill Hannan of Escondido, California.

Enclosed some more photos and two SAM newsletter pages from Dan Walton, Beechcraft engineer in Kansas. SAM is the <u>S</u>ociety of <u>A</u>ntique <u>M</u>odelers, who specialize in flying older design models, including, you will note, at least a few flying wings.

Cordially,

Bill Hannan

[illegible] article elsewhere in this issue—Ed.]

This from our April speakers Barnaby and Lynne Wainfan.

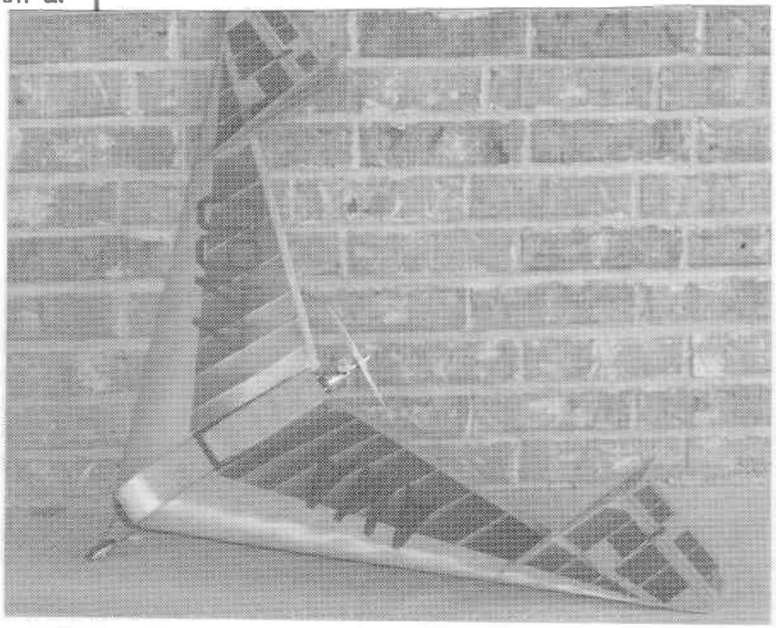
Dear Bob and June;

Barnaby and I wanted to let you know how much fun we had on our visit. The TWITTs are such nice people; very enthusiastic and <u>positive</u>!

We thought the plans for Barnaby's Cyrano model might fit into the Newsletter. They're kind of sketchy but we've seen many built from these plans.

Again, thanks for the enjoyable weekend. We may drop in again when we need a full night's sleep (that bed was <u>so</u> comfy)!

Lynne and Barnaby Wainfan



Flying Wing gas model. Original by "Tex" Rickard, San Antonio, TX, 1938. This 1/2 A Texaco Model by Daniel Walton.

Left: Daniel Walton and his "Li'l Misery." Right: Al Backstrom and his "Arup," flown at the 1987 Seguin, Texas SAM Championships.

Our most recent subscribers, Gil and Marybelle Metcalf of Gardnerville, Nevada write:

Dear Bob,

We certainly enjoyed seeing you and June again at the recent get-together in Santa Ynez, and hope too see you again at the "Workshop" in Tehachapi.

Enclosed is a check for my TWITT membership. Long live TWITT!

I am putting together a folders with pictures and information on the Schapel SA-882 flying wing project for the TWITT Technical Library and archives [The Metcalfs sent a beautifully organized binder with photographs and specifications of the machine—Ed]. It should be on its way in a few days, as soon as I let Rod Schapel know. Since we live so far away I don't know how I can help much, other than contributing things to the technical library and the newsletter from time to time.

I have been trying to sell my Duster sailplane so I can get a Mitchell U-2, but too little interest so far. Not much selling. I have some flying wing designs, but I have to finish my motorglider project before I can take any wing projects past the flying model stage.

Thanks for the TWITT Newsletter; I enjoyed it very much.

