No. 309 MARCH 2012

T.W.I.T.T. NEWSLETTER

Electric Flying Wing (left wing) - 13 foot wingspan, Eppler 334 airfoil. Side by side with 11 foot Klingberg flying wing. Source: http://www.chrisgood.com/rcplanes/wing_13_foot/index.htm for more construction photos. Outboard trailing edge appears to be split drag rudders.

T.W.I.T.T.
The Wing Is The Thing
P.O. Box 20430
El Cajon, CA 92021

The number after your name indicates the ending year and month of your current subscription, i.e., **1203** means this is your last issue unless renewed.

Next TWITT meeting: Saturday, March 17, 2012, beginning at 1:30 pm at hanger A-4, Gillespie Field, El Cajon, CA (first hanger row on Joe Crosson Drive - Southeast side of Gillespie).

THE WING IS THE THING (T.W.I.T.T.)

T.W.I.T.T. is a non-profit organization whose membership seeks to promote the research and development of flying wings and other tailless aircraft by providing a forum for the exchange of ideas and experiences on an international basis. T.W.I.T.T. is affiliated with The Hunsaker Foundation, which is dedicated to furthering education and research in a variety of disciplines.

T.W.I.T.T. Officers:

President: Andy Kecskes **(619) 980-9831**
Treasurer:
Editor: Andy Kecskes
Archivist: Gavin Slater

The **T.W.I.T.T.** office is located at:
Hanger A-4, Gillespie Field, El Cajon, California.
Mailing address: P.O. Box 20430
El Cajon, CA 92021

(619) 589-1898 (Evenings – Pacific Time)
E-Mail: twitt@pobox.com
Internet: http://www.twitt.org
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Meetings are held on the third Saturday of every other month (beginning with January), at 1:30 PM, at Hanger A-4, Gillespie Field, El Cajon, California (first row of hangers on the south end of Joe Crosson Drive (#1720), east side of Gillespie or Skid Row for those flying in).

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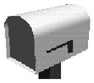
PRESIDENT'S CORNER

This is a mixed issue this month with some more from Jim Loyd on his model, a thread on engines related to the Mitchell U-2 and then the second part of Weyl's paper on wing tips for tailless aircraft. I hope you enjoy the diversity.

I was surprised there wasn't some feedback on Jim Loyd's plank proposal since it looks like it could be an easy build due to the simple lines. Don't forget that one of the reasons for TWITT is to promote design and construction of tailless aircraft, and one way of doing that is by the sharing of information and experience. Please take another look at the February issue and pass along what you thought of the ideas and comments to some of the points he made in his letter.

Spring is almost here so I am expecting some of you have been building during the winter months so how about sending along some pictures, like Jim did, and let all of see what you have been up too. Since it is "always" sunny in southern California I have been working diligently on my 1-26 restoration project even though it is not a flying wing. It is the best I can do at this point, so forgive me for deviating from the "true" path. I look forward to seeing what you have come up with.

Andy



LETTERS TO THE EDITOR

February 26, 2012

Hi Andy,

The Rohr 2-175 book is finally printed. The first shipment of books is due to arrive on March 1, 2012. We were able to add more color photos to this first addition thanks to one of Walt Mooney's sons.

There is an attached flyer for the book purchase if you have any interested people. The book turned out better than I expected. The price is slightly more than what I wanted as a target earlier because printing and delivery costs have increased for this year.

Ordering information is also on my website, as of today.
http://www.fraseraerotechnologycompany.com/Rohr_2-175_71X_FanJet_Book_Review.html

Sincerely,

Richard Fraser
<rcfraser@pacbell.net>

(ed. – I have included the one page flyer on another page of this issue. There has always been interest in this one-of-a-kind tailless design that unfortunately didn't survive corporate politics. I think the price is reasonable and the book will probably answer a lot of the questions everyone has had over the years.)

February 26, 2012

Enclosed is my latest design for the Arup type flying wing. The winger weather has kept us from testing it. I'll let you know when we have some test flight results.

Jim Loyd
Thornton, CO

(ed. – Jim is obviously very busy with various flying wing projects both real and developmental. I have included copies of his latest model design. It looks to be electric powered and there should be plenty of room for the battery pack in that fuselage. Thanks to Jim for showing us this and offering to keep us informed.)

Mitchell U-2 Bulletin Board Threads

How Does the U-2 Fly?