Best regards,

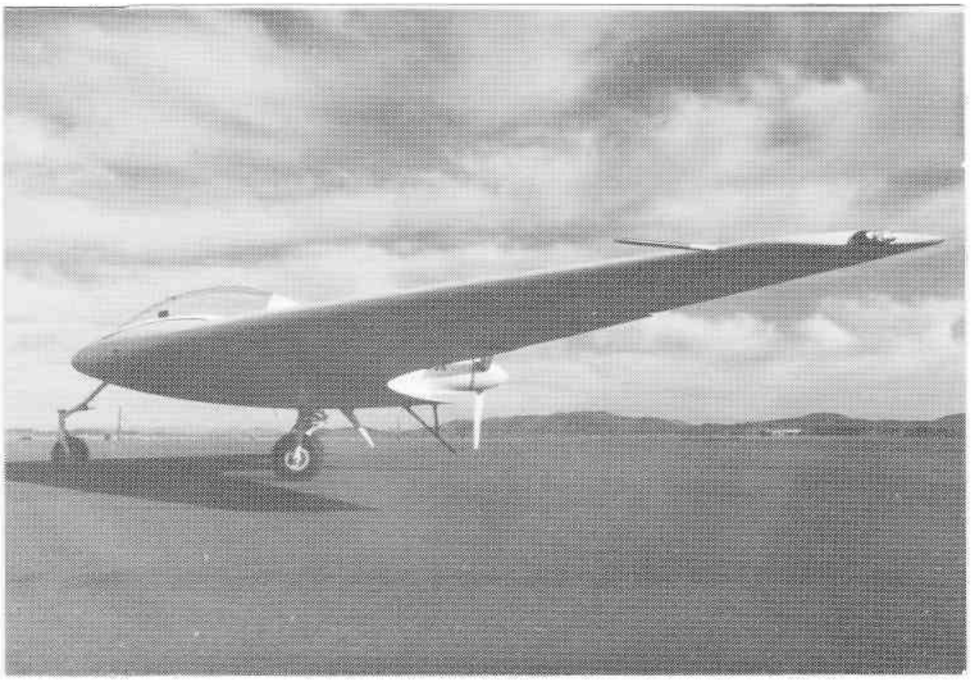
Gil & Marybelle

Thank you for the info on Rod Schapel's beautiful ship. We'd like to hear more about your projects, too, and would be especially grateful for photos of models, 3-view drawings and so on. Good luck selling the Duster.

Marc de Piolenc

HAVE YOU EXPIRED?

Beginning with Newsletter Number 21, mailing labels have included a four-digit code for the year and month of the last newsletter the subscriber will receive under his current subscription. If your label reads "8805," for example, your last Newsletter will be this one, May 1988. **Some of you have already expired and are receiving this issue in lieu of a renewal notice** [the cost to us is about the same, and we thought you might prefer being notified this way]. Please check your label now, and take the time to renew if your subscription is expired, or nearly so. While we're at it, let us remind you that all back issues are still available at $ .75 apiece. Subscriptions still cost $ 15.00 per year. Payment must be in US Dollars. Please don't let us lose you!



Schapel SA-882
[Photo courtesy of Gil and Marybelle Metcalf, with the permission of Rod Schapel]
More on this machine in a future issue.

SCHAPEL SA–882
PROOF OF CONCEPT AIRPLANE

PRELIMINARY SPECIFICATIONS

GROSS WEIGHT, LB	1984
EMPTY WEIGHT, LB	1372
USEFUL LOAD, LB	612
MAXIMUM FUEL, GAL	57
WING SPAN, FT	34
WING AREA, FT^2	160
ASPECT RATIO	7.23
SEATS (2-SEATS OPTIONAL)	1
ENGINE, MAZDA 2-CHAMBER ROTARY, HORSEPOWER (OPTIONAL ENGINES AVAILABLE)	180

CONSTRUCTION: ADVANCED COMPOSITE MATERIALS UTILIZING
EPOXY-GLASS-P.V.C. FOAM SANDWICH METHOD

Stalling Phenomena and the Tailless Aeroplane—IV

By A. R. Weyl, A.F.R.Ae.S.

Previous instalments of this article appeared on pp. 427, 478, and 624.

FOR the following discussion of the stalling properties of swept wing systems, the consideration of problems of stability and trim at the stall is essential. Static stability is the faculty of a system to return to a position of equilibrium when a disturbance has displaced it from this position.

This general definition obviously loses its value when considering longitudinal stability at the stall. For the pilot it is of no use if his aeroplane assumes a position of equilibrium at an incidence within the critical range of stalling incidences and tends, when disturbed, to return to this incidence. Moreover, the unsteady flow conditions prevailing at the incipient stall would make such a conception quite incompatible with static stability. Hence, qualification of the conception of static longitudinal stability is desirable before considering the stall.

The pilot will be satisfied if the aeroplane from any stalled attitude, tends to return to incidences which are associated with smooth flow over the wings, i.e., below the incidence of maximum lift. Stability in stall shall hence be presumed when, at the stall, the aeroplane tends to decrease its incidence when left to itself ("stick-free" stability). If the reverse is the case, so that tail heaviness appears, the aeroplane shall be considered unstable in pitch at the stall. The condition of return to a state of equilibrium is thus being disregarded for our purpose, even if the aeroplane should go from the stall directly into a dive—as stable conventional aeroplanes usually do.

Static longitudinal stability is best considered in relation to the "aerodynamic centre." This is the point about which, for all incidences of normal flight, the pitching moment remains unchanged. When the centre of gravity coincides with this point, the aeroplane has neutral static longitudinal stability. When the centre of gravity is in front of the aerodynamic centre, the aeroplane is statically stable in pitch. When the centre of gravity is aft of the aerodynamic centre, the aeroplane is longitudinally unstable.

The conception of a stationary aerodynamic centre holds only for an incidence range well below that at which separation phenomena occur at the wing. And even this statement has to be qualified for aerofoils for which the linear relation between the pitching moment and the lift (or, more exactly, normal-force) is retained over a substantial range of incidences, for example, from that of steep glide to that of best climb. It may, for instance, not hold for many laminar-flow (low drag) aerofoils which often exhibit a kink in the lift curve (Ref. 72), due to a sudden forward movement of the transition point towards the leading edge at incidences well below the stall. Such a sudden shift in the aerodynamic centre will, of course, greatly affect the stability quantities: when the aerodynamic centre shifts forward, the longitudinal stability is decreased or even lost; if it shifts back, the stability is increased.

In this connection, partial flow separations near the trailing edge will also become of importance for the longitudinal stability of tailless wing systems. This is to be considered when choosing laminar-flow aerofoils for a tailless aeroplane.

At incidences near to the stall, i.e., when separation phenomena begin to occur at the wing, the conception of a fairly stationary aerodynamic centre does not hold. Hence the consideration of stability has to be based entirely on the direction in which the previously nearly stationary aerodynamic centre shifts. When it shifts towards the leading edge, a tail-heavy tendency will appear; the aeroplane becomes longitudinally unstable and tends to raise its nose. Thus, the aircraft tries to increase its incidence, and if not corrected, the stall will be aggravated. Only the effectiveness of the elevator can then extricate the aeroplane from the stalled attitude.

When the aerodynamic centre shifts backwards towards the trailing edge, the stability is increased, and, unless corrected, a nose-heavy moment will return the aeroplane to a smaller incidence. This stability at the stall is thus making the aeroplane unstalled. Since, however, the static stability is greatly increased in its magnitude, the elevator control will have to be powerful in order to overcome a tendency to fall into a dive. For judging the behaviour of a wing system at the stall, the shape of the curve of the pitching moment as a function of the normal-force (or, approximately, the lift force) is clearly helpful.

Swept-back Wing Systems

Sweep-back gives to the stall of a wing similar qualities as does symmetrical taper in plan, only to a rather aggravated extent. Under otherwise equal conditions, a premature stall at the tips increases in severity with increase in the angle of effective sweep-back.