Well, the U-2 handles quite well in crosswind considering his size and weight. The 'rudders' are almost in line with the main gear so there is no weather vaning. In flight, it feels like a light machine, very low wing loading. It will bob the nose up and down in thermals to keep the speed constant. Very stable in bank. The original canopy is a loss. I did not install it, too short and too low. I installed a canopy, which is longer and higher. If I remember right, sitting in it ready to take-off, I can see the ground 10 feet from the nose. It is easy to land, very forgiving (if rigging is right). However, I always had airbrakes in it so it does not flare forever in ground effect. Roll rate is slow, so it is hard to get in a thermal and stay there and the glide as far as I tested is 13/1 and a sink rate of 400 fpm. Adding a foldable prop increased the glide by less than 1.5 unit and the sink rate went down by 50 feet. It is more a WOW machine than a motor-glider. For light conditions, it is nice to fly. It does not take a lot of trust to push it at 55 knots.

Guy

U-2 Engine Choices

I was wondering what the general views are on engine choices for the Mitchell U2? I have read of several engines that have been used on this plane. Is anyone better than another? My Uncle is big on the Rotax 503 and has used these on two of the planes he has built. I did read a manufacturers warning on the Rotax that they can fail in flight leading to all kinds of 'undesired' outcomes. I lost an engine once in a Cessna 182 during take off and climb. It happened at 2000 ft. (610 Meters) AGL. Not fun! This kind of thing will certainly lead to reduced undergarment service life! Thanks for your replies.

Vic

The beauty of the old ultralights is stall speed. I would not want neither to loose power in a 182!!! A lot less of mass inertia to stop when you touch down at 30 weighing 500 pounds than 50 weighing 1500!!! 2000 feet in a U-2 gives you more or less 4 minutes to react and you glide 20,000 feet. A lot more than the 182. IMHO the 503 is the least 'non-trustable' 2 strokes around...Do not forget, it is an old ski-doo technology that they added 2 extra spark plugs and called UL motor. So the price for parts went dramatically high. However, there is a good support for it, and a lot of parts all around and it has a good history if YOU follow their rules...which comes as expensive as a big mill like in your 182!!! It has good power for it's size, easy to cowl with the fan cooling. I think it is awfully too big for the U-2. It would push the U-2 over its limits, which nobody really knows...I am running a little 4 cyl. Konig (with reduction) which produces at best 160 pounds of trust and I can max out at 80 mph. The 503 pushes probably twice that trust. 25 to 35 hp with reduction is plenty of power for the ship. Two strokes are a lot better now than 30 years ago when the Cuyuna 30 hp was THE BIG motor for a 2 seater and Lazair were flying with 2 5 HP chainsaw motor! Still I would put a Continental or Lycoming if they were a lot smaller!!! and cheaper!!! Good choice would be....

-a known motor with an history
-parts and support available locally
-25-35 hp with reduction
-preferred 2 cyl. instead of 1 big banger. Lot less vibration...

Like Joe says, the Thor 200 looks very promising, we'll have to wait and see as far as durability, it is very light. That means, it will have to be far away from the wing for CG purpose, which was the case for the first proto running (I think) a 15 hp McCulloch direct drive. Difference is with the Thor, it will develop more than twice the trust. Trust line will have to be very accurate and it might affect pitch stability with power change. I would question the reduction unit as far as how much mass inertia of a prop it could support. Rotax had problems with that until they set up limit for each reduction they have. Perhaps the Thor with the 'dampening shaft' is less prone to wear out the reduction...I would be very curious to see one of those really looking good little motor...

Guy

Thanks Guy. Very good input. I went flying this past Sunday afternoon with a friend in his Nimbus 4. The glide ratio of 60:1 was amazing! It would be nice to increase the glide ratio of the U2 to that of the Nimbus, but I think it would require a complete redesign and in reality, it's like comparing apples to oranges. That said, I'll take your input about the 503 seriously. I'm convinced there are other (perhaps better) choices available. Thanks again.

Vic

Hi, Vic--

You certainly could have a flying wing with 60:1 performance but it would be huge and expensive. Probably the same weight as the Nimbus 4 and one or two meters more span. Developing a prototype might cost as much as $500,000

Back in the late 1950s August Raspet showed that you could get a plane like the Horten 4 up to about 43:1 without too much change and going higher is just a matter of more span.

http://users.acsol.net/~nmasters/H-IV-report.html#figure13

If you want to build a U-2 with the best glide it can achieve find a strong low profile engine and build a fairing around it. Fair the landing gear and intersections. Spend some extra time with a long sanding block making sure the wing is smooth and free of waves back to the spar.

Norm Masters

Yes good points Guy. I'd like to add a couple of generalities on the subject of two stroke motors to keep in mind.