Since with tailless, swept-back aeroplanes, two- or three-purpose controllers are located in the regions of the wing-tips, the consequences of incipient stall in these regions are severe. An aggravating factor is that the incipient stall at the wing tips shifts the aerodynamic centre farther forward. The consequences of this have been mentioned.

The stall at the tips of a swept-back aerofoil is premature; it sets in long before the rest of the aerofoil is affected. For this, several distinct and yet interconnected phenomena are responsible:—

(a) Outwards flow components acting in the boundary layer on the negative-pressure side of the wing;

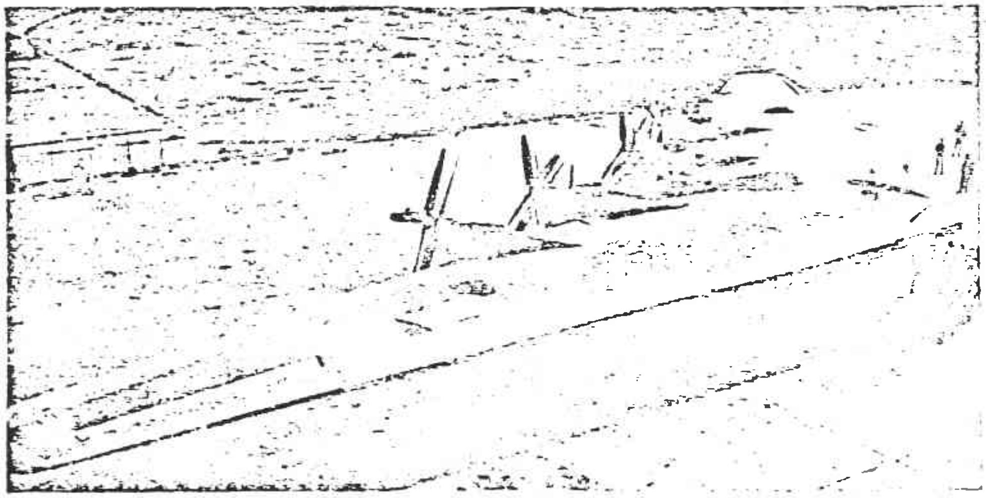
(b) The appearance of higher section lifts at the wing tips; strip induces upwash (di)

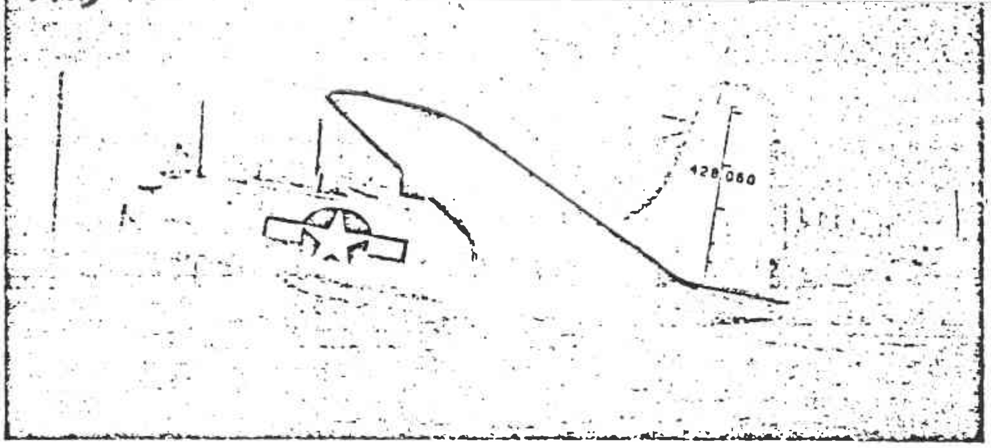
(c) Variation in the effective aerofoil section shape at the tips, due to the span-wise outward-flow components on both wing surfaces;

(d) Interaction of the inward flow due to the wing-tip vortices on the boundary-layer material accumulated over the wing-tips, at the negative-pressure side.

The intensity of this inward flow increases with approximately the square of the lift coefficient, and is reinforced by the outward flow on the lower wing surface which is induced there by the sweep-back of the wing. This was shown by the experiments of G. T. R. Hill on the adjustment required for rudders located underneath Pterodactyl

LARGEST TAILLESS.—The Northrop XB-35 bomber is the most ambitious tailless aircraft so far produced. With a span of 172 ft., and a gross weight of 162,000 lb., the XB-35 is powered by four 3,000-b.h.p. Pratt and Whitney Wasp Majors. It has built-in slots and split flaps at the wing-tips for control in yaw.





FORWARD SWEEP.—This tailless glider, the Cornelius XFG-1, has a swept-forward wing and is intended as a flying fuel tank for the Superfortress behind which it is towed. During these long-range operations, the XFG-1 is pilotless although, of course, for ferrying purposes, a pilot is carried.

wings. The interaction of this inward flow on the upper wing surface and the outward-directed flow at the wing-tips has the effect of (1) bringing the stale boundary layer to stagnation and hence to accumulation at the tips; and (2) changing the character of the stall locally over the tip region, by reason of induced turbulence.

(e) In addition there is a local increase of the effective Reynolds Number at the tip region, by increase of the effective aerofoil chord. This, too, is an effect which is due to the outward flow of the swept-back wing.

(f) When, as generally maintained, the outward flow is mainly restricted to the boundary layer, between the latter and the flow stratum above it, a vortex sheet can be expected;

(g) When wing-tip disc fins are attached to the swept-back wing, the factors that would affect the stalling characteristics are: (1) accumulation of boundary-layer material inboards of the fin; (2) formation of an expanding passage which will promote premature separation at the tip; (3) mutual interaction between the circulations about the wing tip and the fin, at attitudes other than that for zero-lift; and (4) sweep-induced inflow in the region of the leading edge of the wing.

(h) When partial-span, split, or trailing-edge flaps are deflected at a swept-back wing, the character of the stall changes. It occurs at a smaller incidence and shows a tendency to become more abrupt. The pertinent factors would seem to be:—(1) An increase in the effective wash-out from wing root to wing tip; (2) increased outflow on the upper wing surface outboard of the flapped region, while that over the centre of the wing is reduced; (3) tendency to premature stall just outboard of the flap, due to the discontinuous lift distribution along the span; (4) increased outward flow on the lower wing surface, due to the inclination of the flap to the plane of symmetry (sweep effect of the flap); and (5) variation of the inflow over the wing-tips from pressure equalization at the tip, which, in this case, exceeds that predicted by Prandtl's "lifting-line" theory, due to the gross lift discontinuity caused by the flap.

The span-wise flow components in the boundary layer are due to the sweep of the leading edge. Directly at the leading edge and somewhat above it, the airflow has an inward-directed component. This changes to a pronounced outward span-wise flow which increases as the flow approaches the trailing edge. This span-wise flow is simply the result of pressure gradients between equal-chord stations along the span. The region of the inward flow at the leading edge is very small and, for all practical purposes, without significance. It is due to the steep rise from high to low pressure on the upper surface of a lifting aerofoil immediately aft of the leading edge. Farther along the chord, the negative pressure decreases towards the trailing edge. The chordwise flow in the boundary layer is hence slowed down, and since the neighbouring outboard chord station has a smaller pressure, the flow will assume a definite outward direction.

As a result of this span-wise flow, stale boundary-layer material is transported towards the tips, where it accumulates, especially in the region of the trailing edge. It accumulates because, at the tips, there is an inflow velocity component due to the exchange of pressure around the tip, from the lower surface of the wing to the upper surface. The thickened boundary layer thus created over the tips of a swept-back aerofoil is greatly inclined to break away from the wing surface, i.e., to cause a premature stall. On the other hand, the centre portion of the wing experiences delay in the stall, because the boundary layer over it is continuously being removed in a span-wise direction and replaced by more vigorous flow material.