Most of the good high power/weight two stokes fall into two categories. The low power ones typically below about 150cc are fitted with expansion chamber exhausts to get the power/weight ratio and the pipes can be an issue when looking at cowling the engine for nice aerodynamics. Vibration is not too bad with these and can be handled with good soft mounts, but still there are issues with cracking exhaust mounts etc. Larger ones (Thor 200 excepted) tend to be real vibration monsters if they are single cylinder types. The vibration issue also affects the choice of carburetion since heavy vibration results in foaming in a carburetor, which uses a float, bowl so often you see the diaphragm carbs, which are quite fiddly, and maintenance intensive and are always a compromise in tuning. (Note again the Thor 200 can use a slide carb due to the anti-vibration shaft). Then you get into multiple cylinder two strokes and the weight and size goes up substantially, tuned pipes may not be used but now you have dual manifolds so there is still a large exhaust system and dual carbs to balance, but the vibration is usually much less so you can at least use carbs which can be reasonably tuned and don't have diaphragms that change over time and have to be replaced yearly. This is why the Thor motor got my attention. It is something new. BTW I have no connection to the company or anyone who is connected to the company so I'm not trying to advertise anything here, I just have been looking at all the realities of ultralight engines for a while and wanted to summarize some of the issues here for some people who might not realize all the trade offs / issues.

Joe Street

Hi, Guy--

The longer motor mount might change the mass moment of inertia about the pitch axis. This would affect pitch damping (basically slow the pitch response). It would also affect spin characteristics. I know that that in the case of inertia of the wings you definitely don't want extra mass outboard because that not only slows your roll responses but could also increases the odds of tumbling after a stall. I'm not sure about mass spread out on the longitudinal axis. I'll see if I can get a real engineer to educate me on that and I'll get back to you.

Here's a videoed physics lesson on mass moment of inertia:
http://www.youtube.com/watch?v=m9iHEanmNWc

It's not specific to aircraft stability but folks who never had a physics class (or just don't remember that far back) it may be helpful

Here's a tech report that explains how tumbling is an inertia problem related to the weight of the wings:

http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19970011185_1997012329.pdf

Here's a video of NASA doing tumble tests in a vertical wind tunnel:
http://www.youtube.com/watch?v=vEl529ImNzs

Norm Masters

Hi Norman,

I found one Koenig SC430 for cca 200Eur here (Austria):
http://www.ebay.at/itm/Sternmotor-Ultralight-KONIG-SC-430-komplett-/160736147352?pt=Flugzeuge_Teile&hash=item256c9ef798

Maybe one interesting 4stroke could be Verner JCV360, as it flies on PG trikes and too on faster ultralights - kit produced by friends near of me - see video :
http://techproaviation.cz/katalog-detail/letadla/merlin-100-ul?lang=en

Probably useful is Solo 2350 - often used in sailplanes.

Too some of rotaries could be fine Parajet for PG and next one on UL:
http://www.youtube.com/watch?v=lMzRuNf3T8I

Regards, Jeri

The Biboxter looked interesting and I thought of it like a modern replacement of the KFM engine, which was used on the U2 by some, but I emailed them about a price and never heard back. Maybe that was too early in the development (about a year ago I think). I don't know but I expect it is going to be a vibration machine like the KFM.

The JCV 360 I have some real doubts about using belt reduction drives at power levels above 30hp. Also they claim 26kg but they don't say if that includes exhaust and radiator/coolant which I'm pretty sure it wouldn't so you are looking at some serious weight for that 38hp but since it is liquid cooled and overhead cam it could be expected to be a quite reliable engine. Vibration is a question. However they also have some nice looking multi cylinder radial air cooled engines but no details. I'd like to know more about them!

The Hirth is pretty much known about and you can read a lot on forums. Be prepared to change the belts a lot on a 50hp belt redrive!

Joe Street

Looks Like a U-2

Darned if it doesn't look like a U-2. Looks like a new engine option, also!

http://www.flyingmag.com/news/new-x-56a-aircraft-examine-flutter?cmpid=021612&spPodID=030&spMailingID=5199527&spUserID=MTMwMzgwNTkwNTQS1&spJobID=194458525&spReportId=MTk0NDU4NTI1S0

crusader6c

No, the X-56A has swept back wings, more like the SB-13 than Don Mitchell's U-2 Plank design.

I agree about the Thor 200 Motor - incredibly light and high power output. The Parascender's Market really needs compact designs.

However, this is designed to fit on someone's back. It will be a very wide (if short) installation on a U-2. Quite challenging to fair this well.