The character of the premature tip stall is influenced by the pressure-exchange flow around the tips. At the square-cut tip, the inward flow is greatest near the leading edge, where the maximum negative pressure is developed at a lifting aerofoil, and as in the case of the induced drag, it increases in intensity with the square of the section lift. The result is that by the mixing of this flow component with the outward flow component due to the sweep, a region of vorticity is presumably formed at the tip. Consequently, a violent "front" stall will occur locally, when the incidence is sufficiently high.

The hypothesis put forward above seems in good agreement with experimental observations. It is also in agreement with observations of Soulé on the influence of sweep-back and aspect ratio (Ref. 74). It explains the surprising increase in the negative slope of the pitching moment/incidence curve which was found at sweep angles approaching 66 degrees and aspect ratios of about 2.5. The negative slope suggests a stall nearer to the root than to the tip, and this might be caused by a vorticity region farther inboard from the tip (due to the small aspect ratio). At larger incidences, the slope becomes positive because the inflow from the tip vortices is then no longer sufficient to delay the stall at the tips. Possibly, this is only a part explanation of what actually happens in this case, but it may help towards a clearer understanding on the basis of more experimental research.

Connected with the interaction between two opposing span-wise flows in the boundary layer is also the observation that, for the wing system mentioned, beyond a certain characteristic incidence, the lift increment with incidence improves. This does in fact occur at the identical value of incidence at which the negative slope of the pitching moment is found. This would suggest that the tips were partially stalled at the smaller incidences (small inflow and large outflow) and became unstalled at the characteristic incidence due to the "scouring" effect of the more intensive inwards flow arising from the pressure equalization around the tips.

That the effect of the abrupt "front" stall at the tips is not relieved by the provision of wing-tip discs, is probably due to the fact that the latter form expanding passages at the wing-tip near the trailing edge and hence cause a stall there too.

The effect noted under (b), i.e., that untwisted swept-back aerofoils have the property of higher effective incidences, hence higher lifts, at the tips, is due to the intensity of the vortex sheet which represents the swept-aerofoil in respect of the induced drag. As the result of the higher effective incidences, the lift grading over a swept-back wing is, at incidences well below the stall, fuller than that corresponding to the elliptical shape. Consequently, when the wing incidence approaches higher values, the tip regions reach their maximum section lifts first and hence stall first. This effect of premature stall is present with tailless aeroplanes, but in practice is far less important than the effect of the span-wise flow components. In fact, in most cases it is well neutralized by the wing twist required for stability. It does, however, necessitate the adoption of a somewhat higher effective wash-out than stability would demand for a straight wing having a tailplane in lieu of the swept-back tips.

The effect under (c) is, more or less, the result of the span-wise deflection of the flow at both surfaces. The result is that the aerofoil section which becomes effective for the relative air-flow has a larger chord but equal thickness and camber. Hence the reduction of the effective section thickness and section camber reduce the value of the local maximum lift and also its critical incidence. The effective section is also made liable to display an abrupt "front" stall. The effect is not very pronounced, but would, however, deserve of a closer investigation, since it may well lead to improved wing-tip designs. German investigations have shown that, at the tips of