Andy Coles

Hi all,

I have been wanting to take some issue with cavalierly tagging air-cooled 2-strokes as "unreliable" as some have done because there is a possibility that much of the problem is "operator error". The phenomena of "shock cooling" is suspected and debated in conjunction with the air-cooled 4-stroke engines. Shock cooling refers to the theory that damage to air-cooled aviation piston engines may occur because of an excessively rapid decrease in temperature. The situation arises on descent from altitude. In this condition, the engine is abruptly throttled back so it is developing much less heat. In a descent, the plane's airspeed may be retained or may actually be allowed to increase thereby increasing the cooling rate of the cylinder walls and heads of the engine. The internal parts (piston, connecting rods, etc.) retain heat and remain expanded while the cylinder walls cool and contract. As the metals expand and contract under the differential temperatures, the dimensional changes in the engine may exceed tolerance limits. Or so goes the theory.

The phenomena could be exacerbated in the 2-stroke engine because internal cooling and lubrication of a 2-stroke is largely derived from the cooling flow of the intake air/fuel/oil mixture. When throttled back suddenly and severely, the engine is largely deprived of this cooling flow and lubricant at the very time it probably needs it the most. In addition, there are some pilots out there who have modified their 2-stroke carbs in a way which allows them to lean their engines in the same manor that we are taught to lean the 4-stokes. But in the case of the 2-stroke one major effect of leaning the air/fuel mixture is to simultaneously lean the oil supply. Could failure to enrich the fuel mixture prior to a decent deprive the engine of sufficient lubricant? It is intuitive that scored cylinders or seizure may result over time from these types of repeated abuse.

Interestingly enough, only one of the 3 CFIs that I have extensively worked with in 4-stroke aircraft was openly concerned about shock cooling and that one CFI taught a decent routine which tied rpm reduction to altitude reduction. In my humble opinion, it should be a precautionary practice used by every 2-stroke aircraft pilot.

Even though many pooh pooh the idea of shock cooling in Lycoming and Continental engines, should we continue to abusively operate our 2-strokes and then cavalierly dismiss them as unreliable?

Roger Olander

September, 1945 AIRCRAFT ENGINEERING

Wing Tips for Tailless Aeroplanes

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

Movable Tips

Swiveling "contractible" wing tips, which can be extended forward and folded backward were a feature of the tailless project of Jose Weiss in I903. Weiss wished to achieve a variable wing area; he claimed to have discovered that the speed of an aeroplane depended solely on its wing loading, the airscrew thrust being without influence.

As another possibility, the sliding tip deserves mention. Apart from the use of such devices at telescoping wings (e.g., Makhonine), the sliding tip can be a means of control. As such, it was anticipated in 1910 by Al. Pfitzner, an Austrian collaborator of G. H. Curtiss, who constructed a biplane at which the control in roll was effected by the outboard or inboard sliding of the wing tip. Though it is not obvious that such an arrangement could be of advantage for a modern design, its efficiency can scarcely be doubted.

As aerodynamically forming parts of wing tips, rotatable ailerons may be considered. In general, they are unsymmetrically shaped aerofoils, which are obliquely mounted on a vertical axis at the structural tip of the wing. When turned about the axis, the aerofoils form either drag or lift producing elements, and it is fairly easy to secure an aileron control giving favorable yawing moments. The rotatable aileron seems to have been introduced by A. Baumann in 1912 and realized in a more effective form by K. N. Pearson in 1927, and was successfully tried on a conventional light aeroplane. It is not improbable that the incorporation of a similar control device in a diffuser tip could be utilized with advantage on a tailless aeroplane.

Diffuser Wing Tips

In the historical survey reference was made to the diffuser-type wing tip, and emphasis was laid on the possibility that this might solve many of the problems which still govern the development of tailless aeroplanes.

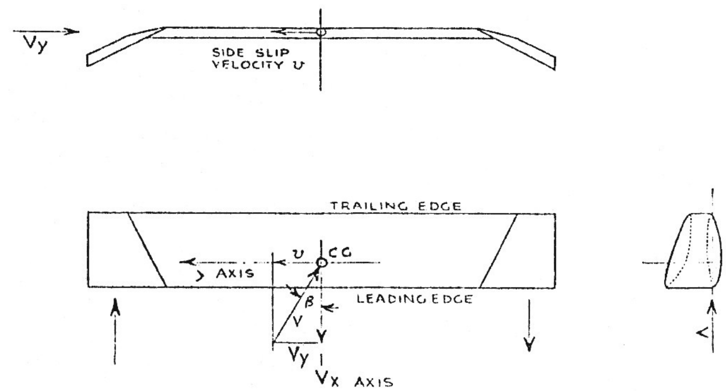


FIG. 4.—*Elementary diffuser wing tip*

A diffuser as understood in turbine and blower engineering, is a device which generally converts velocity energy (i.e. the kinetic energy of a flowing fluid or gas) into pressure energy; it is based on Bernouilli's law (without taking thermo-dynamics into account and as long as frictional losses within the boundary layer and mixing losses may be neglected). (The counterpart of this is a nozzle.) The classification of diffuser wing tips for all "negative wing tips" (as J. W. Dunne termed such devices) embracing the wide category of tilted-down and distorted wing tips, may perhaps not be deemed entirely adequate, since their action cannot be accurately described by stating that velocity energy is transformed into pressure energy; more appropriately, they would be described as devices which diffuse vorticity from a lift-producing wing into the undisturbed air flow at the tips of a wing. However, as a general designation for the whole variety of shapes and effects, it might serve its purpose, till a more appropriate term is found.

Superficially, the ordinary diffuser tip has much in common with the gull wing, i.e. with a wing having anhedral in its outer portion, while the inner portion has positive dihedral. Gull wings of this kind have, for aerodynamic reasons, often been employed with high-performance sailplanes, while their adoption for aeroplanes is usually dictated by purely structural considerations.

In normal flight the air at the side of a lift-generating wing has an ascending component. Lanchester referred as early as 1907 to up-currents which are generated beyond the tips due to the finite span of the wing; he also stated quite correctly that a flow of air around the wing tips from the under surface of the wing (positive-pressure region) to the upper surface (negative-pressure region) forms a sort of vortex fringe. Such equalization of pressure is a loss of energy expended for obtaining lift and a diminution of the lift, which is theoretically available in two-dimensional flow.

Part of this "induced" drag can be avoided, i.e. wasted energy recovered, by the adding of appropriate wing tips. Lanchester who realized this, suggested his "capping planes"; he also recommended raking the wing tips so that the trailing edge of the wing becomes greater than its leading edge. Both devices are indeed effective but, for various reasons, are not practical.

In 1914, C. Wieselsberger calculated the strength of the ascending component of the air beyond the wing tips on the basis of the horseshoe vortex system; he also proved the economy of flight in V-formation (which migrating birds had already found out many thousands of years ago), thus giving a clear indication that the energy recoverable from this ascending component is by no means negligible. V. Parseval, in 1921, estimated the energy, which is carried away by marginal vortices and drew attention to the suction effect at the tips, which deteriorates the lift/drag ratio near the tips.

The equalization of pressure, which occurs at wing lips, causes the airflow at the wing surfaces to assume directions, which have components normal to the plane of symmetry of the wing ("span wise" flow). The deflections are, for straight flight, of course, zero at the centre of the wing, while to port and starboard of the centre line, the deflection of the air flow is increasing towards the tip (local disturbances of the flow neglected).

On the upper (dorsal) surface, where at incidences of lift, a negative pressure predominates, the airflow has a span wise component which is directed inward, i.e. from the tips toward the centre. On the lower (ventral) surface, the airflow is deflected toward the tips. Near the tips, the airflow relative to the direction of flight (seen from above) is no longer in accord with the theory of two-dimensional flow, and conventional methods based on two-dimensional theory break down. This relates also to the common aerofoil theory of the induced drag; the only way of theoretical treatment remaining is the very elaborate general vortex-sheet method given by V. M. Falkner.

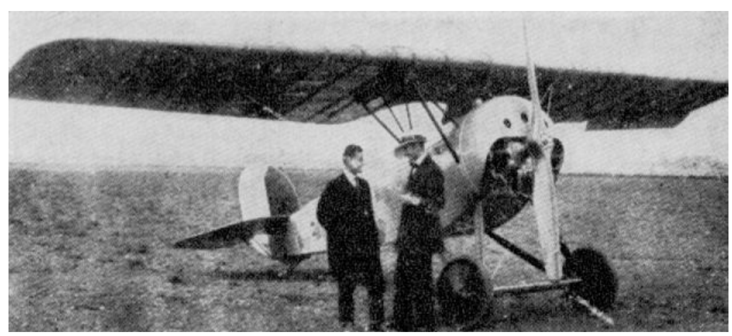
The energy represented by such span wise flow components is wasted. The flow deflections caused by the pressure gradient on the wing surface result, for a given lift, in drag which is additional to the profile drag (caused by skin friction and form drag). This additional (induced) drag increases with the square of the lift:

$$C_{D_i} = \frac{C_L^2 \cdot S}{\pi \cdot b^2} \text{ (for elliptical lift distribution over the span)}$$

Apart from this loss and judging solely on the evidence of wind-tunnel experiments, span wise flow components appear rather insignificant for the aerodynamical characteristics of wings, except at incidences near the maximum lift and for wings having pronounced sweepback. There are, however, reasons to suspect the general validity of this common and convenient conclusion. Aerodynamicists agree that wind tunnels tend to interfere with the three-dimensional flow of the boundary layer at wings of finite spans