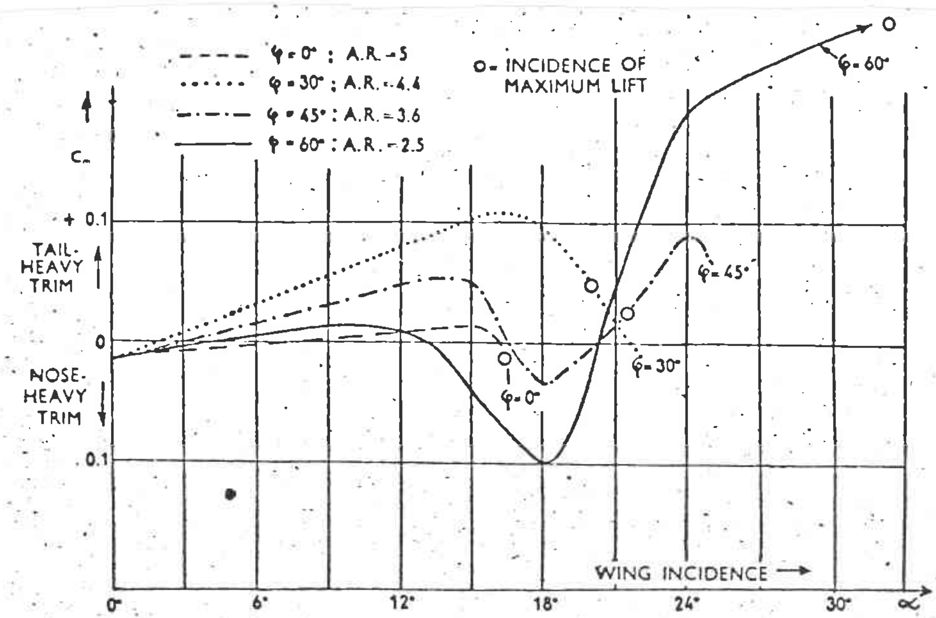


FIG. 7.

SHAPE OF PITCHING-MOMENT CURVES IN RESPECT TO WING INCIDENCE. FOR DIFFERENT COMBINATIONS OF SWEEP-BACK AND ASPECT RATIO (A.R.)
[FROM N.A.C.A. TECH. NOTE No. 1088]

swept-back aerofoils, the chordwise pressure distribution shows more pronounced peak pressures. Such peaks in the pressure distribution give larger adverse pressure gradients in the chordwise direction and hence promote early flow separation.

On a swept-back wing, the deflection of a flap affects the stalling characteristics at least as much as the deflection of a flap on a straight wing, while the lift increase diminishes with the angle of sweep. At larger angles of sweep, the stall occurs much earlier, when a flap, either of the split or of the plain type, is deflected. This is just as valid for part-span as for full-span flaps.

As to the nature of the stall, the experimental evidence is still scarce and contradictory. The U-wing type seems to be the most promising both for high-lift and character of the stall, when the flap extends over the straight portion of the wing. In general, the stall experienced with partial-span flaps leaving the tips without flaps seems to be better than with flaps up. G. H. Lee (Ref. 84) has attributed this to the diminished delay of the stall at the wing root which follows from the span-wise removal of boundary layer material in this region: in the case of deflected flaps, this removal is reduced.

Many tailless aeroplanes and gliders of the Dunne type have been afflicted by these effects. The Horten brothers, for instance, found (Ref. 15) that their first glider with swept-back, pointed wings displayed uncontrollability in circling flight and began to spin against all control manœuvres. They appreciated later that premature tip stall had been the primary cause of the trouble. During all their later development work, the retention of a substantial wash-out under all control combinations has formed one of the principal design considerations.

G. T. R. Hill investigated about 20 years ago, in a wind tunnel, a series of tapered wings with different angles of sweep (Ref. 73). The aerofoils had R.A.F. 30 section, an-aspect ratio of 6, a taper ratio of 3, and effective angles of sweep of 5 degrees, 24 degrees and 34 degrees respectively. He found that, contrary to the behaviour of standard rectangular aerofoils, the centre of pressure moved forward when the stalling incidence was reached, and that this forward shift aggravated with increasing angles of sweep. In other words, Hill discovered that, at the stall of swept-back wings, the aerodynamic centre shifts forward, producing a pitching moment which tends to increase the incidence still further, while decreasing the static longitudinal stability.

For this reason, Hill has since given preference to the U-wing, instead of straight tapered and swept-back wings. The U-wing has a rectangular centre-section to which swept-back and tapered outboard wing panels are attached. The behaviour of each portion tends to counteract that of the other at the stall.

On the other hand, Hill discovered that an increase in the angle of sweep diminished the abrupt and severe drop of lift which occurs at the stall beyond the incidence of maximum lift. Various investigators have since confirmed this phenomenon, and double peaks in the lift curve have also been observed. N.A.C.A. test results prove that, with increasing sweep-back, the lift curve becomes more gradual at the stall and free from abrupt discontinuities. This again is in good agreement with flight tests of swept-back aeroplanes and gliders which in general have given evidence that the stall becomes more gradual when the sweep becomes more pronounced. This observation has, however, nothing to do with the longitudinal instability to which we referred above.