Wings at which span wise flow components are impeded, for instance by rib webs protruding from the wing surface (e.g., the Kon. E. III monoplane of Rethel) have proved outstanding flying qualities which might have had their cause in a fuller lift distribution and in decreased induced drag. Span wise flow

(ed. – Although not in the original text, here is a view of Rethel's E.III monoplane.)



components may also well improve the behavior at the stall by directly affecting the transition vortex. Full-scale observations, especially those made by W. E. Gray and research by H. B. Irving have established the importance of span wise flow components on the dorsal surface upon the behavior of the boundary layer. Today, the fact is accepted that the separation of the boundary later from the upper surface of a wing (stall) is involved with span wise flow.

Moreover, measurements of the pressure distribution over wing-tip discs have proved that such flow components are not at all negligible. The recoverable or utilizable flow energy seems commonly underestimated. Wings at which high-lift devices are operating, give special scope for arrangements utilizing the wasted flow energy.

On thick cambered aerofoils of rectangular plan shape, E. N. Fales found a pronounced span wise flow along the dorsal surface. He concluded from his wind tunnel experiments on boundary layer flow, that a change in flow over the cylindrical upper surface involving transition from a pronounced span wise direction to normal direction with increasing incidence is responsible for the improved lift/drag ratios at higher incidences, and that this phenomenon is peculiar to thick aerofoil sections which have their maximum camber unusually far back. This conclusion is, as will be shown later, debatable. Fales' flow photographs also disclose a slight span wise deflection of the flow along the lower surface within the range of the boundary layer. Unfortunately, this evidence cannot be deemed quite conclusive since the experiments were made in the presence of a central shield, which may have favored premature separation at its joint with thr aerofoil, by forming an adverse pressure, gradient.

Pronounced three-dimensional flow is the cause of the abnormal characteristic (reduced induced drag, delayed stall with very high maximum lift: absence of aerorotation), which are particular to aerofoils of very small aspect ratio. In this respect, the shape of the wing tips has proved to be of primary importance for the aerodynamical qualities of the wing.

Al. See has claimed that "side-wind" components (side-slip) are essential, for the soaring of birds by way of assisting span wise flow. His theory of the "*vent louvoyant*" dates actually from 1908 and contains the assumption of a drag reduction caused by an angle of yaw. This theory is now assisted by Budig's "oblique-attack" effect to which further reference is made below. L. Breguet has refuted See's theory of soaring on the ground that this would imply a continuous deviation from the original course. Budig's contentions were then still unknown.

With wings with a sweep (either forward or back), span wise deflection of the airflow is enforced by the plan shape. With a swept-back wing, for instance, the flow suffers deflection toward the tips, on the upper surface as well as on the lower one. This deflection is superimposed on that causing the induced drag and, as a result, on the upper surface of a swept-back wing, the directions of both causes of flow deflection are opposed to each other, while on the lower surface, both flow deflections are in the same sense, giving a pronounced flow component directed toward the tips. On the upper surface of such a wing the resulting flow deflections are undecided. When the sweep-back is very pronounced, there will be a span wise component directed toward the tip, at least at small angles of incidence, while at large angles of incidence and with less pronounced angles of swept, the component due to pressure equalization will prevail. The superposition of two flow-deflecting effects explains why the common horse-shoe vortex theory of induced drag does not hold for aerofoil shapes with sweep. It also explains the deviations of the actual lift distribution over the span front that calculated by the ordinary methods (employing the conception of a lifting vortex line).

Span wise deflection of the airflow of wings is also influenced by the distribution of incidence, along the span (twist). The higher the local lift at or near the tips, the more pronounced will be the span wise components caused by the marginal vortices. Wash-in (Buzzard category) can, hence be expected to give decided three-dimensional flow. Wing tips producing down-lift while the rest of the wing generates up-lift, might greatly decrease the dissipative pressure equalization around the tip, and may thus give a somewhat decreased induced drag, on the expense of net lift.

Since tailless aeroplanes generally have some effective sweep and twist, they will obviously exhibit marked span wise deflections of the airflow over the wings. Span wise flow components decrease the effective circulation, which produces the lift; they thus imply loss of flow energy. The marked three-dimensional flow at swept-back wings also accounts for their low values of maximum lift.

Few measurements have hitherto been published giving the amount of span wise flow of swept-back wings. All are consistent. G. T. R. Hill mentions wind-tunnel tests on a model of the Pterodactyl I, in which flow deflections of 3 deg. at top speed (small lift coefficient) and of 15 deg. at stalling angle (maximum lift) were measured on the lower surface well inboard of the (floating) tips. The effective sweepback angle was approximately 23 deg. The direction of the span wise flow component was toward the tip. Similar observations on the Pterodactyl IV gave about 13 deg. deflection on the lower surface near the tips at the stalling angle. Again, the effective sweep was approximately 23 deg. Such large span wise flow components fully account for the high drag caused by wing-tip disks on swept-back wings. The disks on the Pterodactyl IV had their own drag doubled when fitted to the wing.

On the dorsal surface near the tip of a swept-back wing, the superposition of the deflection caused by the shape, with the pressure-gradient deflection results in practical cases often in a slow outward-flow component appearing just forward of the trailing edge. This causes, at incidences at which the pressure gradient reaches certain values, regions of flow disturbance with ensuing local separations of the boundary layer; eventually a premature stall takes place and controllers near the tips are much affected.

At and near the stall, transverse-flow components are of primary importance for the behavior of the boundary layer. The effect of local accelerations on the flow is greatly accentuated and it should be realized that, for this very reason, the Lanchester-Prandtl theory does not hold in the range of high lifts. The theory does not consider that the vortices shed at or near the tips are inter-twisting very close to the trailing edge.

M. Koehle made wind-tunnel investigations at and near the stall during non-steady motions, measuring the flow directions. The model wings had rectangular plan shape with square-cut tips; they were with and without washout. The effective Reynolds number approximated 0.22 x 10^6. For unstalled conditions Koehler found the aerofoil theory in fair agreement with the experiment. When the flow approached separation, however, considerable span wise flow was observed, either caused by the pressure gradient or, with a wing in rolling motion, because of inertia forces. When the wing rolled, parts of the boundary layer of the inner aerofoil sections were transported towards the tips and prevented, by energizing it, a break-down of the flow there, thus delaying the separation of the boundary layer from the surface. Even the Coriolis acceleration may assist to prevent separation at the critical transition condition. *(An effect which may be of some importance for slow-roll maneuvers and also for phenomenon of self-recovery from a spin, after or during the first rotation, with certain aeroplane types.)*

Fortunately, progressive engineering science traces secondary phenomena, which are causing losses, in order to utilize wasted energy to some good purpose. The exhaust turbine from which the gas turbine has sprung, is a perfect example of this tendency in technical development.

It is logical to apply the same principle to span wise flow components on aeroplane wings. *A priori*, it would seem possible to derive from this wasted flow energy, forces and moments which are beneficial to stability, trim or control. Also it might be conceivable by conduction or restriction of span wise flow to delay stalling phenomena near the tips. Both these possibilities lead to the consideration of diffuser wing tips.

The observation of soaring birds shows that their wings assume an attitude with downward tilted tips. Moreover, these wing tips seem to be the main device by which control and trim are effected during the soaring. E. J. Marey, in about 1880, appears to have been the first to try the effect of such tips on paper gliders. K. Steiger-Kirchhofer to whom we have already referred, also came from the observation of soaring gulls to the conception of diffuser tips. J. W. Dunne arriving at the same solution, emphasized the yawing stability secured by this device and made the first successful full-scale application. Another full-scale application was made by Horatio Barber on his Valkyrie tail-first monoplanes in 1910; it remained an experimental feature.

Wald. Geest, the German experimenter, derived his diffuser wing shape also from studies on bird flight. He arrived at the importance of this shape for tailless aeroplanes in 1906 by noticing a gull flying merrily with the tail feathers removed. He secured in 1907 patents for a wing the surface of which was bent from inward to the tips with simultaneous twist so that the inner part had positive and the outer part negative incidence. A variation of the aerofoil sections along the span was also provided. Conventional aeroplanes provided with this diffuser wing built and tested before 1914 gave very promising performances, and if their difficulties in construction (bent and twisted spars), rigging and transport could have been overcome, the Geest wing would not only have been in extensive practical use, but would have given cause for a thorough study of the diffuser wing, tip.

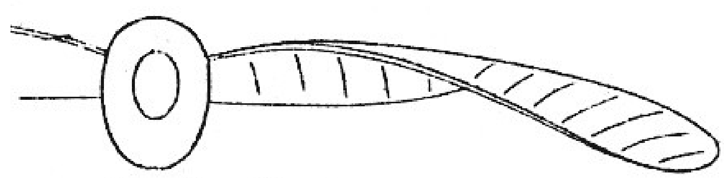


FIG. 7.—*The Geest wing of 1907*

Early in 1913, Dunne's "negative wing tips" raised considerable interest in the circle of British aeronautical engineers. A. E. Berriman agreeing with Dunne, expressed the belief that with the aid of such devices, lateral stability could be achieved. He pointed out that "downward pressure" (i.e., down-lift) on the tips was characteristic, and that "sensitive longitudinal stability of the weathercock order" (i.e. static longitudinal stability) was also essentially achieved. Yawing control should be effected by warping the tips, the inside wing having its negative incidence accentuated, since the addition of a vertical rudder would be unnecessary and ineffective. Berriman suggested that the natural state of a bird's wing might not be one with a permanently negative angle of incidence, and that, in general, its camber seemed to be washed out towards the tips. "It seems probable that Nature's design has succeeded in combining efficiency with security.... The flexible tip, it would seem, may automatically come into action as a virtual fin to make recovery from sideslip more sensitive."