G. T. R. Hill has, incidentally, made another attempt to prevent the unstable forward movement of the aerodynamic centre near the stall, by the provision of a cut-out at the centre-section of the Westland-Hill Pterodactyl Mk. IA (1927). The attempt was, however, not successful, as, at the same time, it increased the induced drag unduly.

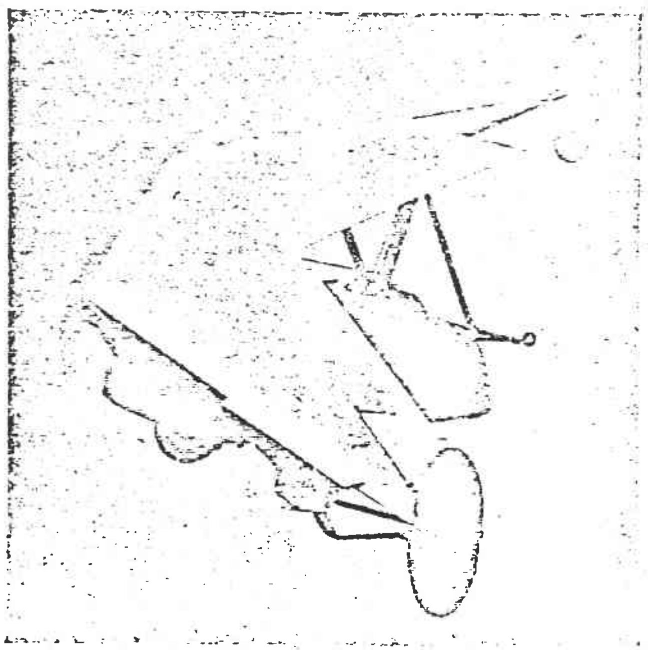
For many design purposes, a consideration of the curve of pitching moment as a function of the incidence seems instructive.

During the War, the N.A.C.A. have made systematic wind-tunnel tests and tests in the free-flight tunnel with swept-back wing systems having sections of the N.A.C.A. 230 family. Moreover, they have carefully collected and sifted the results obtained on swept-back wing systems for other purposes, and from the tests made in Germany. This comparative work is given in an important paper of A. Soulé (Ref. 74), and in several Technical Notes by W. Letke and A. Goodman (Ref. 75), and by J. A. Shortal and B. Maggin (Ref. 76).

The systematic investigations carried out by the N.A.C.A. were based on the structural consideration that the ratio of the wing-panel length to the thickness of the wing at the root should not exceed a figure ("criterion of structural efficiency") which was beyond the domain of practical possibility. Present-day values of this criterion are up to 30 to 35, but, in one case at least, a value of 50 has been obtained. Hence the Americans took a value of 50 as a possible optimum for the near future and based the variation of their aerofoil plan shapes on this. In other words, they varied the angle of sweep as well as the aspect ratio, in order to retain a value of 50 for the ratio between the wing-panel length and the wing-root thickness. Consequently, an aerofoil with a root section of 12 per cent. thickness gives an aspect ratio of 8 with a taper ratio (root chord/tip chord) of 2, without sweep. With sweep, the panel length is increased.

The structural consideration indeed proves that large angles of sweep imply low aspect ratios. The systematic variation observed by the N.A.C.A. is hence of immediate practical value. It is, however, less amenable to basic research which tries to investigate the factors of aspect ratio and of taper separately.

(to be continued.)



"Aeroplane" photograph

1934 EXPERIMENTS.—The Westland-Hill Pterodactyl Mk. V appeared in 1934. Powered by a 700-b.h.p. Rolls-Royce Goshawk steam-cooled engine, it was the last of a series built between 1926 and 1934, and was designed by Professor G. T. R. Hill.