Hankin seems to emphasize that for soaring in light winds, "negative" tips give security.

A theory of the "negative wing tip" considering the stability in horizontal gust on the basis of Bryan's method, was put forward by J. H. Hume-Rothery. According to this investigation, the "negative" tip makes the rolling and yawing stability quite independent of each other. Hume-Rothery realized that tilted-down tips must be compensated for because of their anhedral effect, by some dihedral in the main part of the wing. F. Wenk's original patent of 1919 (Lit. 77) contained all characteristic features of the diffuser tip, though an explanation of its action was not offered. From this the Weltensegler tailless airplane was derived.

L. Breguet tried to prove, in 1925, that the M-shape of the wings of soaring birds (seen from the front), is essential for the exploitation of horizontal pulsations of the wing, in dynamic soaring. Without the gull shape, he maintained, the internal energy of the wind cannot be utilized.

Anhedral of the wing system caused by a diffuser tip needs consideration, since it has often been the predominant feature. Dihedral gives static stability in roll (L_v rolling due to side-slip). Anhedral of the tips seems to imply a tendency for the wing to "dig in" when side slipping. Thus the advantage of purely tilted-down tips is by no means obvious. For gull wings, the moderating influence of the wing bend on the effective dihedral call be calculated. A closer investigation, however, indicates that the contribution to the stability in roll by tilted-down wing tips is not quite so straightforward to assess. Effects of oblique air flow will influence the aerodynamic forces in side-slips; thus one partial effect of side-slip may well cancel the other with the result that--in spite of apparent anhedral--the stability in roll is not markedly deteriorated by tilted-down tips, especially in a wing having effective sweep-back.

Moreover, with birds, the wing tips are not simply tilted downwards. The axis of curvature of the plane of the wings is not in the direction of flight, but intersects the plane of symmetry of the wing in front of the leading edge. J. W. Dunne was probably the first to realize this; he incorporated this oblique tilt in his "negative wing tips". Also, it does not seem to have escaped Steiger's attention, and it forms the principle of the Geest wing.

(ed. – It appears that these two figures should have been included in the first part of this paper published last month. They were sort of out of order in the actual document.)

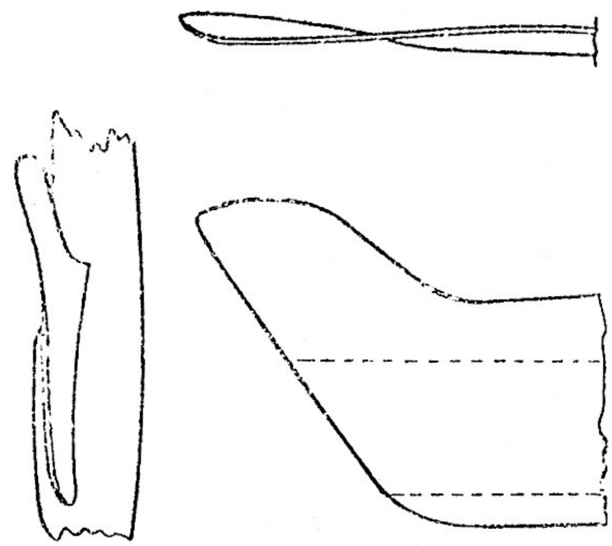
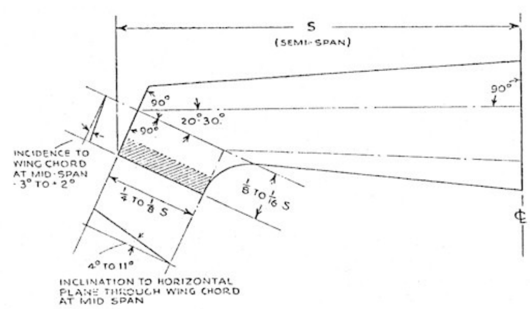


FIG. 5.—*Zanonia wing tip of a 1912 monoplane*

FIG. 6. — *Typical Zanonia wing tip: Focke-Wulf wing according to a 1930 patent which was actually utilized on transport and training aeroplanes of this firm*



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